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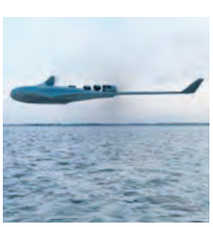

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Pay attention

If there's one thing engineers like – at least judging from the feedback we receive via our website – it's complaining about their salaries. Of course, you could probably say the same about any industrial sector; but in this issue we set the facts straight with the inaugural Engineer Salary Survey (page 42).

With more than 4,000 respondents answering questions on a variety of work-related topics, we think our survey is the largest of its kind in the UK. It gives us hard information about where engineers in various engineering and manufacturing sectors are employed, how old they are, how happy they are in their work, the gender divide in the sectors and, of course, how much they are paid.

One surprising finding is that regardless of their job satisfaction – only 35 per cent think their salaries suitably reflect their workload – in all sectors, more than 80 per cent of engineers expect to be in their current job for the next five years. By age, the largest percentage of engineers are in the 50–54 band, while only 12 per cent are under 30: a sign of the looming skills gap in the next 10 years as the older cohort retires. Gender disparity is also marked: just 5.5 per cent of respondents were women. We will be publishing a longer version of the analysis, including an interactive salary benchmarking tool, on our website on 29 June.

One of the survey findings – that civil engineering has a higher proportion of women than any other sector – is discussed in more detail in our Women in Engineering feature (page 48). Elsewhere, our features take an in-depth look at aerospace. Our cover story (page 18) explores one of the most advanced features of modern aircraft: the turbine blades that convert the energy in jet fuel into movement. The blades are single crystals of a nickel 'superalloy', and their manufacture by casting is probably the most advanced feat of metalwork achieved anywhere in the world.

"Only 35 per cent think their salaries reflect their workload

We also take a look at what a new generation of seaplanes might look like (page 23) and ask industry experts how technology is shaping civil aviation (page 28). We also look at machining technologies for composites, increasingly important in aerospace (page 35). Finally, we asks one of the senior engineers of Bosch, a company at the forefront of 'Industry 4.0', the machine-connectivity revolution, how this new development can help manufacturers.

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The Norma M-20 concept car will compete at Lime Rock Park, Connecticut

AUTOMOTIVE

Off to the races

Plastic engine looks set for debut in Norma M-20 concept car

BY GLYNN GARLICK

An automotive engine mostly made from plastic will be tested in a racing car in 2016.

US engineer Matti Holtzberg has teamed up with Belgian chemical company Solvay to work on the Polimotor 2 project.

This is a four-cylinder, double-overhead CAM engine that will be installed in a Norma M-20 concept car to compete at Lime Rock Park, Connecticut, US.

Using plastic usually raises concerns over how it will deal with the heat in an internal combustion engine.

"Everybody always asks that question," Holtzberg told *The Engineer*. "The exhaust port and the combustion chamber is an aluminium casting that's moulded into the cylinder head and then the pistons run in either a cast iron or a nikasil-coated bore.

"There is metal where the heat is and that is about the only two places. Everything else is a composite material," he added.

Holtzberg, president of Florida-based Composite Castings, had success with his first Polimotor engines in the 1980s, when they were used in an Amoco Chemical Company-sponsored racing car.

Amoco eventually stopped competing, but Holtzberg continued improving the engines. The importance of lightweighting and fuel efficiency then led to a renewed interest in the technology.

"That is why I'm bringing all of this back, to show the automotive industry what you can do. They will see it racing so they can't say it doesn't work."

Solvay will provide up to 10 thermoplastic components to demonstrate lightweighting through metal replacement.

These will include the water pump, oil pump, water inlet/outlet, throttle body, fuel rail and cam sprockets.

The aim is to develop an engine weighing between 63kg and 67kg – about 41kg less than today's standard production engine.

Coventry University's director of low-carbon vehicle programmes Bernard Porter said there is an overall trend to reduce the weight of power units.

"Whether plastics could really accelerate that trend or would even be particularly relevant I think is a bit more open to debate," he said.

"I think it would be foolish for anyone to say it looks unfeasible, but on the other hand there are a lot of technical problems to overcome. I can only imagine that the companies involved are fairly confident they know how to do that," he added.

Imperial College's London professor in turbomachinery Ricardo Martinez-Botas said that to be successful the technology would need to show it could deal with the issue of cooling, the peak pressure related to modern turbo boost systems, and gaining customer confidence over maintenance, repairing and obtaining and replacing parts in a car with a plastic engine.

"This engine will need to be cooled because the temperatures of combustion are huge, so the question is whether you alleviate some of the cooling that would normally be necessary for a metal engine, and if you do then there is a benefit with a plastic engine," he said.

Holtzberg said that his racing car engine would reach 450bhp at 8,000rev/min. "It is turbocharged. It will have two atmospheres of boost. There are some design things that I do to take stress out of the block that I can't go into but I will tell you that the material is twice as strong as the grade of cast aluminium used," he said.

"If you don't do it then nobody will ever do it. I look back 20 years and if you had told me BMW was going to have a carbon-fibre car I would say you were crazy."

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MEDICAL

Feeling the pressure

Optical sensor could enable measurement of ICP in trauma victims

The new optical device will work on infrared light

BY GLYNN GARLICK

An optical probe could allow doctors to continuously measure intracranial pressure (ICP) in trauma victims using a non-invasive method.

Dr Justin Phillips has received £46,000 through a Royal Academy of Engineering and Leverhulme Trust Senior Research Fellowship so he can develop the device. The money will allow him to undertake research for a year from September, by paying for a lecturer to cover his teaching and admin work at City University London.

"This is an optical sensor so it will work on infrared light," said Phillips, a senior lecturer in biomedical engineering at the School of Mathematics, Computer Science and Engineering.

"The skull is fairly transparent to infrared, so the light passes through the skin and the bone and penetrates the brain tissue. The arteries in the brain are pulsating just like the arteries everywhere else.

"The probe detects some reflected light, and the light is reflected from the brain tissue and it is modulated by the pulse, so as the arteries pull an entry in time with the heartbeat, they absorb a differing amount of light and you can record a pulse signal. By analysing the shape of the pulse signal, we can work backwards and calculate the pressure surrounding the arteries, which is the pressure we are trying to measure."

One problem to overcome will be eliminating readings from blood vessels in the scalp, Phillips said.

Raised ICP is a life-threatening condition that can result in the compression of brain tissue and a reduction in the flow of oxygenated blood to the brain.

Standard methods of monitoring are invasive, involving drilling the skull and inserting a sensor in the brain. Non-invasive methods such as examining the retina or eardrum do not offer continuous monitoring and are tricky to perform.

Phillips previously worked on developing invasive methods of monitoring cerebral oxygen saturation in head-injury patients using fibre-optic sensors. He now works on non-invasive monitoring, so his research will combine his past with his present.

He expects the sensor will be self-adhesive and about 5cm long and 2cm wide. It will be placed on a patient's forehead and connected to a display to provide a continuous reading of the ICP.

ENERGY

Increased concentration

Researchers develop method of solar-powered energy production

BY JULIA PIERCE

Researchers at City University London are developing a method of reliable, storage-free, solar-powered energy production that requires only half the land of photovoltaic cells for the same power output.

The concentrated solar power system (CSP) coupled to micro-gas turbines (MGTs) can be installed in standalone mode to provide electric power for remote locations without grid electricity or can produce carbon-free power for the grid.

The MGT converts thermal energy to mechanical power, which can be used to generate electricity. The system is expected to be modular, with each unit producing power in the range of 3–10kW.

The units can be stacked to form larger power plants in a similar fashion to photovoltaic solar parks or wind farms. However, they can also include a combustion chamber fuelled by gas or biofuels to produce electricity when the sun is not shining, reducing the need for expensive energy storage.

The technology is part of the EU-funded Optimised Microturbine Solar Power system (OMSoP) project led by Prof Abdulnaser Sayma, which began in 2013 with eight partners from five countries.

"The novelty about the technology that we are developing is to replace the fuel and combustion chamber by a receiver placed at the focal point of a parabolic solar dish," said Sayma. "The concentrated solar power heats up the air before it is expanded in the turbine to produce mechanical power.

"Our research aims at resolving many technological challenges to produce a working unit that can be operated by solar power."

inbrief

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Ready for referendum?

Manufacturers are calling for a referendum on EU membership to take place at the earliest opportunity in order to alleviate uncertainty engulfing industry. The call was made by EEF ahead of the expected publication of a referendum bill as part of the Queen's Speech. EEF believes it is not in the UK's long-term interest to wait until 2017. Instead, it should take place in May or autumn 2016.

Older and wiser

A new report suggests that older and retired engineers could help develop new products for Britain's ageing population. IMechE's *21st Century Engineering for an Ageing Population* suggests that government and industry should ensure all major contracts for public infrastructure have an earmarked budget catering for older users.

Vision of the future

The government is being urged to help in the creation of an 'industrial revolution' in schools and colleges, quality apprenticeships and industry-focused higher education. The Skills Vision – handed to the business secretary Sajid Javid – has been compiled by Semta, the not-for-profit organisation that represents 138,000 companies in advanced manufacturing and engineering.

Worth its salt

Storing hydrogen in salt caverns and converting it into a power source could help meet the UK's future peak energy and load-following demands. The proposal is put forward in an Energy Technologies Institute report titled *Hydrogen – The role of hydrogen storage in a clean responsive power system*. This utilises findings from a study into the technologies used in hydrogen production, stores themselves and the sector that converts hydrogen into electricity.

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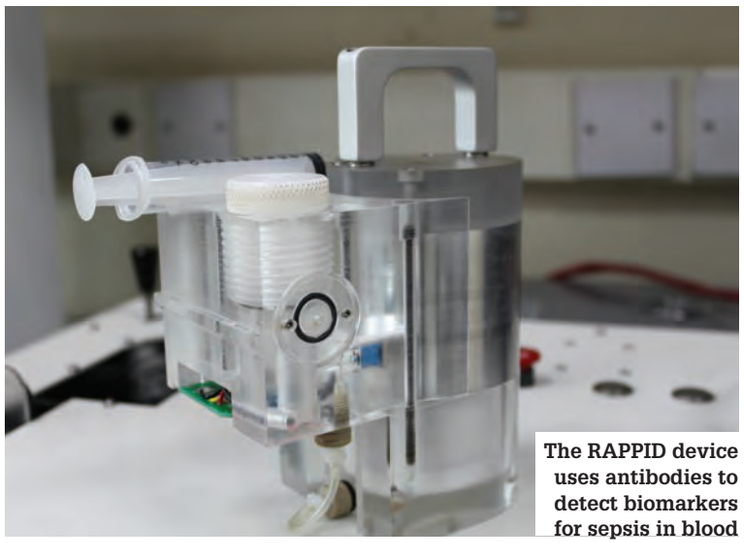


The RAPPID device uses antibodies to detect biomarkers for sepsis in blood

MEDICAL

Device detects sepsis within 15 minutes

UK-developed portable diagnosis tool has successfully completed preliminary trials

BY HELEN KNIGHT

A portable device designed to diagnose the deadly condition sepsis has successfully completed preliminary trials.

The device, being developed by Leicester-based engineering company Magna Parva with funding from Innovate UK, uses antibodies to detect biomarkers for sepsis within blood samples.

Sepsis is a common yet deadly condition in which an infection triggers an extreme immune response, resulting in widespread inflammation, blood clotting and swelling. If left untreated, the disease can lead to organ failure and death.

In the UK alone, sepsis is thought to kill 37,000 people every year, but despite this there is currently no effective tool for diagnosing the disease.

The RAPPID diagnostic tool is designed to detect markers for the disease from a sample within 15 minutes.

A sample preparation tool first removes the plasma from the cellular material within the blood.

It then concentrates the remaining plasma by vacuum boiling, ready for it to be fed into the biosensor. The plasma is then washed over a chip containing the antibodies.

If there are any sepsis antigens within the sample, they will bind to the antibodies, causing the system to resonate at a particular frequency under certain wavelengths of light, explained company director Andrew Bowyer.

"There are a phenomenal number of biosensors out there, but they all need sample preparation, meaning that the sample has to be cleaned up or concentrated first, and that has to be done within a laboratory environment," said Bowyer.

"With the RAPPID device we are doing it all in one system," he added.

The device not only identifies the existence of the pathogen within blood samples, but also measures the levels of several key markers, to identify at what stage in the disease the patient is, as well as to ensure the right treatment is given.

"What clinicians want to know is how far along you are in the sepsis curve, and whether you would respond to antibiotics or steroids," said Bowyer.

"So this is a diagnostic tool to aid that clinical decision-making process," he added.

Following the completion of the preliminary trials, the device will now need to be tested in further large-scale clinical trials, in order to ensure that it can be reliably used as an effective diagnostic tool.

The company has announced that it also plans to integrate the sample preparation system into the biosensor itself.

MEDICAL

Developing concept

Low-cost instrument could help prevent deaths from postpartum haemorrhage

BY HELEN KNIGHT

Thousands of women die in the developing world every year from severe bleeding following childbirth. Now a low-cost device designed to prevent deaths from the condition, known as postpartum haemorrhage, has been developed in the UK.

The device, called a uterine balloon tamponade (UBT), was developed by engineers at product consultancy Cambridge Design Partnership (CDP). It is designed to be simple to use, even by staff without specialist training.

Postpartum haemorrhage is believed to be responsible for 57,000 deaths each year worldwide, the overwhelming majority of which are in developing countries.

In 2012, the World Health Organization recommended that UBT, in which a balloon is inflated inside the uterus to stem the bleeding, could be used to treat the condition when drugs prove ineffective or are unavailable.

However, commercial UBTs can cost a few hundred dollars each, and must be carefully inserted utilising specialist equipment in an operating theatre by trained obstetricians, effectively putting them out of reach of many hospitals in developing countries.

Instead, doctors in the developing world have been trialling the use of so-called "condom catheters", in which a condom is tied to a urinary catheter at a cost of around $5 (£3.25).

But even this cheaper alternative requires some specialist equipment and significant training to assemble and use successfully, according to Lucy Sheldon, human-centred design specialist at CDP.

In contrast, the CDP device is designed to be easily inserted by staff with minimal training, with markings to ensure that it is placed at the right depth without the risk of damage to the uterus.

To inflate the balloon to the required level, the user then simply lifts a liquid-filled bag to different heights, which are again indicated by markings, explained Sheldon. "Gravity works to inflate the balloon," she said.

RAIL & MARINE

Strong points

Research could lead to improved switches and crossings for the UK's rail industry

Robust railway switches and crossings that last longer and require less maintenance are under development at Huddersfield University's Institute of Railway Research.

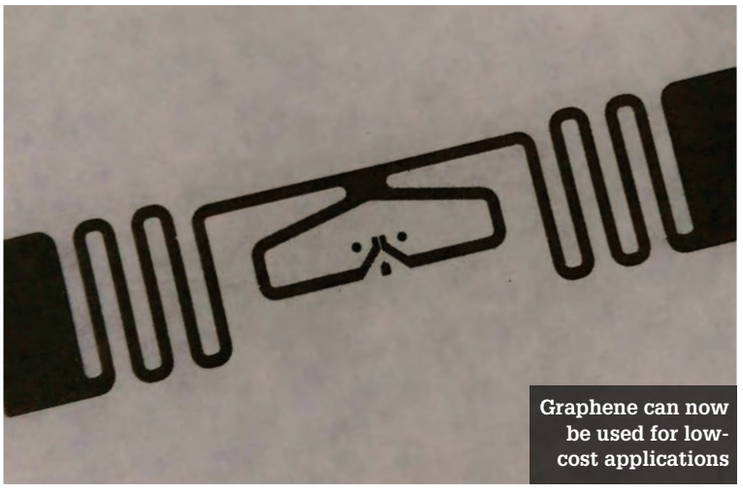
Used to guide trains to their correct route, these 'points' are are prone to wear and tear because the blades of switches are made of thinner rail and also have to take extra-heavy loads as they guide vehicles at speed.

"We are modelling the contact between the wheel and rail,' said Prof Simon Iwnicki, director of Huddersfield's Institute of Railway Research.

"We will also be looking at the rails' support structure," he added.

"The models have the ability to model problems such as a gap under the track, so we can see how this affects the forces over this. The ideal is to guide the wheel over the switch as smoothly as possible, which can be achieved by changing the track support's stiffness or the wheel geometry."

The research is part of a £6.5m, five-year EPSRC-funded project named Track to the Future. ***JP***



Graphene can now be used for low-cost applications

ELECTRONICS

Printing graphene is a delicate matter

Material can now be created more cheaply

BY HELEN KNIGHT

A low-cost method for printing graphene onto materials such as paper and plastic could take industry a step closer to low-cost consumable electronics.

Graphene, a sheet of carbon just a single atom thick, has previously been hailed as a wonder material thanks to its strength and conductive properties.

But to date the process used to make printable graphene ink has limited the surfaces it can be applied to, making it unsuitable for low-cost applications.

Now, researchers at Manchester University have developed a technique to allow graphene to be printed onto even delicate materials such as textiles, paper and plastic, according to Dr Zhirun Hu, lead researcher on the project.

The researchers published their results in the journal *Applied Physics Letters*.

"The ink could be used for low-cost consumable electronics such as security RFID [radio-frequency identification] tags or wearable electronics," said Hu.

To make a printable graphene ink, flakes of the material are mixed with a solvent.

Conventionally, a binder such as ethyl cellulose is also often added, in order to help ensure that the resulting ink sticks to the surface, while also increasing its conductivity.

However, these binders can only be used once they have been broken down via annealing. This means the material cannot be applied to heat-sensitive materials such as paper or plastic, as they could not withstand the process.

To counter this, the researchers have developed a technique to improve the conductivity of the graphene ink without the use of binders. The ink is first printed onto a surface and allowed to dry, before it is then compressed with a roller.

> **"The antenna performed well enough to be used in wireless sensors**

By compressing the ink in this way, its conductivity is increased by 50 times. The resulting graphene laminate is also almost twice as conductive as those inks made with a binder.

"[Before rolling] the graphene flakes are not well connected," explained Hu. "So when you press them, you get a good contact between each individual nano-flake, and that increases the conductivity."

To test whether the new ink would be suitable for use in wireless applications, the researchers printed an antenna, 14cm long and 3.5mm wide, onto a sheet of paper.

The antenna performed well enough to be used in RFID tags and wireless sensors, according to Hu.

MEDICAL

Smart mobility cane spots familiar faces

Blind people are alerted to friends and family

BY HELEN KNIGHT

A smart walking cane equipped with facial recognition technology could allow blind people to identify approaching friends and family members.

The XploR mobility cane, which is being developed by students at Birmingham City University using smartphone technology, is said to be capable of recognising faces up to 10m away.

When the cane detects a recognisable face from the bank of stored images on its internal SD memory card, it alerts the user by vibrating.

It then guides him or her to the friendly face utilising audio commands transmitted through a Bluetooth earpiece.

The lightweight walking cane is also equipped with a GPS receiver, allowing it to help the user navigate around unfamiliar areas.

The cane is being developed by three information, communication and technology (ICT) students at the university: Steve Adigbo, Waheed Rafiq and Richard Howlett. Adigbo's grandfather is blind, so the student has first-hand experience of the needs of the visually impaired.

Before developing the walking cane, the students visited the Beacon Centre for the Blind in Wolverhampton, to carry out market research as well as to determine which key features would make the device most helpful to users.

As well as a desire for high-specification technology features, people at the centre stressed the need for the cane to be lightweight and easy to use, according to the students.

The team is now planning to return to the centre later this year to give people there an opportunity to test the walking cane, as well as to explain the device's training and security features to them.

The students have already presented their XploR cane to medical and healthcare companies in France and Luxembourg, and they plan to travel to Germany later this year, to meet with other organisations.

The project forms part of LILA, a European initiative designed to encourage entrepreneurship.

ENERGY

Moving experience

Radar could cut costs in the energy sector

Space-based radar technology could help reduce costs in the energy sector. Synthetic aperture radar (SAR), which is carried on spacecraft including Europe's Sentinel-1, is able to detect slight movements of a few millimetres.

Energy companies could use it for the structural monitoring of offshore wind turbines, detecting fallen pylons or identifying sites for turbines, according to academics at Strathclyde University.

"A lot of what we are looking at doing, trying to talk with the energy sector, is really to say to them 'here are things that are already happening and being used elsewhere' and taking proven technologies and applying them to different challenges," said Dr Malcolm Macdonald, director of the Scottish Centre of Excellence in Satellite Applications at the university.

SAR uses the motion of its antenna over a target region in order to provide finer spatial resolution than is possible with conventional beam-scanning radars.

The distance the SAR device travels over a target creates a large 'synthetic' antenna aperture. Usually the larger the aperture is, the higher the image resolution becomes. *GG*

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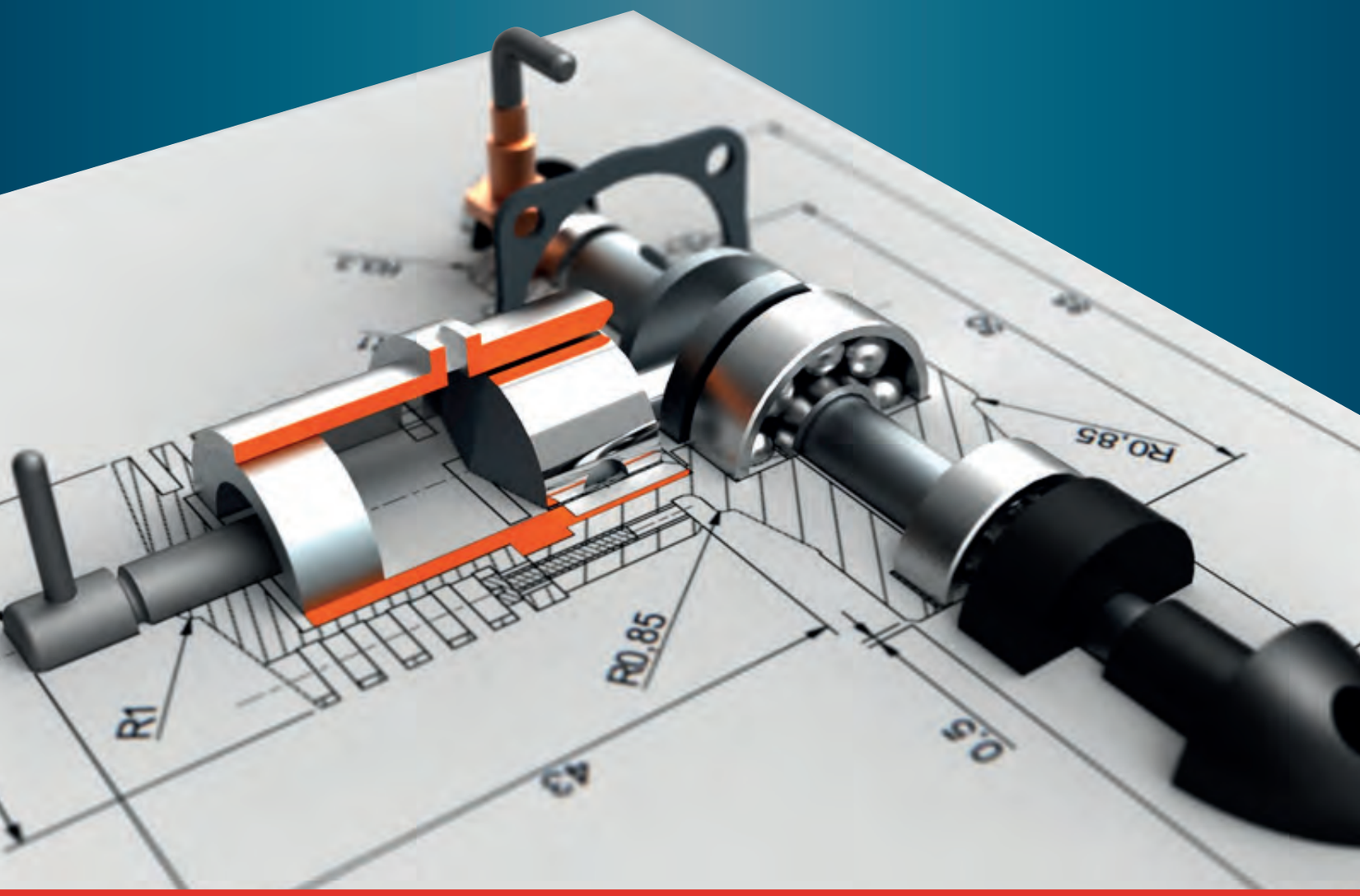

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Let the sun shine in

The drive for clean technology has resulted in a 'race to the top' for the photovoltaic research community, says Prof Ravi Silva

It is nearly 40 years since the discovery of electrically conducting polymers by Prof Alan Heeger, Nobel Laureate, and nearly 30 years since the first organic heterojunction photovoltaic (PV) device was reported. Given the concentration of research undertaken around the world, organic (including organic-inorganic hybrid) solar cell technology is now a maturing technology, with academic breakthroughs progressing in increasingly rapid timescales.

The drive for cost-effective, clean technology has resulted in a 'race to the top' for the PV research community. Innumerable headlines point to 'hero' devices that deliver 'miracle' discoveries; however, there are issues in giving these reports the 'benefit of the doubt'.

The reporting of organic PV (OPV) device and material performance mirrors that of a number of technologies in recent years, where discovery is hyped and, after initial interest, becomes undervalued by commercial representatives.

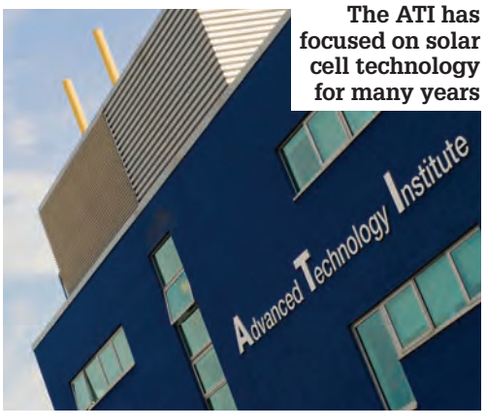
This issue has undermined the solar cell research community. Based on a study by Zimmerman *et al*, carried out on 375 publications in peer-reviewed journals, the authors identified (by comparing the short-circuit current density obtained through the current-voltage sweep versus quantum efficiency measurements) that a significant fraction (more than 37 per cent) of publications overestimated device performance.

Robust reporting methodologies and measurement protocols are not being widely adopted in the PV research community. This may be because in the initial stages of PV development there was no clear understanding of the protocols. However, it is now nearly a decade since Shrotriya *et al* described measurement procedures for characterising organic PV.

With the ever-increasing focus on obtaining higher device power conversion efficiencies (PCEs) for OPV, there is a need to ensure devices are measured accurately.

Typically, the devices reported within this 'race to the top' are single devices with little evidence of repeatability or simple statistical analysis of a sample population. This gives an overestimate of performance capabilities, undermining the technology in the eyes of industry.

National measurement institutes offer standardised measurement facilities for ascertaining PV device performance, but are invariably expensive and time consuming. Given that a researcher may change the formulation of OPV layers on a weekly basis, the process is not cost effective for researchers. This causes research groups to report against similar reference devices fabricated in their laboratories, with the associated variation in production and measurement quality.



The ATI has focused on solar cell technology for many years

> **"Any incorrect belief formed in development will lead to a lack of confidence in the field**

Venturing beyond selective estimates of performance, it is also sobering to note how these reports are erroneously placed in the context of the research field as a whole. Consider the well-known PV efficiency chart created by the National Renewable Energy Laboratory (NREL) as a guideline. Although researchers place confidence in the chart, it needs to be questioned if the chart itself is the best source for the comparison of technologies.

For example, can perovskites with 18 per cent efficiency over a few square millimetres be compared to a crystalline silicon cell that can deliver 25 per cent over ~144cm^2? Moreover, the former have been indicated on the NREL chart as being unstabilised. So is the comparison often made with silicon PV technology appropriate?

Shouldn't a system that is considered to be a promising contender as a future PV technology display a sufficient level of stability for it to be incorporated into such an important performance chart? This is not to devalue the potential of perovskite technology, once scaling and manufacturability of large-area devices has been achieved. But in the case of crystalline silicon, the technology took more than two decades to mature, and expecting solution-processed PV products to be purchased over the counter in a few years enters the realm of fantasy.

Clearly, the research community should be careful, as any incorrect belief formed in the development of the technology will, over time, lead to a lack of confidence in the field. Similarly, policy makers and funders need to note the time spans required to deliver real-world products.

Although the ultimate aim is to contribute to finding a solution to the renewable energy problem, it is imperative that performances reported for PV technologies become aligned with 'best practice' so we build on the work carried out in laboratories around the world towards a greener and more sustainable future.

Solar cell technology has been a focus of Surrey University's Advanced Technology Institute (ATI) since 2002. Its work has focused on the application of inorganic nanotubes and nanoparticles in OPV devices. Working directly with industry has resulted in the integration of carbon nanotubes that act as additional charge generation sites that help increase the current extracted and improve device performance. Industrial collaboration has also ensured that the ATI focuses on devices whose performance values are realistically achievable during the transfer of knowledge from lab to manufacturing plants.

This article is based on correspondence from the Advanced Technology Institute in the journal Nature Photonics, *published April 9 2015.*

Prof Ravi Silva Director of the University of Surrey's Advanced Technology Institute

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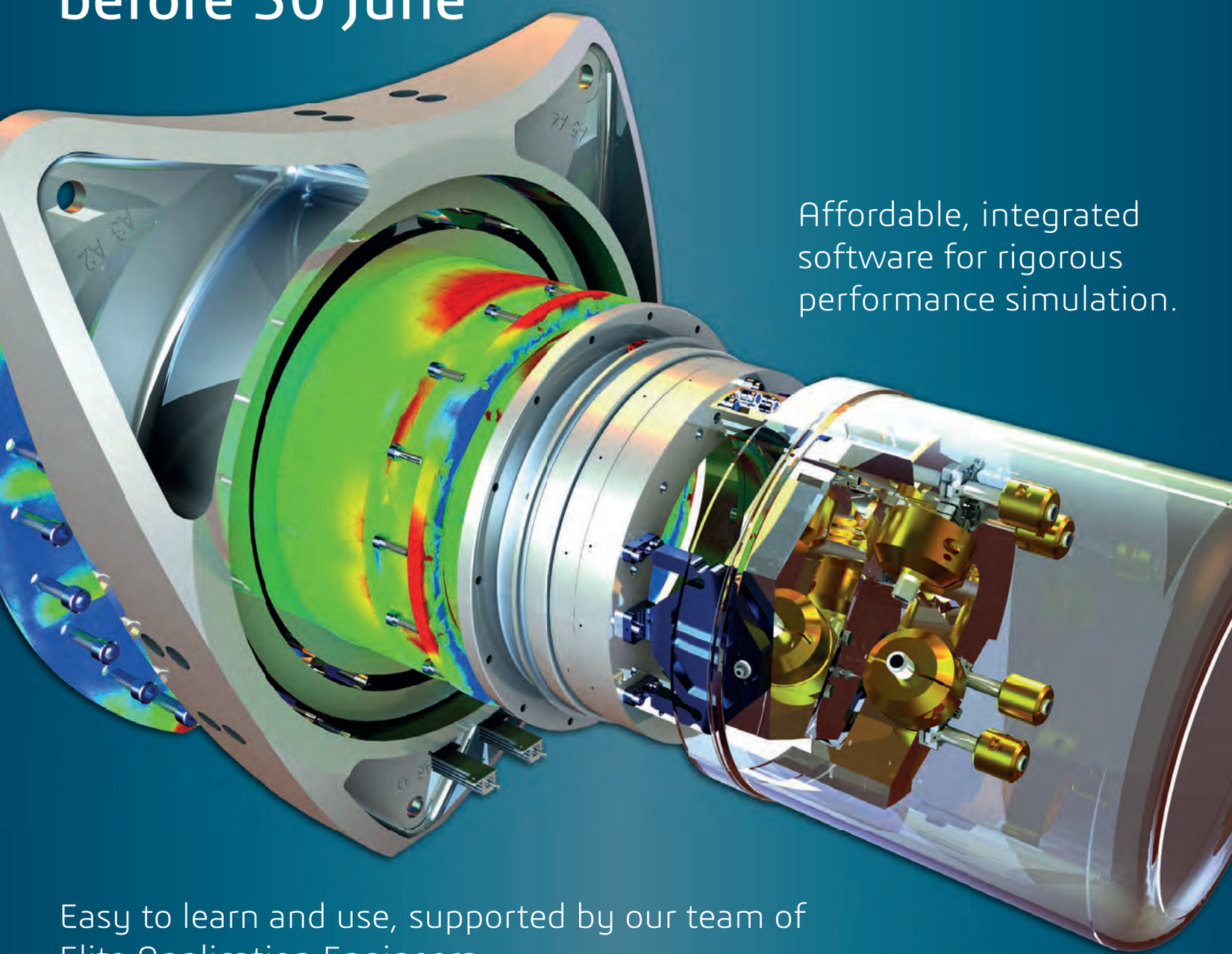

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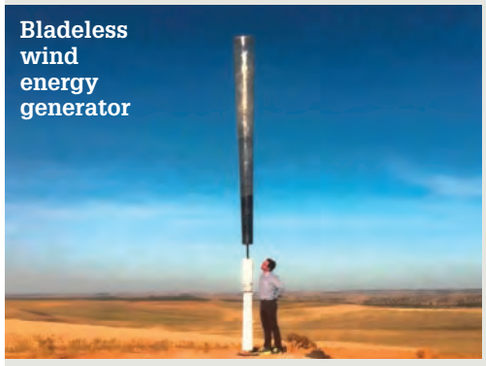
Spanish company proposes bladeless 'wind turbine'



Bladeless wind energy generator

Our report on a new type of bladeless wind energy generator attracted both interest and scepticism

I doubt this device will make enough energy to justify its manufacture. It just doesn't intercept enough area of wind or create large enough movements for a cost-efficient generator.
John Barton

The previous comment is an obvious issue, but I would assume you would have many of these poles together in an array to extract the energy from the wind. Personally, I have often thought that there are many other elegant ways to extract the energy from the wind beyond the currently in-vogue methods. I'm not sure that deliberately designing something to vibrate is a good idea because it will lead to cycle fatigue problems in everything that is mechanically connected.
Chris Longbottom

Sounds like something-for-nothing syndrome. Anyone remember cold fusion?
Anonymous

This is nothing more than an academic curiosity. Look at their website and then make your mind up. As has already been said, this is much less efficient than a bladed generator and the vibration will snap it off at the bottom due to fatigue. They say it is silent – the vibration is directly coupled to the ground; would you want to live near that? Sorry to be negative, but this won't go anywhere except into the archives of failed crowdfunding projects.
John Moran

What a load of nonsense. This has nothing to do with reality and they clearly don't understand how a real wind turbine works by efficiently extracting energy way above the ground where the wind blows the strongest.

Chris P
Fantastic idea. Go ahead and build them. Only then we'll see if the technology works or not. I vote for the 'can do/si, se puede' attitude on this. If only there would have been so many 'bring it down' comments when all the time-wasting and dumb-inducing apps, smart (?!) watches, virtual-reality eyeglasses, violin-playing or crepe-flipping robots and a gazillion other useless stuff were not only created but funded in the billions. We need the best and cleanest energy technology urgently, so this Spanish company would get my investment. It would be also an emotional homage to the engineer who built the Tacoma Bridge and stood on it in great pain while the wind was destroying it under his feet.
Sylvia Leahu-Aluas

All you naysayer self-appointed experts think you know everything. It's not a conventional turbine and so what if it does not output as much? It won't kill birds, make lots of noise and flicker. Materials are available that can last many thousands of vibrations without snapping off. Maybe that part can be swapped out periodically – who knows? Certainly not you know-it-all people. Nothing is perfect in the first version; at least they are working at it.
Nick G

Maybe this would work; it stands a chance if it's made strong enough. And maybe if they used a solar array around its column, it could also generate when the wind isn't blowing.
TykeEng

inyouropinion

EUmembership

Strong opinions abounded in response to our poll on the renegotiation of the UK's membership of the EU.

■ In the US, we are dealing with a terrible trade deal proposal that could be devastating to commerce and the worker (engineer). It is the Trans-Pacific Partnership (TPP). If the UK has any chance of getting out of 'partnerships' like this, or not entering into them, do it. They are nothing but a hindrance to commerce and the growth of a nation. They sap monetary funds from the government that could be better spent elsewhere. Our legislative bodies are being railroaded into passing the TPP into law without getting a chance to read and discuss the documentation. Maintain your independence, UK. Stay united against the tyranny of greed.
Thomas Crowell

■ The whole EU issue is rather populistic. Take the movement of people. Gay German engineers can't marry in Germany, but they could marry in England and Ireland. And now Britain wants to block them from coming here? Great timing.

If Cameron wants to stop immigration into 'benefits street', he should change the laws for everybody. With child support for children that don't live in Britain, that's easy: apply at the council where the child lives. Provide regular health screening for children. If children do not appear at the health screening, check the parents for neglect. Compare data for screening and child support.

From a technical point of view, Britain should encourage critical thinking and creativity from an early age. Reduce the pressure from children and young people. Let them develop relationships and art in kindergarten until age six. There is still enough time to learn reading, writing and calculus. I also think that marrying and joining the army at 16 is too early. Sixteen is the right time to start an apprenticeship.

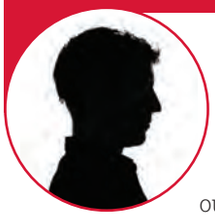
Looks like there are many thing more pressing than leaving the EU. First of all, make children and youth calmer; less excited, less excitable, fewer knife fights, less stressed. More time to think and dream and make proper decisions.
Ralf

■ Membership of the EU has made the UK lazy, introverted and less 'gung-ho' in chasing overseas business. So-called experts talk of an EU market of 500 million persons. Just three non-BRIC countries such as Mexico, Indonesia and Nigeria number about 500 million persons. It would be far better, over the next 25 years, to chase the business of emerging economies in Asia, South America and Africa than a saturated, sclerotic, wealth-declining EU. As for EU access, an EFTA along the lines of Norway and Switzerland is a better scenario for the UK over the next 25 years. The above would enrich the UK far more in making it way more zealous in chasing overseas trade and high-value orders from large, reasonably immature, much faster-growing economies. We should also back ourselves a lot more than we currently do.
Mike Brennan

■ Restricting immigration? How do we get a motivated, educated and skilled workforce to work in industry? My company employs a lot of so-called immigrants at every level. They are far better employees than the UK equivalent.
Ken Warden

■ My industry is highly regulated at UK and EU level. It is only thanks to common standards that we can export all over Europe. If the UK was to leave the EU, the whole gas boiler industry would still have to adhere to European legislation.
M Matthewson

thesecretengineer



Our anonymous blogger reflects on one of the few times he's had reason to proudly proclaim his profession to a stranger

The Engineer is the pre-eminent publication for our profession. Therefore, unsurprisingly, I regularly make my way through the articles online. One piece that recently caught my eye was about the way engineers are portrayed in popular culture, the responses of the readership being as interesting as the original text. It brought to mind one of the few times that I had reason to proudly proclaim my profession to a stranger.

Returning from holidaying in Devon, my wife and I decided to take in the scenic splendour of East Prawle and, after a pleasant wander among the verdant fields, we settled at the Pig's Nose Inn for lunch. Soon after our food arrived the electricity failed and then we were asked to leave due to the small matter of a fire having broken out. Naturally we took our beer and sandwiches with us onto the green, but by the time we had finished them there was still no sign of the fire brigade.

The family who owned the pub didn't seem technically minded so I wandered towards the smoke and got chatting to another holiday maker. He turned out to be a senior technical bod at a red-brick university. We stepped in and soon located the vintage exposed fuse board that was ablaze; it was high up over a large fridge and next to a small open window that we couldn't get to.

We gathered as many CO_2 extinguishers as we could and sent the family outside. My new-found colleague switched the mains feed off using a wooden broom handle and between us we contained the fire. Unfortunately, due to the window, we couldn't get it completely out.

At one point, I got the young lad of the family to take me to a couple of additional fuse boards in order to isolate it, thinking this might help if copious amounts of water was required once Fireman Sam showed up. Soon after that we ran out of extinguishers. Having agreed it was time to get the hell out, we made sure the building was clear and then left it to burn. Thankfully the fire engine turned up a couple of minutes later and the pub was saved.

It was while isolating the building that the lad asked me if I was a fireman. Taking full advantage of the situation, I looked him squarely in the eye and after a moment's pause replied: "No son, I'm an engineer."

Scotty: the most trustworthy engineer ever

Join the debate at **www.theengineer.co.uk**

Oilprices

Our Viewpoint on the implications of low oil prices by Gordon Edge of Renewables UK gathered a spread of opinions.

■ With lower fuel costs, construction of renewable energy power stations will be cheaper. Actually, the right time for installing renewable energy stations is when construction costs are low. When the prices jump, you want to be able to make use of your new equipment.
Ralf

■ This article is based on the presumption that we need to continue reducing our consumption of fossil fuels, and that such fuels are about to run out. Neither is the case. There are plenty of fossil fuels remaining, especially with new methods of extraction being developed. There is also an assumption that the current crop of renewables is a workable alternative to fossil fuels. I say no. Nuclear fusion is the only viable alternative to fossil fuels currently available. We should drop these other 'alternative' technologies as they will never succeed and are reliant on tax payers and energy consumers continuing to subsidise these inherently faulty concepts.
Chris Longbottom

■ Oil is used for electricity generation with diesel-generating sets. In the UK, these are standby power sources but in much of the world they are power sources to off-grid villages. This application is now very vulnerable to solar energy whether on a household scale for new installations or on a village scale for generator set replacement. In these places, the cost of fuel delivery can be huge, irrespective of the cost of the fuel itself.
Philip Owen MIET

■ As a counter to green dreams, let's return to engineering reality. From *The Daily Telegraph*: Prof Colin McInnes, James Watt chair of Glasgow University's school of engineering, told MSPs the closure of the nuclear plants and Longannet means a "reconfiguration of our energy supply from one which is dependable to one which is intermittent". He added: "I worry we're over-egging onshore wind to the long-term detriment of affordable electrical energy."
James G

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Going the distance

The skills, knowledge and drive of the young engineers taking part in this year's Shell Eco-marathon were clear for all to see

One way to describe the function of engineers is to say they find solutions to problems. The rising cost, and in some cases the diminishing availability, of fuel means there's a real need to come up with new ways to power getting from A to B. In recent weeks, I've come across two interesting examples of how engineers are applying their knowledge of fuel consumption to power vehicles: the first is to see how fast you can go in a manure-powered bus; and the second is to go as far as possible on one litre of fuel (or equivalent).

The 'Bus Hound', painted to look like a Friesian cow, was powered by liquefied biogas produced from cow manure. It managed to set a land speed record for a standard bus by clocking up a lap speed of 77mph – pretty impressive when you consider it wouldn't normally go above 56mph. The chief engineer involved said the stunt was aimed at bringing to light the viability, power and credibility of buses fuelled in this way. I'd say it's certainly done that, particularly as Reading Buses has now challenged other operators to try to beat its time.

More remarkable in my book, however, were the entries for this year's Shell Eco-marathon in Rotterdam. With 200 student project teams from nearly 30 countries racing, with a choice of seven types of fuel, there are some wonderful vehicles on show – all designed to eke out that last 'drop' of fuel. The skills, knowledge and – if you'll excuse the pun – drive of the young engineers taking part were clear for all to see. You can't make a vehicle travel the distance from Rotterdam to Moscow on a litre of fuel without putting the hours in. That's an incredible 2551.8km/litre; compare that with the winning 320km/litre in 1985 for a sense of the impact of engineering innovation in this field.

The competition was fierce and the innovations truly inspiring, but the Eco-marathon is much more than the competition. As well as the main attraction, the organisers invite local schools and families, engaging them in hands-on activities, talking to real engineers and scientists and getting them thinking about where science and engineering could lead them.

It was interesting to see that the team there also wants to highlight the breadth of options and opportunities within engineering. This mirrors the approach of activities within the Tomorrow's Engineers programme, including the current Energy Quest and the Big Bang programme that brings to life the science, technology, engineering and maths being taught in the classroom at national, regional and local events.

> **"The innovations were truly inspiring, but the Eco-marathon is much more than the competition**

While Berkshire residents may tell the tale of the black and white 'cowpat-powered' bus, I would hope that the young engineers participating in the Eco-marathon and those who went along with their classmates and families will be inspired to learn to do more. I hope their experience has a real impact both in terms of their future engagement with the engineering and design principles involved and the contribution those ideas may make to the future reduction of energy consumption.

From next year, the Eco-marathon will be held in the UK, providing a global platform to showcase the UK's young engineering talent. We must drive more UK entries to the competition and seize the opportunity of a major event at an iconic London landmark to inspire the competitors and innovators of the future.

The winner of the prototype hydrogen fuel cell class at the 2015 Eco-marathon, from Eco-Runner Team Delft of Delft University of Technology

Paul Jackson is chief executive of EngineeringUK

Jewel in the crown

An ancient form of metalworking is being used to create turbine blades for jet engines. Stuart Nathan reports

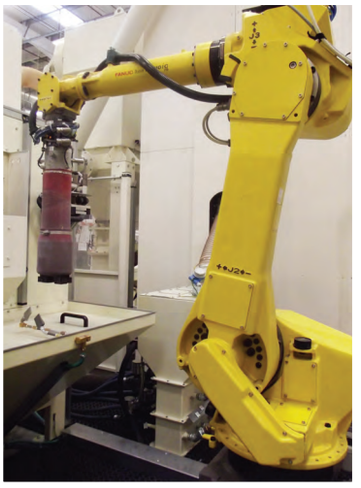
Casting is one of the oldest and most basic methods of metalworking. If you can make a fire hot enough to melt a metal, and manufacture a crucible to melt it in and a mould that can withstand the heat, you can cast complex metal forms; and we've been doing it for millennia. The oldest-known casting is a copper frog made 6,000 years ago in Mesopotamia. Many of the gleaming marble sculptures of Ancient Greece are in fact more recent Roman copies of originals that had been cast in bronze: the few surviving originals, such as the Riace Bronzes of Greek warriors found in the sea off Sicily, show the incredible sophistication and level of detail achieved by these long-dead masters of metals.

Yet this most ancient of skills is still in use today, and indeed is still being developed. Its most recent incarnation is arguably the most advanced procedure that has ever been undetaken in metals, and is vital for one of the emblematic activities of the modern world: routine air travel. It is to be found in the UK's historic centre of metalworking, Sheffield, at Rolls-Royce's Advanced Blade Casting Facility (ABCF), a facility purpose built near Sheffield University's Advanced Manufacturing Research Centre in Rotherham.

The components the ABCF is producing are not ones that most people ever see: they are the turbine blades that are hidden away in the hottest part of jet engines. For from the decorative brilliance of Greek bronzes, they combine a utilitarian appearance with complexity of form and function and a jewel-like internal perfection: weighing only about 300g and small enough to fit in the palm of a hand, they are in fact perfect single crystals of a metal alloy whose composition has been fine-tuned over many years to operate in the hellish conditions of the fastest-moving part of a jet engine.

"Back at the birth of the jet engine, Sir Frank Whittle's prototypes were made entirely of steel," said Rolls-Royce chief of materials Neil Glover. "Steel is great for strength and surface hardness, but if you need high-temperature performance it isn't actually very good; 450–500°C is about its limit."

Its unsuitability led to a search for a more temperature-resistant material, and jet makers turned to nickel alloys. Relatively abundant, with large deposits in Australia, and low in price, nickel melts at 1,728K (1,455°C) and is resistant to corrosion – both valuable properties for components that function inside a jet engine. Even more important is its ability to form alloys, and the particular property of one of those alloys, a compound known as gamma-prime in which nickel combines with aluminium, to retain its strength at



Left: **Rolls-Royce's chief of materials Neil Glover and a Trent XWB engine**
Right: **an automated process at the blade casting facility**

high temperatures. "In steel or even titanium, the strength rapidly drops off as you reach 40–50 per cent of the melting point," Glover said. "Nickel alloys retain their strength up to 85 per cent of the melting point."

And engine manufacturers make full use of this property. Jet engines work by positioning turbine blades, which spin in the current of hot gases expanding out of the combustion chamber, on the same shaft as the compressor blades that force air into the engine at high pressure. So at the back of the engine, the low-pressure turbine blades, which operate in a gas stream that has cooled down somewhat, are on the same shaft as the large fan blades at the front of the engine, which accelerate air to generate the engine's thrust. This shaft runs through the middle of the shorter, wider intermediate pressure (IP) shaft, which again has turbine blades at the back and compressor blades at the front. Outside this is the high-pressure shaft, which runs the compressor that forces air into the combustion chamber itself. The combustion chamber is annular, with an exit ring at the back controlling the flow of exhaust gases, and it's here where the single-crystal blades are found. The gases, fresh from combustion, are at around 1,700°C; and the shaft spins at speeds in excess of 12,000rpm.

This means the blades operate in an environment several hundreds of degrees hotter than the melting point of the nickel alloy. To stop them melting, the metal must be cooled. This is done via two mechanisms: the blades are coated with a low-conductivity ceramic; and they are riddled with a complex, branching structure of internal channels. "Air is drawn from the HP compressor, routed through the core of the engine and into the root of the blades," explained Glover. "It passes through the cooling channels and exits through a myriad of holes in the surface of the blade, to create an envelope of cool air around the blade. So the metal is never above its melting point, even though the environment is. The cooling air isn't actually that cool; it's at about 600–650°C, but we have to take it from the hot core of the engine so it has enough pressure to get through the channels and out of the holes. It's still enough to keep the blade temperature down to about 1,150°C."

Heat is vital to jets; the hotter they can operate, the more energy they can extract from their fuel. This is the major point of competition between engine makers, so over the six decades jets have been in operation, forcing the temperature higher, and developing turbine blades that can withstand the heat, has been one of the most important technology races in the sector. It's been a gradual process, Glover said, culminating in the development of single-crystal blades in the late 1980s.

The single-crystal structure isn't intended to cope with temperature, however; it's to make the blades resistant to the huge mechanical loads that result from their rotational speed. "Every single blade extracts power from the gas stream equivalent to a Formula One car engine," Glover said. "And the centrifugal force on them is equivalent to the weight of a double-decker bus."

Normally, metals are composed of many crystals – ordered structures of atoms arranged in a regular lattice, which form naturally as the metal cools from a molten state. These crystals are typically of the order of tens of microns in size, positioned in many orientations. At high temperatures and under strain, the crystals can slide against each other, and impurities can diffuse along the boundaries between the grains. This is known as creep, and it badly affected early turbine blades, which were forged from steel and later nickel bars.

The first stage in development was to get rid of any grain boundaries at right angles to the centrifugal loading, which led to the development of blades that were cast so the metal crystals all ran from top to bottom. Later, this was optimised further by casting single crystals, with no grain boundaries at all. It's a highly complex process: not only must the blades be cast with the internal cooling channels already in place, but the crystals are not homogeneous. Rather, zones of different composition and crystallographic structure exist within the blade.

"You can think of nickel superalloys like these as being like composites," said Rolls-Royce's aerofoil turbine materials technologist Neil D'Souza.

> **"In steel or even titanium, the strength rapidly drops off as you reach 40–50 per cent of the melting point**
> Neil Glover, Rolls-Royce

"It's a mixture of two phases, one of which – gamma-prime – gives rise to the sustained increase in strength at high temperature."

When it crystallises, nickel forms a structure known as face-centred cubic (fcc); each cube has a face with five atoms, one at each corner and one in the middle. When alloys are made, generally the atoms just swap in and out of the fcc lattice. But under the right conditions, aluminium and nickel combine in such a way that nickel goes to the centre of the faces and aluminium to the corners. This is known as a precipitate; it forms islands of greater order within the bulk of the alloy, about half a micron in dimension, packed closely together in a rectilinear formation. Because the size of the lattices of the precipitate and the less ordered bulk alloy are almost identical, they are all part of the same crystal. ->

Purple built: **Rolls-Royce's new Advanced Blade Casting Facility**

"We now know that we have consistent product coming out of the wax process, whatever the time of day
Steve Pykett, ABCF

"You could imagine building a ball and stick lattice model," said Glover. "In the bulk alloy, you'd place the balls representing the components of the alloy, about 10 different elements including nickel, aluminium, chromium, tantalum and titanium, pretty randomly, and when you got to the gamma-prime precipitate you'd put in this ordered arrangement of aluminium at the corners and nickel in the middle. It's all on the same regular lattice, oriented the same way, so it's all the same crystal, but you have these much stronger regions where there's the array of gamma-prime precipitate."

But this doesn't just happen naturally. To make the blades, the first stage is a ceramic 'core', of the form of the tortuous internal cooling channels. Wax is injected around this to form the shape of the aerodynamic blade, plus several other features that assist in the casting process. Platinum pins are inserted to support the core inside the wax; then the form is 'shelled' by coating it in an slurry of alumina-silicate material to form a ceramic coat. Several more coats of different compositions are applied and then the wax is melted out to leave a void in the shape of the blade. This is investment or 'lost-wax' casting, the same technique those Ancient Greek sculptors used to make the Riace Bronzes.

Molten metal is then poured into the mould, which is placed inside a furnace to keep the metal molten. At the base of the mould is one of the additional casting features: a helical structure about the same shape as three turns of a standard corkscrew. Known as the pigtail, this is attached to a plate that is cooled by water. Once filled, the mould is slowly withdrawn from the furnace into a cooler chamber. The metal starts to solidify at the chilled plate, and crystals begin to grow into the pigtail. The crystals grow in a straight line in the direction that the mould is being withdrawn, but because of the pigtail's twisted shape, all but the fastest-growing crystals are eliminated. Only a crystal with the correct orientation emerges into the blade mould proper, and the gradual withdrawal of the mould ensures the crystal continues growing through the melt into the rest of the space.

The formation of the vital precipitates results from careful control of the external temperature and from the design of the mould; those multiple layers of ceramic determine how fast the heat from the molten metal can dissipate, and this provides the extra finesse to achieve the required internal structure. The platinum pins holding the core in place diffuse into the alloy without affecting its properties.

Steve Pykett: **manufacturing manager at ABCF**

Once solidified, the casting is removed from the mould and the first of some 20 processes begins to prepare it for assembly into an engine. First, the ceramic cores are dissolved away with caustic alkalis. Then the extra features for casting are machined away. The holes for the cooling air to escape are drilled using electrical discharge machining, which forms the required hole geometry to direct the air to the points where it is needed. Finally, the blade receives its insulating ceramic coating by electron-beam plasma deposition.

The ABCF in Rotherham concentrates on components for large civil airliner engines because, with the advent of aircraft such as the Airbus A350 XWB, for which Rolls-Royce has developed the Trent XWB engine, this is where the company sees its main growth coming from.

Costing some £110m, the ABCF was built to automate as much of the production process as possible. "Single-crystal casting is expensive, and many parts of the process have traditionally been very hands-on," said ABCF manufacturing manager Steve Pykett. "Our people are fantastically skilled, but they're human, and no human is going to produce the same quality of work at the end of a shift as they do at the beginning."

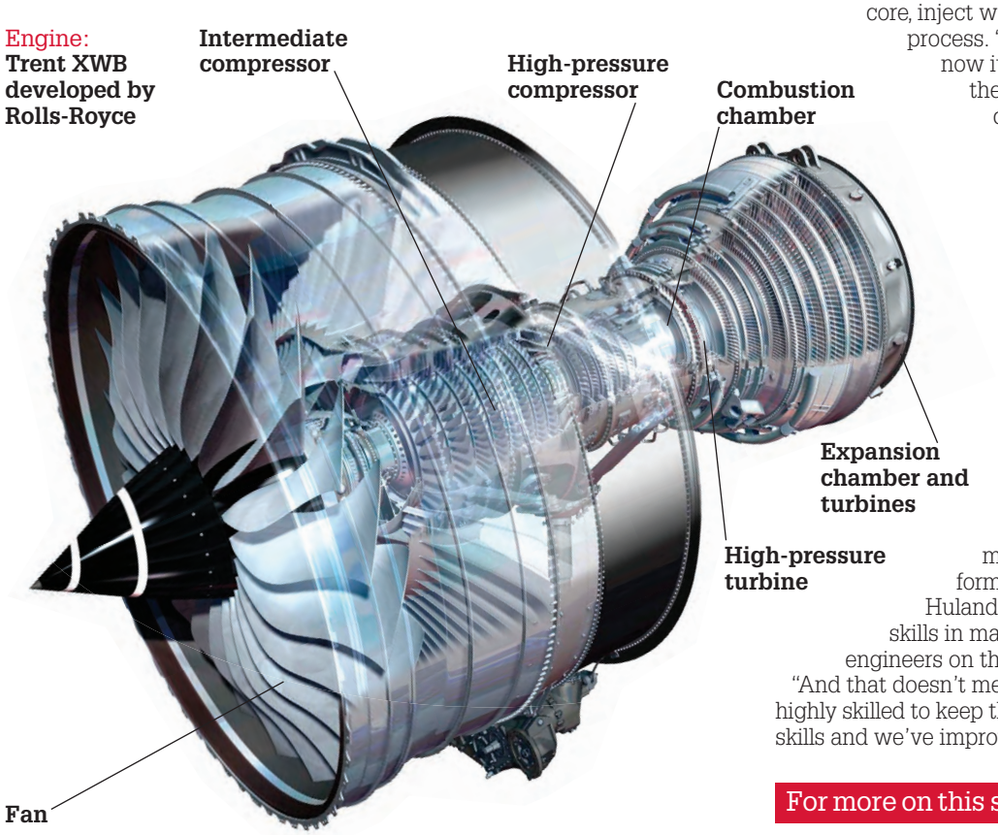
The production of the wax assembly is a good example of this philosophy. "You'll always find a wax room at an investment casting foundry," Pykett said. "It requires hand-eye co-ordination and dexterity to make the wax form, but that doesn't deliver consistency."

Working with the Manufacturing Technology Centre near Coventry, Rolls-Royce developed an automated system to hold the ceramic core, inject wax, pin the core in place and conduct the assembly process. "It used to take a whole shift to make an assembly; now it takes an hour," Pykett said. "But time was not the main driver here. We now know that we have consistent product coming out of the wax process, whatever the time of day, and that gives us a solid platform from which we can reduce cost."

Some other processes have also been automated, including the dressing operation to remove the sacrificial features of the casting. The blades then go into inspection, where Rolls-Royce has replaced five processes with two. The castings are then shipped to another plant at Crosspointe, Virginia, for further machining of the features that will allow them to be attached to their discs in the engine, and for drilling of the cooling holes; they come back to a plant in Annesley, Nottinghamshire, for coating.

"This process is so complex, with precise control of temperatures and materials handling to manage, virtually atom by atom, how the blades are formed," said casting manufacturing executive Mark Hulands. "What we've done is to transfer some of the skills in making these components from the manufacturing engineers on the line to the process developers," Hulands said. "And that doesn't mean we've de-skilled. Our engineers still need to be highly skilled to keep the processes running smoothly, but they're different skills and we've improved the consistency so we can drive costs down."

Engine: **Trent XWB developed by Rolls-Royce**



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Plane sailing

Researchers have developed a design concept for a transatlantic flying boat featuring a blended wing body. Glynn Garlick reports

Classic flying boats lost popularity in the 1950s because they were inefficient compared with more aerodynamic airliners able to fly large numbers of passengers directly to land-based airports.

However, as rules on pollution and noise get ever tougher, limiting expansion at many major airports, the flying boat could be on its way back.

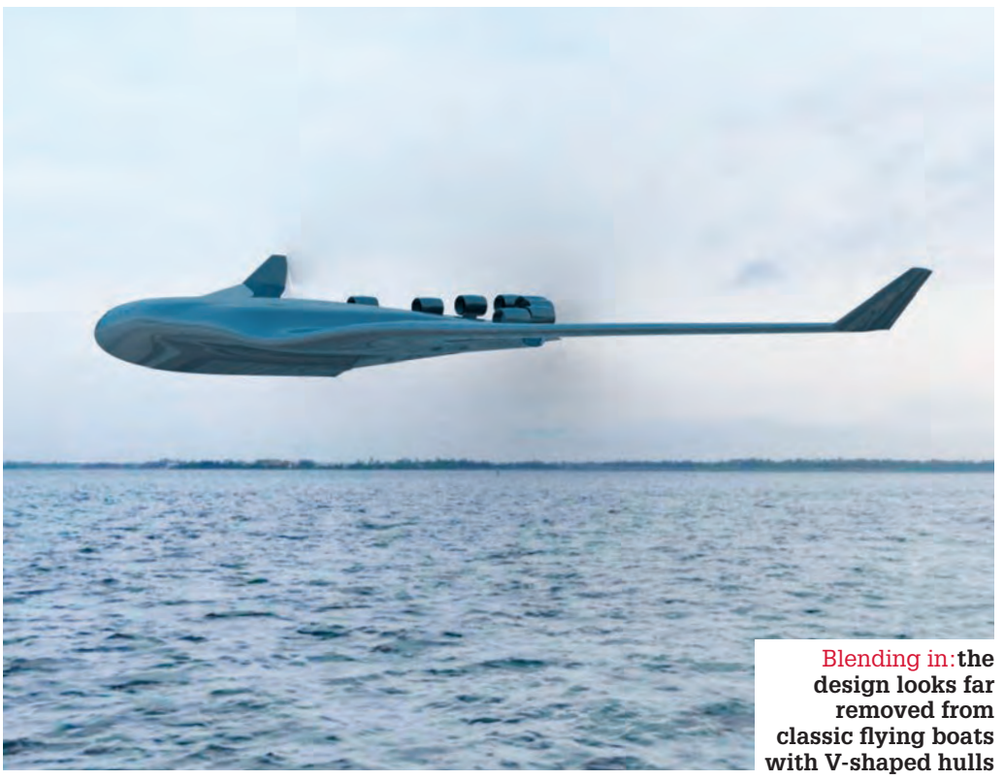
Researchers at Imperial College London have developed a design concept for a transatlantic flying boat that would move the low-level flight paths of large aircraft offshore, away from heavily populated areas.

The design uses a blended wing body and looks far removed from classic flying boats with V-shaped hulls such as the Short Sunderland, the Saunders-Roe Princess or the Hughes H-4 Hercules 'Spruce Goose', but it does meet all airworthiness requirements.

"What we really wanted to do with this project is take a look whether the application of new technology, and the new ideas coming into industry such as blended wing bodies, would actually result in an aircraft that is designed both conceptually, so in the overall configuration, and in the preliminary design process, that can actually alleviate the historical downsides of a flying boat," said Dr Errikos Levis, a teaching fellow at Imperial's Department of Aeronautics.

"Seaplanes of the past had a weight penalty and an aerodynamic penalty, and fuel consumption is inversely proportional to both, basically. So the bigger the weight penalty, the more fuel inefficient you are, and the bigger the aerodynamic penalty, the more fuel inefficient you are."

The team designed a range of aircraft from a 200-passenger model capable of flying 5,600km to a 2,000-passenger behemoth able to fly 15,000km.



Blending in: **the design looks far removed from classic flying boats with V-shaped hulls**

The 2,000-passenger model is about 80m long and 20m high from bottom to tip, and has a 160m span. The Airbus A380 is 72.72m long and 24.09m high and has a wingspan of 79.75m. The A380 has a range of 15,200km and typically seats 544 passengers, although it can carry a maximum of 853.

As far as operating on choppy water and aircraft efficiency was concerned, the researchers found that biggest was best. "The fact you are operating from seas means that you will have to either make a choice to put in wave barriers, maybe somewhere offshore to cut down the intensity of waves coming in, or you are going to have to accept that you are not going to be able to take off some of the time," Levis said.

"Overall, size actually solves the problem, in addition to making the aircraft more efficient overall. The bigger you go, the more likely you are going to be able to use it 24/7, 365 days a year."

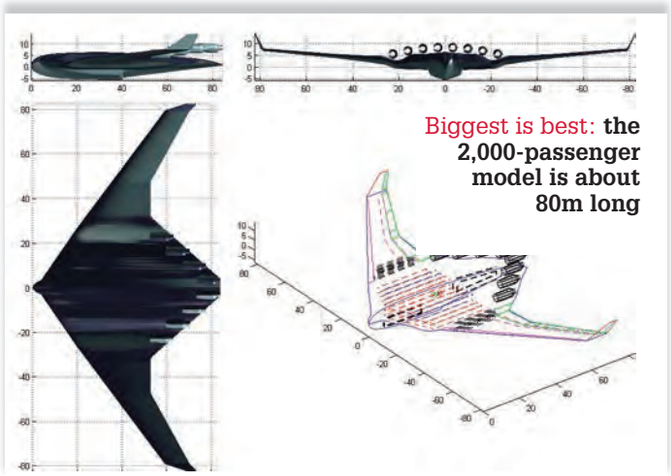
Size also helped to solve the problem of emergency egress from a blended wing aircraft caused by the large number of passengers and the placing of emergency exits dictated by the shape of the craft.

"With traditional blended wing bodies, it is actually a pretty big deal, but in our design, because we have to raise the wings high enough above the waterline so that they don't get hit by spray, there is a very nice, almost vertical or slightly sloped side just underneath the wing that extends the entire cabin length," Levis said.

"Now obviously similar issues to a standard blended wing body will appear here because you have a very high passenger density in the middle and a smaller perimeter area from which they can egress, but this design tries to maximise the surface area available for emergency exits to be placed. It doesn't completely solve the problem but it does go some way towards a solution."

Classic flying boats suffered increased drag and structural weight because their fuselage had to be shaped and reinforced to allow them to operate on water. While the blended wing body design allows the aircraft to float, it offers reduced drag when it is in the air.

"What we found is that by using this particular configuration, we could get rid ->



Biggest is best: **the 2,000-passenger model is about 80m long**

of a lot of the structural penalties that were associated with things such as tip floats," Levis said.

Tip floats ensure flying boats are laterally stable on the water surface. They provide drag and weight, not only by their use but because their weight has to be counteracted by strengthening the wing to take on the extra weight at the tip.

"What we did instead was say is there any way we could use part of the fuselage or part of the wing to provide lateral stability," Levis said. "What you see is there is a hull that rides up. Outboard of that there is a proportion of the fuselage that stays almost parallel or even has a little anhedral [goes downwards]. That means that the aircraft can actually right itself and maintain itself on the water using a very thick piece of structure that doesn't need to be strengthened substantially because it is already supposed to take substantial loads when flying."

The design needs to have excellent fuel efficiency if it is to compete with traditional aircraft. Current state-of-the-art aircraft require around one to 1.1 megajoules per available seat kilometre, Levis said. "For a 550-passenger aircraft, we are getting 1.149 megajoules per available seat kilometre, and going up to 2,000 we can get that down to 0.94, so it is substantial improvements, although that assumes that we can fill the aircraft."

The engines are on top of the fuselage, which limits the effects of spray. The design was found to provide a massive amount of empty volume in the lower part of the fuselage, as passengers cannot be underneath the waterline for safety reasons. This led to the idea of using alternative fuels such as hydrogen, which is more environmentally friendly but takes up about four times the volume per energy given compared with Jet A-1, according to Levis.

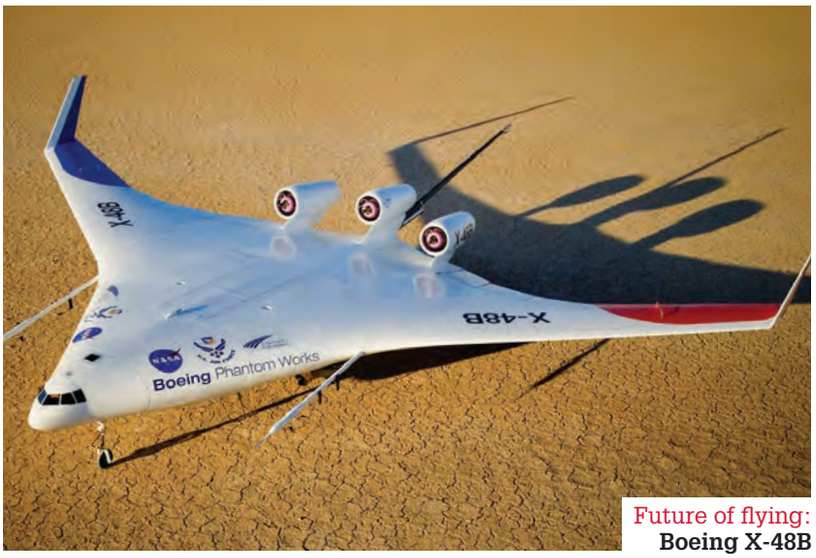
Using advanced materials would also help provide the improved efficiency required. "As far as materials available we were thinking of using advanced composites throughout," Levis said. "The problem is that in early design you can't really quantify the exact effect that a particular composite would have, so we actually stuck with assuming a conservative assumption of five to 10 per cent weight reduction due to that, which seems to me the value that aircraft designers are hoping for to be achievable when using composites and advanced methods."

The aircraft would be fuelled in the same way as a conventional airliner, while maintenance could be undertaken in a dry dock. Another option might be a beaching cradle allowing the aircraft to get in and out of the water using its own power, as seen with the Martin SeaMaster in the 1950s, although the sheer size of the design might prevent this.

However, that size allows more passengers, and could lead to less metal in the sky, and aircraft flying to coastal airports, according to Levis. Although more infrastructure would be needed than for an old-style flying boat, it should be smaller and cheaper than that needed to build or expand inland airports to allow them to welcome ultra-large aircraft.

"Out of a number of the biggest hubs out there or the many cities that are expected to become massive, a big percentage of those are either on the coast already, and the airport is already coastal, or the city itself is within 50 miles from a coast, which is reasonable enough for transport with high-speed railway or something."

Seaplane of the past: **Saunders-Roe Princess**



Future of flying: **Boeing X-48B**

Levis stressed that the aircraft was a non-optimised design and more detailed modelling was required. One issue the team faced was a lack of data on the constraints of using the ocean as a runway. To overcome this, very conservative estimates were used in terms of weight and power, so more detailed modelling could lead to an aircraft offering even more efficiency.

"Things we are looking at are ground effect aerodynamics; how the aerodynamics of the aircraft would work in this particular configuration in ground effect," Levis added. "One of our hopes is that it would possibly allow us to land slower, thus relieving some of the stresses on the fuselage, thus allowing the fuselage to be lighter as well.

"We are trying to develop better methods for the weight estimation of the fuselage itself, something that is rapid but accurate, as within an optimisation framework speed of computation is actually very important.

"We are also looking at the aerodynamics in a bit more detail and the hydrodynamics of how it is going to take off; how the unique intricacies of this particular design affect it; and how can we get more information about the shape of the hull into the design process earlier and see how they interact with other design considerations that we have."

In the end, the use of such aircraft will only take off if they are more efficient than conventional airliners.

"Big business would have to be the one to take this on and convert it because there is no way a start-up could look at something this big," Levis said. "Truthfully, 2035 onwards is where we are looking at right to have a step-change. That is where the planning is for the step-change in aviation to occur.

"Planning this far ahead is required for projects where there are so many unknowns, and that is not only for flying wing seaplanes; that is also for flying wing landplanes. You look at the NASA N+1, N+2 and N+3 [a silent aircraft that sends no carbon into the atmosphere], and the kind of timeframe they have set; it is really around the 2040s they are expecting to have such bold ideas materialise."

Meanwhile, major aerospace organisations are looking into the possibilities of the aircraft configurations the Imperial team has been studying, including NASA and Boeing, which collaborated on an experimental blended wing body called the X-48. "Boeing has ongoing blended wing body research activity to advance the state of the art and be prepared to shape the market with appropriate products," said Katie Zemseff of the Seattle aerospace company's engineering, operations and technology department. "Our research on the topic did not end with the completion of the X-48 work. Most of the current research, done together with NASA, is in wind-tunnel testing to investigate design concepts. Boeing studies many concepts for future commercial aircraft, taking into account market demand, customer requirements and production capacity, and makes decisions based on this research. Boeing believes the concept could be developed in the next 15–20 years for military applications such as aerial refuelling and cargo missions."

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Dr-Ing Werner Struth

Member of the Board of Management, Bosch

Education
1982: studied mechanical engineering at RWTH Aachen
1988: completed PhD in general and theoretical mechanical engineering

Career at Bosch Group
1989: senior expert, tool development
1990: section head, operations scheduling
1992: department head, ABS/ESP Generation 5.0 Project
1994: vice-president, assistant to the chairman of the Board of Management, Robert Bosch
1996: executive vice-president of manufacturing, quality and purchasing, Nippon ABS, Japan
1999: executive vice-president of manufacturing, quality and purchasing, Bosch Braking Systems, Tokyo
2001: chairman of the Board of Management, Coordination, Manufacturing, Quality and Human Resources, Bosch Braking System, Japan
2002: executive vice-president of Manufacturing and Quality, Diesel Systems Division
2005: president, Coordination, Manufacturing and Quality, Chassis Systems Control Division
2012: member of the Board of Management, Robert Bosch

Bosch Group board member Dr Werner Struth says that Industry 4.0 is driving a major reorganisation of industrial production. Jason Ford reports

In the space of four years, Industry 4.0 has grown from an industry buzzword to a multibillion-euro marketplace that in Europe alone is predicted to attract annual investments of up to €140bn (£100bn) per annum to 2020.

Industry 4.0 – or the Fourth Industrial Revolution – represents a shift change in the capabilities of the Internet of Things (IoT). It can be broadly defined as an evolution in IT systems that connects people, systems and devices to improve productivity and services.

According to Bosch, the IoT is driving a major reorganisation of industrial production by connecting machines, systems, workpieces and products to create intelligent production systems that can control each other autonomously without manual intervention.

Estimates vary, but Bosch predicts there will 14 billion connected devices by 2020. For many in the developed world, elements of daily life are already connected in some way to the cloud, be it with mobility, smart homes or other situations where interactions are made on smartphones and similarly connected devices.

It is in this context that Dr-Ing Werner Struth, a member of Bosch's board of management with 35 years of production experience asks: "Do you think production and manufacturing will be kept out of this domain?"

Struth's employer operates more than 250 production facilities worldwide, with projects related to connected production in progress in around 100 of them, notably in Homburg where more than 200 hydraulic valves are assembled into a single value stream on an assembly line. Using an RFID chip on the workpiece, the nine stations

Fair swap: **sensors on components and machines let objects exchange data**

on the line recognise how the finished product is to be made and which stages are required. Displays show personnel the corresponding working instructions for the version that is to be processed.

"By means of organising our suppliers and customers, we've reduced inventory by 30 per cent value," said Struth. "That is cash. We also increased productivity of the logistics system and decreased costs, consequently, by 10 per cent."

Bosch gained a head start in this burgeoning industrial arena when Dr Siegfried Dais, currently a limited partner of Robert Bosch Industrietreuhand, chaired the Working Group on Industry 4.0, which in 2012 presented a roadmap to the German government on how to implement the concept.

> **"We have increased productivity of the logistics system and decreased costs, consequently, by 10 per cent**

Step forward three years to Hannover Messe 2015 where technology demonstrators including Bosch's Remote Service Manager, which facilitates the servicing of machinery over the internet, and Process Quality Manager, which uses operational data from bolt-tightening machines to avoid risks in real time, vied for the attention of attendees.

According to Struth, the strategy taking Industry 4.0 forward at Bosch is based around its well-established competency in the provision of software, services and sensors, which in turn defines what is 'revolutionary' about Industry 4.0.

He said: "We know how to make software; we have 15,000 software engineers, 3,000 of which are working on IoT and services in the broader scope, not just Industry 4.0.

"We are one of the world's largest manufacturers of MEMS sensors, having connectivity so thus being ready to be 'wired', so to speak, to the internet to transmit data. We have business models [that answer] what to do with that [data] for our internal factories, [and] for our external customers.

"We have more than 250 factories on a global basis, so we have the user domain knowledge, from serious mass production from the automotive business to single-piece production in the project business. And we are an elite provider of Industry 4.0 solutions, which is our software suite for enterprise resource planning or manufacturing execution systems.

"The technological platform... has a high degree of maturity to start with, so what is the new part? The new part is that out of the potential of connectivity, the achievement of data collection and the analysis of data that will lead to new business models that haven't been seen so far.

"New business models include [those] with external customers [and] with our internal processes in order to achieve higher productivity [and] efficiency."

Struth noted that Germany, the US, South Korea and China are leading the way in embracing Industry 4.0, but conceded that implementation in his homeland is still evolving and that lessons are to be learnt from other countries, particularly the US, which applies a large degree of flexibility with its business modelling and expertise in information communications technology to Industry 4.0.

"Germany is one of the largest manufacturers – and exporters – of production machines so there's a huge tradition in this basic stone and iron business, I'd say, with high-precision equipment and processes," said Struth. "But Germany is not that strong in cloud and internet technologies and the development of business models.

"If we manage to combine the creativity in business model creation and the domain knowledge on how to run a cloud- and internet-based business with the technological domain of production... [then] this would be the ideal solution and that is what we are working for."

Gartner has forecasted that manufacturing, utilities and transportation will be the top three industries using IoT this year, with 736 million connected devices in use.

For manufacturing SMEs, opportunities await in Industry 4.0 because, as Struth highlighted, the technologies that make Industry 4.0 viable are probably employed on the shop floor already to make the concept of the decentralised 'smart factory' a reality.

"There have been... a lot of technological evolutions in the past – wireless connectivity, for example," he said. "But this is not attributed to Industry 4.0. We [at Bosch] have a huge amount of sensors that we can use in order to identify acceleration, humidity, air pressure [and] temperature... which can be used to control equipment and processes that have already been developed – and remain in development. These are not attributed to Industry 4.0. Rather, it's a kind of toolbox that is used by Industry 4.0 to take those tools out of the box [to] make a new application."

While too modest to suggest how the UK's SMEs should run their businesses, he does believe initial first steps into Industry 4.0 can be made with first-step implementations that do not require large amounts of capital expenditure and can manage the value stream of materials in the factory in order to drive down logistics costs and inventories.

The essential element of Industry 4.0 is, however, being able to grasp the holistic nature of the concept in order to exploit the myriad of potential solutions provided by it.

"This comes from my heart – we must not mix up Industry 4.0 with automation," said Struth. "The major part of Industry 4.0 is getting more information from my production system, being able to analyse this information, gain new business processes and optimise the entire value stream."

What's in the air?

Four experts answer your questions on the latest developments in civil aircraft. Stuart Nathan reports

The big idea: **Boeing's concept aircraft**

Civil aircraft technology has developed considerably over the past decades, but from outward appearances it takes an expert to detect any changes in most airliners. Is a change on the way? And what technologies are being developed that might affect the way that most of us fly? We put your questions to a panel of experts from academia and industry.

- **Chris Gear (CG),** chief technology officer and senior technical fellow, GKN Aerospace
- **Jessica Kowal (JK),** environment, international development and policy, Boeing
- **Dr Rob Hewson (RH),** senior lecturer in aircraft design, Department of Aeronautics, Imperial College
- **Prof Jonathan Morrison (JM),** chair of experimental fluid mechanics, Department of Aeronautics, Imperial College

What is the actual means of achieving any of the proposed changes, especially as none of the major players will take the risk of radical change?

CG: I believe these changes will occur when environmental pressures, i.e. oil prices, start to increase, and tougher legislation with tighter regulations on engine emissions and noise come into play in 2030 and again in 2050. Today's aircraft will need work done on them to achieve these requirements. Until then, OEMs can play safe with products and stay with existing industrialisation. The unknown factor will be China and if it starts to innovate then things might move quicker in the western world, but this is probably unlikely in the next 15 years.

How likely is it that these changes will include a move towards autonomous aircraft?

CG: There will be some move towards autonomous aircraft but mainly in military, not civil, due to safety and passenger discomfort and the security aspects with multi-sensor devices that can be hacked into. I think all the real development will go into military or private aircraft for a long while.
RH: There are already autonomous civil aircraft operating; the rapid increase in the use of remotely operated rotorcraft for filming is one area. DHL has delivered time-critical goods to a pharmacy on the island of Juist 12km from the north coast of Germany by an unmanned aerial vehicle, and both Google and Amazon are exploring the use of such vehicles to deliver packages. I believe large commercial aircraft will have pilots in the cockpit for the foreseeable future, in part due to passenger perception. The level of automation in the control of aircraft is set to increase, with the role of the pilot continuing to become increasingly that of a manager of the complex engineering system.

Is it true that the real medium-term innovations are to be found on the ground with ideas to help reduce greenhouse gas (GHG) emissions from taxiing?
CG: Definitely the application of electrical wheel devices for moving aircraft around the airport would help noise and engine emissions, especially in the large airports we are seeing proposed in Europe and that exist in the rest of the world. There is still more to come from innovations in engine performance and operating temperatures.

> **“Definitely the application of electrical wheel devices for moving aircraft would help noise and engine emissions, especially in the large airports being proposed in Europe**
> Chris Gear, GKN Aerospace

RH: There is ongoing research on the powered taxiing of aircraft, most notably the Electrical Green Taxiing System developed by Honeywell and Safran, reducing GHG emissions while the aircraft is on the ground. However, this is only a small part of the large and long-term effort to reduce GHG emissions from civil aviation; recent developments include the development of lightweight composite materials to produce light and very light structures – reducing the amount of fuel and emissions required for the aircraft to fly, the development of materials capable of operating at high temperatures, leading to more efficient thrust, and advanced aircraft aerodynamics – reducing drag, thrust, fuel and emissions. There have also been a number of flights that have operated using biofuel, reducing reliance on oil reserves and potentially decreasing GHG emissions. A number of these biofuels are already certified for normal operational use in aircraft.
JM: GHG emissions can be reduced by improvements to engine efficiency; flight-path management and airframe frictional losses. The last is probably the most challenging, and significant improvements to engine efficiency have already been made. Biofuels offer something for decarbonising flight, but the social impact of growing biofuels on a thirsty, hungry planet is significant.
JK: Rather than focus on one or another innovation as the ‘real’ or ‘best’ opportunity, the broader point is that aviation has to pursue an ‘all of the above’ strategy to meet our ambitious goals regarding the environment.

This is why Boeing’s strategy includes all of the key elements:

- Design and delivery of new, more efficient aircraft such as the 787, 737 MAX and 777X, which will reduce fuel use and emissions by as much as 30 per cent compared with the aircraft they replace;
- Ongoing efficiency improvements of in-service models, such as adding winglets that can improve efficiency by single digits;
- Investment to modernise air traffic management systems, which can improve efficiency by up to 12 per cent for all aircraft using them;
- New software/digital technologies that pilots and airlines can use to save hundreds of pounds of fuel, and emissions, per flight; and
- Development and commercialisation of a global supply of sustainable aviation biofuel that is price competitive with petroleum jet fuel. Using a 50 per cent blend of sustainable biofuel in an aircraft reduces emissions on a lifecycle basis by 25 per cent or more compared with a flight with 100 per cent petroleum.

To the more specific point of your question, there are certainly emissions reductions to be found on the ground, such as ‘one engine taxi’ or electric taxi systems.

For example, Boeing has worked with the Israeli Aerospace Industries (IAI) to certify IAI’s product TaxiBot for the 737. TaxiBot allows aircraft to go from gate to runway and back without using the engines, and thus saving fuel and emissions.

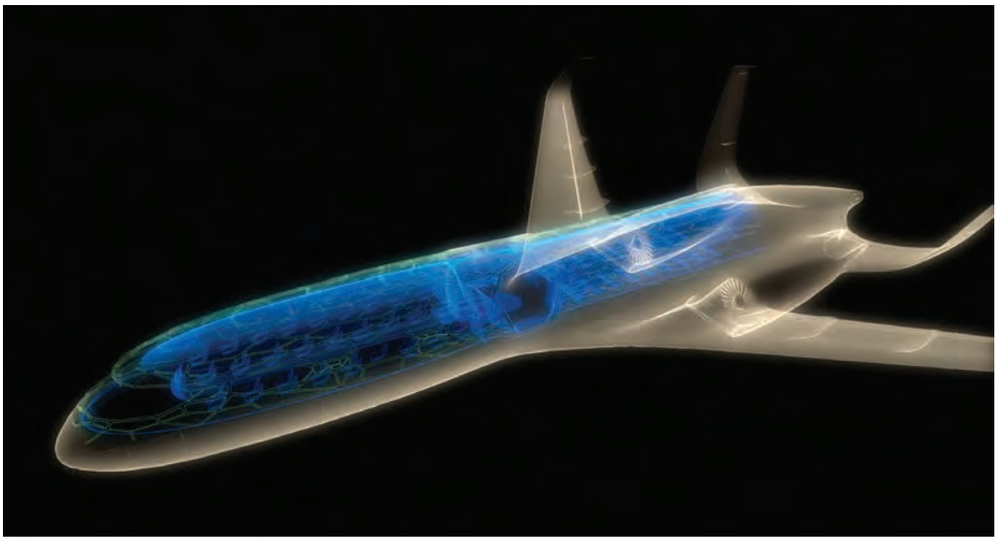
In the UK, Boeing is part of the Sustainable Aviation coalition, which is a partnership of manufacturers, airlines, airport operators and NATS, the air traffic management provider. Ground operations is one area in which Sustainable Aviation is looking for additional emissions reductions.

Are you in a position to look seriously at 3D-printed metal parts? If so, what sort of parts are you looking to use and what real advantages are they bringing? Does the process speed up delivery of an aircraft (very helpful to the customer), bring operational benefits to the customer or is it a combination of these and other factors?
CG: We are very much involved with making additive manufactured aircraft parts and the processes that can be used to make these parts along with the production of the raw powder material that is essential in qualifying the processes and material strength. Additive manufacturing (AM) brings big benefits in material optimisation. The AM process only uses the material needed to make a finished part. It has a very small amount of waste material generated from the process compared with a machined rib where 90 per cent of the billet is removed to get a finished part. The parts being considered are medium-sized components today due to the working section of the machines, ->

Model aeroplane: **GKN additive manufacturing**

“ 3D metal parts are already flying on aircraft; these include brackets attaching components together, printed from both plastic and metal

Dr Rob Hewson, Imperial



Top: **Airbus concept aircraft**
Bottom: **BAE Systems' flapless FLAVIIR aircraft**

but the part complexity is extremely high and it gives you the ability to design and make a part that in the past was impossible to achieve. So the overall weight and costs are much less compared with a typical machined part. The process can seriously speed up the manufacture of parts needed for an AOG [aircraft-on-ground] item.

RH: 3D metal parts are already flying on aircraft; these include brackets attaching components together, printed from both plastic and metal. The metal printed parts are typically aluminium alloys. The advantages are that they do not require as much tooling to manufacture [specialist component-specific manufacturing tools] and can provide new design flexibilities. This allows the design of parts that perform better than those designed to be manufactured using conventional processes. This can lead to unusual structures being designed, some of which have unusual shapes similar to those encountered in nature, for example the branches of a tree or the skeleton of a bird.

Are there any innovations afoot in essential aerospace services – ATC, weather forecasting and so on – that are helping airlines to reduce noise and GHG emissions?

RH: Yes, improved real-time navigation and surveillance is being developed to allow aircraft to fly more directly to their destination, sensing and avoiding other aircraft that may be encountered en route. There have also been studies done on developing cruise descents, where through careful planning of the aircraft arriving at an airport a continuous descent to a landing can be achieved. This means that the time and fuel-consuming 'hold' is avoided while the runway is vacated by other aircraft.

JK: Alongside continuous improvement of Boeing's commercial product line – for example, the Boeing 787 Dreamliner family is at least 20 per cent more fuel efficient, with an equivalent reduction in emissions and a 60 per cent smaller noise footprint than the aircraft it replaces – Boeing is also innovating in digital services we provide to our airline customers and test for potential future use.

For example, the Boeing Fuel Dashboard provides aircraft operators with a comprehensive total fleet view of operational fuel consumption, offering broad savings opportunities. Airlines, business aviation operators and military organisations can gain insight into current fuel usage through all phases of flight. This visibility enables better decision making to reduce fuel consumption, costs and emissions. In addition, we offer real-time weather updates and other types of data analysis to support customers' fuel-efficiency efforts. In addition, Boeing tested a wide range of software technologies on our ecoDemonstrator 787 in 2014 that can reduce noise and fuel use.

As two examples that also address your original question, the ecoDemonstrator 787 tested:

- Advanced GLS Cat III navigation using a ground-based augmentation station (GBAS), which customises approach paths to reduce community noise and allow greater airport access in some locations; and
- Boeing collaborated with NASA to test its ASTAR Airborne Spacing system.

For long-haul flights, can we get a supersonic, quiet, beautifully designed, clean aircraft, for example an electric Concorde, at an affordable price with maximum comfort for all passengers? Can we make flying a wonderful experience again with the added bonus of zero-pollution [noise, GHG and so on]?

JM: The energy density required for supersonic flight is much greater than that for subsonic flight.

CG: Not for a long time unless you want to go outside the atmosphere in a rocket device, but the take-off and landings will be noisy.

I'd like to ask the panel how feasible they think the concept of electrically powered civil flight is – particularly given Airbus's growing interest in the technology.

CG: Definitely going to happen in smaller vehicles with less range over the next decade, possible in civil craft if the energy storage systems can be made light enough, can recharge in flight and are safe to operate. We are still a long way from finding an energy source with that much power and that duration that is not a combustion device today. The probable step could be a hybrid solution that can provide the burst of power for take-off and charging while in flight. The weight of the electric motors will also be a factor and the possible development of new materials for these motors.

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Test flight: **Boeing's ecoDemonstrator 787**

JM: The real challenge is the energy density required. It so happens that fossil fuel provides this – as would nuclear, but I wouldn't advocate that. Electrically powered aircraft would require much improved battery efficiency – and batteries are heavy. There are composite materials being developed that offer much more efficient energy storage.

JK: Boeing continually researches technologies to power civilian flight, including electric-powered aircraft.

Having said that, commercial aircraft will require liquid fuel for the foreseeable future because no other energy source – such as electric, solar or hybrid – has been shown to provide enough thrust to get a large aircraft off the ground any time, anywhere. This is in part why Boeing has taken a leadership role in developing and commercialising sustainable aviation biofuel, which represents the single largest opportunity for aviation to reduce its emissions by using an alternative fuel.

We work with partners – airlines, governments, researchers, fuel producers and non-governmental organisations – on six continents to make progress on this.

When it's sustainably produced, aviation biofuel cuts CO_2 emissions by 50 to 80 per cent on a lifecycle basis compared with fossil jet fuel. Approved aviation biofuel is blended directly with petroleum jet fuel, and aviation biofuel actually performs as well as or better than Jet A, with higher energy density and a lower freeze point. Let me know if you want more information about biofuel development.

> **"When it's sustainably produced, aviation biofuel cuts CO_2 emissions by 50 to 80 per cent on a lifecycle basis compared with fossil jet fuel**
> Jessica Kowal, Boeing

'Fluidic flight controls' – these were demonstrated on a model aircraft as part of the BAE Systems FLAVIIR project. Are we going to see this kind of flight control on passenger aircraft, for the sake of lower maintenance or any other reason?

JM: I was involved in the FLAVIIR project. Fluidic controls are usually employed as replacement of flaps so that the aircraft has reduced signature to radar. It is therefore more likely to be developed for military applications.

Ingestion of the boundary layer has been suggested over the years, by individuals such as Fabio Goldschmied and David Birkenstock, as a means of reducing wake drag at the rear of the fuselage. Substantial fuel savings have been claimed. Are these schemes considered to be realistic by the industry, and if so then what research is currently under way?

JM: The only boundary layer suction scheme that has been developed over a number of years is that applied to the leading edge of a wing. This is known as hybrid laminar flow control (HLFC), where leading-edge suction reduces boundary layer growth as well as delaying transition.

Transition increases friction drag by a factor of four or five, so HLFC may be effective here. Generally, the energy applied to boundary layer suction is likely to be more than the benefit in removing the boundary layer.

How will emerging and future manufacturing techniques – for example 3D printing – shape the development of civil aircraft in the future?

CG: They will certainly be in parts of airframes and engines today and this will grow over the next 10 years. The effect will be as replacement of existing items or cost-downs or simplification to one part from many.

Once we start looking at new products and opportunities, then they will have a big impact on the design of products and how we solve some of the restrictions that today's processes prevent us from optimising in our structures.

What limits innovation? Is it the regulations that are clearly necessary for safety? Is it lack of investment? How could the SpaceX of aviation come into being?

CG: I would say investment limits innovation but regulations are a real way of creating innovation as they force you to reconsider the design solutions and set new boundaries to tackle; without them nothing would develop.

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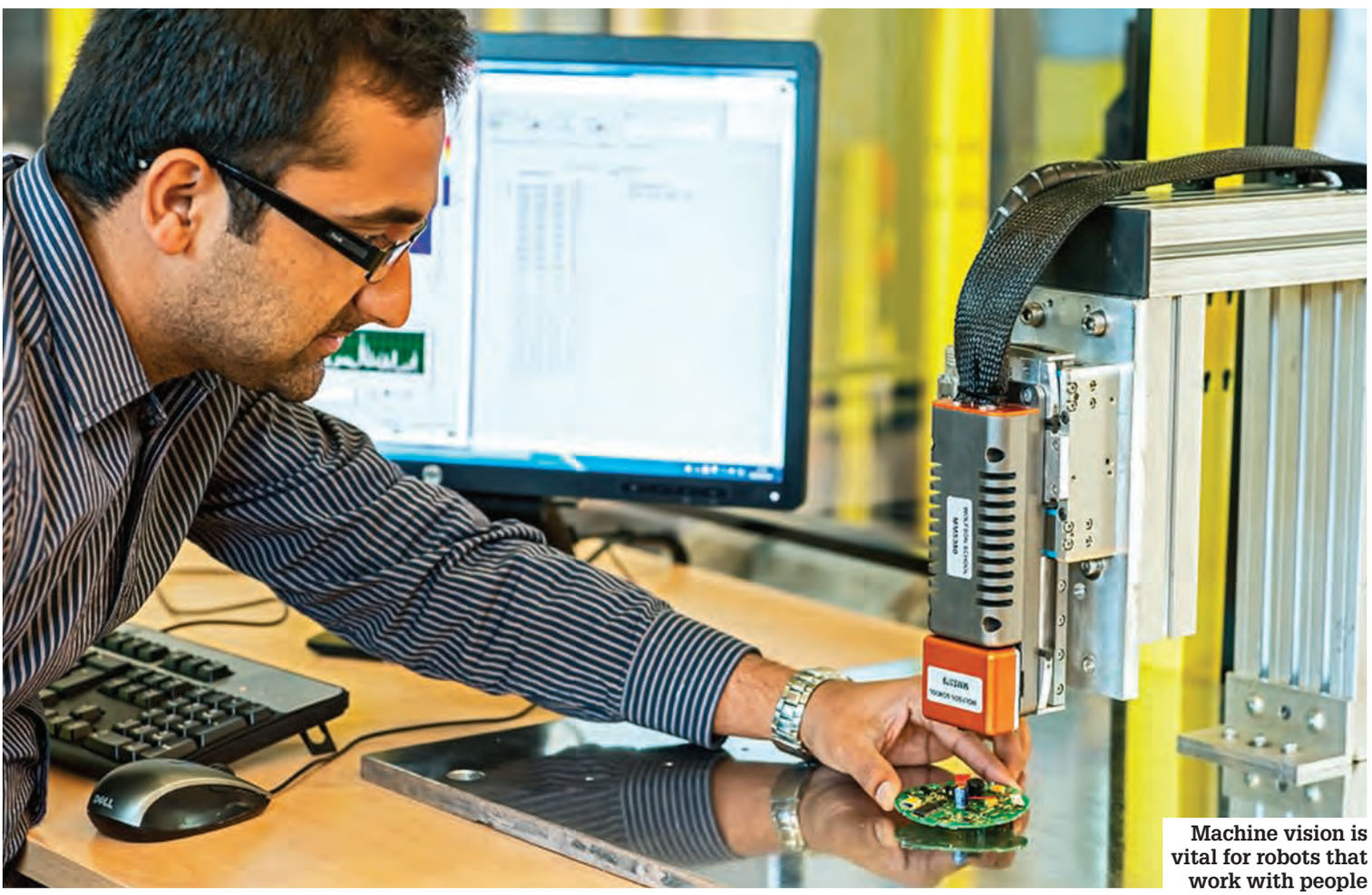
Rethinking robotics

A new breed of robots is emerging that could help labour-intensive industries to cut costs and boost efficiency. Evelyn Adams reports



Machine vision is vital for robots that work with people

Industrial robots have long been hostile, caged creatures. Around humans, their terrific power needs to be curbed; their speed needs to be restrained; and if anyone ventures into their workspace they are shut off altogether.

But in recent years, the barriers between robots and humans have been coming down. A friendlier breed of robots has begun appearing on the factory floor — and with it, the emergence of a new way of working that can cut costs and increase efficiency in labour-intensive industries.

One area that has benefited hugely is the automotive sector. "In an automotive plant, a vehicle is produced every minute, and approximately 1,000 cars are manufactured a day," said Adolfo Suarez Roos, Airbus Group expert and robotics co-ordinator of French National Research Agency project ICARO. Turnover is high, and collaborative robots are able to help workers with repetitive tasks.

Suarez is hopeful the same success can be replicated in the aviation sector. But given that robotics isn't as widely used, the challenges are very different. "[In automotive], a robot has 40 seconds to do its job and the complete programming task takes about a month," he said. "At Airbus, we produce 1.5 aircraft per day, so we have to look at tasks that will last several hours. We need mobile, collaborative robots and a very simple, efficient way to programme the robot."

At Cranfield University, the EPSRC Centre in Intelligent Automation is paving the way to make this a reality in aviation. An important part of the work is understanding how tasks can be divided between industrial robots and human operators to maximise the skills of both. When man and machine are working together over long stretches of time, engineers are looking at how the human can enhance the capabilities of the robot or vice versa. ->

In terms of safety, the university has created a relatively simple system that uses laser scanners and 3D vision to replace physical barriers around industrial automation equipment. The team has already built a demonstration cell that is being used for the installation of movables using a human operator and an industrial robot. A laser finds the mounting points of the movable; a machine then positions it so that a worker can perform the rigging process.

"For the last 15 years, we have mainly developed motion capabilities concentrating on the robot itself," said Christoph Borst, head of autonomy and teleoperation at the Institute of Robotics and Mechatronics, German Aerospace Center (DLR). "Now we're starting to include the human worker and develop a language of interaction — but we need to start with simple paradigms."

Research from groups such as Cranfield and DLR is already finding its way onto the factory floor. For instance, the Airbus Puerto Real plant in Cádiz, Spain, is leading a project to expand the automation of its assembly processes with the use of collaborative humanoid robots to perform repetitive tasks.

The project, dubbed Futurassy, last year began introducing the robots to automate the aeronautical assembly processes that could be used across other Airbus sites.

The first robotic unit acquired by Airbus arrived in Puerto Real from its manufacturer, Kawada, in Japan last year, and has been integrated at the A380 rudder spar assembly station, where riveting is now shared between human assemblers and the robot. Key to the success of this project is safety, and ensuring that the barriers between human and robot are just enough to still allow a productive working relationship.

Meanwhile in Toulouse, Airbus has been using human-integrated robotics for building the A350. Developed by RB3D, a robotic exoskeleton is used by workers to complete jobs on the production line where heavy lifting is needed.

"First we introduced safe, lightweight robots with a single arm, capable of autonomously moving around inside the aircraft to streamline the installation of brackets in the fuselage," said Bernard Duprieu from Airbus Research and Technology. Soon, Airbus plans to install collaborative units with a higher degree of freedom, solving more complex applications in hard-to-access areas and for use at assembly stations with no change in infrastructure.

> **"Now we're starting to develop a language of interaction — but we need to start with simple paradigms"**
> Christoph Borst, DLR

Airbus's 'Factory of the Future' programme is studying the use of collaborative robots for waterproof tests on fuselages, doors and windows. This is a painstaking process that is can be tough on the human body. The robot would track the entire perimeter of the part, recording and listening for noise that would indicate a leak in the frame. Another area being explored for automation is in the manufacture of helicopter blades' skin, which require high levels of precision.

The EPSRC centre is dedicated to the development of automated manufacturing processes

Prof Phil Webb has been working on automation in the aerospace industry for around 20 years and is now a professor at Cranfield University. He believes legacy issues in the aviation sector make the introduction of cage-free, collaborative robots a challenge.

"The limitation is still product volume versus task complexity, which often destroys the business case," said Webb. "This has led to the current interest in collaborative working but for most realistic applications this needs to be taken beyond the use of force/torque-limited robots and into the domain of large-scale industrial robots.

"To support this, we must also remove the existing 'cage-based' safety approach and look at more flexible ways of assessing, detecting, managing and preventing risk. The way in which the collaboration is managed from an employee perspective is also key to its chances of success as we are effectively breaking many existing rules in our deployment of automation."

He claims there is no doubt that the level of automation within aerospace manufacturing will increase significantly over the next few years. Cost pressures placed on the traditional manufacturing centres in North America and Europe mean they soon won't have a choice but to move ahead with collaborative robotics.

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Making the cut

Many issues must be resolved as applications with composite materials multiply. Will Sterling reports

Manufacturers of large structures often need to remove weight from the product, which has pushed the greater use of composite materials. Leading the way are aircraft structures, wind turbine blades, Formula One monocoque cabins and, increasingly, structures on cars. The Jaguar F-Type has carbon-fibre wind mirror covers, bonnet louvres and a variant has a carbon-fibre roof.

The growth of carbon-fibre applications has driven new machining technologies for composites. Machining techniques, cutting tool designs and workholding solutions have been refined, but the biggest area is cutting tool design, with a growing range of tooling companies introducing new designs to overcome the problems of machining composites, which behave very differently to metals. Layers, or plies, of fibre and resin bonded together react differently when placed under the force of a cutting tool.

"The biggest difference is in the chip formation mechanism, which you have no control of for composites, as the material shatters," said Dr Kevin Kerrigan, composites machining technology lead at the Advanced Manufacturing Research Centre (AMRC) with Boeing near Rotherham.

> **"Delamination is one of the biggest challenges for tool suppliers**
> Dr Kevin Kerrigan

Dust is the predominant feature when composite machining, as the cured epoxy resin layers disintegrate and throw up micro-sized particles. The challenge for tool designers is to create a geometry that first deals with the chip formation mechanism and then the damage you encounter with fibre (FRP) or glass-reinforced plastic (GRP).

Damage mechanisms can vary with the bonding of two different materials, the epoxy plastic and the fibre itself. Under mechanical stress, these layers can separate or delaminate.

"Delamination is one of the biggest challenges for tool suppliers, in that there are so many damage types and every application has a different requirement," said Kerrigan. "The tool designer has to design a product for the customer's own needs."

The solution is more cutting edges and diamond-coated carbide tools. Diamond coatings reduce burring on the material surface and extend tool life – diamonds have an low wear rate. The coating type depends on the application. In a high-volume application such as aerospace parts, many companies use diamond-coated chemical vapour deposition (CVD) tools. Carbide is chosen as it is cheaper than diamond to manufacture.

The fastest-growing type of coating is polycrystalline diamond (PCD), made by sintering micro-size single diamond crystals at high temperature. PCD is cheaper to manufacture than monocrystalline diamond.

Manufacturers experiment with the thickness of the PCD layer on the tool substrate to derive different effects. The AMRC is researching ways to bond crystalline carbon to carbide and to how much of the contact surface. "Some tool manufacturers are looking to minimise that contact to reduce the cost of the tool, or more to maximise the life of tool – it's a fine balance," said Kerrigan. ->

The main composite machining types are drilling and edge trimming. Each present different challenges. The variables for both are how the material is stacked and bonded, and the direction of tool approach.

With drilling composites, the approach to the surface will have huge effect on the damage it creates. "With a stack of laminate laid up horizontally, your tool design and the parameters set in your process need to be such that when the tool breaks through, you don't delaminate or generate fibre or epoxy pull-out," said Kerrigan.

A common problem is that when a tool reaches the bottom layer, it bursts through and separates the bottom ply from the rest, or pulls out large amounts of fibre from that bottom layer.

Engineers can use backing plates and peel ply layers to get around this, but some users will place the whole structure inside the machine, so there is no access to the back of the composite.

Consequently, some research, notably by Tobias Pfeifroth in Germany, has been carried out on the effect of the point angle and cutting speeds on hole quality – delamination, fraying and burr formation. Tool companies are devising clever solutions for this.

Exactaform, an independent diamond tooling company, has developed one-shot tooling. "A single tool is used for a single pass at high speeds, removing the need for a roughing and a finishing pass, typically required using conventional tooling," said technical sales engineer Jamie White. Tool costs can be high, but for large volumes the cost is mitigated and even reduced by improved productivity, less tooling and fewer tool changes.

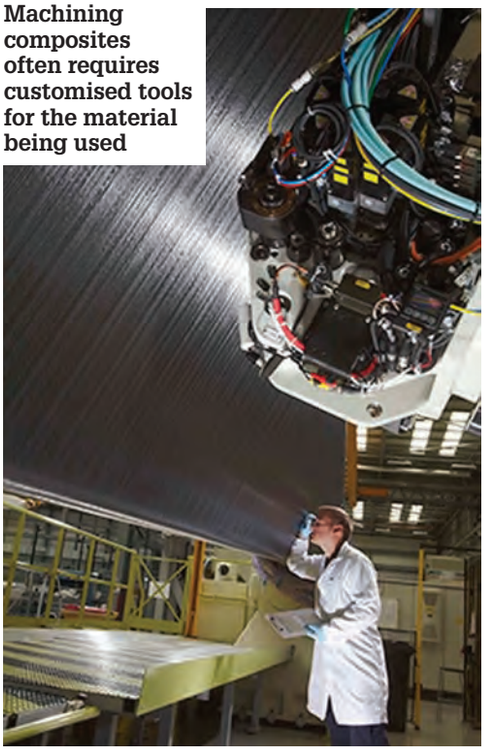
"One-shot routing using PCD tooling is the future for successfully mitigating the difficulties faced with composite-based projects and improving productivity to enable us to keep up with demand," said White.

Edge trimming is often done in the same plane as the laminate sheets, posing problems. The specific needs of edge trimming have led to design innovations. The general rule is that more cutting surfaces compensate for the composite material splintering. KOMET has developed an nanocrystalline diamond (NCD) and HSC NCD multi-tooth composite milling cutters for this application.

A 'burr-style' tool design from OSG is the DIA-HBC4. This has two separate helices, a deep helix like a normal tool, then a second helix going in the opposite direction in the shank of the tool at a much shallower depth. "Those two helices replicate the chip formation process, providing a lot of small teeth making more individual cuts to compensate for the disintegration of the material, which is driven by the strain rate of the material," said Kerrigan.

Carbon fibre has a higher strain rate than metals, so the mechanism failure depends on the fibre orientation to the contact of the tool. Depending on the angle, the effect could be bending of the fibre, and eventually it will snap.

While more cutting edges help – Exactaform has a 12-flute router and companies are working on 16 edges in a 10mm router – the challenge is to fit all those edges into the geometry, where currently the best combination is 12 edges, according to Kerrigan.



Machining composites often requires customised tools for the material being used

DMG Mori's ultrasonic machining improves feed rates

Twin-helix milling cutters compensate for disintegration of composites

Innovations in tooling also include the diamond-to-substrate bonding process. Seco Tools' solid-carbide cutters and drills use a six per cent cobalt substrate and the DURA coating.

Due to the high-grain boundaries-to-volume ratio, the coating can be applied in different thicknesses per application, increasing tool life. According to Seco, "getting the diamond to bond onto the substrate is always a problem due, in part, to the relatively sharp edges of the cutter – but more because of the presence of cobalt, used as the binder material."

So before applying the DURA coating, the cobalt on the surface is reduced using a deep-cleaning process. This roughens the surface, allowing for the deeper seeding of the diamond – resulting in superior bonding to the substrate.

The next step change for composites is how technology can improve tool life. Companies such as Exactaform offer a process to recoat a PCD-coated tool. Another approach is to regrind a PCD tool to rebuild the tool geometry. The potential cost savings for customers who could have regrindable PCD burr geometry is profound.

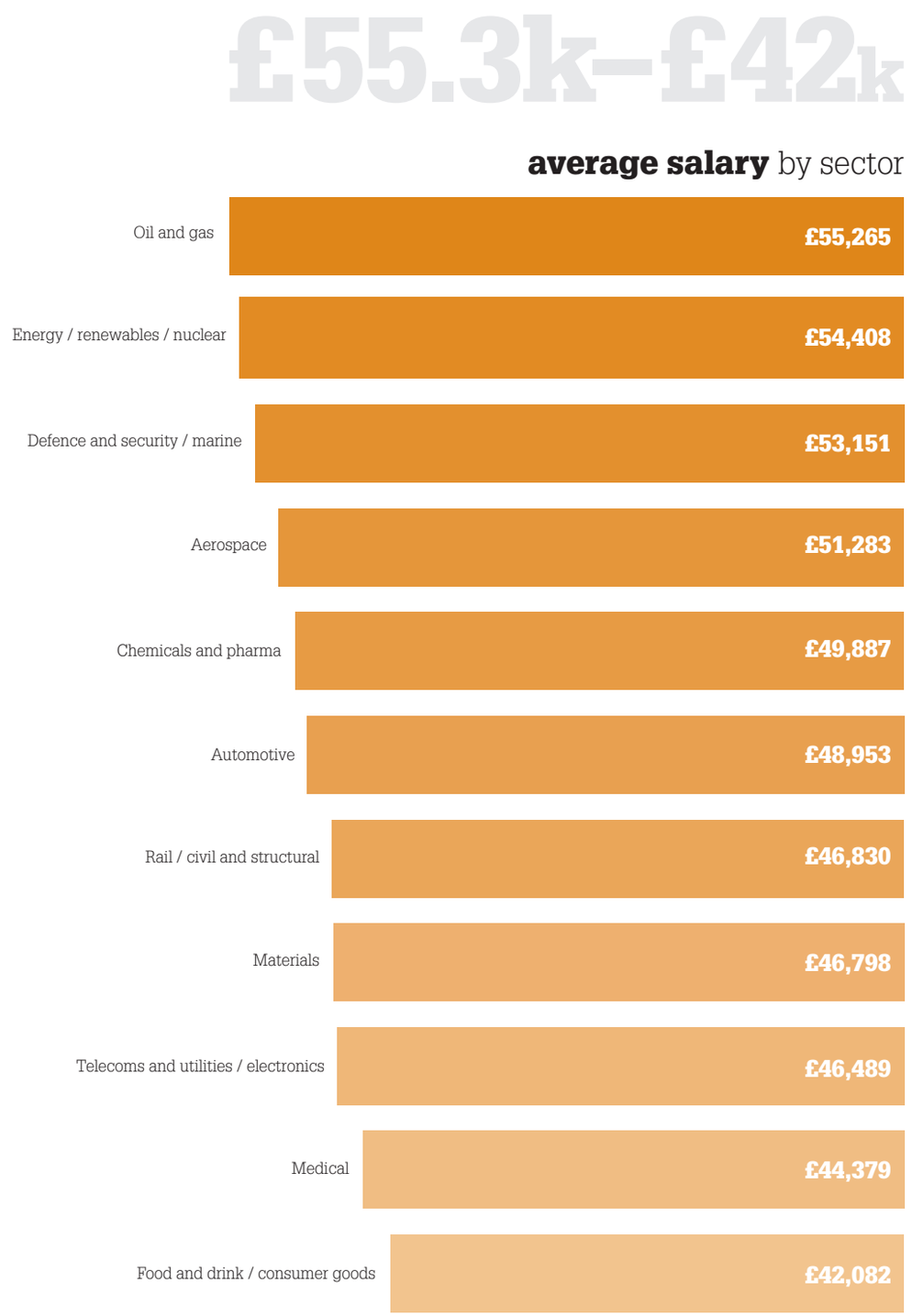
Big companies such as Boeing, Airbus and BAE Systems can incur tooling costs that are upwards of 50 per cent of their manufacturing process. "Any tool cost reduction is massive for the overall process; that's where PCD dominates over CVD."

As well as better tool design, high-volume composite machining has low feed rates that keep throughput down. Ultrasonic machining produces 10-micron amplitude motions of a tool, at more than 20,000Hz or up/down movements a second, while the tool is doing its normal speed and feed. In a trimming operation, as the tool is rotating it is moving in the vertical direction by 10 microns. DMG Mori claims that ultrasonics can improve feed rates by 20 times. Modelling of this at the AMRC shows that the forces exerted on the workpiece are massively reduced.

The race is on to perfect recoated or regrindable diamond-coated tools with more edges, using ultrasonic machining in some cases, to supply the parts in to delivery schedules that some big OEMs insist on. ◉

Pay scale

The results of The Engineer's 2015 salary survey provide a fascinating glimpse into the engineering profession and how salaries vary according to sector, seniority and region



How often do you ask yourself if engineers in a different sector are earning more than you? Or even whether your skills might bring greater rewards in a completely different industry altogether?

In which sectors of industry do engineers feel happiest and most satisfied with their work and pay? And can you expert to earn more in one region than another?

These are just a few of the questions that we set out to answer in our 2015 salary survey. And with 4,365 engineers from across the UK and from 18 sectors of industry taking part, the results provide a fascinating and revealing snapshot of the profession today.

Judging from the tenor of comments on The Engineer website, it is fair to say that UK engineers often feel pretty hard done by when it comes to how much they get paid.

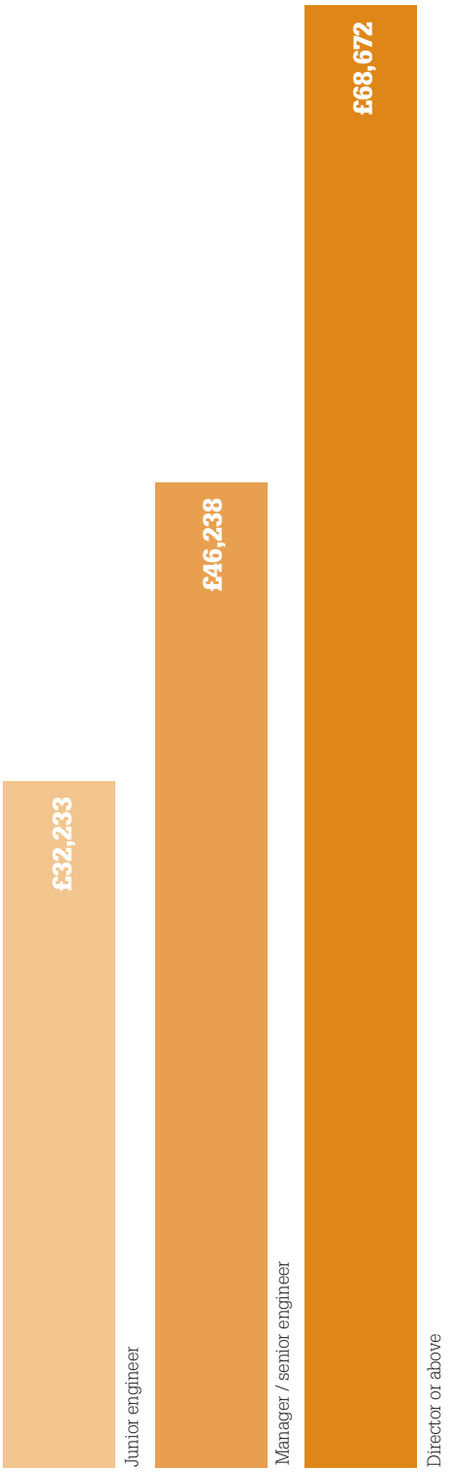
But, as we have frequently reported, while industry doesn't often see the kind of stratospheric salaries commonly associated with some parts of the financial services sector, engineering pay is actually pretty good: well above the UK's national average, and frequently higher than average salaries in other professional sectors.

Our survey results bear this out, with the average salary for engineers across all sectors standing at £45,055.

> **"The highest earnings can be found in the energy and fuel sectors. Engineers in oil and gas top the table, earning £55,265 on average**

This is below the level that professionals working in banking and accountancy can expect, at around £54,000 and £51,000 respectively. But it is above that for both the financial services industry, at around £46,000, and the legal profession, at approximately £39,000.

The highest earnings can be found in the various energy and fuel sectors. Engineers in the oil and gas sector top the table, earning £55,265 on average, while those in the energy/renewables/nuclear industries receive £54,408 and £52,471 respectively. Outside energy and



average salary by seniority

fuel, engineers in the defence and security/ marine sector command the next highest wages, at an average of £53,151.

The largest percentage of the engineers we surveyed work in the UK's booming automotive industry, with the group making up 13.6 per cent of those questioned.

There were few demographic surprises from our sample group. The overwhelming majority — 95.5 per cent — were male, and the average age was 44.

In terms of seniority, most classed themselves as senior engineers or managers, and almost half of those surveyed have worked in engineering for between 20 and 40 years.

It seems that — on the whole — the UK's engineers are a pretty satisfied bunch. And despite only 35 per cent feeling that their earnings suitably reflect their workload, the vast majority (84 per cent) expect to remain in engineering for the next five years.

Over the following pages we've gone into more detail on some of these findings, and looked at what they might mean for both individuals and industry as whole.

david leyshon

Chairman, CBSbutler

Today's 'engineer' has rarely been valued so highly or been so sought after, driven by the current war for talent. The combination of an ageing workforce, decades of under-investment in apprenticeships and a lack of young people entering the engineering professions has resulted in serious shortages at all levels.

In a world where we are faced with mega problems, for example over-population, shortage of resources and environmental issues, it strikes me that engineers have a huge part to play. It is their ingenuity and ability to harness new technologies that will invariably provide the solutions that we all seek.

However, engineering as a profession still has much to do to promote itself as a career of choice. Clearly the misconception of the stereotypical engineer holding a spanner and an oily rag does play its part. Despite many new initiatives to attract young people into the sector, there remain many challenges in meeting industry needs and in closing the skills gaps. Notably, prominent industrialists such as James Dyson have expressed their concerns over the future generation of engineers and indeed the impact this could have on the business economy.

One of the obvious talent pools that has yet to be harnessed is the female population, where traditionally there has been a very low uptake into the engineering industry. Indeed, we only need to look at countries such as Germany where engineering is at the pinnacle of professions to witness a far greater diversity.

With decades of experience in recruiting within engineering across a wide range of sectors, CBSbutler can attest to having specialist insight into both the opportunities and challenges afforded to job seekers. Well-qualified, highly trained and experienced engineers really do have a wealth of options at their disposal — both domestically and globally. Moreover, those individuals who prefer flexibility in their work will find strong demand, lucrative earnings and continuity of employment via freelance contracting.

However, we cannot ignore some of the less positive findings. It is a fact that earning levels within many areas of heavy engineering and manufacturing still lag behind other sectors. Also, a relatively high number of experienced engineers leave the profession through disillusionment with career prospects.

A major challenge is the chronic age demographics befitting strategic sectors such as oil and gas and construction. The decades of failing to attract the younger generation into engineering roles and cutbacks in apprenticeships has certainly taken its toll. The UK has much catching up to do. There is a clear responsibility across government, education and industry to turn around this situation given the severe implications on UK business competitiveness.

In summary, the sheer volume and diversity of job opportunities will ensure that most engineers have a stimulating and rewarding future. The forecasted skill gaps and shortages are unlikely to change for many years, resulting in attractive earnings and progression for talented professionals. At last there is a realisation that 'the engineer' is central to achieving a competitive business economy and is firmly on the map.

"Despite only 35 per cent feeling that their earnings suitably reflect their workload, the majority expect to remain in engineering for the next five years

An even more detailed report on our findings, along with an interactive tool that enables you to benchmark your salary, will be published on our website on 29 June. ->

£45k

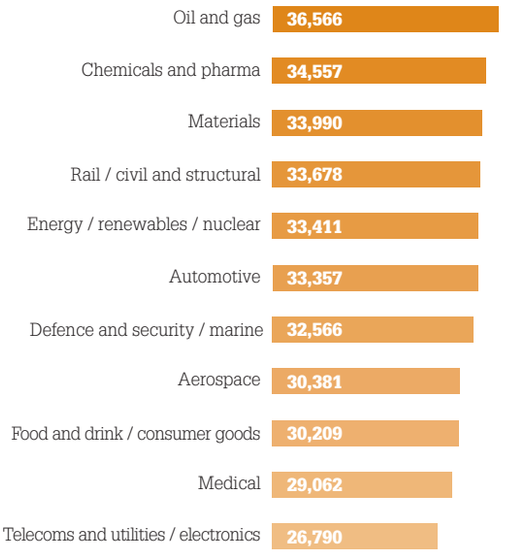
Average salary for engineers across all sectors

average salary by industry

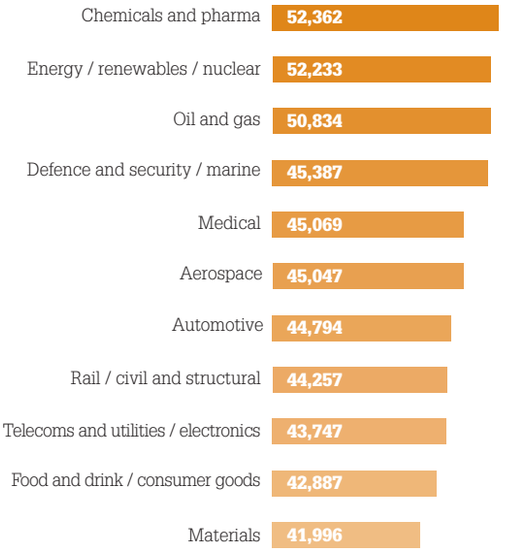
£81.5k

The average salary of directors or above working in the defence and security/marine industries

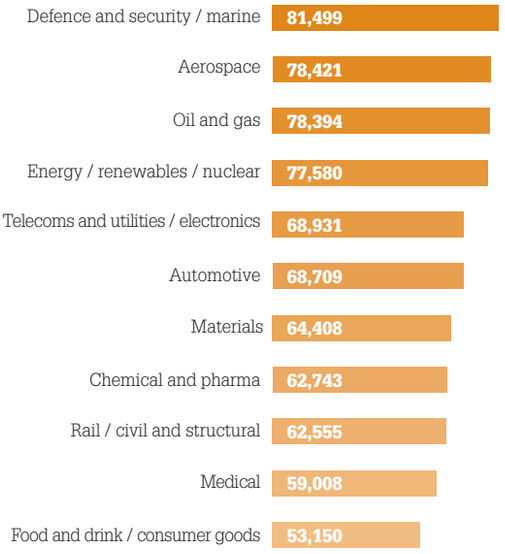
junior engineer



senior engineer / manager



director or above



1. seniority

In terms of seniority, the response reflects *The Engineer*'s audience of senior engineers. More than 80 per cent of respondents describe themselves as senior engineers or above: 45.5 per cent as senior engineers, 31.3 per cent as managers and 6.3 per cent as directors.

The overall average salary for a junior engineer is £32,233; for a manager/senior engineer it is £47,238; and for a director or above it is £68,672.

However, there is huge variation between sectors: a director or above working in defence and security earns almost £30,000 more than someone of similar seniority in food and drink.

What's more, it doesn't follow that the sector

> **"There is huge variation between sectors: a director or above in defence and security earns £30,000 more than someone of similar seniority in the food and drink sector**

that pays the highest director salaries also pays more for its junior engineers and managers. Indeed, salaries for junior engineers in defence and security sit near the bottom of the table, while the chemicals and pharmaceuticals sector ranks highly for both junior and senior engineers.

Interestingly, considering the difficulties that it's currently facing, the oil and gas sector features in the top three for all levels of seniority.

the age of the UK's engineering workforce

The ageing nature of the UK's engineering workforce has been the subject of significant debate in recent years, with many concerned that the impending retirement of many of our most highly-skilled and experienced engineers could lead to crippling skills shortages in a number of key sectors,

But here our survey offers some cause for optimism. Of those questioned, the average age of engineer was 44. Engineers in the civil and structural engineering sector are the youngest on average, at 40, while the oldest in the profession can be found in the process industry, with an average age of 45.

These averages hide a slightly more worrying trend though, since more engineers can be found in the 50-54 age band (16.6 per cent) than any other, suggesting that many will be retiring over the next ten years. Meanwhile, at the other end of the spectrum, just 12 per cent of the engineers we surveyed were under 30.

2. regions

Respondents to the survey were spread throughout the UK and beyond, and provide an interesting glimpse of regional salary variations across the different engineering sectors. The regional spread also provides a reminder that, contrary to perceptions outside of the industry, a high proportion of engineering roles are based in London and the south east.

Perhaps unsurprisingly, London and the south east offers the highest salaries in many of the sectors and for a number of sectors outperforms the regions that are typically regarded as centres of excellence. For instance, automotive and aerospace expertise, which tends to be concentrated in the West Midlands and the south west respectively, commands a higher salary in the south east. Indeed, somewhat surprisingly, our results suggest that the south west actually offers the poorest salaries in the aerospace sector.

Although most regional variations are relatively small, the sector that seems to vary most according to location is automotive. Here, the highest average salary is found in London and the south east (£51,333), while the lowest within the UK (£38,720) are found in Scotland, Wales and Northern Ireland. Some of the highest salaries on offer are found outside the UK.

Job satisfaction levels show minor variations according to region, with engineers in Scotland, Wales and Northern Ireland coming out on top in the happiness stakes (51.6 per cent).

Engineers in the south west are least likely to be happy with their salaries (31.9 per cent believe they are fairly remunerated), while engineers in the Midlands and East Anglia show the highest levels of contentment with their pay (35.6 per cent).

where are the UK's engineers?

26.7%	East Anglia, West Midlands and East Midlands
20.9%	London and south east
18.7%	North
13%	South west
11.7%	Outside of the UK (roughly split between Europe, US and Asia-Pacific)
9.1%	Wales, Scotland, Northern Ireland

"Automotive varies the most according to location. Here, the highest average salary is found in London and the south east

midlands and east anglia

Chemicals and pharma	51,000
Energy / renewables / nuclear	47,776
Automotive	47,330
Telecoms and utilities / electronics	45,710
Aerospace	45,561
Oil and gas	44,886
Medical	42,630
Defence and security / marine	42,102
Materials	41,950
Food and drink / consumer goods	40,659
Rail / civil and structural	40,250

south west

Chemicals and pharma	55,250
Defence, security and marine	48,417
Energy / renewables / nuclear	46,171
Medical	45,769
Telecoms and utilities / electronics	42,670
Food, drink and consumer goods	42,333
Automotive	40,211
Aerospace	39,451
Oil and gas	36,000
Rail, civil, structural	35,438
Materials	33,125

london and south east

Oil and gas	56,667
Energy / renewables / nuclear	55,121
Chemicals and pharma	54,600
Automotive	51,333
Telecoms and utilities / electronics	47,293
Aerospace	47,290
Food and drink / consumer goods	44,654
Materials	44,355
Medical	44,326
Rail / civil and structural	43,760
Defence and security / marine	41,761

north

Energy / renewables / nuclear	52,480
Oil and gas	49,356
Chemicals and pharma	47,893
Materials	44,422
Food, drink and consumer goods	44,205
Medical	43,441
Automotive	43,373
Telecoms and utilities / electronics	41,797
Defence, security and marine	41,066
Aerospace	39,477
Rail, civil, structural	38,344

scotland, wales and NI

Energy / renewables / nuclear	52,757
Oil and gas	50,465
Chemicals and pharma	47,615
Rail / civil and structural	45,200
Food and drink / consumer goods	43,438
Aerospace	41,667
Defence and security / marine	39,565
Telecoms and utilities / electronics	39,375
Medical	39,299
Automotive	38,720
Materials	36,000

outside UK

Defence and security / marine	65,263
Oil and gas	59,457
Aerospace	59,277
Chemicals and pharma	58,464
Energy / renewables / nuclear	51,007
Medical	48,757
Materials	46,414
Telecoms and utilities / electronics	43,004
Rail / civil and structural	39,995
Food and drink / consumer goods	36,041
Automotive	34,974

In partnership with: CBSbutler Precision Resourcing

Sector	Average salary (£)	Average age	Percentage content with salary	Percentage happy in current job	Percentage considering change of job	Percentage likely to stay in industry for five years
Oil and gas	55,265	42	46.9	57.1	46.5	86.1
Energy / renewables / nuclear	54,405	42.6	39.3	57	50.1	86.4
Defence and security / marine	53,151	43.1	28.5	53.6	43	89.9
Aerospace	51,283	42.2	31.9	50.2	49	84.6
Chemicals and pharma	49,887	45	42.2	48.3	52	87.1
Automotive	48,953	44	34	48.7	49.4	84.7
Rail / civil and structural	46,830	40.1	39.4	39.4	52.1	85.7
Materials	46,798	44.2	38.8	59.4	44	84.4
Telecoms / utilities / electronics	46,489	45.2	28.7	41.7	55	80
Medical	44,379	43.1	35.9	51	48.3	80
Academia	43,290	45.5	36.1	48.5	48.4	85.6
Food and drink / consumer goods	42,082	44.1	29.1	46.2	52.6	85.7

3. sectors

Across the UK, average salaries vary from sector to sector. According to our results, the highest average salaries (£54,408) are to be found in the oil and gas sector, while the lowest (£42,082) are paid by the food and drink/consumer goods sectors.

Interestingly, though, as the above chart shows, the engineers working in the UK's highest-paying sectors are not necessarily the most content. Just 39.3 per cent of those working in energy/renewables and nuclear are content with their salary and just more than half are considering a change of job. This contrasts with a 46.9 per cent contentment level in the materials sector, which sits in eighth place with an average annual salary of £46,798.

The highest general satisfaction levels are found in the oil and gas industry, which is perhaps surprising given the damaging impact of the currently low oil prices. Nevertheless, as well as general contentment with remuneration levels, 57.1 per cent of oil and gas engineers tell us that they are happy in their current jobs, and 45.9 per cent feel valued in their current role – this is the highest value among our sample group.

Among the sectors, engineers in the telecommunications, utilities and electronics industries are most likely to want a change of career, with 10 per cent of those questioned reporting a desire for a fresh start. In contrast, engineers in the food and drink sector are the least likely to want to leave the industry, with just two per cent considering a switch.

In terms of benefits, if you are looking for an engineering job that is likely to come with a bonus on top of your salary, head for the process industry.

> **"Among the sectors, engineers working in the telecoms, utilities and electronics industries are most likely to want a change of career**

While just less than half of engineers across all sectors receive a bonus, this jumps to 62 per cent for those working in the chemicals industry. At the other end of the spectrum, just six per cent of those in academia receive a bonus.

Unsurprisingly, engineers in academia have the longest holidays of each of the sectors, with around three quarters benefiting from more than 26 days' paid leave. This compares sharply with the food and drink industry, where only a quarter receive the same amount of paid

chemical and pharma

supported by SRG

"Despite a hostile climate in oil and gas and chemical production, there is never a shortage of engaging opportunities within the chemical and pharmaceutical marketplaces in the UK" – SRG

The chemical and pharmaceutical industries are vitally important to the UK economy.

Every day, the country's pharmaceutical industry spends £12.5m on research and development, while the chemical sector has an annual turnover of more than £57bn.

The average salary in the industries is correspondingly high, at £52,703 per year. The sector is also the most generous for bonuses, with 62 per cent of those in the industries receiving one, compared with an average for engineering as a whole of 47 per cent.

academia

supported by Science & Technology Facilities Council

"Academia offers the opportunity to work on cutting-edge engineering projects, and in exciting locations" – STFC

The UK's engineering research leads the world in its productivity, thanks to the vital collaboration between industry and academia.

The average salary of engineers in academia is £45,247, although this rises significantly to £55,889 for those based in London and the south east.

Just six per cent of engineers in academia receive a bonus on top of their salary – by far the lowest proportion in our survey. Academics are also the most likely to feel overworked and undervalued by their employers, although around half are happy in their jobs overall.

	Percetage that feel valued in current role	Percentage that do not feel valued
	45.9	26.1
	45.8	26.6
	42.3	30.5
	37.9	31.2
	37.4	28.6
	40.5	30
	42.6	23.9
	46.9	23.1
	40.7	28.3
	38.6	24.8
	33	38.1
	37.8	31.9

holiday. It is not all bad news for those in the food and drink industry, though, as they are also the most likely to receive private medical insurance, with 54 per cent of engineers in the sector benefiting from the perk.

In terms of the routes that engineers have taken into engineering, the food and drink industry has the highest proportion of engineers who have undertaken an apprenticeship, at 58 per cent, which compares with an average of 41 per cent for the profession as a whole.

In contrast, the renewables industry has the highest percentage of engineers with a degree; 63 per cent of those in the sector have earned one. This perhaps indicates why renewables engineers can command the highest salaries of those surveyed.

Detailed breakdowns of all of the UK's key engineering sectors will be published in our full report, which will be available from 29 June on www.theengineer.co.uk.

59.4%

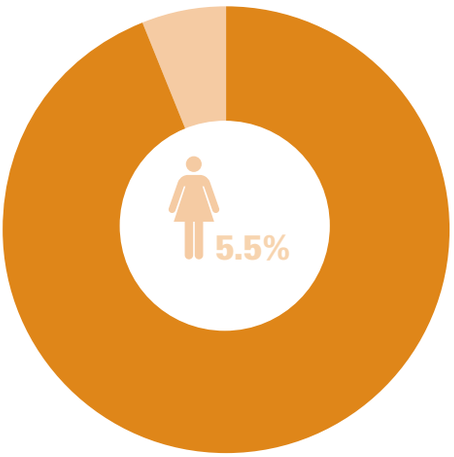
Materials engineers are happy in their jobs

£55.3k

Average salary in the oil and gas sector

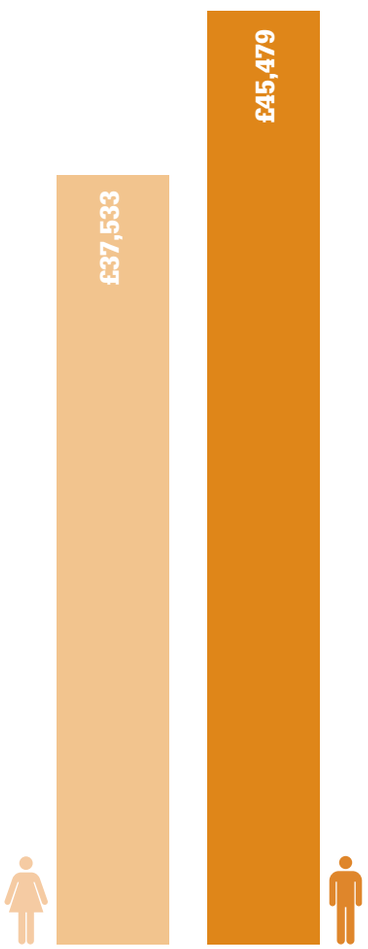
4. gender and diversity

gender split



94.5%

average salary by gender



Addressing industry's gender imbalance continues to be a major priority across all engineering sectors, and our survey results provide a reminder of why this is such an issue – with women making up just 5.5 per cent of our respondents, a figure that echoes other external snapshots.

In the individual sectors, the industry that appears to be doing the best job of attracting women is civil and structural engineering, where 15 per cent of the professional workforce are female (see this issue's careers feature on page 48 for more on this).

> **"The industry that appears to be doing the best job of attracting women is civil and structural engineering, where 15 per cent of the workforce are female**

This is followed by the materials sector, in which 10 per cent are female.

At the other end of the spectrum, however, less than one per cent of engineers in the consumer goods sector are women.

So why is there still such an enormous gender gap in engineering, despite all the hard work of the various bodies to encourage more women into industry?

Despite the striking difference in average salaries (women engineers responding to the survey earn almost £10,000 less than men), it is unlikely that pay is the key issue here. Indeed, this disparity is explained by the higher proportion of men in senior positions (24.4 per cent of female respondents described themselves as junior engineers, compared with just 12 per cent of the males who took part).

What's more, the problem does not appear to be primarily one of job satisfaction, since the women we questioned were only marginally less likely to be happy with their pay and role than their male counterparts.

It also cannot be explained by women leaving the profession to start a family, since the highest proportion of female engineers are in the early-thirties age band, at 19 per cent. This is closely followed by women in their late twenties (18 per cent) and those in their late thirties (13 per cent).

The number of female engineers appears to drop sharply as women enter their early fifties – an age band that in contrast has the highest proportion of male engineers surveyed.

This perhaps suggests that efforts to encourage more women into the profession in recent years are starting to bear fruit, even if much more work is needed.

Promisingly, it appears to be an issue that a large number of engineers agree needs addressing, with more than a quarter of respondents agreeing that the gender gap is an important issue.

Bucking the trend

Civil engineering has proved increasingly attractive for women, despite a low level of women in engineering as a whole. Evelyn Adams reports

Civil society: **this sector has a direct impact on helping community, making it more appealing**

It can be easy to get lost in headline figures on the lack of women in engineering. But dig a little deeper, and some surprising results emerge. For instance, in *The Engineer*'s very own salary survey (see page 42), civil engineering is revealed to be a relatively attractive sector for women.

Despite a very low level of women in engineering overall — around 5.6 per cent of the workforce — the survey of 4,365 engineers revealed that the gender balance is unusually positive, or at least better, in the civil engineering sector. Around 15.3 per cent of the civil engineers responding were women — a figure that is reflected in other industry studies.

According to a recent report by EngineeringUK, mechanical engineering has the lowest proportion of female applicants, ranging from 6.4 per cent in 2009 and 2010 to 8.4 per cent in 2012 and 2013. During the same period, the proportion of female applicants to aerospace engineering declined to 7.6 per cent. The proportion of female applicants in general engineering and civil engineering was similar in 2012 and 2013, at around 16.4 per cent and 16.5 per cent respectively.

But what is it about civil engineering that means it bucks the trend so dramatically? Lani Tan, a project field engineer at Bechtel, working on the Vauxhall Underground Station Upgrade project, believes that the direct impact civil engineering has on helping community helps attract women to the field.

> **"The work of civil engineers improves the lives of so many people. I think this is appealing to both women and girls**
> Lani Tan, Bechtel

"It is easy to see how the work of civil engineers improves the lives of so many people," she said. "Water supply and sanitation mean better health; building schools means better education; better transportation links improve quality of life, etc. I think this is appealing to both women and girls. Other disciplines may not be perceived to be directly helping people in this way."

According to a careers research study led by Atkins, almost four in 10 women who decided to become an engineer had a family connection such as a father or friend who was an engineer. This highlights the importance of having role models, especially for women, as they might give an awareness of what civil engineers actually do and can break down the stigma that civil engineering is only for men. Initiatives in the sector to encourage mentoring may have paid off more so in the civil sector.

While she doesn't have direct evidence for this, Dawn Bonfield president of the Women's

"I think that initiatives for getting more women into the industry should never be targeted at and tailored for women only
Lee Franck, Arup

Engineering Society, claims that women are more aware of what civil engineering entails, compared with, for instance, electrical engineering. "Also, it is linked to creativity and innovation more than other areas of engineering, as there have been a lot of iconic buildings and bridges and other structures over the last few years that have really grabbed public attention," she explained. "Girls respond well to using their creativity and innovation skills, and I think that this is a reason why it is popular."

There is also some evidence that civil engineering is taking a different approach. For instance, UCL civil engineering professor Nick Tyler said he believed his course was missing out on creative students by prohibiting applications due to subject choices made at age 15 or 16. His team has seen a huge increase in applications from women after they decided in 2006 that students no longer require physics or maths at A-level for the entry criteria.

Other universities, such as Southampton, have changed course name and focus to combine engineering with architecture, providing a cross-discipline attraction.

Good work: **civil engineering is seen as more creative than some sectors**

But the civil engineering sector still has much more to do to attract women into the industry. The UK has the lowest proportion of female engineers compared with the rest of the European Union at less than 10 per cent.

Meanwhile, the female membership of the Institution of Civil Engineers is still only 10.7 per cent.

With the UK female workforce being at 45.1 per cent, women are still massively underrepresented in civil engineering and there remains a significant salary gap.

Lee Franck, a senior engineer at Arup, claims the results of *The Engineer*'s salary survey show just how big an issue it is for women. "The fact that a large proportion of women have responded to the salary survey, when compared with the average of women employed in the sector, might be a sign that they feel concerned about the gender wage gap that is still present within our industry and are keen to raise awareness of this by completing the survey," she said.

Dealing with unconscious bias in the work place is a priority for Tan at Bechtel. Often, she said, it is the many little things that add up over time, such as engineers and project managers being referred to as 'he'.

"We need to increase the public perception of what engineering is about so that young women see engineering as a credible career option," added Claire Rose, a senior civil engineer working at Bechtel on the West Coast Route electrification project.

"The sector should target pre-decision making — before GCSEs and A-levels — so that we can attract women to stay on and study science and mathematics so they have the prerequisite courses to make engineering a viable career option at university," she added.

"I personally think that initiatives for getting more women into the industry should never be targeted and tailored at women only," said Franck. "That is why I have become involved in a programme called 'Inspiring the Future', which gives professionals such as myself the opportunity to visit schools and talk about what engineers really do.

"If we can portray our job as the stimulating, diverse and rewarding job that it is, this should be attractive to all genders, break down any false perceptions of barriers or misconceptions and generally get more talented and motivated people into the industry, which is what we need," she added.

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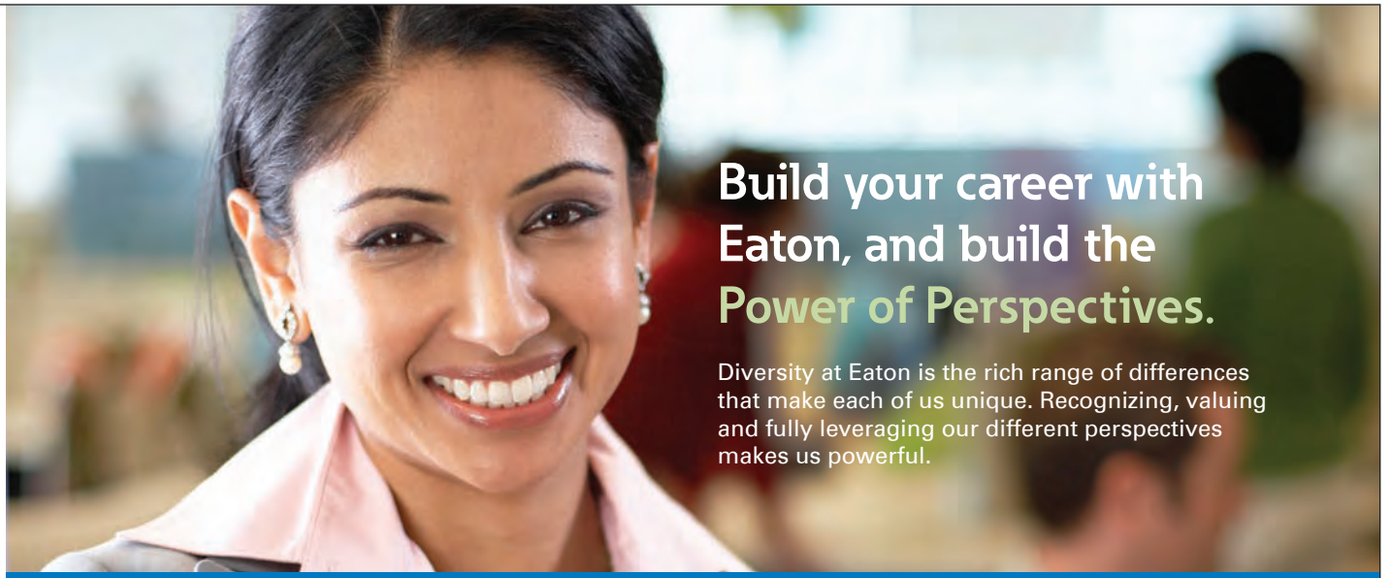

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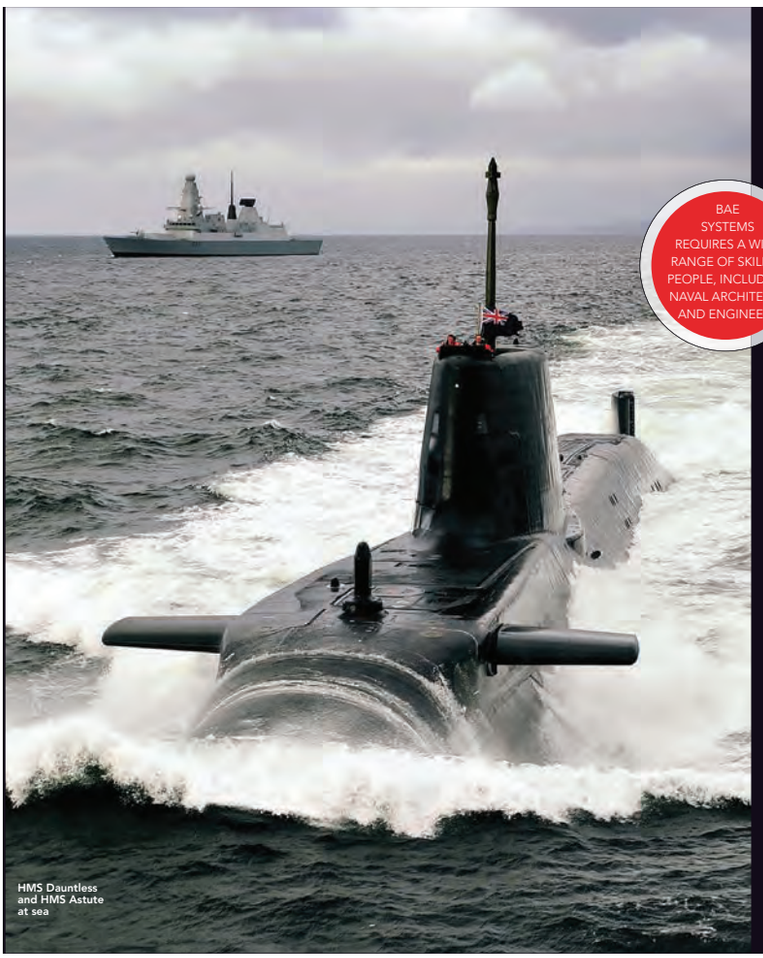
HMS Dauntless and HMS Astute at sea

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Ofgem: the great enabler

Ofgem has a key role in transforming the energy landscape in the UK. As part of its remit to protect consumer interests, it regulates the companies who own and/or operate the electricity and gas networks to ensure that innovative and solid engineering solutions are adopted in the energy infrastructure to meet the challenges of the twenty-first century.

Min Zhu, Associate Partner Electricity Transmission, joined Ofgem back in 2002, and has enjoyed a rich and varied career working on diverse projects ranging from price controls, technical standards and commercial codes, and competitive tenders for offshore transmission projects. Her background at National Grid, where she spent eleven years in a variety of technical and commercial roles, stood her in good stead for the challenges she would face at Ofgem. "People think that engineers don't have a proper place in an economic regulator", she explains, "but we do make a significant impact through our technical input. Achieving the three energy policy objectives – de-carbonisation, security and affordability – entails huge technical challenges. That's what makes an engineering career here so exciting. Through our technically informed and rigorous decisions to enable efficiency, innovation and competition in energy networks, we are shaping the future network infrastructure as well as facilitating the progress of exciting new technologies, such as renewable and storage. We can only do this with the technical and engineering expertise we have in-house, which we seek to enhance from the new experts we are looking for."

Min Zhu: Associate Partner Electricity Transmission, Ofgem

Ofgem offers something genuinely different; and while technical expertise is vital, it is used in a broader context. Staff have an opportunity to influence policy at its very heart. It's a rare and attractive combination, and one that strongly appealed to Min when she first applied for a role as a Technical Adviser at Ofgem, thirteen years ago. "I was seeking to widen my horizons, and Ofgem offered an attractive prospect. I also saw it as an opportunity to make a positive difference in the energy industry and for its consumers."

That difference has certainly been tangible. A recent example is the first round of Ofgem's Offshore Transmission Owner (OFTO) tender regime, which Min jointly oversaw. It encouraged OFTOs to adopt innovative approaches to financing, operating and maintaining offshore transmission assets. A recent independent report estimates that the regime has saved consumers between £200m and £400m. An impressive achievement, but this is not a closed book: with the competitive tendering approach being extended to onshore it is expected to achieve even greater savings.

Work at Ofgem impacts positively on the lives of millions. "This is a meaningful career", Min reflects, and she adds that it's the people that make it possible. The best thing about working at Ofgem? "Working with professional and enthusiastic colleagues who have a common mission." Ofgem places stakeholders at the heart of all its decision-making processes, and this also extends to its staff. Min explains, "It's a very supportive environment. The trust from senior management is unparalleled – here, I have been recognised as a technical expert and depended upon to make critical judgements and decisions. I feel genuinely valued."

This investment in people is visible throughout the organisation – Ofgem considers all parts of the employee experience, and seeks to give their people the support and flexibility they need to perform their roles effectively. As a result, Ofgem offers the kind of work/life balance that may be harder to find elsewhere.

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Closing date: 9am, Monday 29th June.

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The car of the future

Dutch research organisation TNO helps to make vehicles safer and cleaner by allowing cars to communicate with each other, by preventing collisions between cars and cyclists and by optimising fuel combustion

The entire global automotive industry knows how to get to Helmond, a town in the south-eastern part of the Netherlands. Right here, on the Automotive Campus, the Dutch research organisation TNO helps to make vehicles safer and cleaner – for instance by allowing cars to communicate with each other, preventing collisions between cars and cyclists and optimising fuel combustion while limiting tailpipe emissions.

Helmond may only be a small city, but it is part of the Brainport Eindhoven region, which is, according to *Forbes*, the world's most innovative region. Universities such as Eindhoven, Aachen and Leuven are within easy reach, as are the German automotive industry and the European Commission in Brussels that funds vast research programmes related to mobility.

'The majority of automotive activities in the Netherlands take place here,' says Daan de Cloe from TNO. Car manufacturers from around the globe travel to Helmond to have their latest innovations developed and tested in one of TNO's labs, or on the public road between Helmond and Eindhoven, which is regularly used as a test site for co-operative and automated driving.

It is up to the researchers of TNO to demonstrate new concepts and validate simulation models under world conditions. TNO houses the brightest minds in the field of algorithms, modelling, simulation and control, plus state-of-the-art test facilities used for verification and validation. 'Our unique facilities accommodate entire trucks in order to test them under different climate conditions', says colleague Caspar Lageweg. 'To simulate a car driving in the mountains, we lower the pressure in the lab and change the temperature, as if the vehicle were in northern Sweden in the winter. And a few hours later it could be driving through the Sahara.'

This gives the campus a dynamic atmosphere where every day is different, says Lageweg. 'We are a young and international team of which around 30 per cent is non-Dutch. We hardly spend our entire days at the office due to project activities related to our own lab facility, but also due to face-to-face interaction with our customers in Europe, Japan, the US and China.'

TNO inside BMW

De Cloe and Lageweg are both research managers at TNO in Helmond. De Cloe's line of work is all about integrated vehicle safety, for instance: systems for autonomous emergency braking, lane-change assist, automated driving and communication between vehicles. Cars filled with these smart technologies will improve traffic flow and prevent accidents. Lageweg focuses on lowering the CO_2 emissions by optimising the power train.

TNO does not develop these technologies into new products itself. Vehicle manufacturers and their suppliers will be provided with software solutions and tools for modelling, simulation and control. This allows the manufacturers to create safer and cleaner products. 'We sell software that ends up in, for instance, the BMW 5 and 7 series', says Lageweg.

TNO makes computer models of passengers or components such as steering systems. The actual behaviour of a passenger in a car or the combustion process of an engine can be turned into an algorithm. Lageweg explains: 'When we make these models correctly, we can simulate behaviour, and imitate real events. If these simulations are accurate as well, the model is validated: we have proven that it is representative for real-life situations.'

These systems help to optimise the performance of a vehicle, and can be used for integrated emission management or automated collision avoidance. They are programmed to be adaptive and self-learning. 'Eventually, these systems will be able to predict events', says De Cloe. For instance: TNO is working on a methodology to prevent collisions between cars and cyclists. This system is capable of predicting the movement of a cyclist.

Co-operative driving

Until now, most car manufacturers develop sensors and control systems that communicate only with other systems of their own brand. At TNO, the ambition is bigger: the researchers want all cars on the road to talk to each other. This system, co-operative driving, contains multiple sensors that measure the distance between cars and the speed of the individual vehicles. When the distance is too close and the speed too high, the safety system sends a message to the breaking system. This prevents accidents and traffic jams.

Fully automated driving will most likely begin on the highway, thinks De Cloe. 'Highways are more predictable. In urban areas with a high traffic density, the conditions are very complex and the variety of scenarios is enormous. But it is possible. I am convinced that highly automated driving will soon break through,' he says. 'We have already demonstrated this technology in an automated ride with our minister of transport on the public road in Amsterdam.'

De Cloe (left) and Lageweg, research managers at TNO, focusing on safety and emissions respectively

Bridging the gap

The wider focus of TNO, which is not limited to a single car brand or component within a car, is also key to the work of Lageweg. 'Manufacturers are all optimising their specific components within a vehicle. We regard a vehicle as a platform that needs to be optimised as a whole.' One of his projects is a hybrid truck that automatically switches to the electrical engine when entering an emission-free zone. Many cities in Europe are creating emission-free zones, where only vehicles with low CO_2 emissions may enter. This poses a great challenge for trucks, because they still depend on diesel engines.

All these challenges require specific knowledge. Lageweg says: 'It is in our DNA to perform fundamental and in-depth research, but there is always an application within reach. This enables us to bridge the gap between universities and companies. Our goal is to develop radical rather than incremental innovations. We are working on integrated solutions for the car of the future, with a sustainable architecture that works in the long run.'

These challenges are very tough for individual companies to address. Therefore, scientific and industrial clients more often rely on the knowledge of TNO. De Cloe says: 'There is always room for talented new people here, who have strong analytical skills and a critical and problem-solving attitude.'

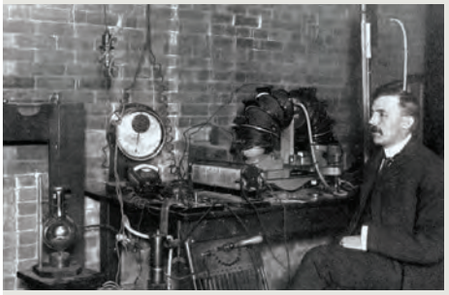
Want to know more about working at TNO? Check out the vacancies.

June1920

The first glimpses of the world inside the atom set *The Engineer* on a speculative path

The Engineer, especially in its early years, was very practical; the stuff of nuts and bolts, big lumps of iron and steel, rivets and steam.

So it was with an almost audible grinding of mental gears that the journal took a stab at describing the world inside the atom and what it might mean to engineers in 1920. This was the height of the discoveries of the quantum mechanical revolution in physics. Ernest Rutherford had split the atom in 1917, and three years later gave a lecture at the Royal Society describing his findings.



The Engineer sent a representative to the lecture, who found himself wondering what significance the discovery of the electron, in particular, might have for engineers.

The article starts with an attitude that is still common among engineers: that a "practical man" might "echo the opinion that has of late found vigorous expression in some quarters, that such research is 'important', but he is content to leave it to a small band of enthusiastic workers whom he is inclined to regard with something between indifference and the semi-contemptuous tolerance that he accords to people who are not 'practical'."

> **"The discoveries were bound to affect our lives and alter the whole aspect of human life**

But, the article adds, it should be obvious that Rutherford's discoveries were bound to "affect our practical lives and perhaps to alter the whole aspect of human life and activities".

The aspect of sub-atomic physics that most excited this reporter was the role of the electron in bonding. The confirmation that atoms are composed of a positively charged nucleus surrounded by negative electrons "serves to show how then atoms, particularly when built up into a crystal, are linked together". The electron is the linking agent and responsible for this cohesion.

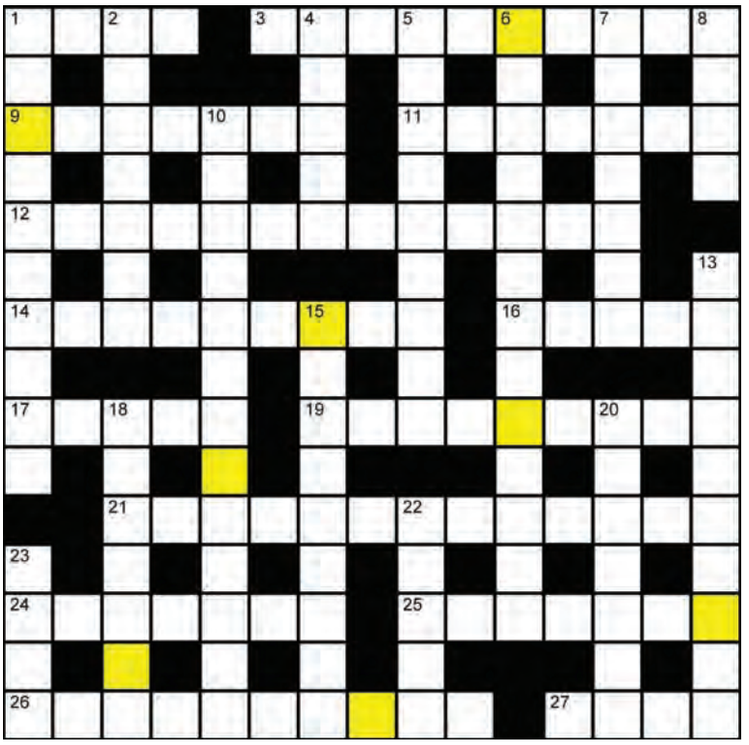
Understanding why electron-mediated bonds give materials their bulk properties was likely to open up a new world of high-performance materials, according to the article. "We might well look forward to an era of engineering materials that should surpass the achievements of the present era of "alloy steels" as much as the iron age surpassed the bronze age," it said.

The report also touches on the possibilities of the energy locked inside the atom, saying that this is indicated by the heat generated by radium as it disintegrates by radioactive decay. ***SN***

For more on this story visit **www.theengineer.co.uk**

prizecrossword

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



ACROSS

1 Shape whose base is a circle and whose sides taper up to a point (4)
3 Original name for sandpaper (5,5)
9 Converts information into cypher (7)
11 Soiled with dirt or grime (7)
12 Device for measuring fluid force (8,5)
14 Russian pioneer of abstract art (9)
16 Compound formed by reaction between an acid and alcohol (5)
17 Mountainous province of Austria (5)
19 Number assigned to the ratio of two quantities (9)
21 Building material of rods and twigs covered with clay (6,3,4)
24 Made by laborious means (4,3)
25 Factory for dressing logs (7)
26 Is included in (5,5)
27 Basic units of electric current (4)

DOWN

1 A miserly person (10)
2 A constituent of an atomic nucleus (7)
4 Light amplification by stimulated emission of radiation (5)
5 Importing or exporting without paying customs duties (9)
6 Large opening in a wall with a single pane (7,6)
7 Chief officer or chief magistrate (7)
8 One step on a ladder (4)
10 Processes of purifying a liquid by boiling and condensing (13)
13 Areas of rural near a town (10)
15 Person lacking intelligence (9)
18 Unfair treatment (3,4)
20 Radioactive metallic element (7)
22 Long narrow passage (5)
23 Hinged or detachable flat section (4)

Last issue's highlighted solution was COLONNADE. The winner is John Finch.

origineering Anthony Poulton-Smith explores the origins of everyday engineering terms

To explain **'wire'**, it is necessary to look first at modern slang. Initially found in the 1950s, the term 'wired' when used to mean 'nervous or tense' is actually from much earlier. When we read of the affluent of old wearing gold cloth, this is describing fine gold wire woven into the cloth. It is easy to see how this would make the garment heavier and more rigid, just as the modern 'wired' would suggest in slang.

Tracing the etymology of this use of 'wire', we find old German 'wiara' meaning 'fine gold work', Old Norse 'viravirka' meaning 'filigree work', Swedish 'via' meaning 'to twist', Latin 'viere' meaning 'to twist or bend' and old Irish 'fiar' and old Welsh 'gwyr' meaning 'bent or crooked'. These can be traced to a Celtic 'viriae' and the Proto-Germanic 'wira', both used in connection with producing bracelets.

These words can be traced to the Proto-Indo-European 'wei' meaning 'to turn', 'to twist' or even 'plait' and thus the original sense was to describe the process of drawing out the metal in finer diameters. This is the same process that produces what we would recognise as 'wire' today.

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