Spring 2016 issue 45

space:uk

Inside Principia mission control

Europe's latest Mars mission launches

UK tech aims to transform spaceflight

UK SPACE AGENCY

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Front cover image Tim Peake waves to the camera during his January spacewalk **Credit:** ESA, NASA

Mars mission blasts off

ESA's first ExoMars mission is blasted into space on a Proton rocket from Baikonur **Credit:** ESA

The joint European Space Agency (ESA) and Russian ExoMars mission is on its way to Mars after launching on a Proton rocket from Baikonur in Kazakhstan. The spacecraft, which consists of an orbiter and lander, will take seven months to reach the red planet.

"It's been a long journey getting the first ExoMars mission to the launch pad," said ESA Director General, Jan Woerner, following the 14 March launch. "But thanks to the hard work and dedication of our international teams, a new era of Mars exploration is now within our reach."

The spacecraft will attempt to sniff out methane in the planet's atmosphere and prove the technology for the next ExoMars mission, which will carry a British-built rover. Scientists working on this first mission include a UK team based at the Open University.

When ExoMars arrives at Mars in October, the Schiaparelli lander will separate from the orbiter and enter the Martian atmosphere. In less than six minutes it will need to reduce its speed from 21,000 to 10 km per hour, using a parachute and thrusters to slow its descent, before a free fall landing from two metres above the surface. At this point its touchdown speed onto the Meridiani Planum will be just a few metres per second.

The lander is demonstrating entry, descent and landing technologies for future missions and will be the only mission to have ever landed during the dust storm season. A package of instruments and a camera will collect valuable entry, descent and landing information.

The lander also carries a small science payload to conduct environmental studies and obtain the first measurements of electric fields on the surface. These, combined with measurements of the concentration of atmospheric dust, should provide new insights into the role electric forces play in lifting dust – the trigger for dust storms.

Big deal

Meanwhile, the Trace Gas Orbiter will – after several months of manoeuvres – enter a circular orbit 400 km above Mars. It will then analyse the atmosphere for trace gases and methane.

ESA's Mars Express mission first detected atmospheric methane in 2004. This made headlines around the world as methane could be from simple life forms, such as microbes. ExoMars will investigate whether this methane results from geological activity within the planet's mantle, or past or present life.

Apart from furthering our understanding of Mars, and maybe even providing evidence of life on the planet, the mission is testing crucial technology for ExoMars 2018. At the heart of this mission will be the first European Mars rover, currently being developed and tested by Airbus Defence and Space in Stevenage.

"ExoMars is a big deal for the UK," said Sue Horne, Head of Exploration at the UK Space Agency. "We're contributing to the Trace Gas Orbiter and leading on the development of a rover that will search for signs of life on Mars. The launch of ExoMars 2016 is an exciting first step."

Tim Peake: the story so far

Launch

British European Space Agency (ESA) astronaut Tim Peake launched on a Soyuz rocket to the International Space Station (ISS) at 11.03 GMT on 15 December 2015. Sat alongside him in the cramped capsule, Russian commander Yuri Malenchenko and NASA astronaut Tim Kopra.

After four orbits of the Earth, the Soyuz approached the ISS and docked at 17.33. The minutes leading up to the docking were tense. The automatic system failed and Malenchenko had to approach the ISS manually. Finally, two and a half hours after docking, the hatches were opened and the crew floated into the space station.

The launch of the Soyuz rocket from Baikonur in Kazakhstan **Credit:** ESA, NASA

Juggling fresh fruit, newly arrived on the ISS in March **Credit:** ESA, NASA

Home in space

Although Peake has undergone years of intensive training, it took a few days for him to adjust to the weightless environment of the ISS. After reviewing the latest safety procedures – in case there is an accident, fire or collision – his first task was to help unload a Cygnus supply ship. He also had to begin his daily exercise regime and first experiments.

Astronauts on the ISS live in the GMT timezone and generally wake up at around 6am. They start and end their days with a planning conference call with mission control. Lunchtime is generally fitted in between tasks but mission planners try to organise the day so astronauts can enjoy an evening meal together.

Spacewalk

One of Peake's first jobs aboard the station was to assist the spacewalk of Scott Kelly and Tim Kopra. Peake's role was to help the other astronauts with their suits and talk them through checklists and procedures.

On 15 January Peake stepped outside the airlock himself with Kopra. The astronauts successfully replaced a faulty unit that regulates power from the station's solar panels.

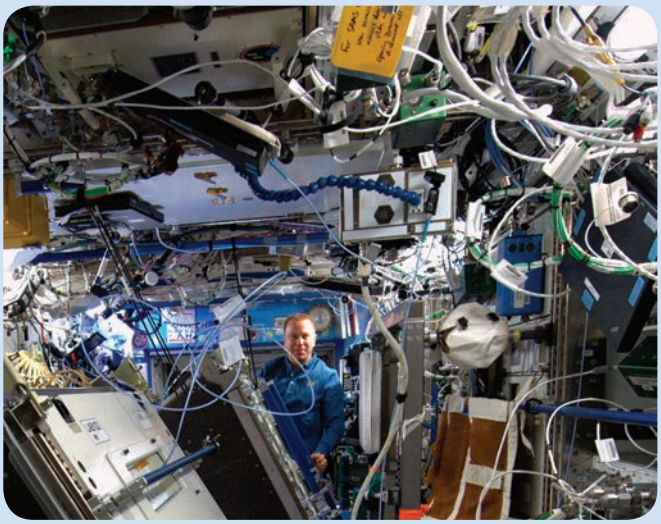
The spacewalk had to be cut short, however, after Kopra reported water accumulating in his helmet. An incident involving a build up of water during ESA astronaut Luca Parmitano's spacewalk in 2013, led to the astronaut almost drowning. The Tims were still able to complete their primary task and got back inside without any problems.

Peake during his January spacewalk **Credit:** ESA, NASA

Earth calling

Peake has spent as much time as possible talking to schools and media back on Earth. On 8 January, students at Sandringham school in St. Albans became the first to make contact with the astronaut via amateur radio. In February Peake took part in the Cosmic Classroom, where he answered questions from school children across the UK and demonstrated the behaviour of liquids in microgravity **(see page 20)**.

As well as linking live with media on Earth, Peake has been working on several education experiments, including using the Astro Pi computers that run code written by schoolchildren. He has even taken part in a space food experiment with chef Heston Blumenthal (broadcast on Channel 4) and presented a Brit award to Adele.



Not as bad as it looks (apparently) – the Tims re-routing cables on the ISS to upgrade the communications system **Credit:** ESA, NASA

Capturing the Cygnus supply ship **Credit:** ESA, NASA

Science and satellites

Much of Peake's time on the ISS is taken up with science experiments (**see page 16**). These include investigating the properties of liquid metals in a special furnace, medical, human physiology and life science studies. He has even launched satellites through a station airlock.

Peake will also be operating rovers on Earth from the ISS. Remote operation of robots from space may be useful for future human missions to the Moon or Mars. In April, Peake will try to control a rover in a test facility in Stevenage.

On 26 March the Tims worked together to grapple an unmanned Cygnus supply spacecraft with the 17-meter Canadarm and dock it to the station.

Return to Earth

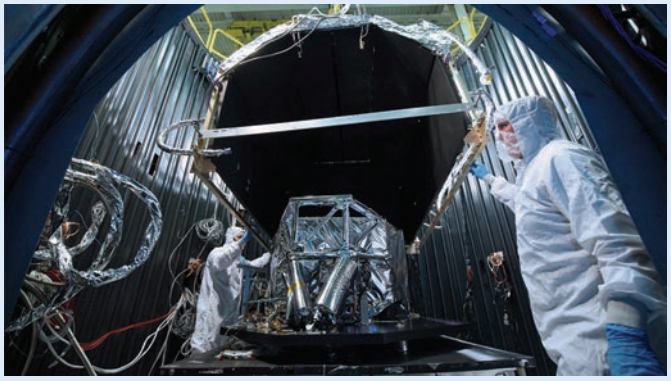
Peake is due to return to Earth on 5 June after what has already proved to be a packed, challenging and exciting mission. Decisions on Britain's future commitments to human spaceflight will be made at the ESA Ministerial meeting in November 2016.

You can follow Peake's mission on the Principia blog: **principia.org.uk** and he tweets from the ISS as: @astro_timpeake

A magical Aurora captured by Peake in January **Credit:** ESA, NASA

Testing MIRI

Testing MIRI's heat shield **Credit:** NASA



Snowstorms, power cuts and severe thunderstorms have not been enough to stop UK scientists and engineers getting the Mid Infrared Instrument (MIRI) through its third campaign of testing at NASA's Goddard test facility near Washington DC.

The UK team is celebrating a highly successful run of tests and is looking forward to the next phase of integration with the rest of James Webb Space Telescope (JWST). When the JWST launches in October 2018 it will be the premier space observatory of the next decade, supporting thousands of astronomers worldwide.

MIRI is one of four instruments on board the telescope and was developed in a collaboration between ESA and NASA. The UK team is made up of a partnership between the Science and Technology Facilities Council, University of Leicester and Airbus Defence and Space, with funding from the UK Space Agency.

Ten year success

A mission that has long outlived its planned life is still working after more than ten years in space.

GIOVE-A (Galileo In-Orbit Validation Element) was launched in December 2005 as a pathfinder mission for Europe's Galileo satellite navigation system. The spacecraft was designed and built by Surrey Satellite Technology Limited (SSTL) in Guildford.

Its mission was to secure vital radio frequencies reserved for Galileo by the International Telecommunications Union, to generate the system's first in-flight navigation signals, and to test a prototype rubidium atomic clock. It also carried instruments to investigate the radiation environment of space.

ESA officially retired GIOVE-A in 2012, but SSTL continues to operate it to gather data. Controllers are hoping for at least another year of operation so they can complete observations of the space environment over an entire 11-year solar radiation cycle.

GIOVE-A on the launch pad at Baikonur in 2005 **Credit:** ESA

Europe's new Sentinel

A new European environmental monitoring satellite is sending back its first data following a successful launch.

Sentinel 3A carries instruments aimed at studying our oceans. It is the third Sentinel mission launched by ESA for Copernicus – Europe's comprehensive program for monitoring the Earth using land-based as well as space-borne instruments.

The UK's RAL Space took a leading role in building a key Sentinel 3A instrument – the Sea and Land Surface Temperature Radiometer. This monitors heat energy coming from the Earth's surface and atmosphere, including forest fires.

The satellite's other two principal instruments are a radar altimeter and a colour camera. The altimeter is designed to make precision measurements of sea-surface height, wave height and surface wind speeds. The camera will examine ocean colour to reveal information about marine ecosystems.

With all instruments now fully operational, ESA scientists have been analysing the first results. "It is still early days but we are looking to exploiting the instruments' full potential and using them together," said Sentinel 3A's project manager, Bruno Berruti. "For example, combining radiometer and colour data will help us to understand the state of vegetation better."

In the UK, Sentinel 3A data is expected to benefit government agencies and industry. DEFRA, the UK government department responsible for the environment, has established a centre of excellence to increase the use of Earth observation data across several policy areas.

More and better monitoring of the oceans will improve ocean forecasting and maritime safety. Data for coastal waters will be used to help predict extreme weather events such as storm surges and flooding.

Sentinel 3A being prepared for launch at the Plesetsk Cosmodrome in northern Russia **Credit:** ESA

Farewell Philae

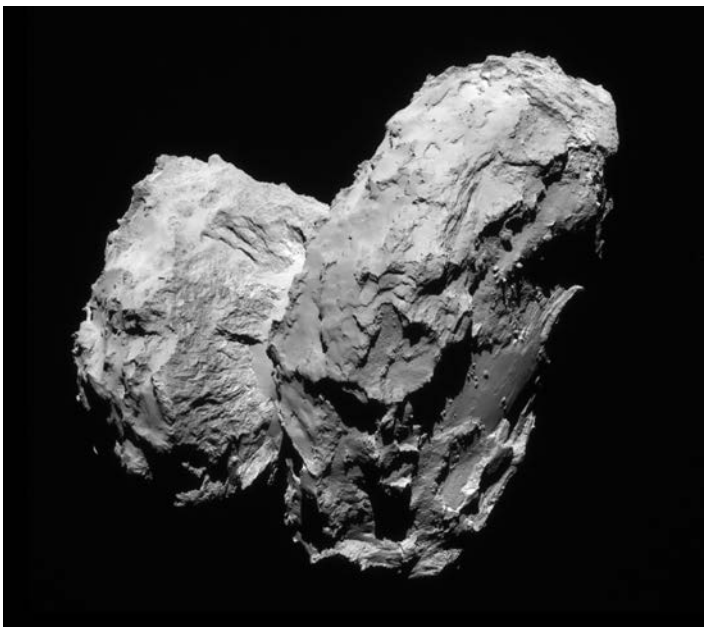
ESA scientists believe they have probably heard the last from Rosetta's Philae lander, which made its historic touchdown on Comet 67P/Churyumov–Gerasimenko in November 2014.

"The chances for Philae to contact our team at our lander control centre are unfortunately getting close to zero," said Stephan Ulamec, Philae project manager at the German Aerospace Centre, DLR. "We are not sending commands any more."

Philae surprised everyone when it made several unexpected bounces across the comet after its harpoons failed to fire and secure it to the surface. It finally came to rest on a cliff, one kilometre away from its planned landing site and without enough sunlight to charge its secondary batteries. Nevertheless, the lander completed 80% of its planned science.

UK scientists and engineers are involved in numerous aspects of Rosetta's orbiter and lander, including a team at the Open University in Milton Keynes who built the lander's Ptolemy instrument. The landing problems meant that the gas analyser had to operate in 'sniffing' mode only but this did not stop it from collecting data.

"History will record that Ptolemy was the first ever instrument to measure the chemical composition of the surface of a comet," said Ptolemy's Principal Investigator, Ian Wright. "I find it slightly humbling to consider that I was given an opportunity to work with colleagues in the UK to design and build a box-of-tricks that would travel a vast distance across space in order to analyse ices that have been preserved since the formation of the Solar System. Effectively, we travelled back in time by four and a half billion years."

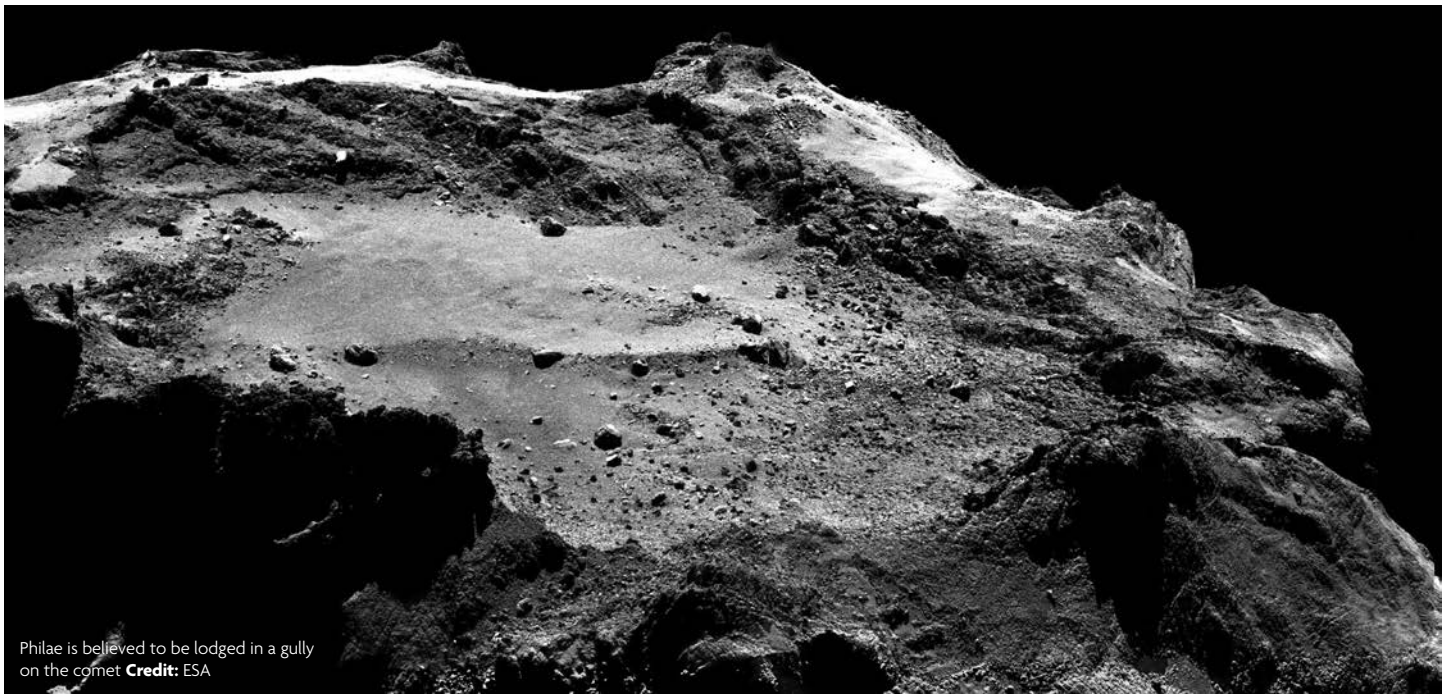


Rosetta will continue to study the duck-shaped comet until September 2016 **Credit:** ESA

"Philae has been a tremendous challenge," said Patrick Martin, ESA's Rosetta Mission Manager, "and for the lander teams to have achieved the science results that they have in the unexpected and difficult circumstances is something we can all be proud of."

Rosetta is now moving away from the Sun towards the end of its mission in September when it too will land on the comet. No one expects to hear from Philae again – its last contact was in July 2015 – but a listening channel will remain open.

"While we say goodbye to our dear friend Philae, it is appropriate to reflect on the vision, the imagination, the technical genius, and the sheer bloody-minded can-do dedication of the humans who have been involved with the project," said Wright. "Our lander is gone, but certainly not forgotten."



Philae is believed to be lodged in a gully on the comet **Credit:** ESA

LISA's mission begins

The LISA Pathfinder spacecraft has begun its science mission, testing the technology for detecting gravitational waves in space.

The discovery of gravitational waves made headlines in February after being detected directly from the Earth for the first time. Confirmation of these ripples in spacetime, first predicted by Albert Einstein almost a hundred years ago, will herald a new era of astronomy.

Gravitational waves are thought to be caused by black holes, neutron stars or colliding galaxies. But even though they are produced by enormous objects or events such as exploding stars, gravitational waves themselves are tiny – a fraction of the size of an atom – which makes them extremely difficult to measure.

Confidence

LISA Pathfinder, which launched in December, is the first gravitational laboratory in space for fundamental physics. The spacecraft, built by Airbus Defence and Space in Stevenage, carries two identical 46mm gold-platinum cubes (or test masses), 28cms apart, in free fall.

These masses are shielded from all other forces except gravity. Tiny thrusters maintain the spacecraft's position and the cubes are linked by laser beams. Any changes in the cubes' position should result from gravitational waves.

UK scientists from the University of Birmingham were involved in designing and building the phasemeter, which measures the separation between the test masses. "Although we're still in the early phases of the mission, the payload on LISA Pathfinder is working extremely well," said Mike Cruise from the university's School of Physics and Astronomy.

"Confidence is building that the mission will be a complete success," said Cruise. "Now that the commissioning phase has been successfully completed, the series of physics tests are beginning. These will demonstrate how accurately we can measure the free fall of the test masses, unaffected by the motion of the satellite."

Excited

A group from the Institute for Gravitational Research at the University of Glasgow, funded by ESA and the UK Space Agency, built the spacecraft's optical bench.

"We developed, assembled, tested and delivered the interferometer that lies at the heart of the mission," said Harry Ward from the University of Glasgow. "This interferometer monitors the positions and angles of the test masses with ultra-high resolution."

The nighttime launch of LISA Pathfinder on a Vega rocket from French Guiana **Credit:** ESA

"After many years of hard work we have been excited and very pleased to see this instrument now monitoring picometer movements of freely floating masses nearly a million miles away from Earth," said Ward.

Preliminary results from the science operations, according to Ward, are also looking good.

"The science team is now in the process of running experiments to better understand the physics of the forces acting on the free-floating test masses," said Ward.

Other UK scientists involved in the mission include a team from Imperial College London that built one of the isolation mechanisms for the cubes, designed to cancel out the effect of cosmic rays, and SciSys UK Limited who developed the onboard software.

Once the innovative technology on LISA Pathfinder has been demonstrated, a more ambitious mission is planned. This would involve up to three spacecraft, each separated by five million kilometres.

From the Agency

At the end of March 2016, our Chief Executive Dr David Parker left the UK Space Agency to join ESA as its new Director of Human Spaceflight and Robotic Exploration. Here he reflects on some of the recent changes that have swept across the UK space community.

Nearly sixty years since the first satellite was launched, daily life has seamlessly absorbed space-based services such as weather forecasting, satellite navigation and satellite TV.

Of all the recent advances in UK space policy, the 25% increase in UK funding of ESA made at its Council of Ministers in 2012 probably had the biggest impact. It's one reason why three-dozen space companies subsequently expanded their presence in the UK or set-up here for the first time. In return, ESA grew its small office at the UK Space Gateway in Harwell, near Oxford, to become the European Centre for Satellite Applications and Telecommunications (ECSAT). It was an emotional moment to see the flags of all the ESA Member States raised in honour on UK soil for the first time. For me, it symbolised the UK anchored in ESA and ESA anchored in the UK.

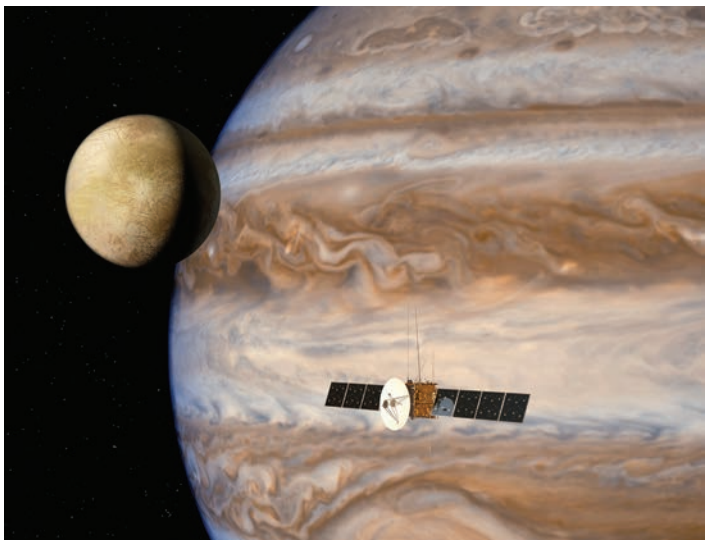
It's also been my good luck to help steer several changes in UK space policy only possible since the Agency was set-up. For example, for some years, a select band of UK scientists had argued the case for involvement in both human spaceflight and what's sometimes called 'microgravity science'.

Via a series of policy reviews, the evidence was gradually assembled that we were missing out on something valuable. But the creation of the Agency made the breakthrough possible. We joined ESA's life and physical sciences programme (ELIPS) in 2012. The simultaneous decision to participate in ESA's human spaceflight programme followed a similar path with policy reviews, which changed established thinking.

The benefits are clear. The UK community has seized the opportunity of ELIPS participation and 100 scientists are now involved. UK technology is being developed that will give the European part of the International Space Station (ISS) vastly improved communications, increasing science productivity. And about half a million young people are involved in education projects built around Tim Peake's six month Principia mission to the ISS.

Only a few thousand extra young people need to take up STEM careers for the mission to pay its way, putting aside the science and commercial returns. Having first met Tim in 2009, it's been a joy to witness him reaching national hero status, cemented when he recently presented a 'Brit Award' to singer Adele, direct from the ISS and reducing her to tears!

JUICE will investigate Jupiter's icy moons **Credit:** ESA



Published by ministers in December 2015, the UK's new National Space Policy (NSP) for the first time captures the breadth of UK space policy in a single document. It sets out the roles and responsibilities for space across Whitehall and beyond while defining the enduring principles of UK action in space. Meanwhile, the International Partnerships in Space Programme (IPSP) has come to the end of its £32m two-year pilot phase. Twenty diverse projects have seen UK businesses tackling real world problems such as delivering education, health advice and land use monitoring via satellite with countries in South America, Africa and the Far East.

In Earth observation we have made great progress with implementing our national strategy and our space science programme has gone from strength to strength. The billion-star astrometry mission Gaia - which uses UK technology for its all seeing 'eye' - has completed coverage of the whole sky and the first data catalogue is released in mid-2016.

The UK instrument for Europe's first mission to Mercury, BepiColombo, was delivered to ESA in May 2015. We can also look forward to Solar Orbiter's journey to the Sun, ExoMars exploring the Red Planet and then JUICE launching to the icy moons of Jupiter in the next decade. Astronomy will be transformed when the James Webb Space Telescope launches in 2018, with the UK-led Mid-infrared instrument at its heart. LISA Pathfinder, built by UK industry, relies on contributions from UK universities to help prove the feasibility of a future space-based gravitational wave observatory.

I am delighted that Katherine Courtney, former Director of the Enterprise Directorate at BIS, has been appointed as acting CEO until the end of 2016, allowing a permanent replacement to be appointed in due course.

Finally, I want to pay tribute to the wonderful team at the Agency, as well as our sponsors in BIS, the Steering Board and many partners in the UK and beyond. Ultimately, it's not policies or budgets that make progress in exploring and using space – it's people. Their dedication, creativity and enthusiasm have defined the success of the UK Space Agency. It is to them that I owe a personal and lasting debt of gratitude.

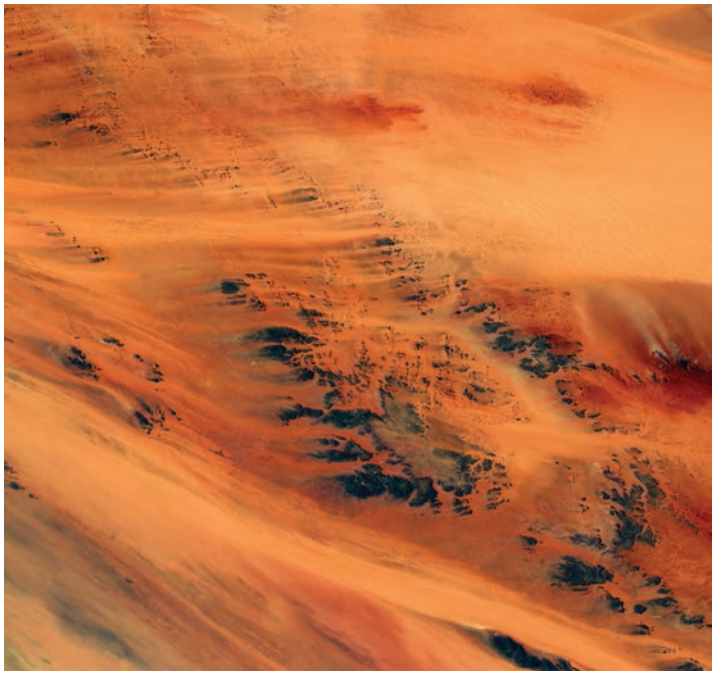
EO Detective

A competition inviting children to suggest places on Earth for an astronaut on the ISS to photograph has received hundreds of entries. Earth Observation (EO) Detective has been run by the National Centre for Earth Observation, the UK's leading research centre for studying our planet using observations from satellites in space.

Although the competition has now closed, resources bringing together 50 years of astronaut photographs and satellite images of Earth are available via the Principia website. To celebrate astronauts' perspective on our changing planet, we have chosen some of our favourites snapped by Tim Peake:

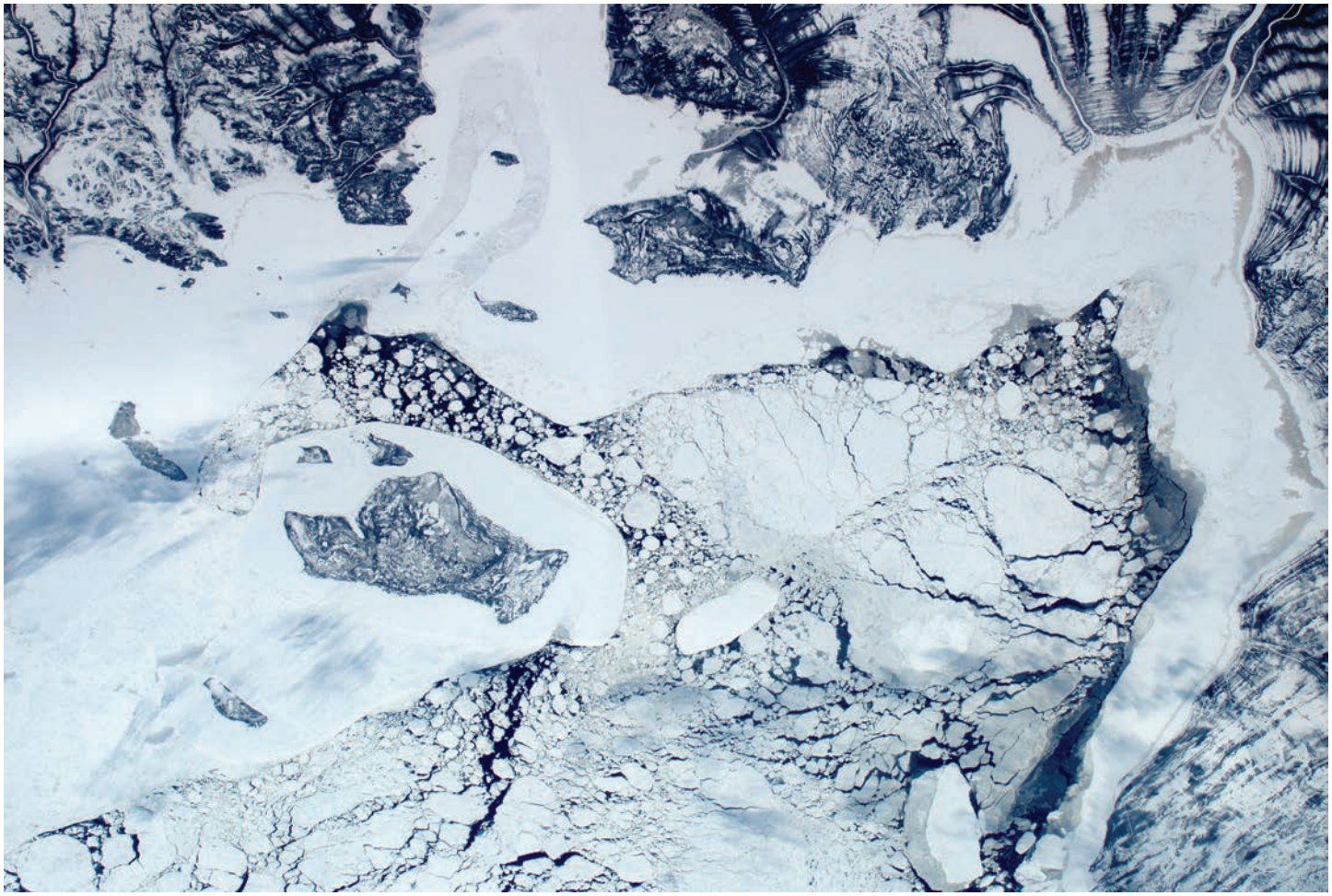
An unusual perspective of Britain at night – looking along the channel with France to the right of the image

Snow on the mountains of south Wales



The Sahara Desert in Chad

Tim captured this picture of San Francisco on 16 March



Spooky patterns of ice and land in northern Canada

All credits: Tim Peake

Spaceplane:UK

Artist's impression of Skylon in orbit
Credit: Reaction Engines

A British designed rocket engine could transform the future of space travel. Sue Nelson reports

"It's the ultimate in terms of spaceplane achievement, but we're looking at other things the engine could do"
Mark Thomas
Reaction Engines

If you have never seen Skylon before, picture this: an aircraft as sleek as Lockheed's famous SR-71 Blackbird but much slimmer – cigar shaped with shorter wings – and without the horizontal stabilisers at the tail. Yet there are small fins on the nose cone, like a guided missile, and there is something about its design that brings to mind an elongated V2 rocket.

So is Skylon a jet plane or a rocket?

The answer is both.

The Skylon spaceplane is an unmanned single stage to orbit launch system. A reusable spacecraft that will take off from a runway, fly into orbit to deliver a satellite, and return to Earth for a runway landing. Unlike the retired Space Shuttle, there will be no need for heavy rocket boosters on launch and its air breathing SABRE engine would drastically reduce the cost way of getting satellites into space.

The recent investment by BAE Systems of over £20 million into Reaction Engines, the company behind the SABRE engine and Skylon design, could make this happen. Together with pledged Government grant funding of £60 million through the UK Space Agency, this financial vote of confidence is likely to ensure that the revolutionary new aerospace venture becomes a reality.

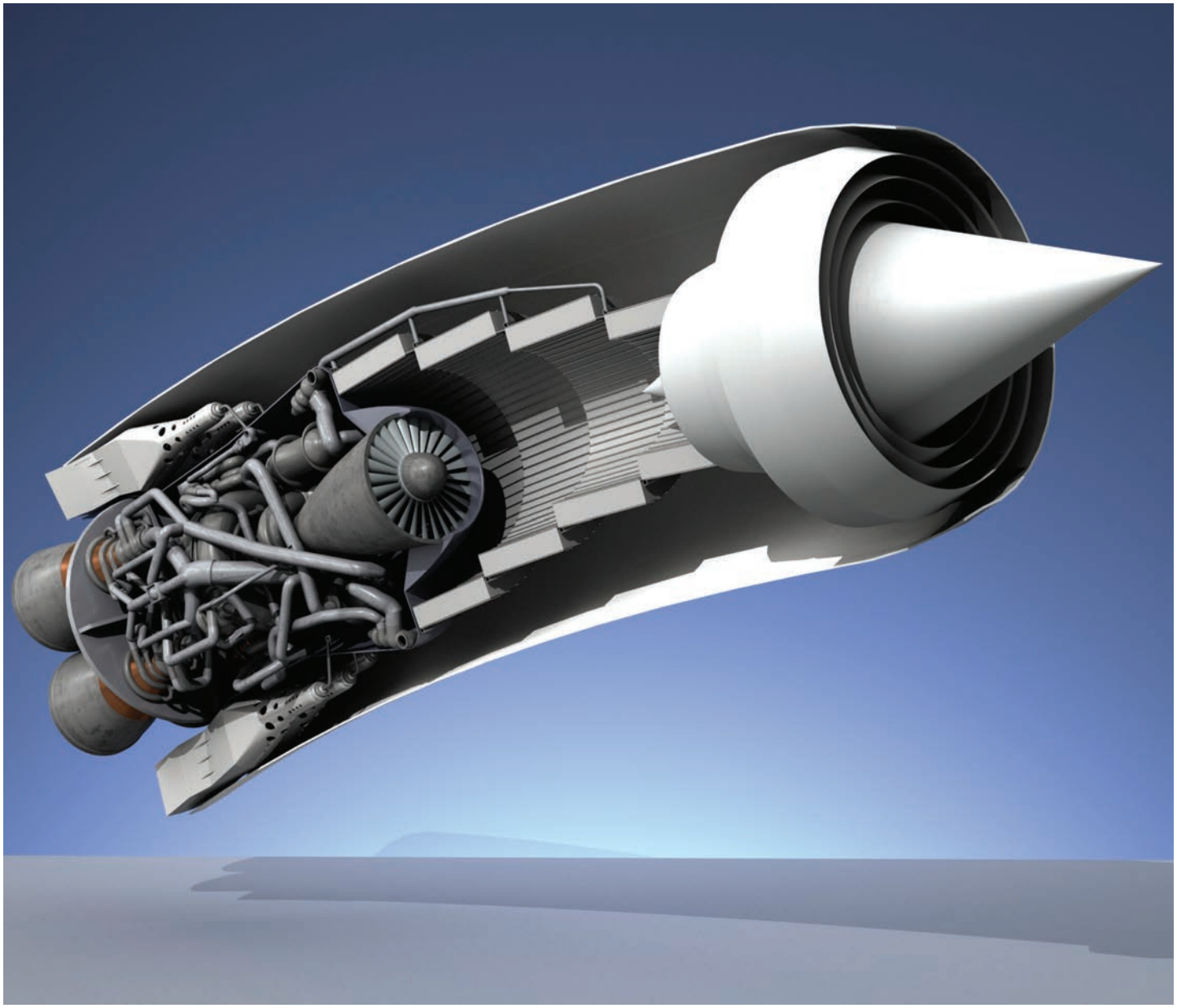
Mach 5

The technology that is attracting so much interest is a new type of engine called SABRE – Synergetic Air-Breathing Engine. This will breathe air and go up to Mach 5 (over 6,000 kilometres per hour) during atmospheric flight before switching to liquid oxygen in space.

"We know that there is a market to develop a more cost-effective launch system than traditional single-use rockets," says Elizabeth Seaman from the UK Space Agency. "We are investing in the SABRE project because it has the potential to transform access to space by providing a cheaper and more reliable way to power a reusable spacecraft."

The SABRE engine uses rocket combustion chambers that employ a mixture of air and hydrogen fuel for the first part of the flight, before liquid oxygen replaces the air in space. But the engine's key technology is a heat exchanger. This will use liquid helium to remove heat from the incoming air, cooling it from 1000 to -150 degrees Celsius in a hundredth of a second. It is this heat that will power an air compressor, improving fuel consumption. No one, however, has put a heat exchanger into a flying vehicle before.

"This is as close as it gets to a Whittle moment – the invention of the jet engine – and what that has enabled," says Mark Thomas, Reaction Engines' managing director. "The world we live in today would be very different without the jet engine and I think we have a great opportunity to seize the initiative and do something similar. It's game changing."



Cutaway diagram of the SABRE engine **Credit:** Reaction Engines

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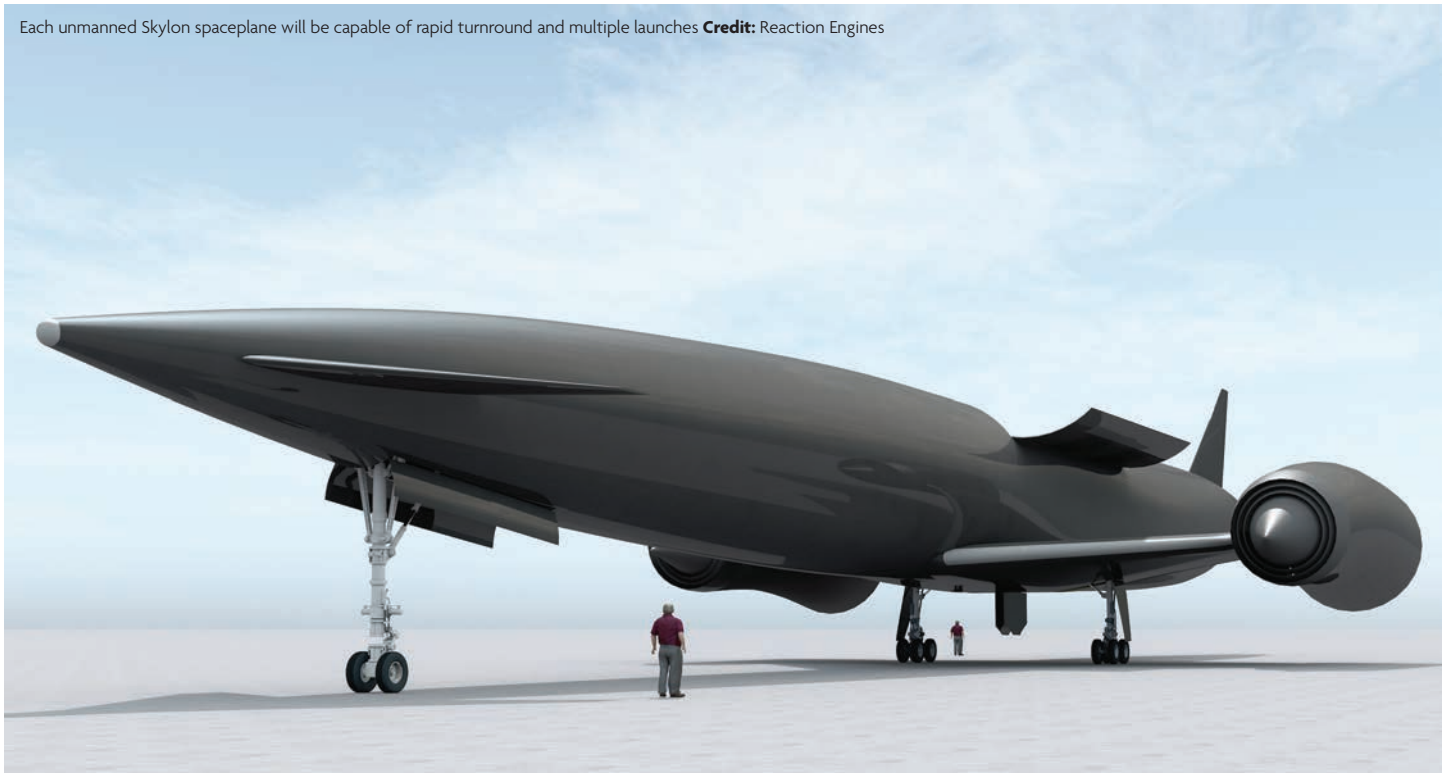

Each unmanned Skylon spaceplane will be capable of rapid turnround and multiple launches **Credit:** Reaction Engines

Rocketeers

Reaction Engines has demonstrated the heat exchanger technology hundreds of times on its test site. "That's really at the heart of the engine," says Thomas. "It's the thing that makes it viable and it's incredibly smart."

"What we need to do," he explains, "is take that heat exchanger into a hot environment because, when it's in the engine for real, it's going to see temperatures of over 1000 degrees and it's going to need to cool that air down to -150 within a hundredth of a second."

Alongside Richard Varvill and the late John Scott-Scott (see right), Alan Bond is one of the three men, or 'rocketeers' as a BBC4 documentary called them, who set up Reaction Engines in 1989 and unveiled their revolutionary plans for SABRE and Skylon.

Since then, ESA and the United States Air Force Research Laboratory have checked-out the engine and the technology. It has also been demonstrated hundreds of times at a test site, a short walk away from the company's base at the Culham Science Park near Oxford.

John Lanfear Scott-Scott, 1934-2015

Aerospace engineer John Scott-Scott, who died in December, set up Reaction Engines with Alan Bond and Richard Varvill in 1989. Scott-Scott specialised in hydrodynamics and was a world expert in high performance centrifugal pumps for rocket engines.

His interest in rockets took hold early. He built his own rockets as a teenager, even distilling the propellant. After studying engineering at Birmingham University he joined Armstrong-Siddeley – which produced cars and aircraft engines – and then Rolls Royce. His work there involved contributing to all the major British rocket projects, including the missile programme Blue Streak.

Scott-Scott worked with Alan Bond on the HOTOL (Horizontal Take Off and Landing project), which evolved into Skylon and the SABRE engine projects. "I am pleased to say that last August we managed to get John over here," says Bond.

"John was still sufficiently bright that he could see what he'd contributed to and see what he'd started. There was a day when it was just three of us. Now there's a brazing furnace and manufacturing facility in Culham. He was really pleased about that."

The UK's Blue Streak missile was developed in the 1950s **Credit:** Airbus Defence and Space

British ESA astronaut Tim Peake captured this selfie – with the Earth and International Space Station (ISS) reflected in his visor – during his January spacewalk Credit: ESA, NASA

UK SPACE AGENCY

Home in space

Astronauts have been living in space stations for more than forty years. These orbiting laboratories have evolved from single modules to vast homes in space where people live and work for up to a year at a time.

Early space stations

The idea of building an orbital habitat dates back to the dawn of the space age. In the 1950s visionaries such as British science fiction writer Arthur C Clarke imagined enormous wheels in space. These would be home to hundreds of astronauts and act as stepping stones to the Moon and Mars.

The first space station, Salyut-1, was launched by the Soviet Union in April 1971. A three man crew spent three weeks living and working in this 20 metre long cylinder. However, when they returned to Earth in their Soyuz spacecraft a faulty valve sucked all the air out of the capsule. Without spacesuits, the cosmonauts died instantly. The first anyone knew of the tragedy was when ground support staff opened the spacecraft hatch.

In 1973 the United States launched its first space station, Skylab. Built from a section of a Saturn 5 rocket left over from the Apollo missions to the Moon, Skylab had a roomy interior with laboratories, sleep and rest areas. It even boasted a shower – one of the worst space inventions ever. Three crews, each of three astronauts, visited Skylab over a period of nine months. During that time they carried out spacewalks, conducted science experiments and learned to understand the challenges of living in space.

Skylab 3 commander Gerald Carr balances pilot William Pogue

A final February 1974 view of Skylab after the last crew had undocked from the station to return to Earth

Mir in 1997 taken by an astronaut on shuttle Atlantis as it approaches for docking

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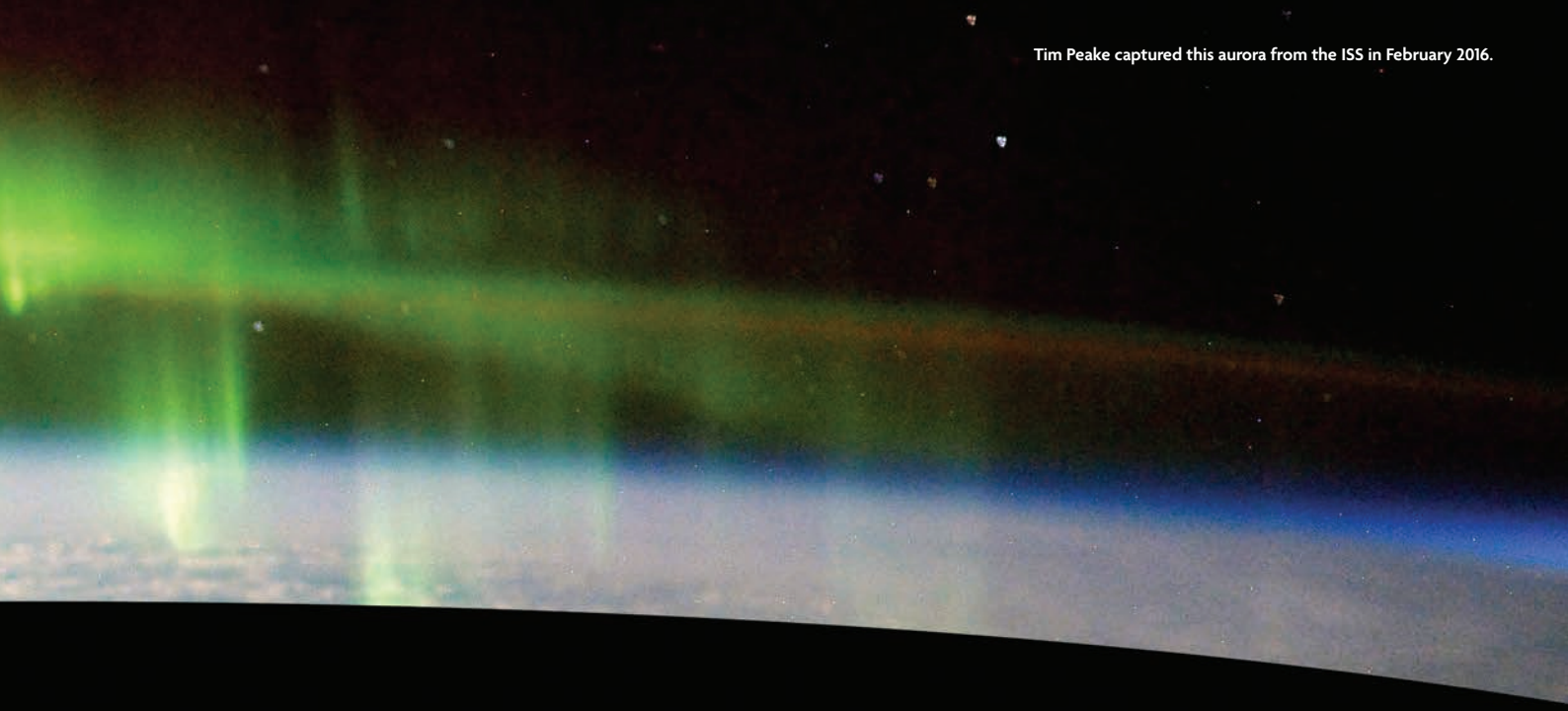


Tim Peake captured this aurora from the ISS in February 2016.

Space station Mir

The first section of Soviet space station Mir was launched in 1986. Over the next few years, further modules were added to enable people to live in space for many months at a time. Between 1994 and '95 one cosmonaut, Valeri Polyakov, spent 437 days on board.

Mir remained in orbit for a total of 15 years and hosted visiting astronauts from many nations. The first British astronaut, chemist Helen Sharman, visited the station in 1991. During her eight day mission she carried out experiments and spoke to UK schoolchildren from orbit.

Following the collapse of the Soviet Union, a Space Shuttle docking port was fitted to Mir and during the next few years a total of seven US astronauts lived and worked alongside Russian cosmonauts. These included British-born astronaut Michael Foale who was on board the station when it was hit by a robotic supply ship. The collision ruptured one of the modules and only speedy actions by the crew prevented a tragedy. Despite the accident and an earlier fire, Mir proved it was possible for people to live in space for prolonged periods. The space station's design formed the basis for the Russian sections of the International Space Station (ISS).

Shannon Lucid exercises on a treadmill inside Mir in 1996

Building the ISS

Building a giant 420-tonne structure 400 kilometres above the Earth designed for continuous human occupation was never going to be easy. Teams in multiple countries, speaking several different languages, had to design and build tens of thousands of components and get them to fit together.

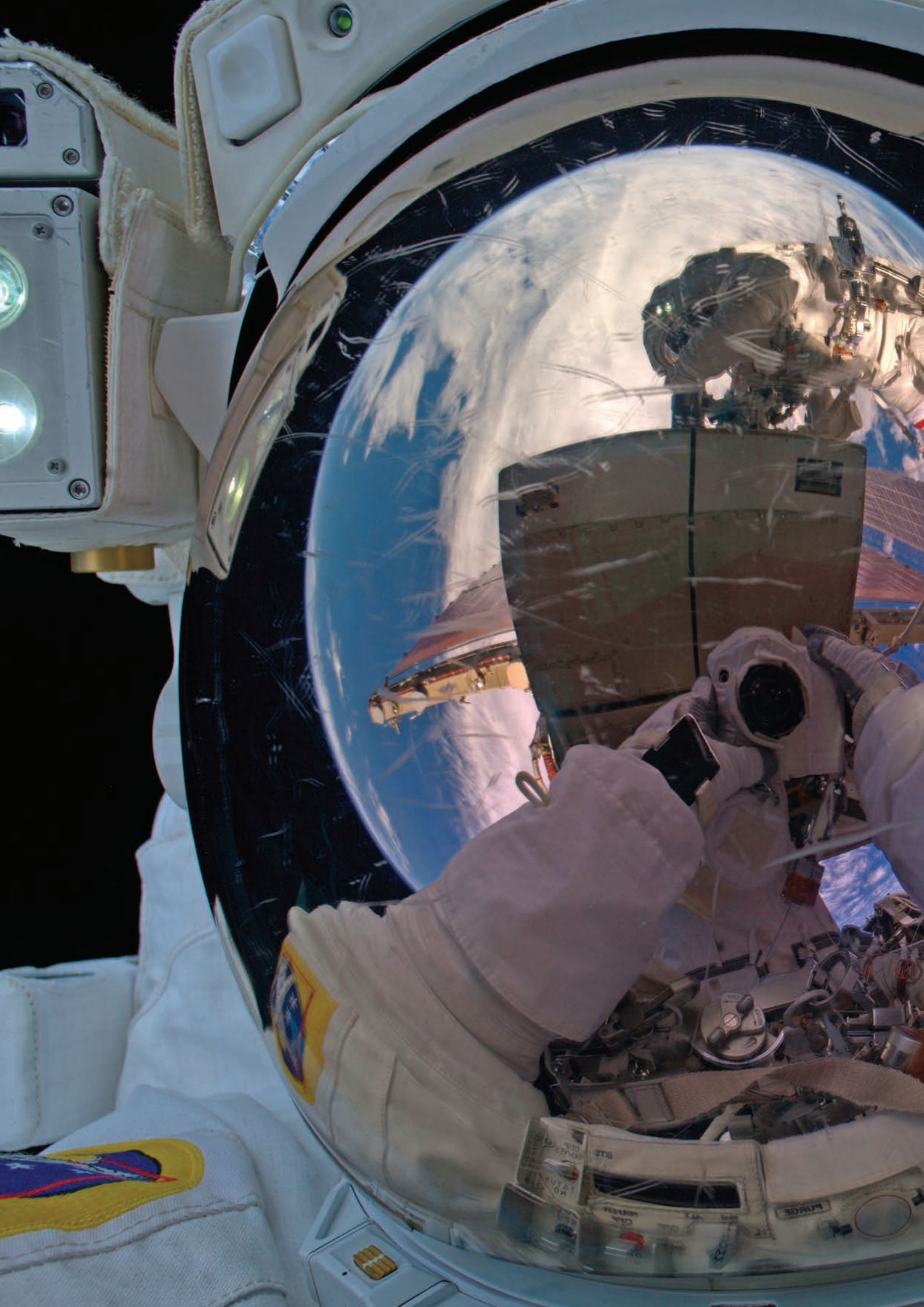
The first section of the ISS – the Russian Zarya module – was launched in November 1998 and the first crew took up residence two years later. By February 2001, the US Destiny laboratory had been added and there were six further construction missions that year. The Space Shuttle played a crucial role in delivering, positioning and joining new modules.

With the European Columbus laboratory, Japanese Kibo lab and Canadian robotic arm attached, by the end of 2010 the station was almost complete. On 24 February 2011, as the ISS passed over Turin, ESA Italian astronaut Paolo Nespoli and US astronaut Michael Barratt used the robotic arm to manoeuvre the final main section of the ISS, the Leonardo Module, into place.

The station has been continuously occupied since 2000 and is likely to be inhabited until at least 2024. ESA astronaut Tim Peake is the first British astronaut to visit the station, his home in space for six months.

The first ISS crew of Yuri Gidzenko, William Shepherd and Sergei Krikalev lived on the station from November 2000

Tim Peake selfie taken during his January 2016 spacewalk



Optimum design

Bond has a definite deadline to work to. "The next stage is to put an autonomously operated engine on test and we're trying to do that by the end of this decade," he says, "which is like the famous Kennedy statement about getting to the Moon."

The Government money comes with an added incentive: It depends on Reaction Engines meeting specific technical milestones as the company expands and continues to develop and test the engine.

As with any engineering programme, the engine designs evolve – be it the nozzles or the combustion system. Five years ago, for instance, the company was working on an engine variant called SABRE 3.

"SABRE 3 is a very nice lightweight engine but it's got a prodigious fuel consumption," says Bond. "Now we've moved in the direction of reducing fuel consumption but the penalty is that the engine gets heavier."

"We are still trying to find what the optimum design of engine looks like," he says. "We're just about there for the specification of the engine that will be on test in 2019."

Other aspects of the design, such as re-entering Skylon into the atmosphere, have proved smoother than expected. "We thought it would require special ways of handling the heat loading on parts of the wing during re-entry," Bond admits, "but more recent analysis has shown that we actually overestimated the difficulty of that problem, so that looks simpler."

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Skylon will be very different to the Space Shuttle, seen here just before launch in 2009 **Credit:** NASA

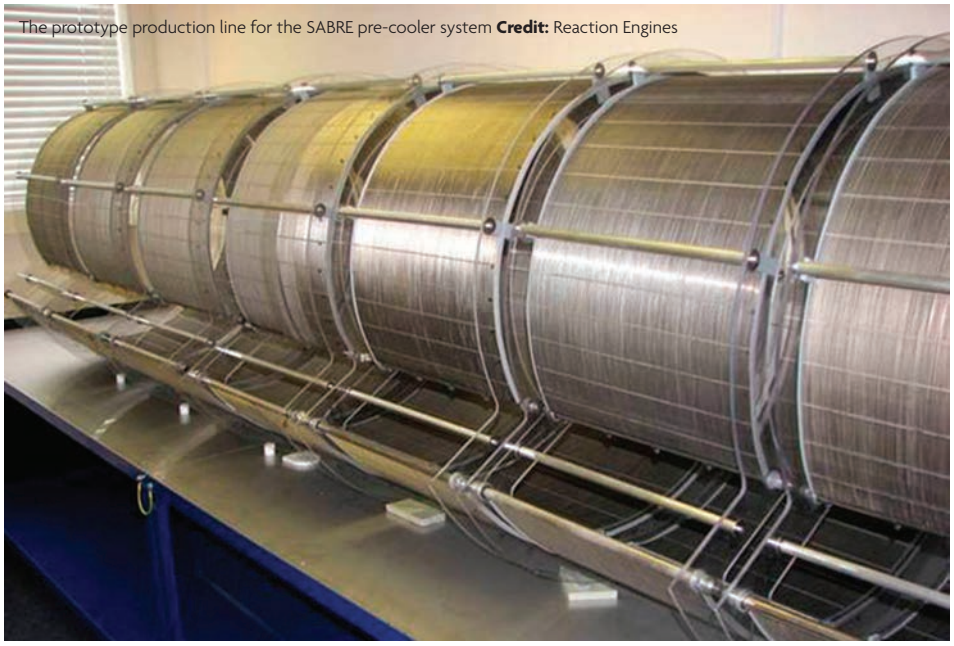
Outstanding

Reaction Engines has also reinvented the manufacturing process of joining two metal joints together, known as brazing. Inside the pre-cooler manufacturing facility on site, I am shown a brazing furnace (designed by Scottish company Consarc) and the difference their new process makes on the joints, which are scrupulously clean.

"In one of our heat exchangers there are two million tube joints," says Bond, "and if those joints are not perfect we lose helium through those joints."

"If that helium leakage is sufficiently high it'd stop the engines from working so we've got to be able to braze the joints with over 99% efficiency," he says. "Having got to the point where we can do that is outstanding."

Although the theory of heat exchangers is relatively straightforward – Bond says you could write the equations down "on two sides of A4" – making them in practice is the hard part. Bond likens the challenge to the early days of the modern semiconductor industry.



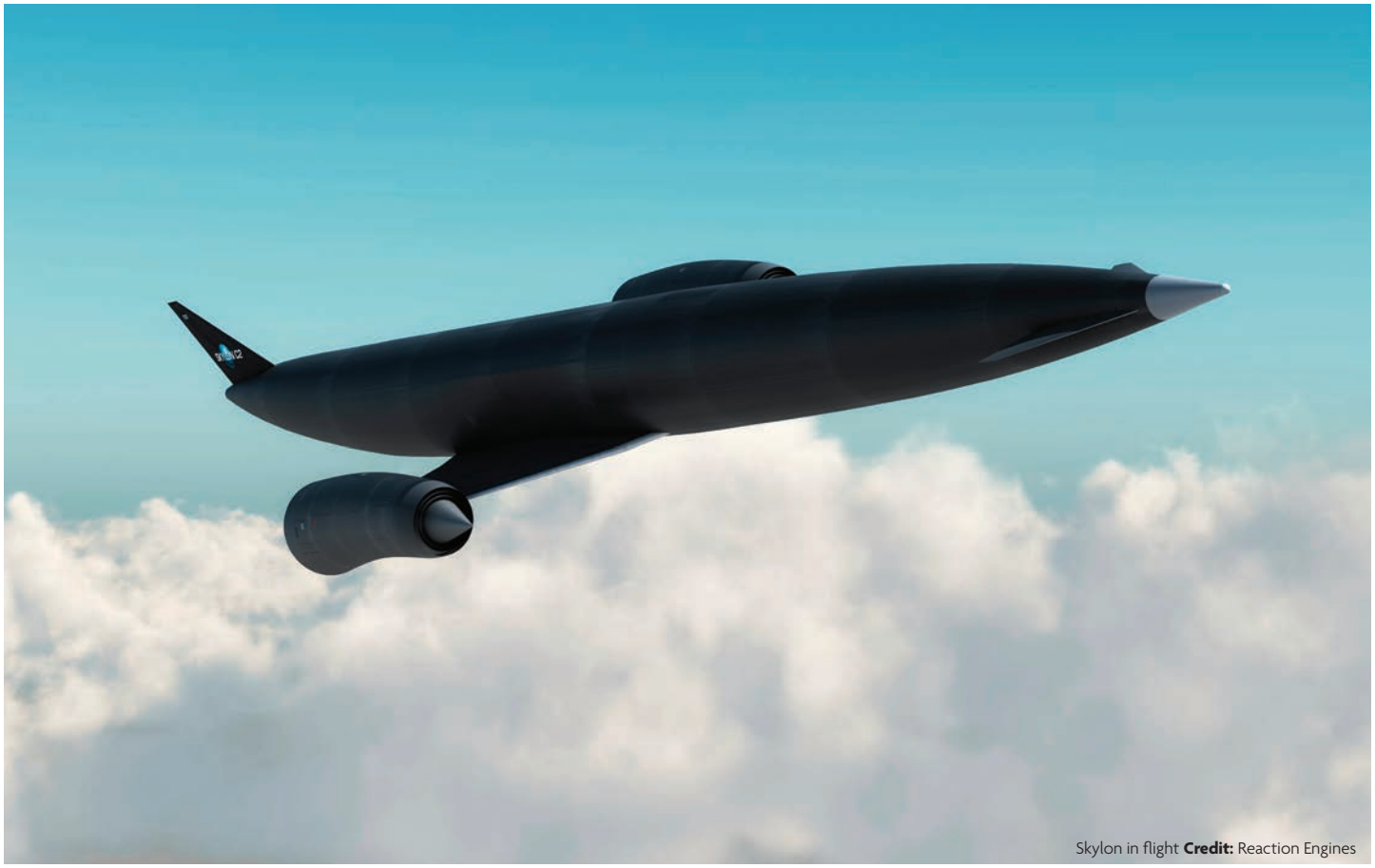
The prototype production line for the SABRE pre-cooler system **Credit:** Reaction Engines

"At the moment it's still an expensive process but future potential for these types of engines is absolutely huge," he says. "So having got the first part of the brazing process sorted is very exciting."

Fortunately, the UK Space Agency also sees the potential in the project. "We recognise that such an innovative technological development will not be without its challenges," says Seaman.

"But we are confident that there will be an engine on test by the end of the decade."

"The government grant is an incredible affirmation of what we do," says Reaction Engines' Finance Director, Tom Scrope. "This investment comes at a very good time as we morph from a research outfit to a development organisation."



Skylon in flight **Credit:** Reaction Engines

Expanding

This transition is visible. When I last visited Reaction Engines in 2011, the company was located in one of the Culham site's smaller buildings. It moved to a significantly larger building in 2014. There are now 84 employees and the business is expanding with offices above the manufacturing labs on the ground floor.

"We've got an incredibly talented workforce who are highly committed," says Thomas. "They are multi-skilled, extremely intelligent and agile about the way they do things."

"We're recruiting about three to four new people per month," he says. "Mostly engineers, design engineers, aerodynamicists, a few rocket scientists and progressively more development engineers – people who know how to put programmes together to test things."

Thomas, a former chief engineer at Rolls Royce, joined Reaction Engines in May 2015 and Scrope says his appointment has been another positive step forward for the business. "Bringing Mark on board was a major change as he has experience of big engine delivery programmes," says Scrope. "We were looking to make that move from great physics into great technology."

Marathon

The company is close to securing a new test site facility ten times the size of the existing one. "In addition to the £60 million, we are bringing in other sources of funds to build our ground based demonstrator by the end of the decade," says Scrope. "The more successful you are, the more money you need."

The technology used in the SABRE engine also has applications beyond Skylon. "It's the ultimate in terms of spaceplane achievement," says Thomas. "But we're looking at other things the engine could do."

"There's a strong interest in the UK around small launchers," he says. "We're looking to understand if the SABRE engine is a candidate for some of those small launchers."

The launch of the giant Delta 4, with the first Orion spacecraft in 2014. Fundamental rocket technology has changed little over the decades – Skylon has the potential to transform the industry **Credit:** NASA

After decades of research, the future is looking bright for Reaction Engines. Engineering something completely new was always going to be a marathon rather than a sprint.

"I regard it more like 40 years of aimless wandering in the wilderness," says Bond, laughing. "Taking that analogy a step further, the promised land is in sight."

The Columbus Control Centre (Col-CC) in Oberpfaffenhofen **Credit:** ESA

Principia: mission control

Behind every astronaut there are dozens of people on the ground ensuring the flight goes smoothly and safely. Richard Hollingham meets the mission controllers keeping British ESA astronaut Tim Peake busy:

The attractive village of Oberpfaffenhofen near Munich has much to recommend it. Surrounded by forests and lakes, the community boasts an historic church, a few shops and a couple of bars serving hearty Bavarian stews and frothy lager.

The village can also claim a direct line to the International Space Station (ISS).

Less than a kilometre from the main street, within a German space agency research facility, flight controllers are overseeing every minute of Tim Peake's working day.

On the giant screen in the Columbus Control Centre (Col-CC), the British astronaut can be seen floating through the space station's Columbus laboratory 400 km above the Earth. Other screens display Peake's daily timetable, the position of the ISS, status of communications links and spectacular exterior views of the Earth from space.

"All the work the astronauts do in Columbus is overseen from here," says ESA Mission Director, Berti Meisinger, who led the team supporting the first part of Peake's Principia mission, Expedition 46. "We're also responsible for the module itself – the temperature, cooling and power."

When astronauts are working on the multiple experiments lining the walls of Columbus, flight controllers sitting at consoles in Col-CC can virtually look over their shoulders and talk them through procedures and checklists.

"Tim's whole day is planned to the minute," explains Meisinger. "He has detailed procedures so he knows step by step what to do – for example how to install an experiment on board."

"Often the astronauts have questions and they call down," she says. "We talk to them and coordinate the answers, depending on the task being performed."

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Lungs

Although the main control room is the most eye-catching part of Col-CC, much of the work to maintain Columbus, as well as co-ordinating with other control centres and science teams across Europe, goes on behind the scenes and usually begins months in advance.

The team at Col-CC has recently overseen one of the most complicated experiments of Peake's entire mission. Known as the Airway Monitoring Experiment, this study is designed to assess the health of astronauts' lungs.

On Earth particles in the air will eventually settle. In the microgravity environment of space, however, they will continue to float around in the air. The fear is that, over the long-term, this could cause lasting damage to spacefarers' lungs.

During the experiment Peake and his US astronaut colleague Tim Kopra, would have to wear masks connected to monitoring equipment to measure the nitric oxide they exhale, an indicator of any inflammation of the respiratory system.

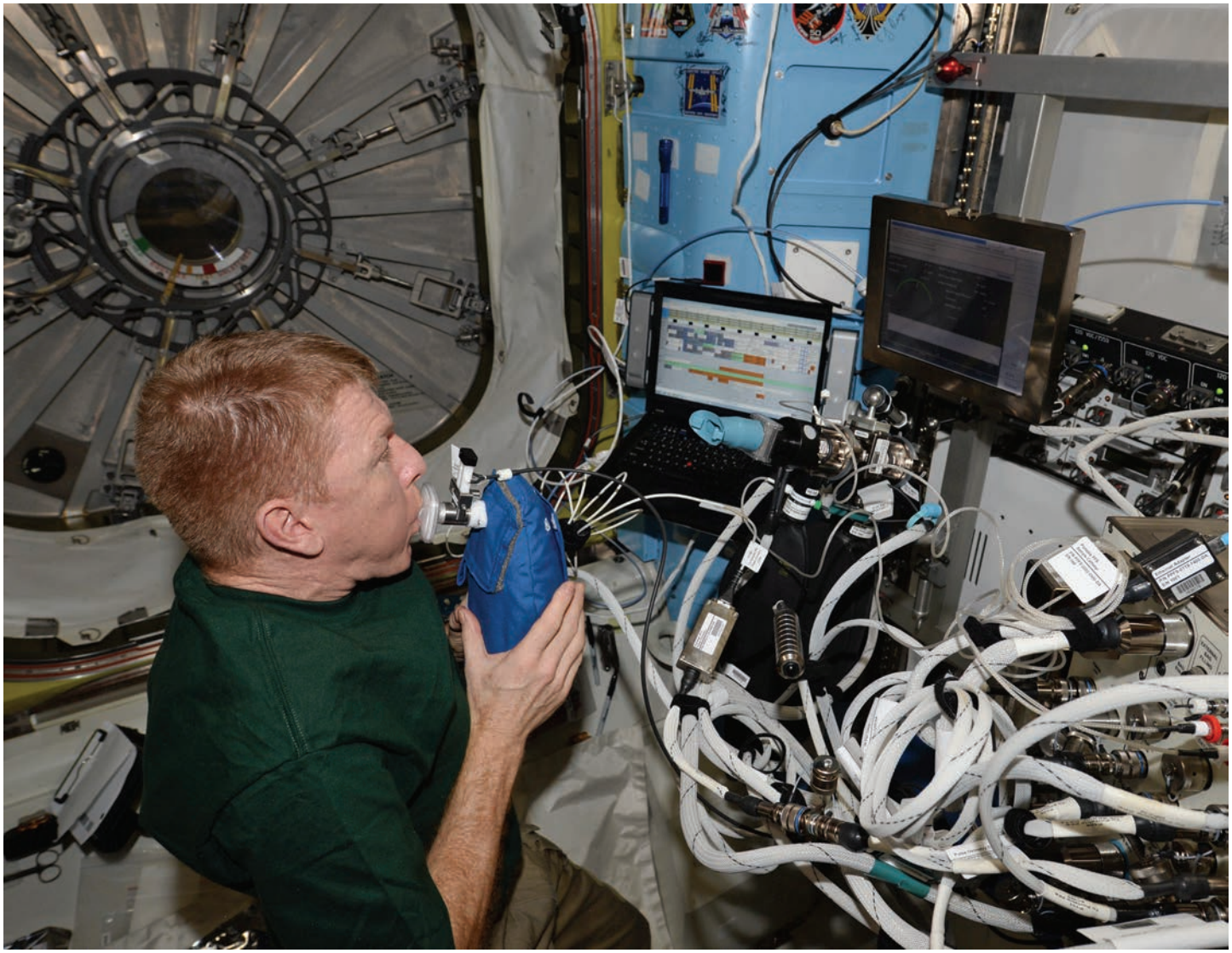
To make the procedure even more interesting, the astronauts needed to be sealed in one of the ISS airlocks, with the air pressure reduced. This was to simulate the environment of a space habitat on the Moon or Mars, where dust is likely to be a constant problem.

"Six months ago the team behind the experiment came to us to have their procedures checked," says Daria Margiotta, who was responsible for making sure the experiment ran smoothly. "We also had to check the experiment didn't conflict with anything else going on at the same time, particularly as it was taking place in an airlock."

"Working with our international colleagues, we then have to find a good day and time to carry out the experiment," she explains. "As it gets closer we start to refine the procedures and send them up to the crew."

Thanks to all those months of hard work, in late February, the experiment went ahead without a hitch.

"I've never done anything that's this fun, or felt this important"
Carrie Olsen
Payload Operations Director



Tim Peake in the ISS Quest airlock during the airway monitoring experiment **Credit:** ESA, NASA

The control centre at NASA Marshall. The UK flag is among those on the ceiling **Credit:** NASA

Destiny

But that is just a single experiment. At any one time there are dozens of studies taking place in the laboratories of the ISS – some automatic and some requiring astronaut involvement. The ISS crew also needs to have time to eat, sleep, rest, exercise, clean and carry out repairs on the station. Although flight controllers at Col-CC are responsible for coordinating the efforts of European experiments on the station, to make sure everything runs smoothly, they need to work with other teams around the world.

The main mission control centre for the ISS is in Houston, Texas. Staffed around the clock, the NASA team here is ultimately responsible for the safety of the station and crew. Operating in parallel – and able to take over completely if necessary – is mission control Moscow, which normally oversees the Russian section of the ISS. There is also a control centre in Japan, for the Japanese module, and one in Canada to oversee operations of the station's robotic arm.

The other control centre Peake talks to, on an almost daily basis, is known as the Payload Operations Integration Center. Located at NASA's Marshall Spaceflight Center in Huntsville, Alabama, this control room oversees science operations in the US Destiny laboratory. It is similarly kitted-out to Col-CC. Staff sit behind rows of consoles, with banks of monitors, overlooking giant screens displaying the current status of the station, crew and experiments. The ceiling is covered in panels representing the flags of ISS partners, including the UK – an unusual display in an American government facility.

"The flags on the ceiling are my favourite feature," says Payload Operations Director, Carrie Olsen, as we look on from the observation gallery. "It's a good reminder that this is an international effort every day."

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Tims

But right now, the Marshall team has a slight communications problem. With two astronauts called Tim on the station, they have to be clear in their conversations with the ISS to distinguish between the two.

"When they're working together, we refer collectively to them as the Tims," admits Olsen. "I'm sure they love that."

"Normally, we're a first name basis kind of operation but we have to be more specific with the Tims right now," she says. "When they call us we always know which one it is, because one has a lovely British accent."

Although the teams on the ground are sitting at desks 400 km beneath the astronauts they are working with, they still consider them colleagues. But what are astronauts like to work with?

"As with any humans working in close contact, it's amazing how much you come to know them," says Olsen.

"One thing I'll say about the Tims is by week two they were just blowing the doors off it," she says. "Sometimes before the morning conference we've seen they've done a bunch of stuff, they're doing great...they're really easy to work with."

Meisinger agrees that Peake is a joy to support. "He's working fantastically and extremely hard," she says. "I'm always amazed when I have my weekly teleconference with him what a good mood he's in and how positive he is with everything."

Space missions have always been a team effort and ISS mission controllers are essential to ensure their astronaut colleagues, spinning around the Earth at 27,000 km per hour, remain safe, healthy and get their work done.

"I've never done anything that's this fun," says Olsen, "or felt this important."

Lost in space

One of the toughest jobs at NASA's Payload Operations Integration Center is that of Stowage Officer. "This poor soul has to keep up with every bit of equipment we use on the ISS," explains Olsen.

This would be hard enough in a research facility on Earth. In space, however, when you put something down, such as a screwdriver for example, it drifts off to another part of the station. The role of the Stowage Officer is to know where everything is stored – essential when astronauts are gathering equipment together for an experiment – and try to track things down when they go missing.

Olsen admits that some items have never been found. "Sometimes we find things years later in the back of equipment racks."

ISS astronauts spend most of their day working on science experiments **Credit:** NASA, ESA

Tim Peake floats in the ISS Cupola module with packets of rocket seeds flown to the ISS as part of the Rocket Science education experiment **Credit:** ESA, NASA

Principia space classroom

Tim Peake's Principia mission is inspiring children, students and teachers across the UK. Sarah Cruddas reports:

When astronaut Scott Kelly returned from the International Space Station (ISS) in March, he brought with him an extremely precious cargo: two kilograms of rocket seeds. Their arrival had been eagerly awaited by school children and educators across the UK.

"Several thousand schools will receive some of these seeds from space," says Tom Lyons from the European Space Education Resource Office (ESERO) in York. "This has been one of our most popular experiments."

Students will grow and compare seeds from the ISS with seeds that have remained on the ground, to see if there are any differences. As well as helping to encourage interest in horticulture, the aim is to understand what growing plants in space can teach us about life on Earth.

The experiment also has the scientific goal of investigating whether space has a detrimental effect on the seeds. After all, the success of future missions to the Moon or Mars will depend on us being able to grow our own food on these alien worlds.

Passion

The Royal Horticultural Society rocket seed experiment, aptly named Rocket Science, is just one of many space projects built around Tim Peake's six-month mission as Britain's first ESA astronaut. An extensive programme of activities is capturing the imaginations of young people and their teachers across the country.

"We have learnt a huge amount but I think our teachers have learnt even more," says 11-year-old Hannah from Rode Heath Primary in Cheshire.

Space activities at Rode Heath have been spearheaded by year 4 teacher and Space Ambassador Julie Wiskow, whose enthusiasm for space has been rubbing off on her students. "I absolutely love space and I am passionate about making education purposeful," she says.

Tim's mission has inspired projects for all ages at the school. Many of these were developed long before the British astronaut rocketed into the public eye. "We had early exposure to him as a school," says Wiskow. "He has tweeted us, he emails us and he follows our projects. It just means so much."

Last year Wiskow developed a 'space passport' scheme, covering a wide range of curriculum subjects. These were designed to not only inspire students studying science, but also history and art. This innovative approach to education saw the school win a runner-up award in the prestigious Rolls-Royce annual science competition. The prize money has been used to buy a 3D printer.

"We are so proud of what we have achieved," says Wiskow. "Space is such as an amazing hook for children, what I love is that you never know what's going to happen."

"Our children believe they can do anything now," she adds. "It's pulled the school together so we are working together with one goal, you can see the excitement in the children's eyes."

Cosmic Classroom host Kevin Fong takes a question from the audience at the World Museum in Liverpool
Credit: UK Space Agency

Cosmic

Rode Heath was one of many schools across the UK that took part in February's Cosmic Classroom. This live broadcast event, hosted by medic and TV presenter Kevin Fong to an audience of some 300 schools, saw Tim Peake answering students' questions from the ISS.

Although there have been plenty of space education resources before, Tim's mission really seems to be firing the imagination of young minds. "They are so excited, they have ownership," explains Claire Seeley, a space ambassador who works with schools in Suffolk. "He's a Brit, he's one of ours, they have seen him on the TV and in the media telling his story."

The Principia educational outreach programme has been carefully developed by the UK Space Agency over several years to inspire education across the curriculum and for a range of ages. For example, the Astro Pi project ties in with the computing curriculum. "I have been able to teach the younger ones how to programme and use code," says eight year-old Rebecca, also from Rode Heath Primary.

"Overall we have about 30 different projects," explains Libby Jackson from the UK Space Agency, whose role is to manage Tim's education outreach programme. "It's a unique opportunity, to have such a sustained education message."

Other programmes on offer to schools include EO Detective, which involves analysing photos taken by astronauts from space (see pages 8-9). This project ties in with the geography curriculum. There are also drama activities and the Space to Earth challenge, which encourages kids to 'train like an astronaut' – travelling 400 Kilometres as a group during Tim's mission through a combination of running, swimming and cycling.

Marshmallows

Human spaceflight and Tim's Principia mission have been incorporated into all the master class activities at the National Space Academy in Leicester. The Academy also uses videos of demonstrations that Tim has conducted and filmed onboard the ISS. Students at the master classes have been getting to grips with mini rocket launches, experiments involving marshmallows to show how to survive (or not) in space and demonstrations of spacesuits, all accompanied by videos of Tim.

"Tim has made himself available at every opportunity to engage with students through his tweets, videos and link up sessions," says Sophie Cottis-Allan, National Space Academy Lead Physics Teacher. This availability to communicate from space has added to the educational value of the mission. "To have Tim, in our modern digital age, sharing everything he has been doing, captures the children's imagination," adds Jackson.

"Several thousand schools will receive some of these seeds from space"

Tom Lyons

European Space Education Resource Office

Amazing

One of the most spectacular education projects has seen the British astronaut link-up live with students in schools across the country via amateur radio. "To be able to take the magic of sitting in the room when you hear Tim's voice cracking over the radio, you can just see the excitement and engagement," says Jackson. Her favourite example is when a collection of schools in Powys, mid-Wales received a call. "It touched everyone and even the kids not normally excited by school were set alight by it".

Tim may just be one person in space, but his mission is helping followers young and old. For teachers like Julie Wiskow her involvement has even opened new doors. "I am now working with Manchester University on some engineering projects," she says. "It's made my teaching and own learning that much more exciting."

Even after Tim returns to Earth in June, the legacy of his mission will continue.

"My passion is to get children to think independently and not to be frightened of having a go," says Wiskow, whose hope is to meet Tim when he returns from space. "I am hoping this will stick with them," she says.

Details of all the ongoing education and outreach projects surrounding Tim's mission can be found on the Principia website: principia.org.uk

Megan and Jack working on a nutrition experiment linked to Tim's mission **Credit:** Rode Heath Primary

:space in the classroom

The UK Space Agency and its partners have put together an exciting programme of activities for schools, education groups and individuals so that as many people as possible can benefit from Tim Peake's mission.

All the education activities are available on the mission website: **Principia.org.uk**

You can also check the ISS tracker to see when Tim is passing over your house or school and give him a wave.

Space to Earth
Here is a challenge: get together as a group and track the distance you travel – running, cycling, swimming, scooting (any form of sport) – to accumulate your distance and aim for a total of 400km, the height of Tim Peake's orbit above the Earth.

The challenge motivates a wide range of students at KS2/3 especially those not ordinarily keen on sport. Registered schools will get unique Tim training data and those completing the challenge will have an opportunity to apply for a visit to the European Astronaut Centre in Germany and for places at the Farnborough Futures Day. You can register on the Principia website.

Mission X
Primary and middle school teachers can still also sign-up to be part of Mission X 2016 and train alongside astronaut Tim Peake: trainlikeanastronaut.org

To register, you will need to use the code: MARS2030. The Mission X team will then explain how the UK Space Agency can support you and provide ideas on how you can deliver Mission X in your school. The more schools in a locality, the more opportunities there are to organise teacher training and other special events.

Space education conference
The UK Space Agency will hold a schools conference later this year to celebrate the work of students from across the country in support of the Principia mission. The conference will allow students to present their work to Tim Peake as well as scientists, education experts and representatives from the UK space industry.

Careers in space

The Space Placements in Industry scheme (SPIN) provides an introductory link for undergraduate students considering employment in the space sector. It also helps space sector organisations find the most talented and enthusiastic people to ensure the future success of their business. The doors are now open for 2016. Contact **Katharine.Bowden@ukspaceagency.bis.gsi.gov.uk** for more information.

ESA astronaut Samantha Cristoforetti on the ISS treadmill. Astronauts train for two hours a day to stay fit **Credit:** ESA

Thales Alenia Space is a major European space manufacturer but a relative newcomer to the UK. Head of strategy, sales and marketing, Nigel Towers, tells space:uk how they aim to compete:

Nigel Towers
Credit: TAS-UK

Image top right: BepiColombo will be Europe's first mission to Mercury
Credit: ESA

Bottom image: Nigel began his space career working on an instrument for the Hubble Space Telescope, seen here during its final servicing mission in 2009
Credit: ESA, NASA

Where can you be found in the UK?

Thales Alenia Space UK (TAS-UK) started off at Harwell in 2014 as part of the space hub – predominantly developing propulsion engineering for satellites and systems engineering.

Then TAS-UK bought the space division of Systems Engineering and Assessment in Bristol and took on around 35 highly skilled engineers with a lot of space experience. We have a clean room and build electronic space instruments, such as the Broad Band Radiometer (BBR), for ESA's Earth observation missions.

We also have a large propulsion production facility in Belfast and are building an additional clean room there. Since 2014 we've more than doubled in size, with 110 people in three locations and plans to grow.

Why choose the UK?

It's part of our strategy to increase our European footprint. We're very strong in Italy and France and wanted a strong UK presence. At the moment Airbus is the only prime contractor for large satellites. Our vision is to become a credible competitor to Airbus.

What missions are you currently working on?

We're continuing to produce the BBR and are providing electronics units for the BepiColombo mission to Mercury and EarthCARE mission, electronics units and a propulsion system for ExoMars, and a propulsion unit for ESA's NEOSAT satellite communications programme. We're also looking at SMILE, the joint ESA-Chinese programme, and hope to be the prime contractor for the payload – the part of the spacecraft where all the science instruments are located.

What is your background?

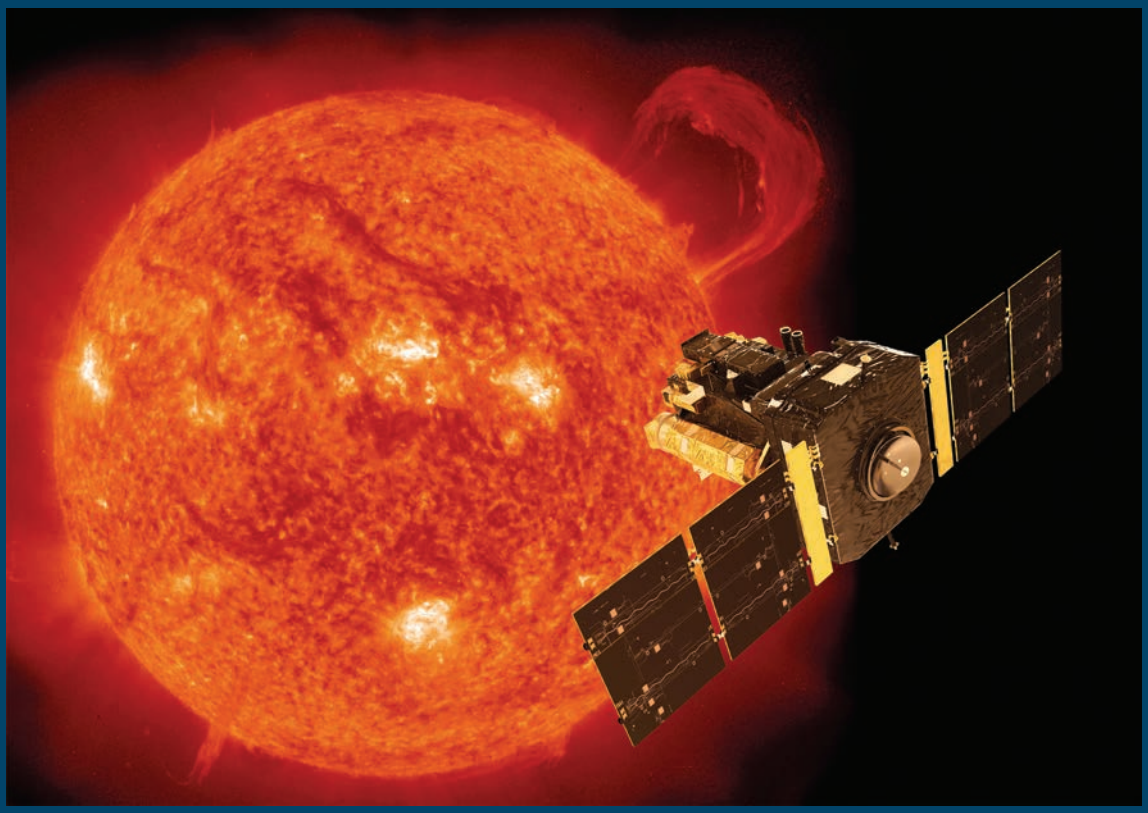
I graduated in mathematical engineering from Loughborough University and, for the first ten years of my career, worked on the Hubble Space Telescope. That included over seven years working in the United States with NASA and the Space Telescope Science Institute in Baltimore.

I was very fortunate as I started off as an engineer developing a detector and took it all the way through to the astronomers using it in space. Then I worked on programme management for the Envisat mission, before moving into the business side of space. It's been an interesting career path.

Who does your company want?

We're looking for highly skilled engineers and are recruiting quite aggressively at the moment for experienced engineers and graduates.

SOHO



Artist's impression of SOHO combined with a real image of the Sun captured by the satellite's extreme-ultraviolet imaging telescope **Credit:** ESA

The Solar and Heliospheric Observatory, SOHO, is a joint ESA–NASA mission that has been studying the Sun for more than two decades.

Launched in December 1995, SOHO was originally planned as a two-year mission. The spacecraft occupies a vantage point 1.5 million kilometres from the Earth and orbits around the first Lagrangian point – a location in space where the gravitational forces of the Sun and Earth balance each other.

SOHO carries 12 instruments, which study the Sun's interior, atmosphere, and particles in its corona. The spacecraft helps us to predict space weather and investigates the origin of the solar wind – the stream of charged particles that travel outward through the Solar System.

SOHO does not simply observe the Sun. It has discovered some 2,000 comets, more than any other instrument in the history of astronomy.

Companies from 14 European countries, led by Matra Marconi (now Airbus Defence and Space), were involved in building SOHO. The payload module carrying the scientific instruments was assembled in Portsmouth. The UK has also been heavily involved in developing and operating SOHO's Coronal Diagnostic Spectrometer. Data from this instrument helps us to understand both the Sun's corona and the solar wind, and has been used in around 34,000 scientific papers.

In 1998 operators lost control of SOHO following the failure of its onboard gyroscopes. However, engineers were able to upload new software and regain control of the satellite – a first in space operations.

Produced by RCUK's internal service provider on sustainable forestry paper
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