NEW

AMAZING TECHNOLOGY

EVERYTHING YOU NEED TO KNOW ABOUT THE WORLD'S BEST TECH

SPECIAL EFFECTS

The digital graphics that have you on the edge of your seat

NEXT-GEN SPACE PLANES

Step on board the Dream Chaser

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TOMORROW'S TECH TODAY

Discover incredible innovations and take a look inside top technologies

FORMULA 1

Uncover the cars behind the world's biggest motorsport

Digital Edition

FUTURE

TWENTIETH EDITION

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HOW IT WORKS BOOK OF

AMAZING TECHNOLOGY

Today's world has been shaped by innovation in technology, so much so that modern life is incomparable to that of mere decades ago; how we communicate, travel and explore our world is almost unrecognisable. Smart gadgets and domestic inventions like mobile phones and drones have revamped our daily lives, sure, but we often forget how the world has gradually evolved around us thanks to pioneering minds and engineering genius. So take a look around you and imagine what your life would be like without the amazing technology seen in this bookazine. It's time to celebrate the coolest concepts that have come to fruition, including robots, electric vehicles, space travel, smart cities and superdrones – to name just a few. So get ready to be inspired!

AMAZING TECHNOLOGY

Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Compiled by **Sarah Bankes & Phil Martin**
Senior Art Editor **Andy Downes**
Head of Art & Design **Greg Whitaker**
Editorial Director **Jon White**

How it Works Editorial
Editor **Ben Biggs**
Senior Art Editor **Duncan Crook**

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Commercial Director **Clare Dove**

International
Head of Print Licensing **Rachel Shaw**
licensing@futurenet.com
www.futurecontenthub.com

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Matthew Eglinton**
Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Managers **Keely Miller, Nola Cokely, Vivienne Calvert, Fran Twentyman**

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Chief Executive Officer **Jon Steinberg**
Non-Executive Chairman **Richard Huntingford**
Chief Financial and Strategy Officer **Penny Ladkin-Brand**

Tel +44 (0)1225 442 244

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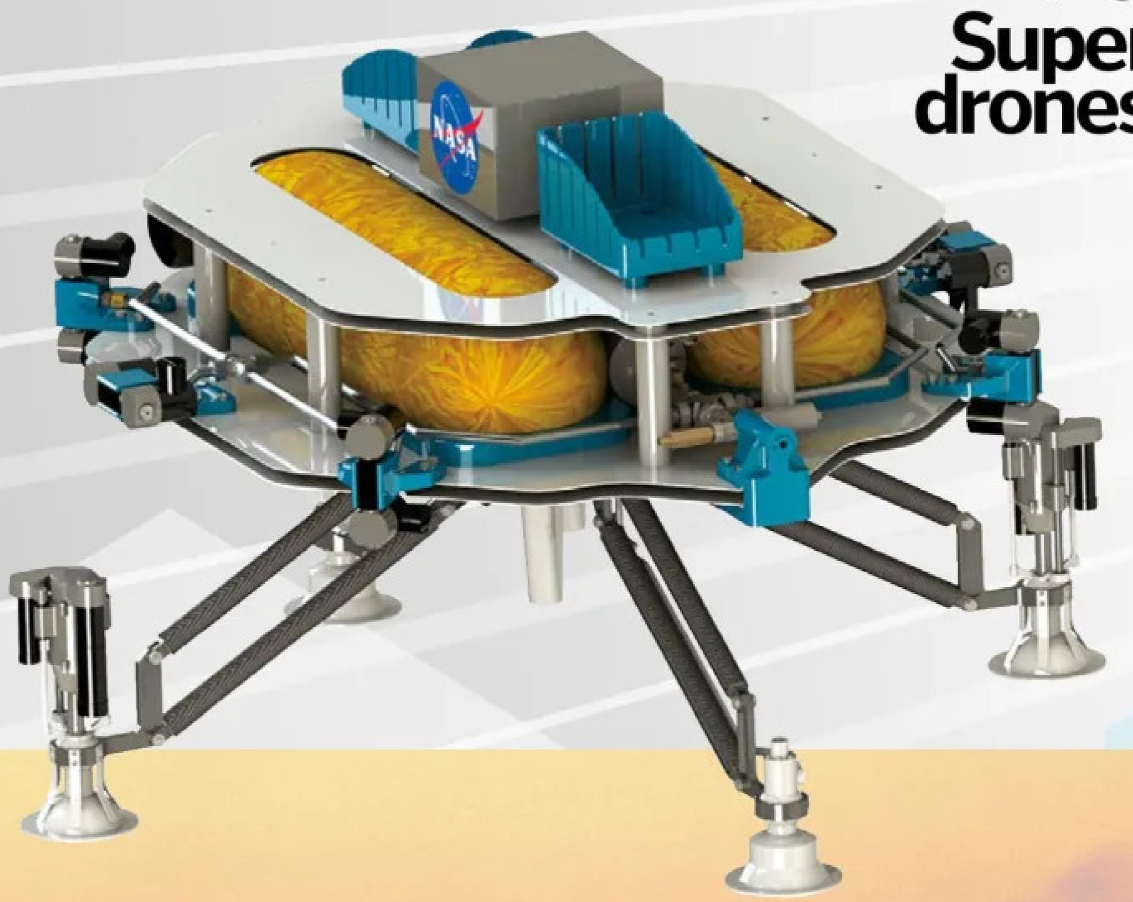

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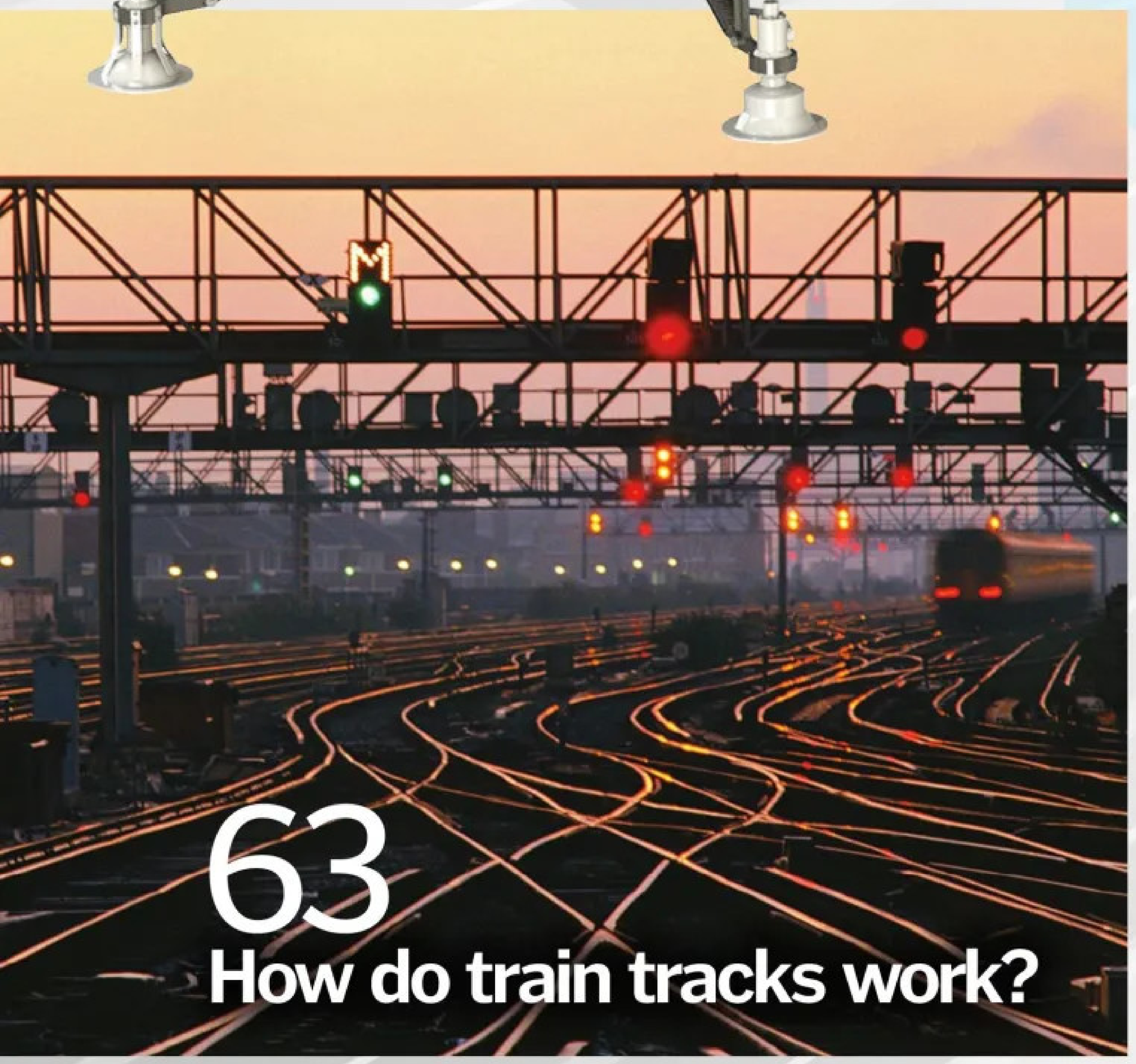

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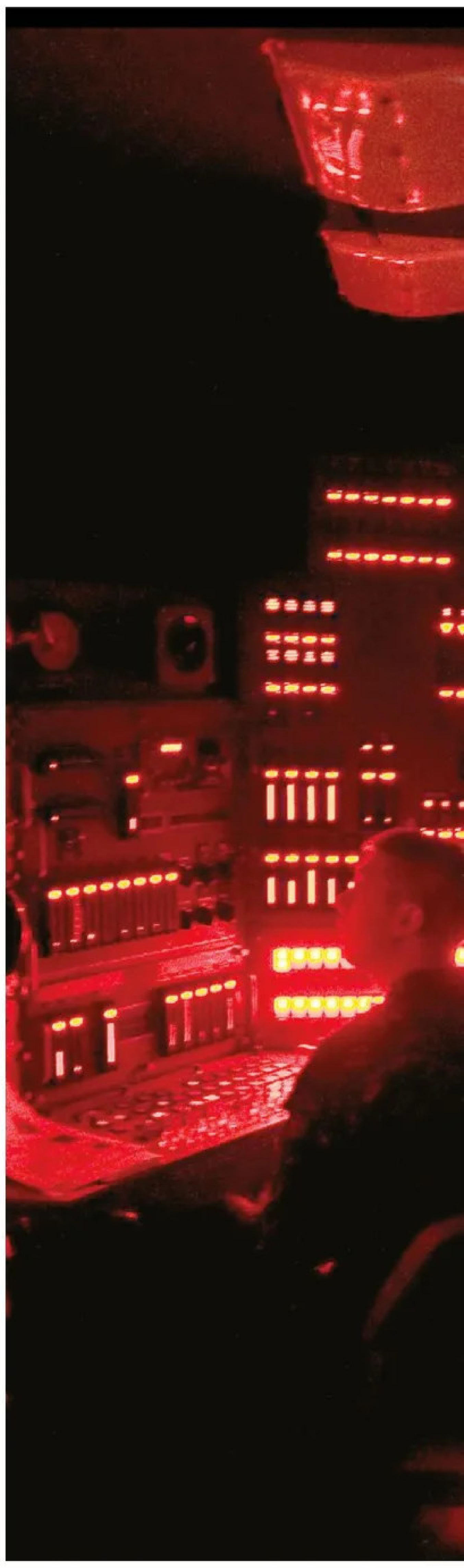

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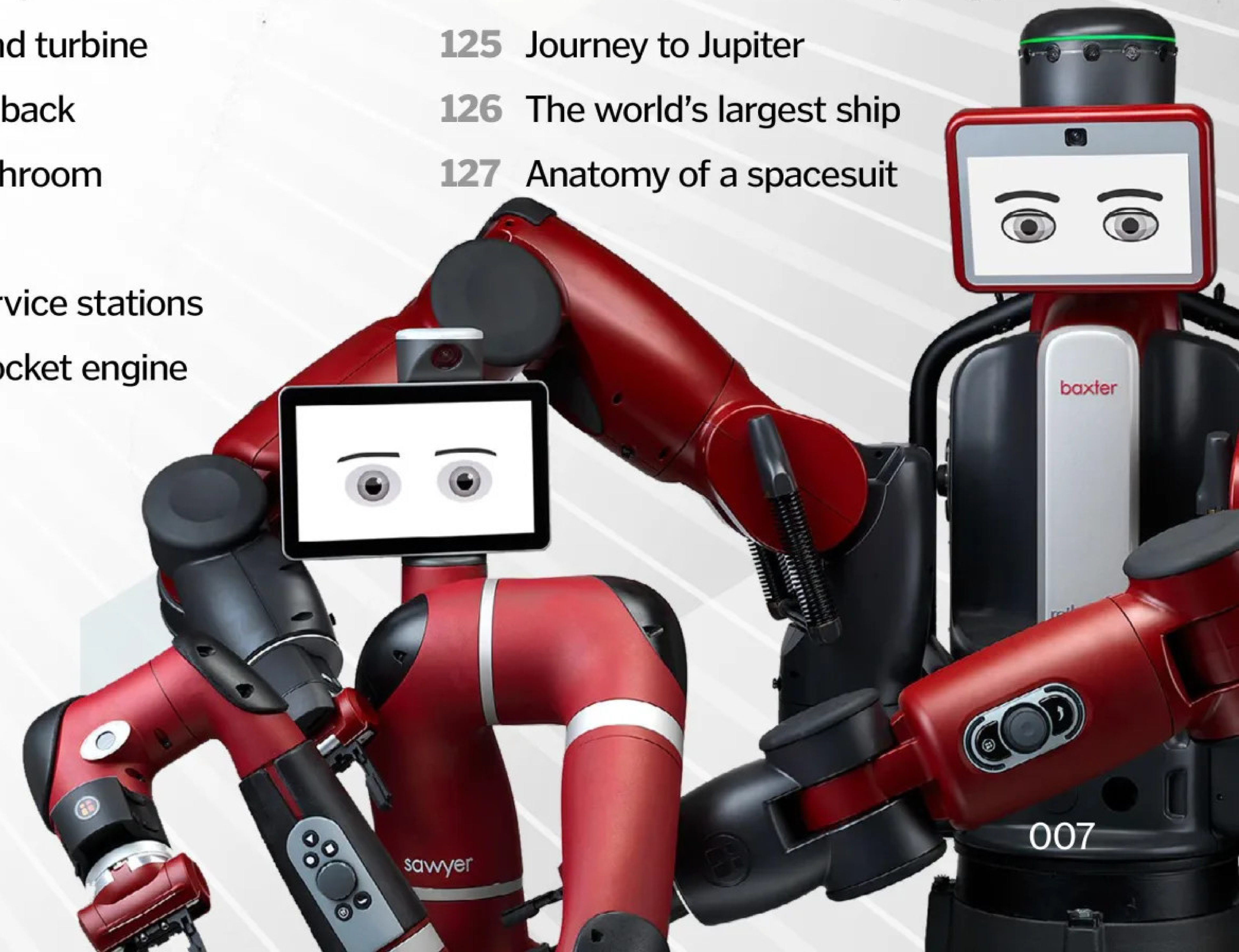


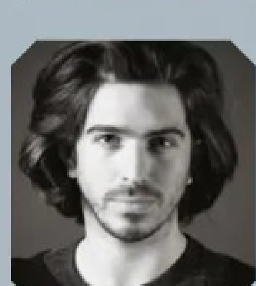
BEHIND THE SCENES

SPECIAL EFFECTS

From spectacular CGI to thrilling real-life stunts, discover how blockbuster movie magic is created

Meet the experts

Some of the biggest names in special effects reveal their secrets



Alexis Wajsbrot
CG supervisor at Framestore
Alexis has delivered stunning CGI effects for movies such as *Edge Of Tomorrow*, *Iron Man 3* and *Gravity*, and recently worked his magic for Marvel's *Dr Strange*.

Chris Corbould OBE
Special effects supervisor
From Batman to Bond, Chris has created amazing stunts and explosions for several blockbusters. He won an Oscar for his work on *Inception*, and has an OBE for his services to film.

Mike Stringer
Prosthetic artist and director at Hybrid FX
Mike's company transforms actors using prosthetics and make-up. His credits include many TV shows and movies such as *Mad Max: Fury Road* and *Lord Of The Rings*.

CGI MAGIC

Creating digital effects that are out of this world


Dr Strange's magical shields were created using CGI in post-production

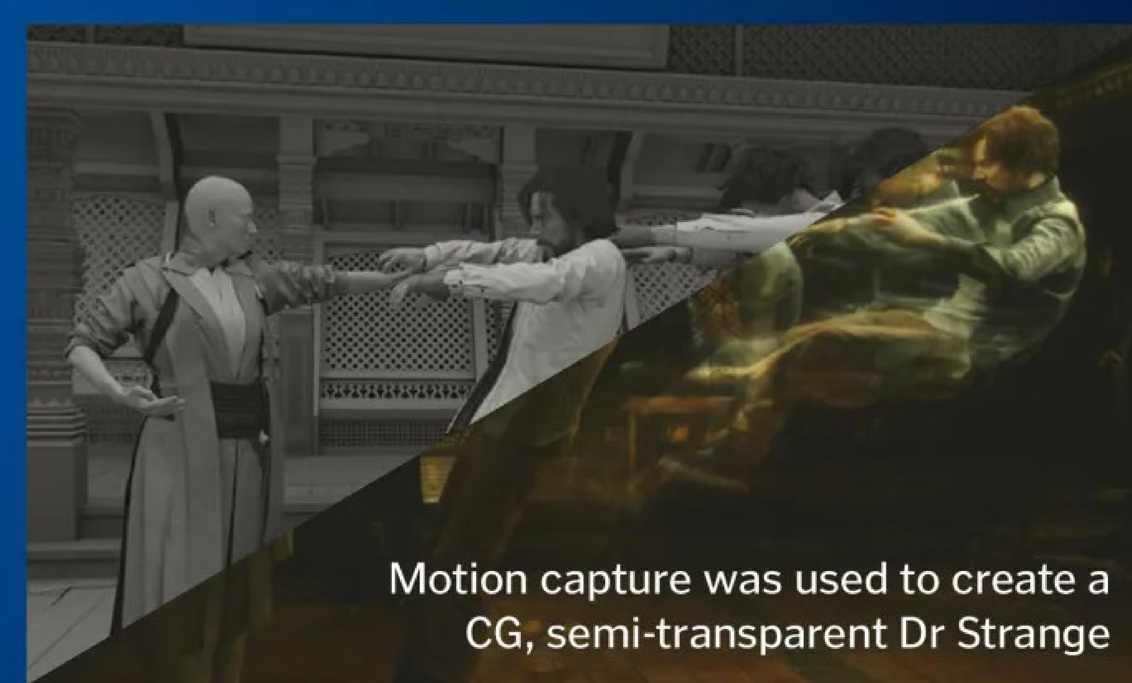
Computer-generated imagery (CGI) has made the impossible possible in movies, from creating fictional creatures and locations, to replicas of animals or outer space. Recent spell-binding examples of this digital wizardry can be found in superhero blockbuster *Dr Strange*, the latest instalment from the Marvel Cinematic Universe. In the movie, surgeon turned sorcerer Stephen Strange learns the mystic arts and travels to other shape-shifting dimensions, so a lot of CGI was needed. The person in charge of the digital effects was CG supervisor Alexis Wajsbrot, who led a team of over 120 people at creative studio Framestore to deliver 350 separate shots for the movie.

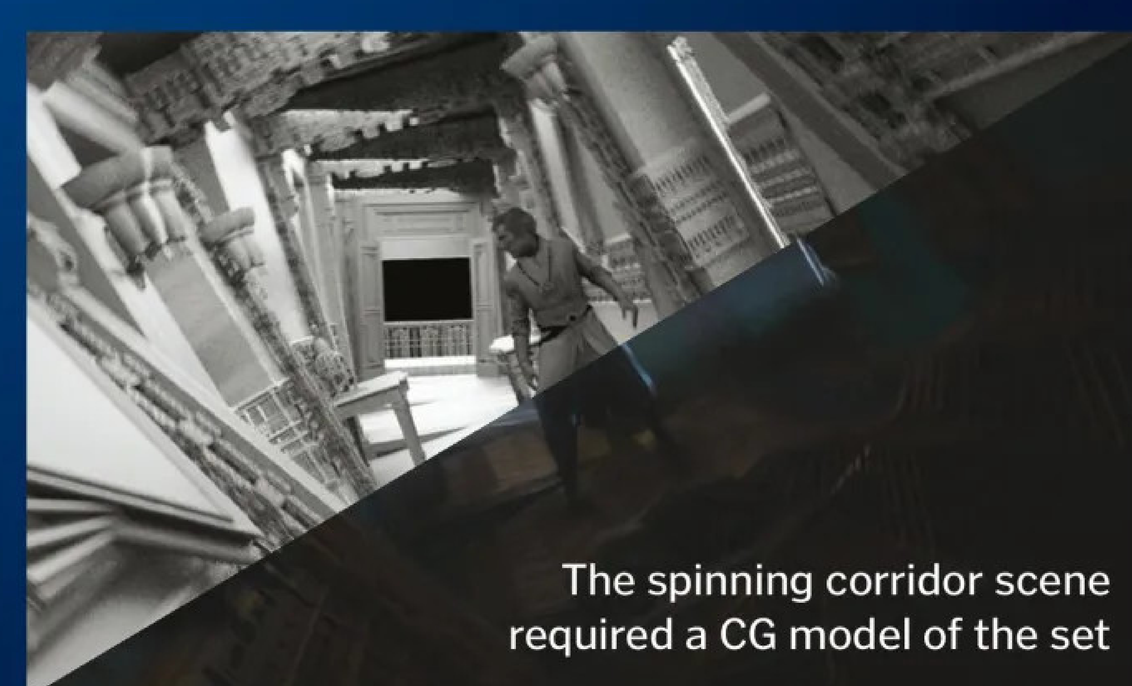
"We have modellers, animators, lighters, riggers, lots of different departments, and as CG supervisor I connect them all together so that we can deliver images to the VFX supervisor for artistic comment," explains Wajsbrot.

Wajsbrot and his team worked on the project for a year, creating 20 different effects. "It was a huge challenge for us because it was the first *Dr Strange* movie, so we had to work out how everything was supposed to look," says Wajsbrot. "It's also such a magical movie, so all of the effects are very subjective. We had to invent a visual language that's going to be reused in *Dr Strange 2* and in *Avengers*."

Astral projection was one of the most complex effects to create. This is when Dr Strange exists in the astral plane, becoming semi-transparent and able to fly through objects. "It required a lot of detail to make the effect subtle, so you can see the presence of the character, but also convey that it's not the normal Strange, he is now in his astral form," says Wajsbrot. Work to create the effect began on set, with motion capture and aerial stunts used to record Benedict Cumberbatch's facial expressions and movements and then apply them to a virtual puppet of Dr Strange. The next challenge was lighting the shot. "When they are in astral mode, the characters are supposed to be emitting light," explains Wajsbrot. "This meant we had to model the whole room, which was a hospital operating theatre for that scene, in an incredible amount of detail, and track each prop to light it from the character."

Thanks to advances in technology, Alexis and his team were able to create these incredible never-before-seen effects in stunning detail, but he believes there is still room for improvement. "On Dr Strange we animated cool and complicated effects that we were not able to do a few years back. Now the challenge is to do them faster and faster as well as better."


Motion capture was used to create a CG, semi-transparent Dr Strange

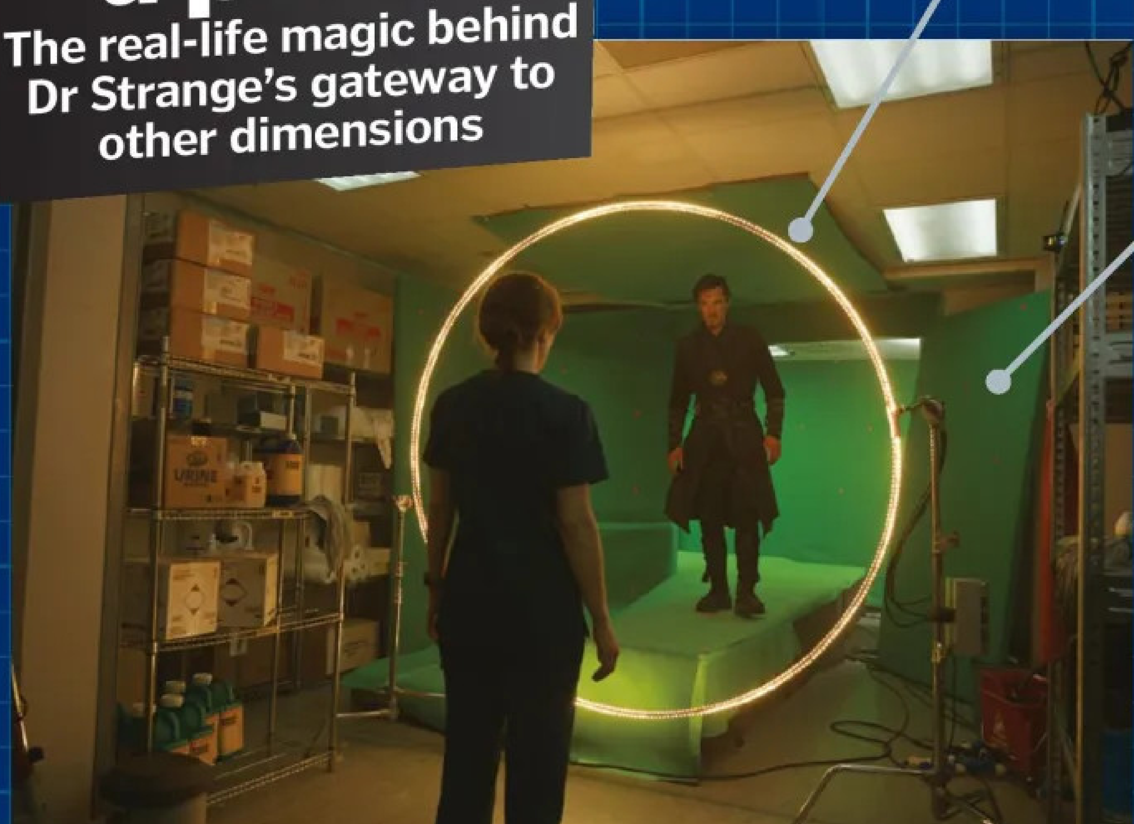

The spinning corridor scene required a CG model of the set

Creating a portal

The real-life magic behind Dr Strange's gateway to other dimensions

LED lights
On set, the portal is created using a ring of LEDs which helps to light the scene.

Green screen
For this shot, Dr Strange's world is entirely CGI, so a green screen is used as his backdrop.



3D animation
Animators add in the sparks in post-production, controlling their length, curvature and intensity.

Finished effect
Finally the CGI and real-time footage is layered together to create the final shot.

PHYSICAL EFFECTS

When high-speed car chases and fiery explosions are all in a day's work

While CGI can make spectacular effects much easier, cheaper and safer to create, some directors, such as Sam Mendes and Christopher Nolan, prefer to use as many practical effects in their movies as possible. For this, they enlist the help and expertise of a special effects supervisor, such as Oscar and BAFTA winner Chris Corbould.

After getting his big break at the age of 16 when he was tasked with opening 500 gallons of tinned baked beans for a stunt on the movie *Tommy,* Corbould has gone on to create awe-inspiring and record-breaking effects for huge movies, including the James Bond, Batman and *Star Wars* franchises.

Where do you start when taking on a new movie project?

First the script is broken down into sequences and then discussed by all major heads of department. During these meetings the director will outline his vision for the film, after which all departments will contribute ideas to achieve this vision.

The next phase is where we design, build, test and video each component of the sequence. It might be a series of explosions as seen in *Spectre*, or it might be a complex mechanical rig such as the sinking hotel in *Casino Royale*. All aspects of the process are videoed and shown to the director for comment. I would say that testing makes up about 50 per cent of our entire workload. Sometimes we will test the same effect 20 times to establish safety parameters along with achieving the highest spectacle.

A major part of our job involves engineering, starting at the CAD (computer-aided design) phase through to the machining, welding and commissioning of each rig.

What's involved in filming these sequences?

Filming all the components that you have been testing over the previous months may involve shipping them all over the world to different locations. On *Spectre* we filmed in Austria, Mexico, Morocco and Italy, so the logistics of making sure that the right equipment and manpower is sent to the right location at the right time is immense. At one stage I had workshops and crew spread over all four locations, as well as preparing major sequences in the UK film studios. The filming period can vary between six weeks on small films to 28 weeks on large blockbusters.

How did you achieve the Rome car chase in the film *Spectre*?

We had eight Aston Martins and four Jaguars all specially constructed for the film. The vehicles were tested almost to complete destruction by the stunt department to discover any weak links. We also had to consider that we were filming the movie in a 2,000-year-old city that cherishes its ancient architecture and would not take very kindly to a car hitting any part of it at high speed.

The stunt cars were adapted with roll cages, safety fuel tanks, hydraulic handbrakes, racing harnesses and much more. In addition, we might have cars with a remote driving pod mounted on the roof, giving the illusion that the actor is driving at high speed while in fact being driven by a stunt performer from the roof. Also, there may be a requirement for a car to crash into static objects. This is usually achieved by taking the engine and all unnecessary weight out and then mounting a steel tube inside. This tube forms a piston, which can then be fired from a static nitrogen reservoir at speed.

The chase itself is a logistical nightmare, with large parts of the city locked off to ensure that nobody walks out their front door into the path of a speeding Jaguar.

How did you go about creating the movie's record-breaking explosion in the Moroccan desert?
We tested approximately 15 different explosion looks that would be multiplied and linked together to form one travelling explosion. The wiring of the ignition system is a crucial part of the operation and must be carried out slowly and methodically. On this occasion we used a system of computerised detonators whereby

> *"It could have been disastrous had Daniel Craig not got the line right"*

each detonator is programmed to go off at a certain time. The only downside is that there is a three-second delay after pressing the button before the sequence starts initiating. This meant that we were pressing the button half way through a line of Daniel Craig's dialogue, which could have been disastrous had Daniel not got the line right. However, Daniel is a true professional and nailed the dialogue.

How has your role changed over the years?
The technology has changed immensely. We can now control hydraulics, pneumatics, winches and ignition systems using computers, while in my early years it was all controlled by people pulling levers and pressing buttons. Computers give us consistency, repeatability and a high degree of accuracy, which in turn means greater safety and financial economy.

What are the benefits of physical effects?
The benefits of practical effects are clear when you are actually watching reality. On *The Dark Knight* we somersaulted a huge articulated truck. The reaction on the day was incredible.

For interior driving shots, David Bautista's Jaguar C-X75 in *Spectre* was actually being driven by a stunt man on the roof

Spectre used 8,418 litres of fuel and 33 kilograms of explosives to make cinema's largest explosion ever

Corbould's team built a massive model of Venice's Hotel Danielli in a giant water tank for *Casino Royale*

For *The World Is Not Enough*, Corbould fitted a helicopter with sawblades that slices through Pierce Brosnan's BMW Z8

PERFECT PROSTHETICS

The painstaking moulding, sculpting and gluing behind some of the greatest movie transformations

> "Transforming an actor into an entirely new character still takes a long time"

When you see a fictional character from a fantasy world on screen, they've not necessarily been created on a computer. All those hard-working movie actors aren't out of a job just yet, as instead of being made redundant they're being made unrecognisable by prosthetics artists and a whole lot of silicone.

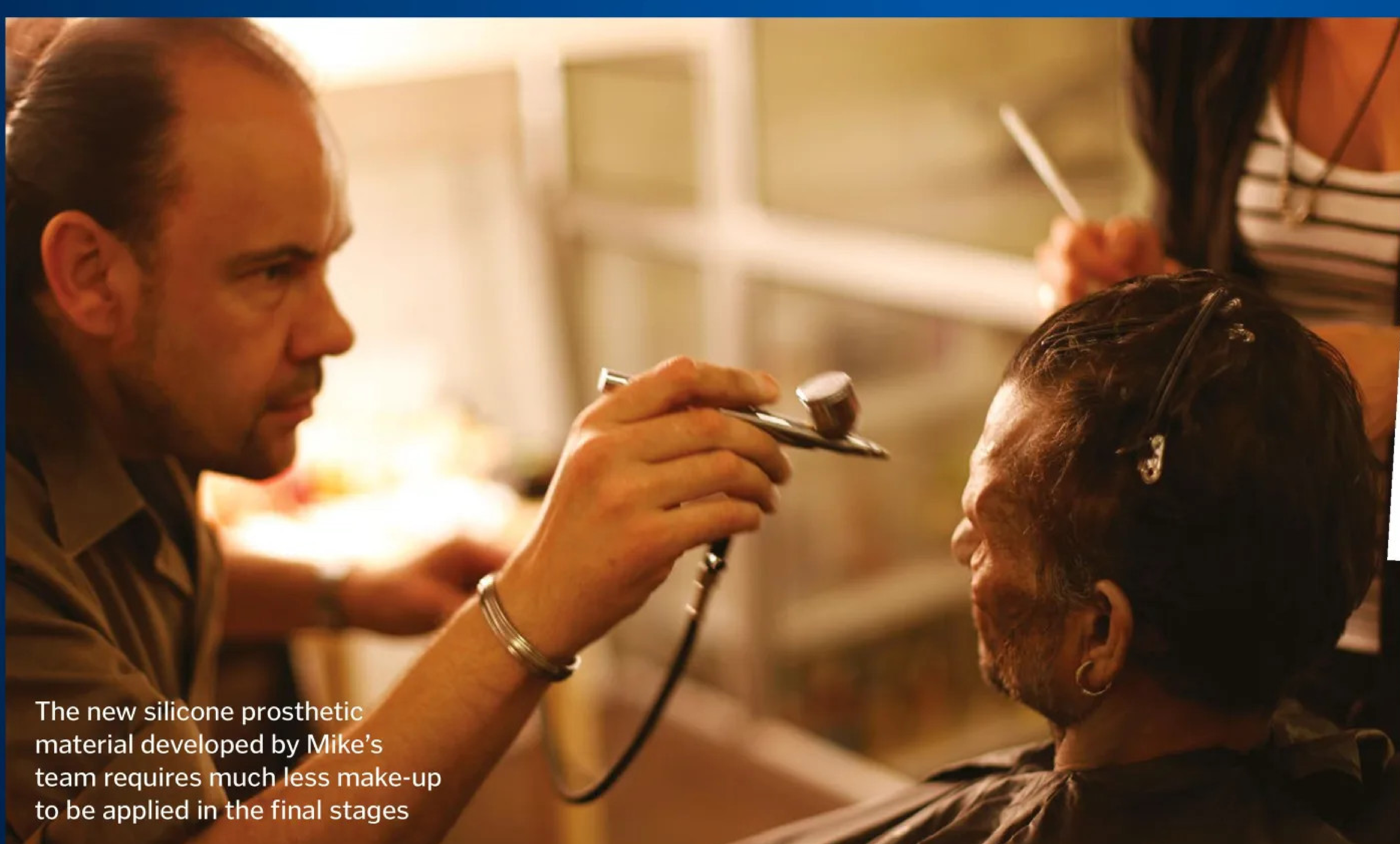
From their UK studio, Mike Stringer and his team at Hybrid FX have transformed the young into the old, the living into the undead, and the human into a dwarf warrior from Middle Earth. In fact, they've even transformed the entire prosthetics industry. Before the movie *The Lord Of The Rings: The Two Towers* was released, the typical material of choice for making prosthetics was soft, squishy foam latex.

However, after Hybrid FX used their newly developed and more flesh-like silicone to create the face of Gimli the dwarf, everyone began using a version of their revolutionary new material for other movies.

That's not the only new technology that has changed the industry though. "3D scanning is very helpful, particularly for full body casts," explains Stringer. "Instead of having to mould someone's whole body, which takes hours and is messy and uncomfortable for everyone involved, the client can simply wear a skin-tight suit and be scanned in five minutes." An accurate model of their body is then cut from rigid foam, ready to be used as a base for sculpting the prosthetics.

Although this has sped up part of the process, transforming an actor into an entirely new character still takes a long time. Prosthetics can take several weeks to create, and then there's the matter of applying them and removing them. "The application time for a full face character like Gimli the dwarf is around three hours or more," says Stringer. "Removal time is also painstaking and needs at least 30 minutes, as the materials cannot simply be ripped off the skin. If they came off that easily, they wouldn't stay on reliably for a whole shooting day of eight hours or more."

That's not the longest time the Hybrid FX team have spent applying a prosthetic though. When working on the 2003 horror movie *Creep*, it took them seven hours every day to transform actor Sean Harris into a hideously deformed killer. "We started at midnight and would be ready for when the crew turned up for the shoot at 7am," Stringer explains.



The new silicone prosthetic material developed by Mike's team requires much less make-up to be applied in the final stages

Mike transformed actress Ingrid Pitt into the leprous character The Sybil for the 2006 horror movie *Minotaur*

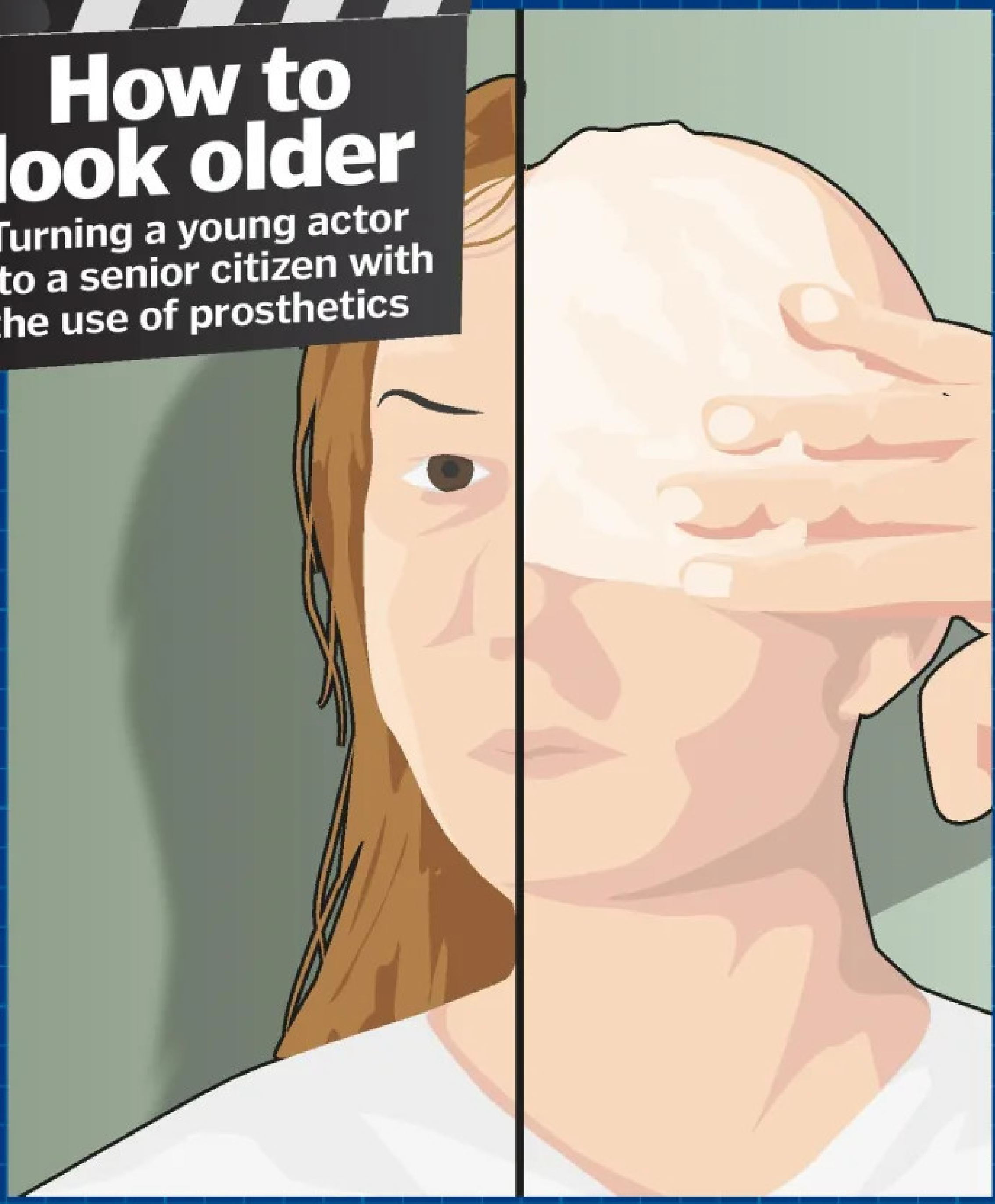
Mike says the secret to creating a gruesome zombie look is often having a good actor underneath

Hybrid FX created Gimli the dwarf's facial prosthetics for the second and third *Lord Of The Rings* movies

DID YOU KNOW? *To create the sound of a lightsaber, foley artists passed the feedback from an old TV through a loudspeaker*

How to look older

Turning a young actor into a senior citizen with the use of prosthetics

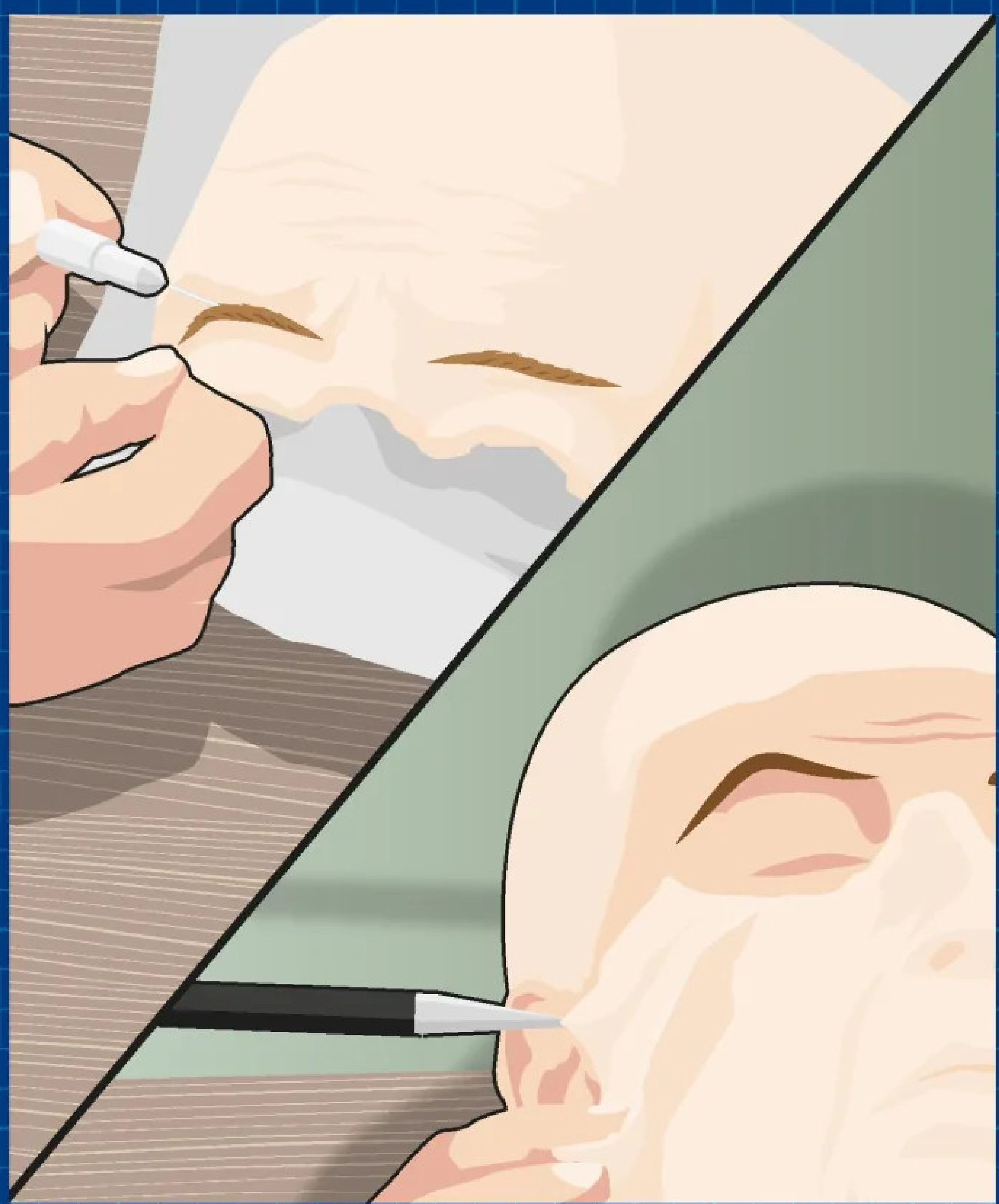


1 Make an impression
The actor's face is covered in alginate, a material usually used to make impressions of teeth, then wet plaster bandages.

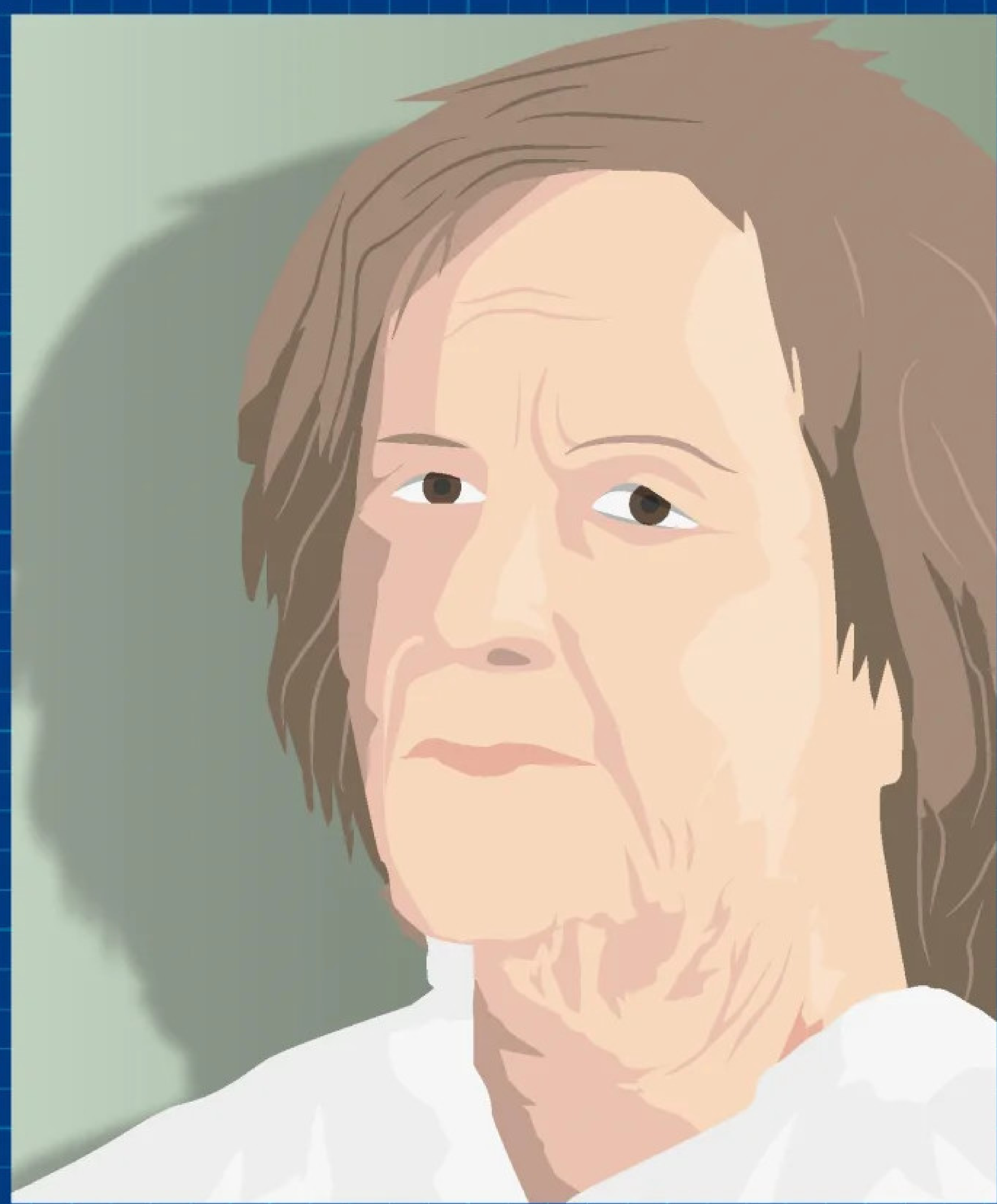
2 Sculpt a mask
Once hardened, the material is removed and lined with plaster, which hardens into a mask. A layer of plasticine is added and sculpted with wrinkles.

3 Make moulds
The plasticine mask is cut into sections and a thin plaster impression is made of each piece. These are covered in plaster to create positive moulds.

4 Pour in gelatine
The plasticine sections are placed on the moulds and covered in more plaster, creating negative moulds. Hot gelatine is then poured inside.



5 Glue in place
The gelatine hardens to form flexible prosthetic pieces. Eyebrows are threaded in before the masks are applied to the actor's face using surgical glue.



6 Add finishing touches
Make up is applied to the prosthetic to create age spots and accentuate the wrinkles. Finally, a grey wig is added.

"The actor's face is covered in alginate, a material used to make impressions of teeth"

Creating sound effects

Many of the noises you hear in movies weren't actually recorded on set. This may be because the sound wasn't made in the first place, such as the hum of a lightsaber, or because it was obscured by background noise and couldn't be used. Instead, the sounds are recorded later by foley artists in a recording studio. They act out entire scenes of the movie to capture the noise of footsteps and clothes swishing before synchronising the track with the picture. When it comes to creating fictional noises, their work often requires the use of some unusual props. For example, if a scene features someone's head hitting the ground, a frozen lettuce is thrown on the floor to create the desired sound effect.

Strange props
A frozen lettuce can be used to create bone or head injury sound effects.

Foley artists use props in order to produce realistic sound effects for movies

AMAZING ANIMATRONICS

The advanced robotics behind some of our best loved, and most feared, movie characters

When movies such as *Alien*, *Jaws* and *ET* hit the big screen, computer-generated effects weren't quite up to scratch when it came to bringing nonhuman characters to life. Instead, real-life robotic versions of the characters were built, with complex engineering and incredible artistry required.

However, even now, when it's possible to make virtual characters more realistic than ever before, some directors and special effects technicians still opt for animatronics. For example, many of the nonhuman characters in 2015's *Star Wars* movie, *The Force Awakens*, were in fact real-life moving robots, including BB-8. The reason many give for using this technique is that they prefer having the character present on set, instead of adding them in later. Some also argue that actors are able to give a better performance if the character is there to interact with and react to.

One of the most groundbreaking examples of movie animatronics was the T-Rex in *Jurassic Park*. While many of the dinosaur's running shots were created using CGI, the close-ups were all of a full-size, life-like robot that stood at seven metres tall and weighed over 4,000 kilograms. An animatronic of that size had never been created for a movie before, and it had to be much stronger and more believable than any theme park robots.

The T-Rex was originally intended to be a human-operated puppet, with large rods used to move the head, tail and limbs. However, it soon became apparent that it would be too big for any human to be able to create the movements fast enough to make them realistic. Electric motors wouldn't be quick enough either, so in the end hydraulics were used.

The finished robot was so big that the ceiling of the workshop where it was built had to be raised by almost four metres, and its base had to be anchored into the ground to stop it toppling over. It was dangerous too, as while gluing its skin in place from the inside, one of the crew got trapped in its belly when a power cut caused it to move. His colleagues had to prize open the jaws to pull him to safety.

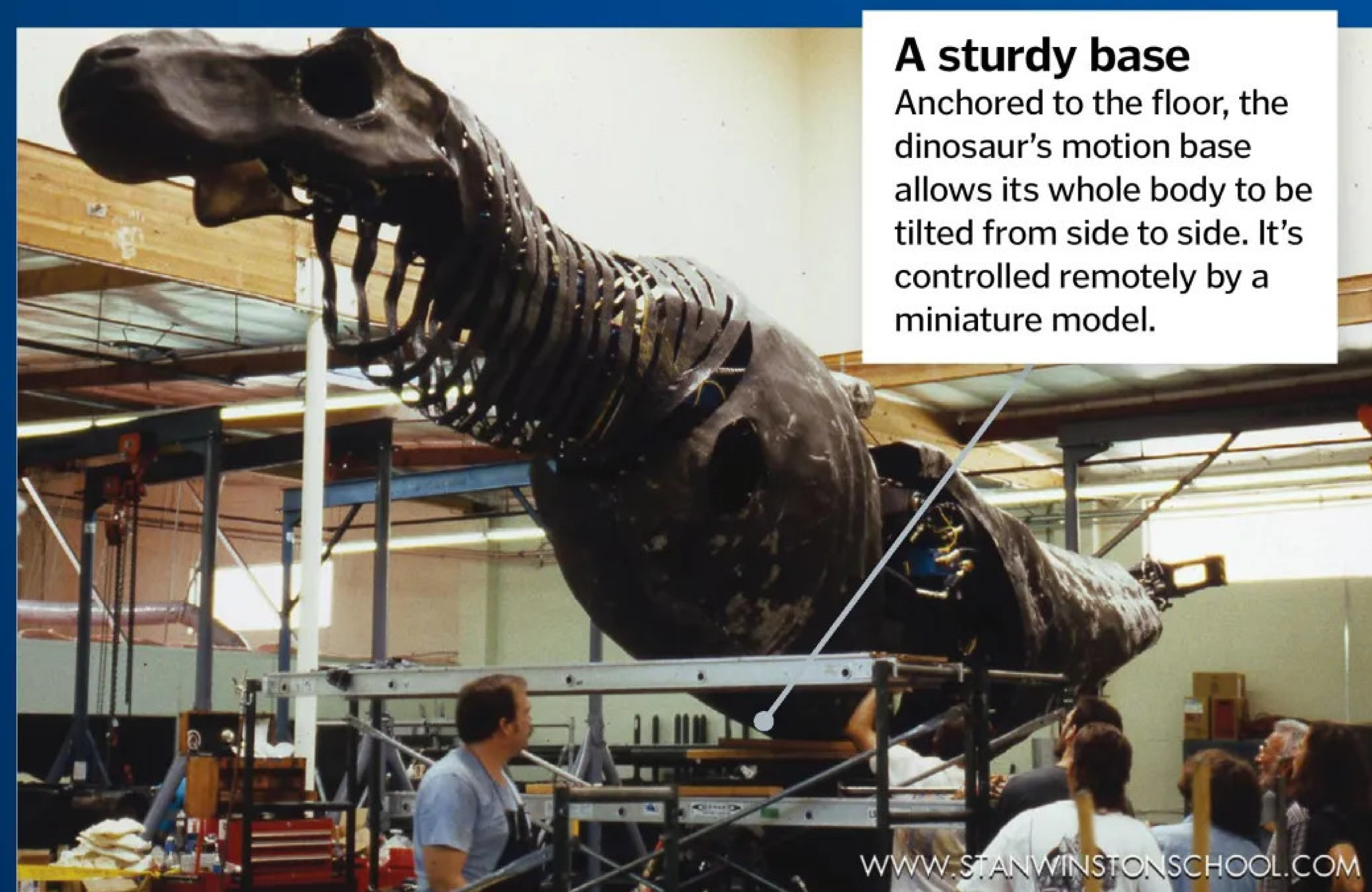
"An animatronic of that size had never been created for a movie before"

Building a T-Rex

Discover how *Jurassic Park*'s fearsome villain was brought to life

1 A metal skeleton
A fifth scale model of the T-Rex is sliced into pieces then each slice is scaled up and cut from wood. These wooden slices are then slotted onto a metal frame.

2 Sculpting the body
The main frame is covered in chicken wire and fibreglass, then a layer of clay. The clay is sculpted to look like T-Rex scales, and serves as a mould for the skin.



A sturdy base
Anchored to the floor, the dinosaur's motion base allows its whole body to be tilted from side to side. It's controlled remotely by a miniature model.

3 Mechanic movements
Alongside the sculpted T-Rex, a moving model is made. A steel frame fitted with hydraulics creates the T-Rex's movements at a speed of two metres per second.

It took the team from Stan Winston Studios months to build the iconic dinosaur

4 **Secure the skin**
Moulded from the original sculpture, the skin is pulled over a carbon fibre frame around the hydraulics. Made from foam and latex, it's stitched and glued in place.

5 **Check mobility**
Each possible movement is tested to ensure that the skin stretches but does not split or sag as the carbon fibre frame expands and contracts.

6 **Finishing touches**
The T-Rex's forearms, eyeballs, tongue and teeth, which are mostly made from foam, are all secured into place, and then it is ready to be transported onto set.

Eerily quiet
With only a gentle hiss from the hydraulics, the crew said the dinosaur was eerily quiet as it moved.

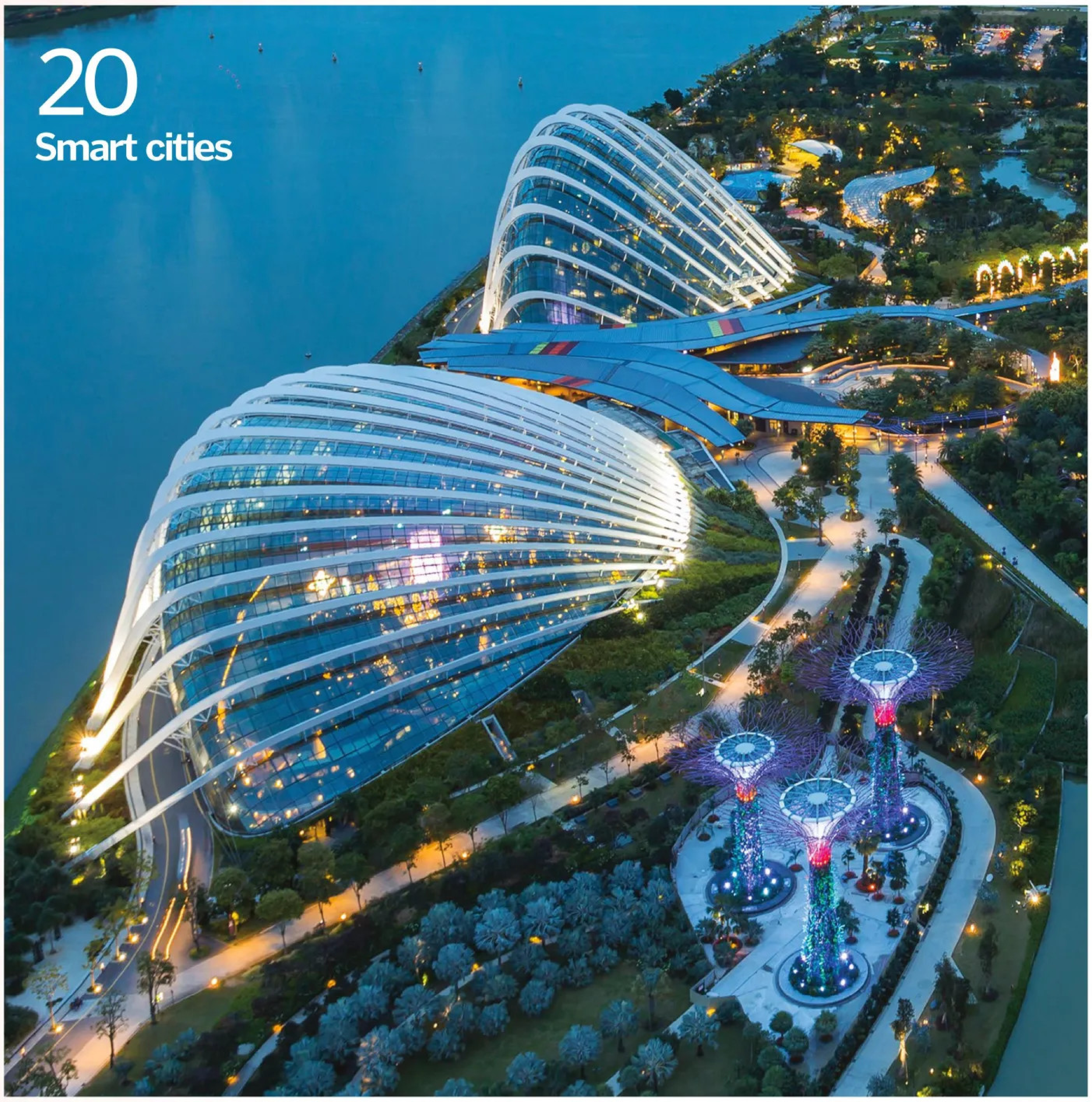
Amazing engineering
The T-Rex's hydraulic valves pushed 60 gallons of hydraulic fluid per minute.

Absorbing water
The T-Rex wasn't built for wet weather. Its foam skin absorbed lots of water on set, making it even heavier.

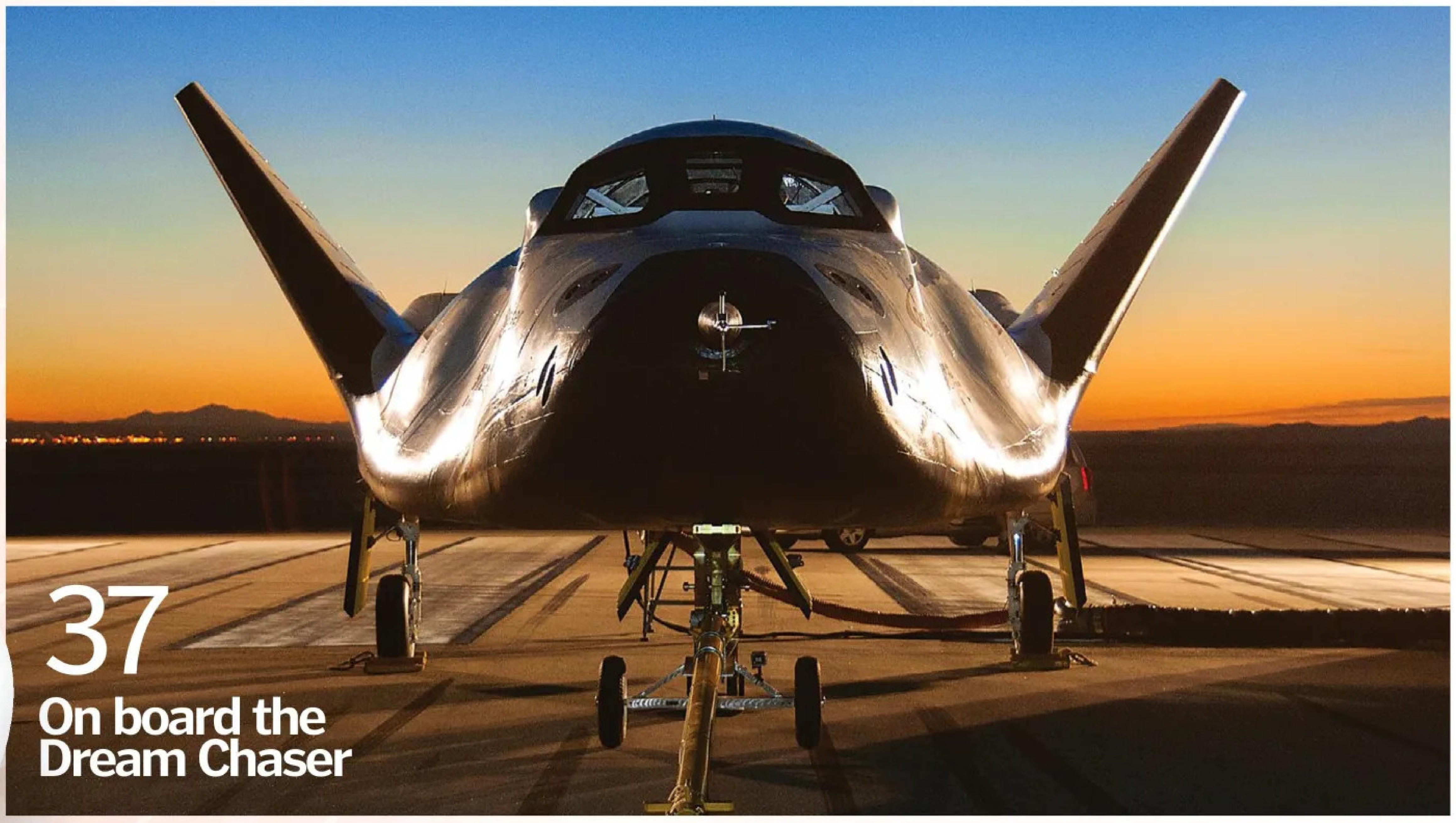
Thick-skinned
The skin was made five centimetres thick to conceal the metal skeleton and hydraulics underneath.

7 **Ready for a close-up**
Cinema history is made!

GADGETS & FUTURE TECH



20 Smart cities



37 On board the Dream Chaser

18 Real-life Star Trek inventions

5 REAL-LIFE STAR TREK INVENTIONS

How the gadgets on board Starfleet ships 50 years ago inspired modern technology

Scanadu Scout

INSPIRED BY… Tricorder

In the show, Dr McCoy's tricorder could scan a patient's body and instantly diagnose a medical problem. The Qualcomm XPRIZE is a competition to develop a real-life version of this device. One contender is the Scanadu Scout, a tiny scanner that measures your heart rate, blood pressure, core body temperature and other vital signs. Simply holding the Scout to your forehead for ten seconds gives an indication of your health and alerts you to any problems via an accompanying app.

Portable diagnostic scanners could revolutionise healthcare

Mobile phone

INSPIRED BY… Communicator

The Trek technology that's had the biggest influence on reality is the communicator. Starfleet crewmembers used these devices to contact one another, and to transmit emergency signals when in trouble.

While working at Motorola in 1973, Martin Cooper developed the first personal mobile phone, and he later admitted that Captain Kirk's communicator inspired his invention. *Star Trek* communicators were sometimes depicted as wrist devices or even worn as a badge, similar to real-life wearable gadgets like the Apple Watch and the CommBadge.

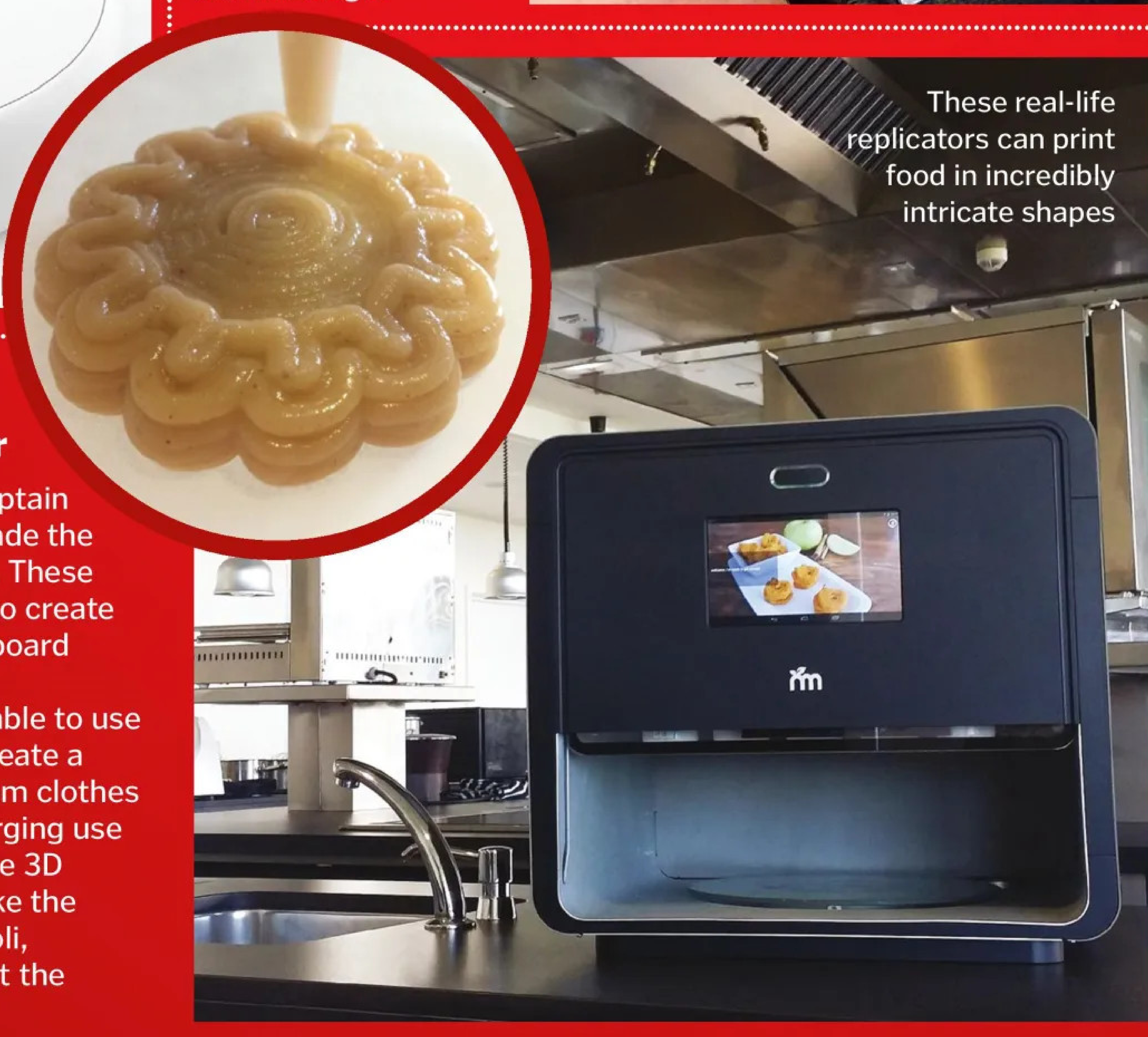

Handheld Communicators bear an uncanny resemblance to flip phones

3D printer

INSPIRED BY… Replicator

"Tea, Earl Grey, hot," said Captain Picard, and the replicator made the drink in a matter of seconds. These fictional devices were used to create meals and other objects on board Federation starships.

In reality, 3D printers are able to use different material 'inks' to create a huge variety of products, from clothes to spacecraft parts. An emerging use of this technology is to create 3D printed food, with printers like the Foodini able to produce ravioli, burgers, biscuits and more at the touch of a button.


These real-life replicators can print food in incredibly intricate shapes

Skype Translator

INSPIRED BY… Universal translator

When you're boldly going where no man has gone before, it helps to understand what the locals are saying. Starfleet crews were given universal translators to seamlessly interpret alien languages.

Microsoft has developed Skype Translator to break down language barriers here on Earth. The program compares your speech to a database of audio snippets in order to compile a transcript. This text is then translated to the desired language and read out by an automated voice.

Skype Translate can convert seven languages during calls

Tablets

INSPIRED BY… PADD

The Personal Access Display Device (PADD) was a hand-held computer used by Starfleet crew. With their sleek design and touchscreen interfaces, these devices are strikingly similar to tablet computers such as the iPad. Tablets have become possible thanks to the miniaturisation of technology. As computer components have got smaller, it has become possible to fit laptop-level hardware into these convenient hand-held gadgets. Tablets' touchscreen designs let users carry out commands with intuitive gestures, like pinch-to-zoom.


By using touchscreen interfaces, PADD props were easier and cheaper to make

How do multicopters take off?

The science and tech that gets commercial drones into the air

Drones, also known as unmanned aerial vehicles or UAVs, come in all shapes and sizes, from the mammoth machines used by the military, to the toys you fly in your back garden. However, while they are all operated remotely, the methods they use to get into the air can differ greatly.

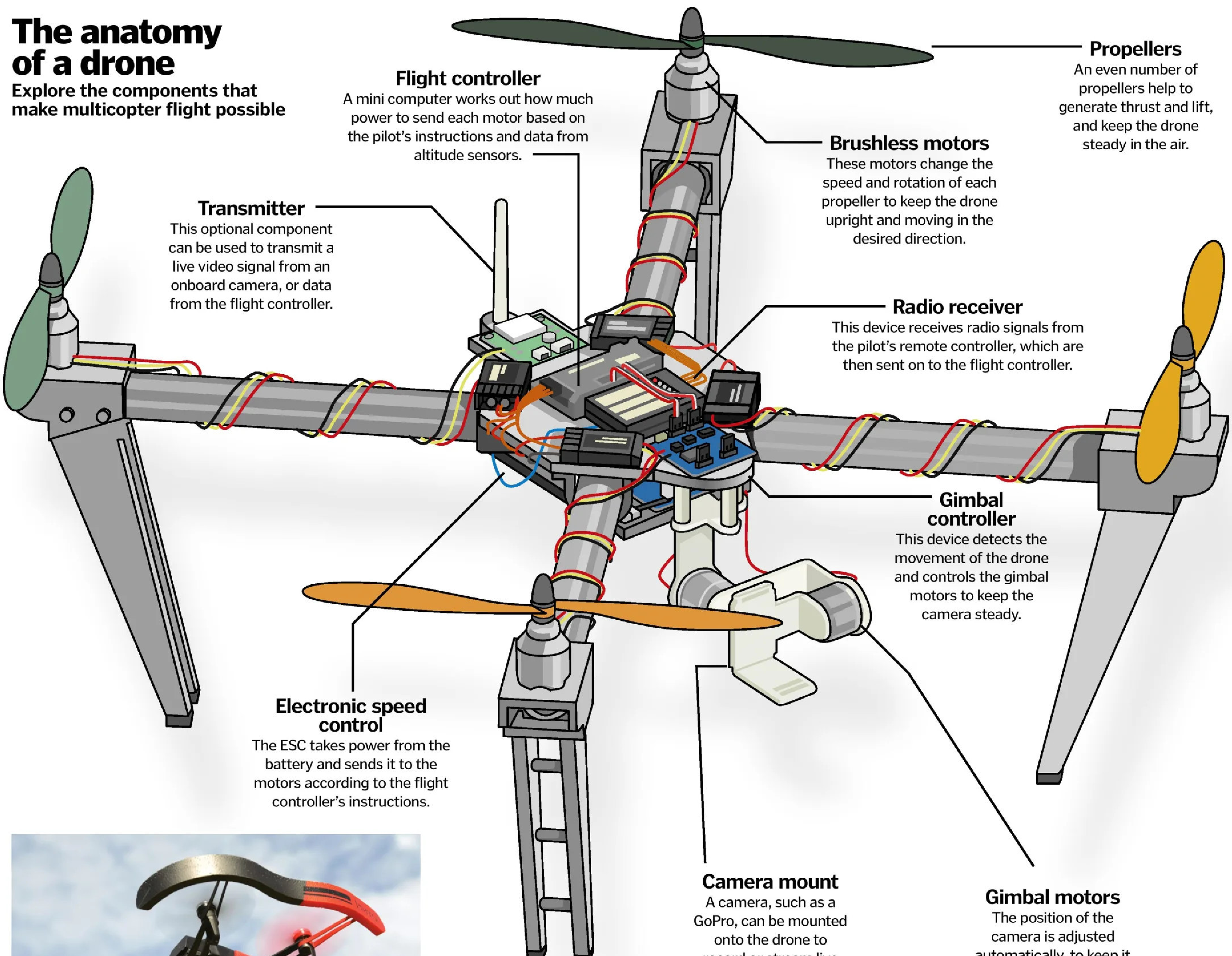
Those that take off like normal airplanes use engines or vertical propellers to create thrust, propelling them forwards and causing air to flow rapidly over the wings. The curved shape of the wings then deflect air, creating a difference in pressure above and below. As the air pressure below the wing is higher, this generates lift to push the drone upwards.

VTOL (Vertical Take Off and Landing) drones however, don't need a runway for take-off. They use engines or horizontal propellers to direct thrust downwards, thereby creating lift that gets them off the ground. This is the method favoured by commercial drones, which often come in the form of multicopters.

These miniature flying machines feature four or more horizontal propellers, which create plenty of thrust to allow them to hover above the ground. The propellers rotate in opposing directions to avoid spinning the multicopter out of control. They can also be used to change its direction by increasing or decreasing the speed at which certain propellers rotate. For example, by causing the propellers on the left side to spin faster, they generate more lift on that side and cause the drone to lean to the right.

The anatomy of a drone

Explore the components that make multicopter flight possible



Multicopters typically have an even number of propellers; quadcopters have four

SMART CITIES

With cities growing faster than ever, what role can technology play in making them greener?

Rebuilding the urban skyline

Tomorrow's city might look familiar, but technology is making it greener, cleaner and smarter than today's

How can we make a city 'smart'? It's a question that keeps a growing number of researchers, designers and architects very busy. Usually described as a key part of the long-promised 'Internet of Things', a smart city is one in which everything is connected, both to the internet and to each other. No matter what these devices do, ultimately the motivation behind employing them in urban areas is sustainability – to use data and technology to make our cities greener and cleaner.

Take Singapore's water network. Sensors embedded throughout the system monitor water pressure multiple times a second. Any changes are reported automatically to a central server, and where a leak is suspected, a team of engineers is dispatched to repair it. Other sensors monitor the water's quality – temperature, pH and electrical conductivity can all point to contamination. In an island city with limited sources of fresh water, a system like this is absolutely invaluable.

In London, traffic lights identify areas of congestion, automatically responding to minimise delays for both road users and pedestrians. Looking further ahead, traffic lights and vehicles will be able to communicate with each other, to gather data on road usage, and to give real-time updates to drivers. On mass transport too, smart technologies are making a difference. Open data is being used to map public cycle schemes and to better understand demands on metro systems.

Leading lights

Not all of these technologies are decades away, as these cities prove

Singapore, Southeast Asia
Singapore's water supply is truly smart. Hundreds of sensors embedded within its pipes constantly measure pressure and identify leaks.

Newark, US
This indoor farm is growing different varieties of leafy greens and herbs. Wavelengths of light boost crop yield while using 95 per cent less water than traditional agriculture.

Berlin, Germany
Berlin is trialling a flexible film that can harvest solar energy. This material can be installed on a building façade, or attached to the outer surface of an air dome.

Worldwide
Many cities and towns now have smart bins that compress waste and alert collectors when they are full. Powered by a solar panel, they can also act as Wi-Fi hot spots.

"Solar-powered, internet-enabled bins schedule their own waste collections"

In Philadelphia, US, electricity generated by braking trains is automatically fed back into the city's power grid, while in the Netherlands, waste electricity is being used to charge the city's electric buses.

But retrofitting smart technologies onto existing infrastructure can be challenging. Imagine that, instead, we simply started from scratch, and designed and built a city with sustainability as its top priority. A city powered by low-carbon sources, which used smart, connected devices to keep everything moving, and which offered an improved quality of life for its residents. This was the ambitious goal of Masdar City, a purpose-built metropolis on the edge of Abu Dhabi.

When its initial design was unveiled in 2008, its developers received plaudits from all over the world. The plans included a car-free transport system that relied on driverless pods run on magnetic tracks, energy harvesting technologies in every home, and a 'net zero' approach to carbon and waste.

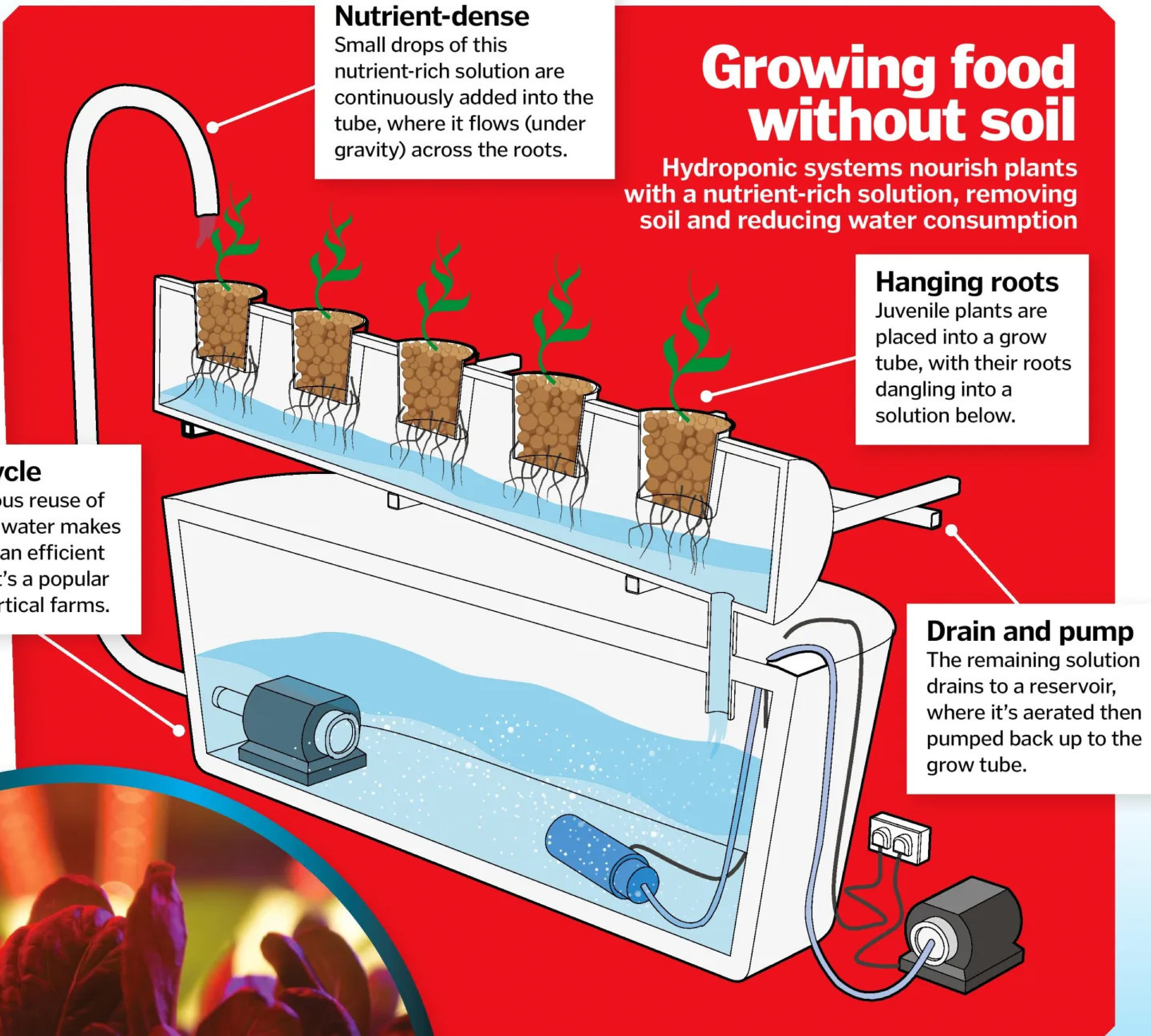
> "Plans included a transport system relying on driverless pods"

Real-life beanstalk
In this futuristic version, vertical farms growing food crops surround a skyscraper.

Vertical farms use fewer resources and less space

Growing food without soil

Hydroponic systems nourish plants with a nutrient-rich solution, removing soil and reducing water consumption



Nutrient-dense
Small drops of this nutrient-rich solution are continuously added into the tube, where it flows (under gravity) across the roots.

Hanging roots
Juvenile plants are placed into a grow tube, with their roots dangling into a solution below.

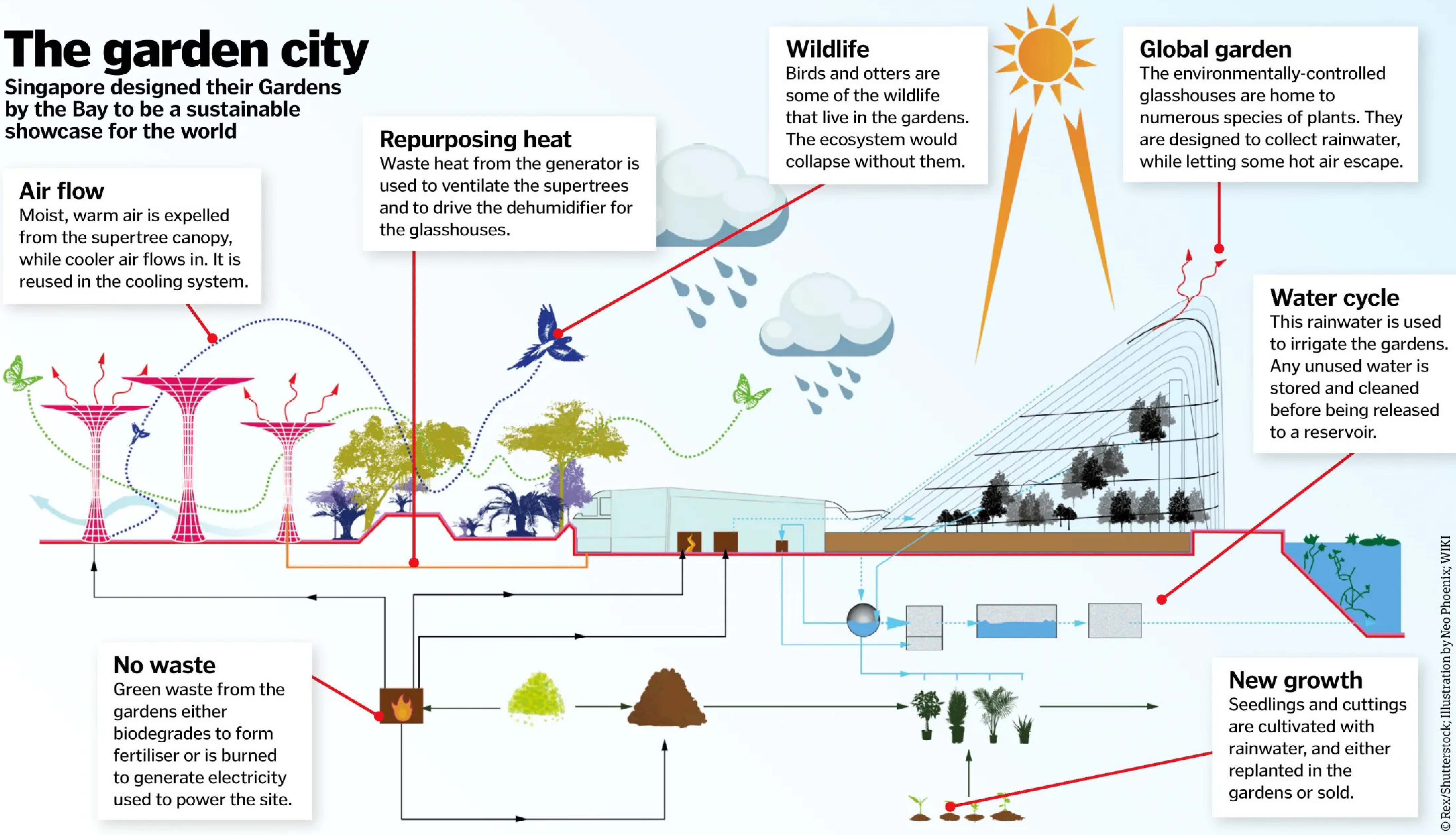
Closed cycle
The continuous reuse of nutrient-rich water makes hydroponics an efficient method, so it's a popular system in vertical farms.

Drain and pump
The remaining solution drains to a reservoir, where it's aerated then pumped back up to the grow tube.

Indoor farms use specially configured lighting to help plants grow without sunshine

The garden city

Singapore designed their Gardens by the Bay to be a sustainable showcase for the world



Singapore's sustainable city garden

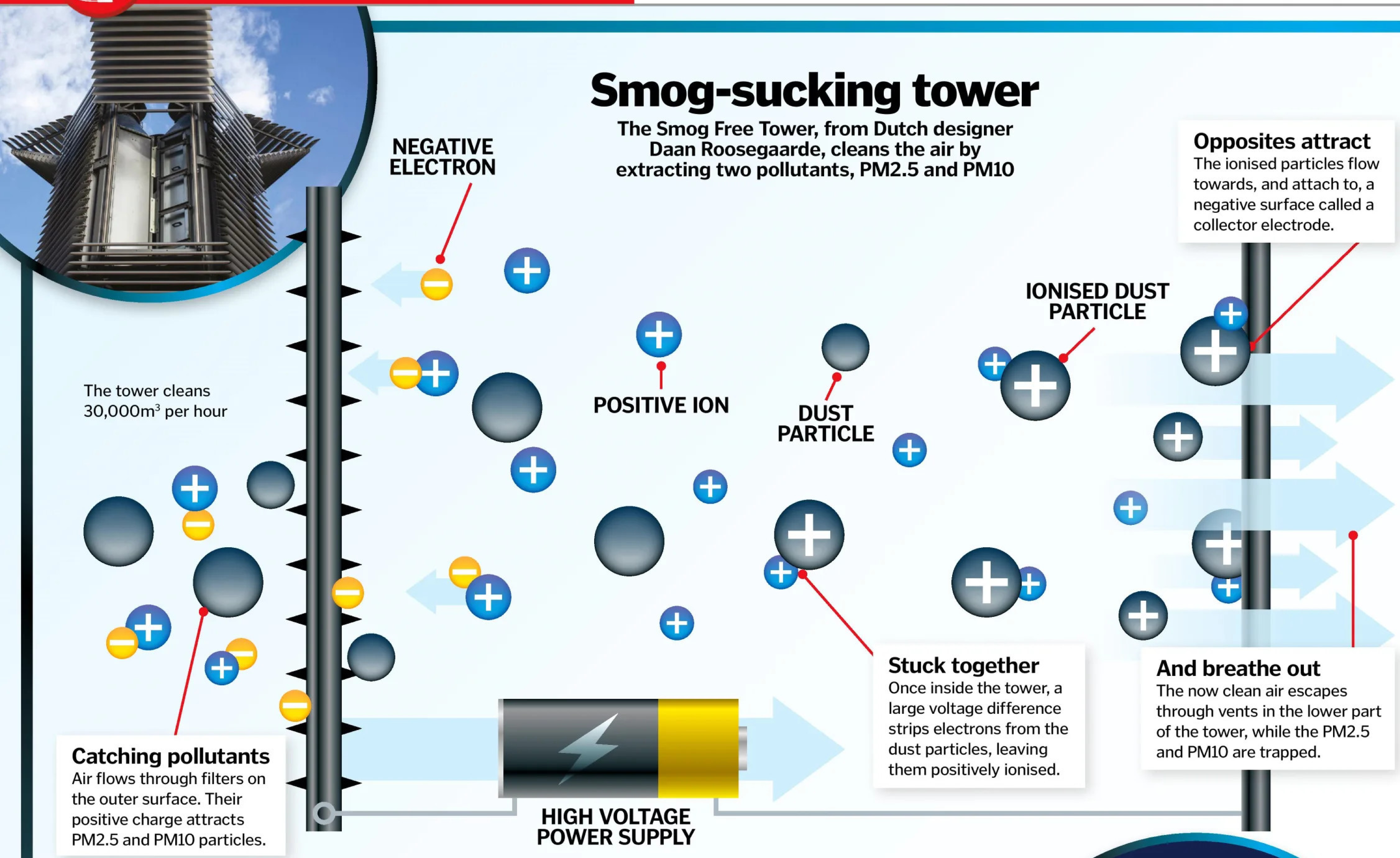
When it opened in 2011, the Gardens by the Bay in downtown Singapore were a flagship project; a way for the city to demonstrate its commitment to growing their 'Garden City' in a sustainable way. By the end of 2015, 20 million people had visited the 101 hectares of parkland, which includes two of the largest glasshouses on Earth.

The site's approach to recycling has become world famous: it collects rainwater, harvests sunlight, and uses decaying plant matter both as a fertiliser and as a source of electricity. The glasshouses are humidity-controlled partly using waste heat produced elsewhere, and the 18 iconic 'supertrees' house almost 163,000 plants, sourced from dry, semi-arid and tropical regions all over the world. Although the Gardens are self-contained, it is hoped that its approach to conservation and sustainability will inspire future cities to incorporate cleaner, greener ideas into their designs.

The Garden's supertrees are vertical gardens, fitted with solar panels and rainwater collection facilities

Smog-sucking tower

The Smog Free Tower, from Dutch designer Daan Roosegaarde, cleans the air by extracting two pollutants, PM2.5 and PM10



Buildings within Masdar City are considerably less energy-hungry than comparable structures in nearby Abu Dhabi, mainly thanks to their airtight insulation and clever design. The bulk of Masdar's hot water is provided by low-cost solar heaters, and most structures tap into the Sun's energy for their electricity needs too. But there were some deviations from the original plan.

First of all, the driverless pods now only shuttle between two stops, having largely been superseded by the growth of electric cars. The population is also much smaller than predicted; originally planned to house 50,000 residents, only around 1,000 people live in Masdar.

The economic crisis of 2008 had a significant impact on the construction schedule, meaning that to date, less than five per cent of the planned city has actually been built. And while Masdar produces much more clean energy than it uses, its developers have quietly set aside their aim of becoming the world's first zero carbon, zero waste city.

Another purpose-built sustainable city is Songdo, South Korea. With a current population of just over 100,000 – just half of what was predicted – it faces challenges on a much larger scale. Thankfully, when it comes to the use of smart technology, Songdo is leading the way.

One flagship project is its pneumatic waste disposal system. Householders separate their waste as usual, but rather than relying on fuel-belching removal trucks, the waste is all managed underground. Sensors in each bin detect how much waste it contains, and once full, it's automatically sucked through a maze of vacuum pipes to a central processing facility. There, food waste gets transformed into compost for the city's parks, and recyclable waste is cleaned and processed.

Greywater – water people have washed in – is recycled in Songdo too, and residents can track their energy and water consumption via a panel at home. Cycle paths are plentiful, and sensors across the city keep residents informed on everything from transport delays to air quality.

Despite the demonstrable benefits that technology like this has brought to these new urban regions, it's fair to say that the jury's still out on how best to build a smart city. Projects like Songdo and Masdar are a head-start on developing the necessary infrastructure, but applying it to established cities is not easy. Even so, with the way that technology is rapidly growing, it seems inevitable that our cities will have the smarts to succeed.


The nature park in the heart of Singapore is dominated by its giant glasshouses

THE RACE FOR A GREENER EARTH

From waste to water, humankind has its work cut out to achieve the eco-friendly world of tomorrow

Water desalination

"Water, water everywhere, nor any drop to drink," as the saying goes. Earth is certainly a watery planet, but as NASA images have shown us, the vast majority (96.5 per cent) of the water available to us is undrinkable seawater. With pressure on water supplies at an all-time high, cities in dry areas have resorted to removing salt from seawater to meet their needs. This process is expensive and uses huge quantities of electricity, but graphene may be able to help. This one-atom-thick material could allow water to pass through while filtering out large salt particles, with much lower energy costs than currently achievable.

This seven-metre-high air purifier has been travelling around China since October 2016

NASA's iconic 'blue marble' image highlights just how much water is on our planet

Air pollution

Studies from the World Health Organization show that the majority of large cities fail to meet minimum air quality guidelines. But numerous technologies are trying to pull pollutants directly out of the urban air. Walls, roof tiles and billboards coated in tiny particles of titanium dioxide can break down the nitrogen dioxides that impair lung function. A series of towers being trialled in China collect two types of particulate matter, called PM2.5 and PM10, which are known to contribute to smog. And in Canada, large walls of fans extract carbon dioxide from the air.

"In 2016 we dumped 40 million tons of electronic waste"

Weights, a neck brace and goggles allow researchers to experience city living with impairments

Ageing population

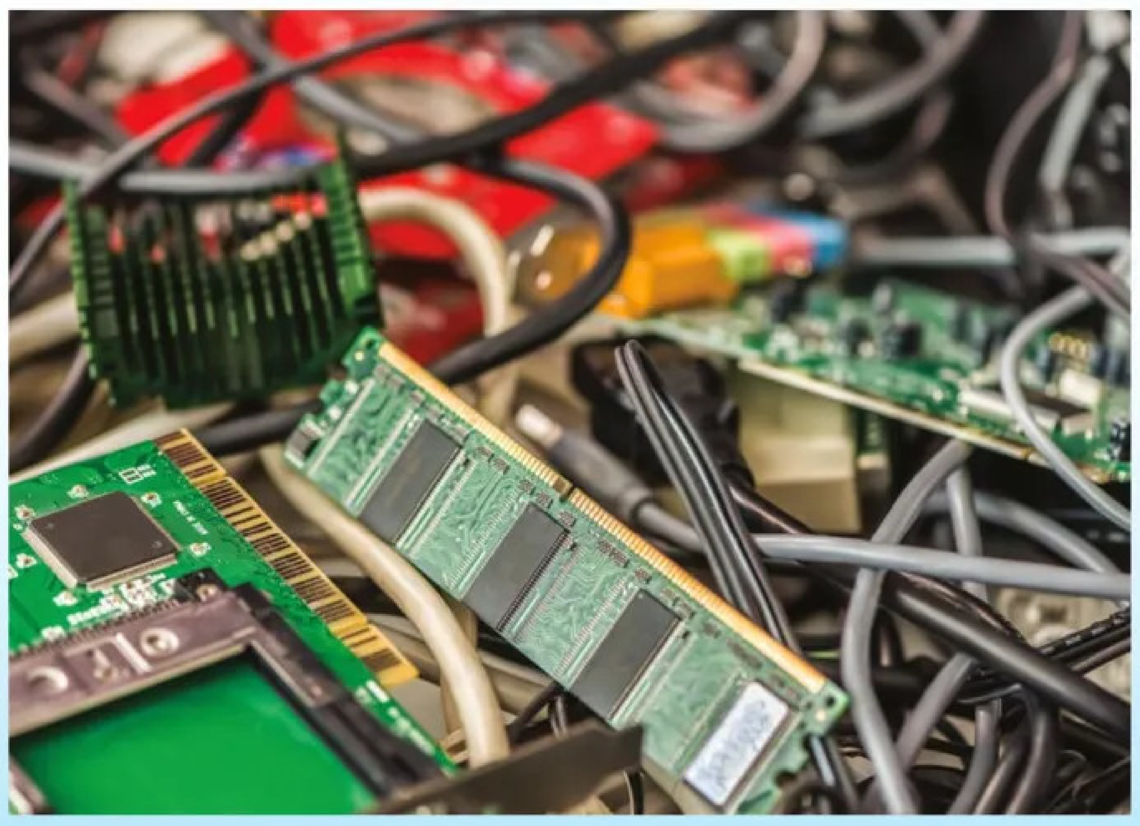
There will soon be more people on the planet aged 65 and over than there are children under the age of five, and an ageing population brings challenges for urban planners. Researchers have developed 'age suits' that mimic the physical challenges associated with ageing, such as sight loss or physical impairment. These are being used to help design better roads and pavements. And high-speed internet is being used to develop better links across generations in cities.

Housing demand

Around 80 per cent of Latin America's population now live in cities, and housing developers can't keep up with demands. But a Bogota-based architecture firm may have a solution. They are constructing safe, secure houses using building blocks made from waste plastic. The raw material is collected from landfill, before being cleaned and ground into a powder. Then it is melted and extruded to form beams, blocks and pillars that lock together to form buildings. A two bedroom plastic house can be built in five days, at a cost of approximately $5,000 (£4,000).

A mountain of e-waste

Electronic waste is the name given to the discarded electronic devices and domestic appliances that litter landfills across the world – in 2016 we dumped 40 million tons of it. But inside every smartphone and computer are small quantities of rare-earth metals. They are difficult to extract from the ground, so researchers are developing ways to 'mine' them from landfills. Their first success was in extracting neodymium from scrapped memory devices, and their work is ongoing.



Most e-waste is processed by hand, which exposes workers to numerous environmental hazards

Supersonic without the boom

NASA has revealed plans for a quieter successor to the Concorde passenger jet

In order to reach New York from London in less than three and a half hours, Concorde cruised at speeds of over 2,180 kilometres per hour – twice the speed of sound. At half that speed, it would break the sound barrier, generating an enormous double sonic boom that could be heard for miles.

This incredibly loud noise led to a worldwide ban on continental supersonic flights, restricting the routes that Concorde could fly. It wasn't particularly efficient either, as it burnt two per cent of its fuel just taxiing to the runway. These factors ultimately contributed to the aircraft's downfall, leading to it being retired in 2003.

Now, NASA hopes to bring back supersonic passenger air travel by making flights greener, safer and quieter. To achieve this it has announced plans to develop a 'low boom' aircraft, which generates a soft thump as it breaks the sound barrier, rather than a disruptive boom.

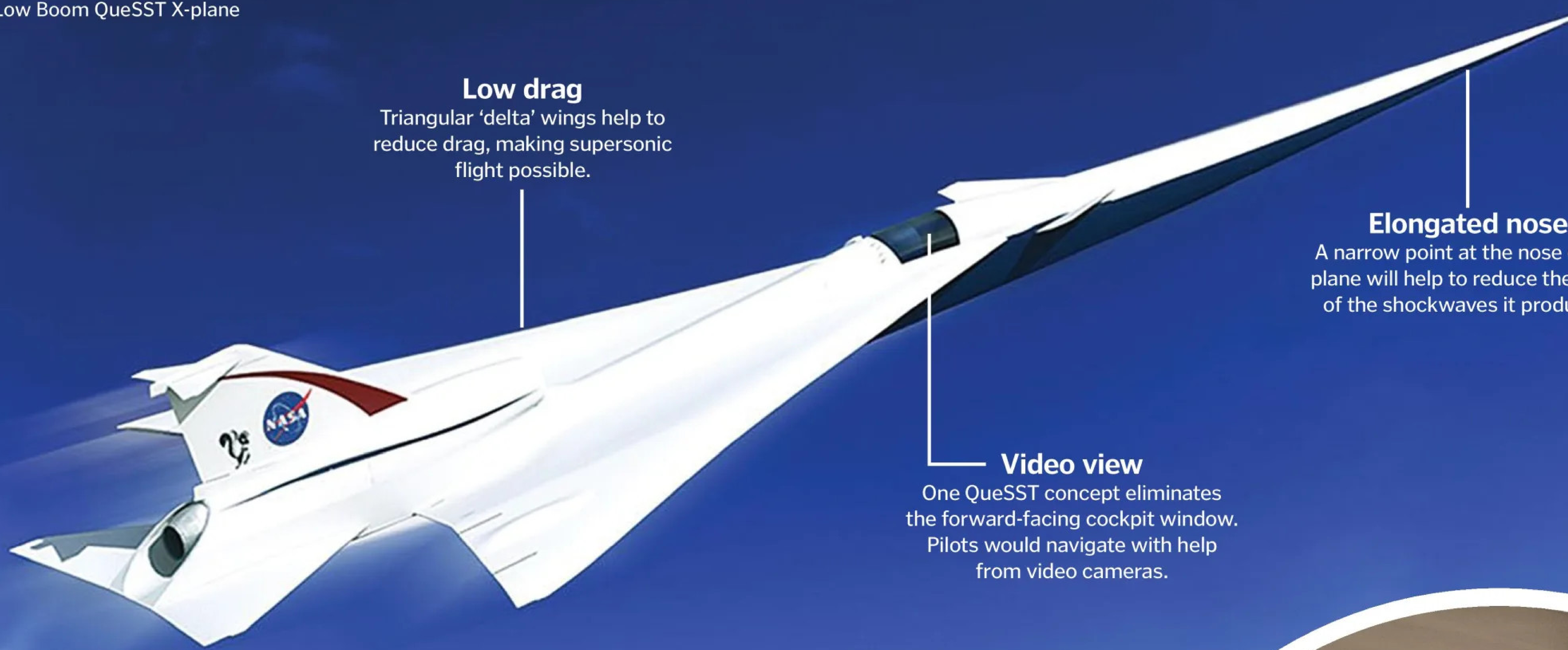
The $20 million contract to design the Quiet Supersonic Technology (QueSST) X-plane has been awarded to Lockheed Martin Aeronautics, and NASA hopes a working prototype will take flight in 2020. To help build this next-generation supersonic jet, NASA has been busy conducting research into sonic booms. It has recently been testing an air data probe that may one day be used to measure the shockwaves generated by supersonic aircraft, providing information that could help improve their design.

What is a sonic boom?

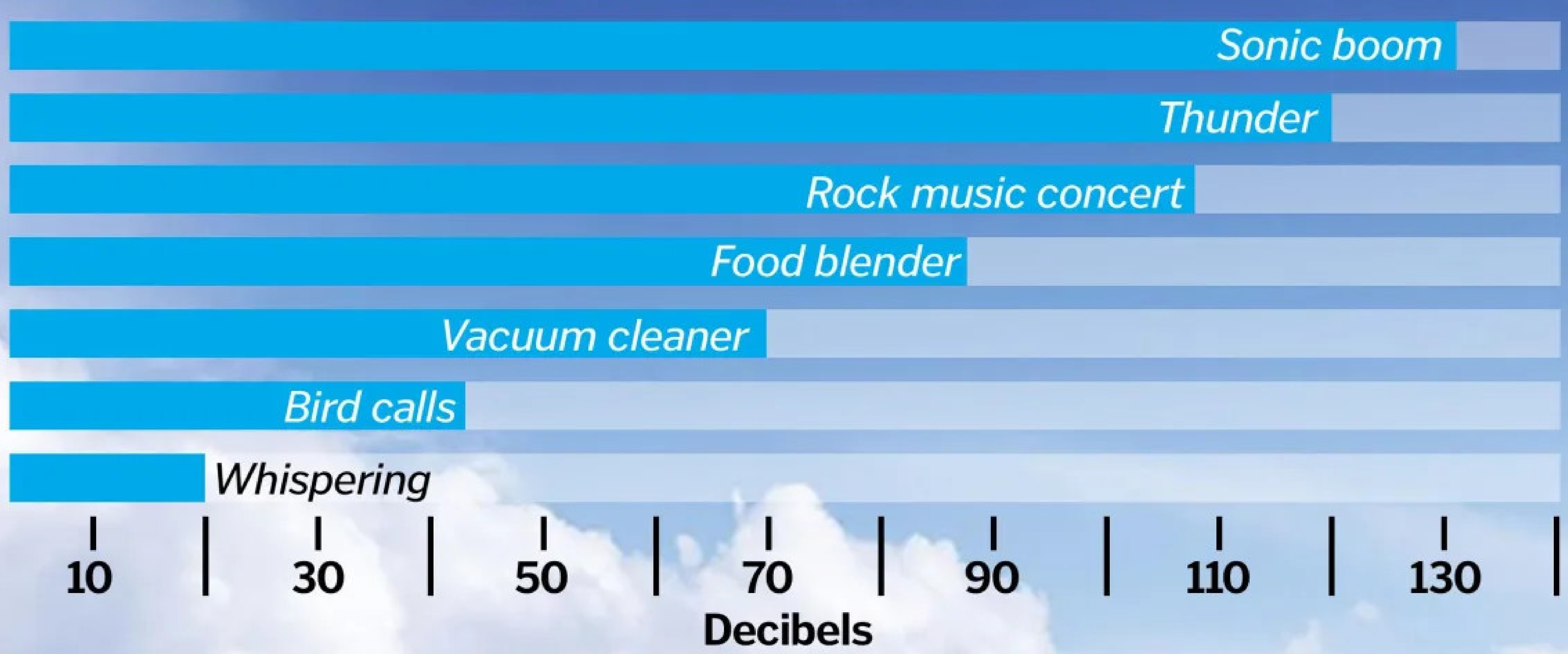
As an aircraft flies, it compresses the air in front of it, producing compression waves a bit like the ripples created ahead of a moving boat. These waves move away from the aircraft in all directions and travel at the speed of sound. When the aircraft itself reaches the speed of sound, the compression waves combine together to create a shockwave, and when this shockwave reaches our ears, we hear it as a loud boom. If the aircraft is travelling faster than the speed of sound, the shockwaves form a cone shape that trails off behind the aircraft, creating a continuous sonic boom.

When an aircraft flies at supersonic speeds, the decrease in temperature and pressure forms a cloud

An artist's concept of a possible design for the Low Boom QueSST X-plane



How loud is a sonic boom?



NASA's supersonic air data probe affixed to an F-15B aircraft for testing

Dyson's air purifier

The fan that removes 99.95 per cent of indoor allergens and pollutants

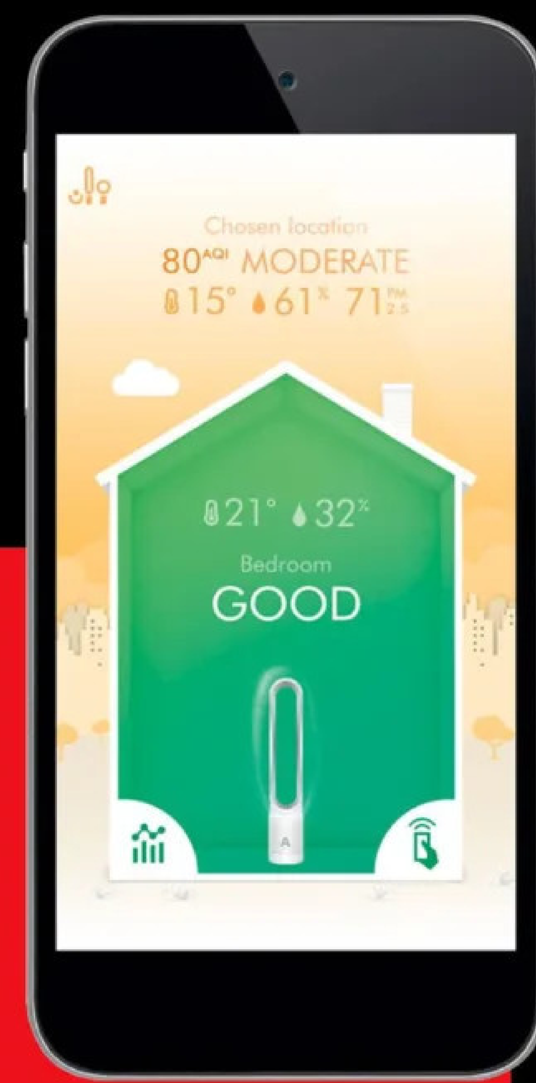
We're all familiar with the allergens and pollutants lurking in the air outside, but did you know that air pollution inside your home can be up to five times worse? As we usually keep our windows and doors closed to retain heat and block out noise, potentially harmful particles often get trapped inside. These indoor air pollutants are too small to see with the naked eye and include gases from cooking and central heating, as well as mould, pet hair and pollen.

"When we talk about physical pollutants in the air we split them into average size brackets identified with a PM [particle matter] number," says Matt Kelly, a mechanical engineer at Dyson. "Most purifiers are reasonably good at capturing PM2.5, which are often linked to health hazards." That's because these particles have a diameter of only 2.5 microns – around 30 times smaller than a human hair – so they can enter the lungs. "But what we have focused on with the Dyson Pure Cool Link is the next size down, PM0.1," Kelly says, "which are particles just 0.1 microns in size and small enough to pass into your bloodstream."

These physical pollutants get trapped inside the mesh of the purifier's dense glass filter, but behind that sits a second filter designed to absorb the toxic and strong-smelling volatile organic chemicals released by cleaning solvents, deodorants and scented candles. Together, these filters remove 99.95 per cent of pollutants from the air that passes through the machine and is pumped back into your home. It also doubles up as a fan to cool you in the summer.

Monitoring air quality

Two sensors located in the base of the Dyson Pure Cool Link constantly monitor the quality of the surrounding air. If they detect a particularly high level of contaminants, such as from the plume of hot air released when you open the oven door, the machine will ramp up its operation to cope with the additional pollution. The information recorded by the sensors is also sent to the Dyson Link app on your smart device, allowing you to keep track of the air quality history in your home, as well as monitor it in real-time.



The Dyson Link app lets you monitor the air quality from inside and outside of your home

Inside the Dyson Pure Cool Link

How does this clever machine clean the air?

HACKING THE HUMAN BODY

YOUR BODY IS YOUR MOST VERSATILE TOOL, BUT WHAT IF YOU COULD IMPROVE IT?

We are limited by our biology: prone to illness, doomed to wear out over time, and restricted to the senses and abilities that nature has crafted for us over millions of years of evolution. But not any more.

Biological techniques are getting cheaper and more powerful, electronics are getting smaller, and our understanding of the human body is growing. Pacemakers already keep our hearts beating, hormonal implants control our fertility, and smart glasses augment our vision. We are teetering on the edge of the era of humanity 2.0, and some enterprising individuals have already made the leap to the other side.

While much of the technology developed so far has had a medical application, people are now choosing to augment their healthy bodies to extend and enhance their natural abilities.

Kevin Warwick, a professor of cybernetics at Coventry University, claims to be the "world's first cyborg". In 1998, he had a silicon chip implanted into his arm, which allowed him to open doors, turn on lights and activate computers without even touching them. In 2002, the system was upgraded to communicate with his nervous system; 100 electrodes were linked up to his median nerve.

Through this new implant, he could control a wheelchair, move a bionic arm and, with the help of a matched implant fitted into his wife, he was even able to receive nerve impulses from another human being.

Professor Warwick's augmentations were the product of a biomedical research project, but waiting for these kinds of modifications to hit the mainstream is proving too much for some enterprising individuals, and hobbyists are starting to experiment for themselves.

Amal Graafstra is based in the US, and is a double implantee. He has a Radio Frequency Identification (RFID) chip embedded in each hand: the left opens his front door and starts his motorbike, and the right stores data uploaded from his mobile phone. Others have had magnets fitted inside their fingers, allowing them to sense magnetic fields, and some are experimenting with aesthetic implants, putting silicon shapes and lights beneath their skin. Meanwhile, researchers are busy developing the next generation of high-tech equipment to upgrade the body still further.

This article comes with a health warning: we don't want you to try this at home. But it's an exciting glimpse into some of the emerging technology that could be used to augment our bodies in the future. Let's dive in to the sometimes shady world of biohacking.

"We are teetering on the edge of the era of humanity 2.0"

IMPLANTS

Professional and amateur biohackers are exploring different ways of augmenting our skin

Electronic tattoos

Not so much an implant as a stick-on mod, this high-tech tattoo from the Massachusetts Institute of Technology (MIT) can store information, change colour, and even control your phone.

Created by the MIT Media Lab and Microsoft Research, DuoSkin is a step forward from the micro-devices that fit in clothes, watches and other wearables. These tattoos use gold leaf to conduct electricity against the skin, performing three main functions: input, output and communication. Some of the tattoos work like buttons or touch pads. Others change colour using resistors and temperature-sensitive chemicals, and some contain coils that can be used for wireless communication.

The electronic tattoos work as touch sensors, change colour, and receive Wi-Fi signals

Fingertip magnets

Tiny neodymium magnets can be coated in silicon and implanted into the fingertips. They respond to magnetic fields produced by electrical wires, whirring fans and other tech. This gives the wearer a 'sixth sense', allowing them to pick up on the shape and strength of invisible fields in the air.

The implants allow the wearer to pick up small magnetic objects

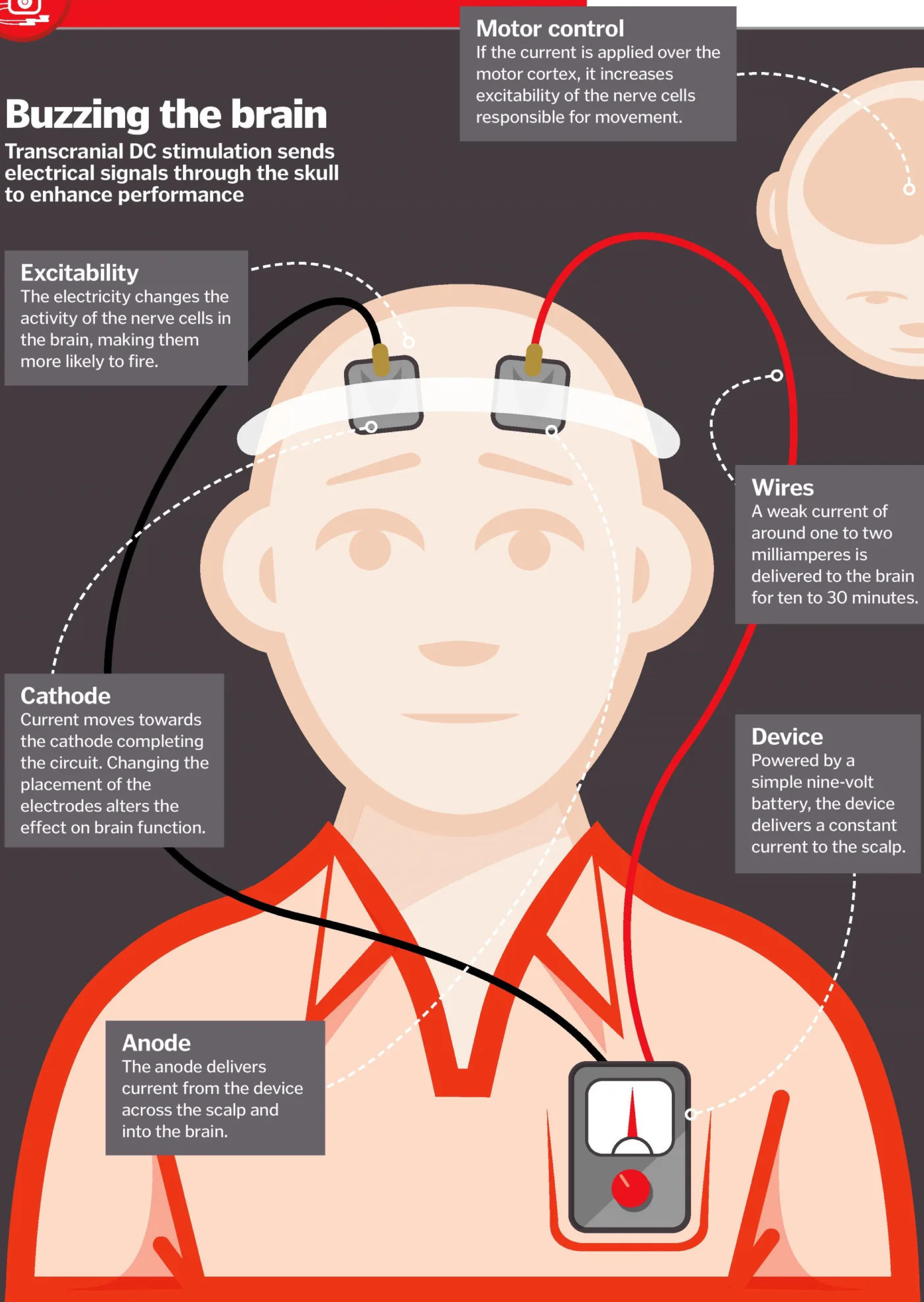
Under-skin lights

Some implants are inserted under the skin to augment the appearance of the body. The procedure involves cutting and stitching, and is often performed by tattoo artists or body piercers. The latest version, created by a group in Pittsburgh, even contains LED lights. This isn't for the faint of heart – anaesthetics require a license, so fitting these is usually done without.

Grindhouse Wetware makes implantable lights that glow from under the skin

Buzzing the brain

Transcranial DC stimulation sends electrical signals through the skull to enhance performance

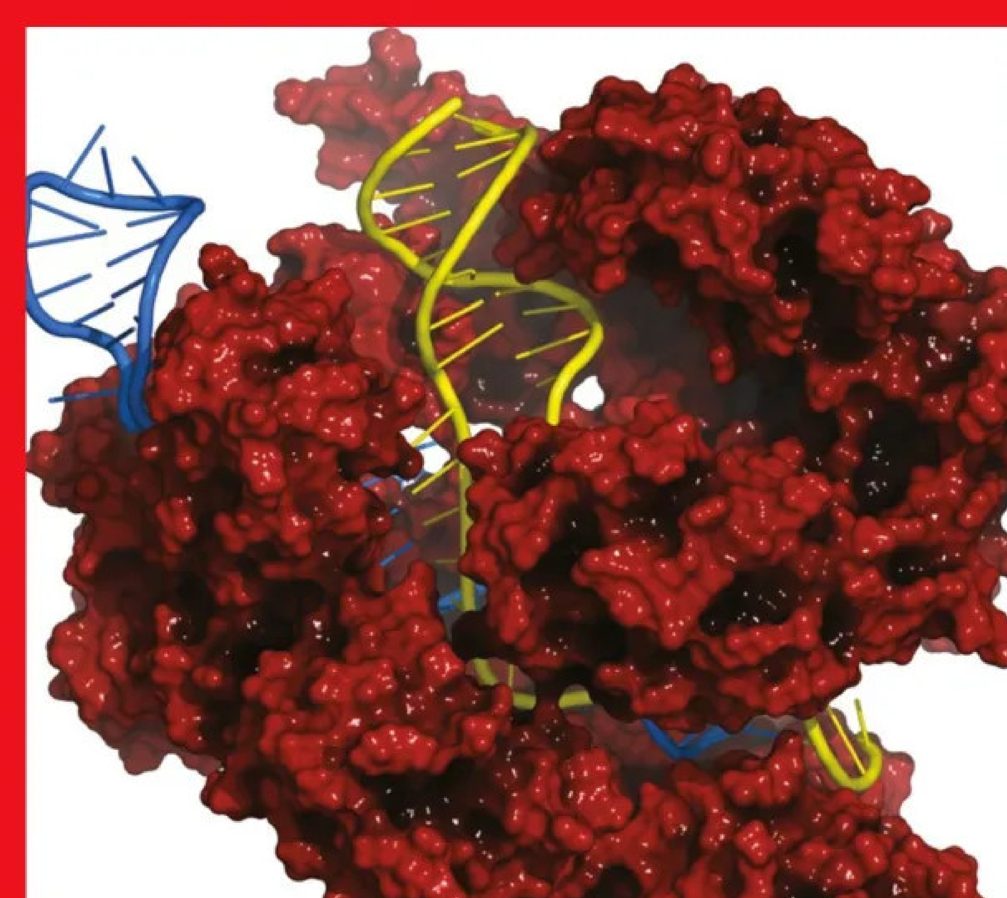


Gene editing

In 2013, researchers working in gene editing made a breakthrough. They used a new technique to cut the human genome at sites of their choosing, opening the floodgates for customising and modifying our genetics.

The system that they used is called CRISPR. It is adapted from a system found naturally in bacteria, and is composed of two parts: a Cas9 enzyme that acts like a pair of molecular scissors, and a guide molecule that takes the scissors to a specific section of DNA.

What scientists have done more recently is to hijack this system. By 'breaking' the enzyme scissors, the CRISPR system no longer cuts the DNA. Instead, it can be used to switch the genes on and off at will, without changing the DNA sequence. At the moment, the technique is still experimental, but in the future it could be used to repair or alter our genes.



The CRISPR complex works like a pair of DNA-snipping scissors

HACKING THE BRAIN

With the latest technology we can decipher what the brain is thinking, and we can talk back

The human brain is the most complex structure in the known universe, but ultimately it communicates using electrical signals, and the latest tech can tap into these coded messages.

Prosthetic limbs can now be controlled by the mind; some use implants attached to the surface of the brain, while others use caps to detect electrical activity passing across the scalp. Decoding signals requires a lot of training, and it's not perfect, but year after year it is improving.

It is also possible to communicate in the other direction, sending electrical signals into the brain. Retinal implants pick up light, code it into electrical pulses and deliver them to the optic nerve, and cochlear implants do the same with sound in the ears via the cochlear nerve. And, by attaching electrodes to the scalp, whole areas of the brain can be tweaked from outside.

> "Prosthetic limbs can now be controlled by the mind"

Transcranial direct current stimulation uses weak currents that pass through skin and bone to the underlying brain cells. Though still in development, early tests indicate that this can have positive effects on mood, memory and other brain functions. The technology is relatively simple, and companies are already offering the kit to people at home. It's even possible to make one yourself.

However, researchers urge caution. They admit that they still aren't exactly sure how it works, and messing with your brain could have dangerous consequences.

Community biology labs

We spoke to Tom Hodder, technical director at London Biological Laboratories Ltd to learn more about public labs and the biohacking movement

Interview bio:
Tom Hodder studied medicinal chemistry and is a biohacker working on open hardware at London Biohackspace.

What is the London Biohackspace?
The London Biohackspace is a biolab at the London Hackspace on Hackney Road. The lab is run by its members, who pay a small monthly fee. In return they can use the facilities for their own experiments and can take advantage of the shared equipment and resources. In general the experiments are some type of microbiology, molecular or synthetic biology, as well as building and repairing biotech hardware.

Who can get involved? Is the lab open to anyone?
Anyone can join up. Use of the lab is subject to a safety induction. There is a weekly meet-up on Wednesdays at 7.30pm, which is open to the public.

Why do you think there is such an interest in biohacking?
Generally, I think that many important problems, such as food, human health, sustainable resources (e.g. biofuels) can be potentially mitigated by greater understanding of the underlying processes at the molecular biological level. I think that the biohacking community is orientated towards the sharing of these skills and knowledge in an accessible way. Academic research is published, but research papers are not the easiest reading, and the details of commercial research are generally not shared unless it's patented. More recently, much of the technology required to perform these experiments is becoming cheaper and more accessible, so it is becoming practical for biohacking groups to do more interesting experiments.

Where do you see biohacking going in the future?
I think in the short term, the biohacking groups are not yet at an equivalent level to technology and resources to the universities and commercial research institutions. However in the next five years, I expect more open biolabs and biomakerspaces to be set up and the level of sophistication to increase.
I think that biohacking groups will continue to perform the service of communicating the potential of synthetic and molecular biology to the general public, and hopefully do that in an interesting way.

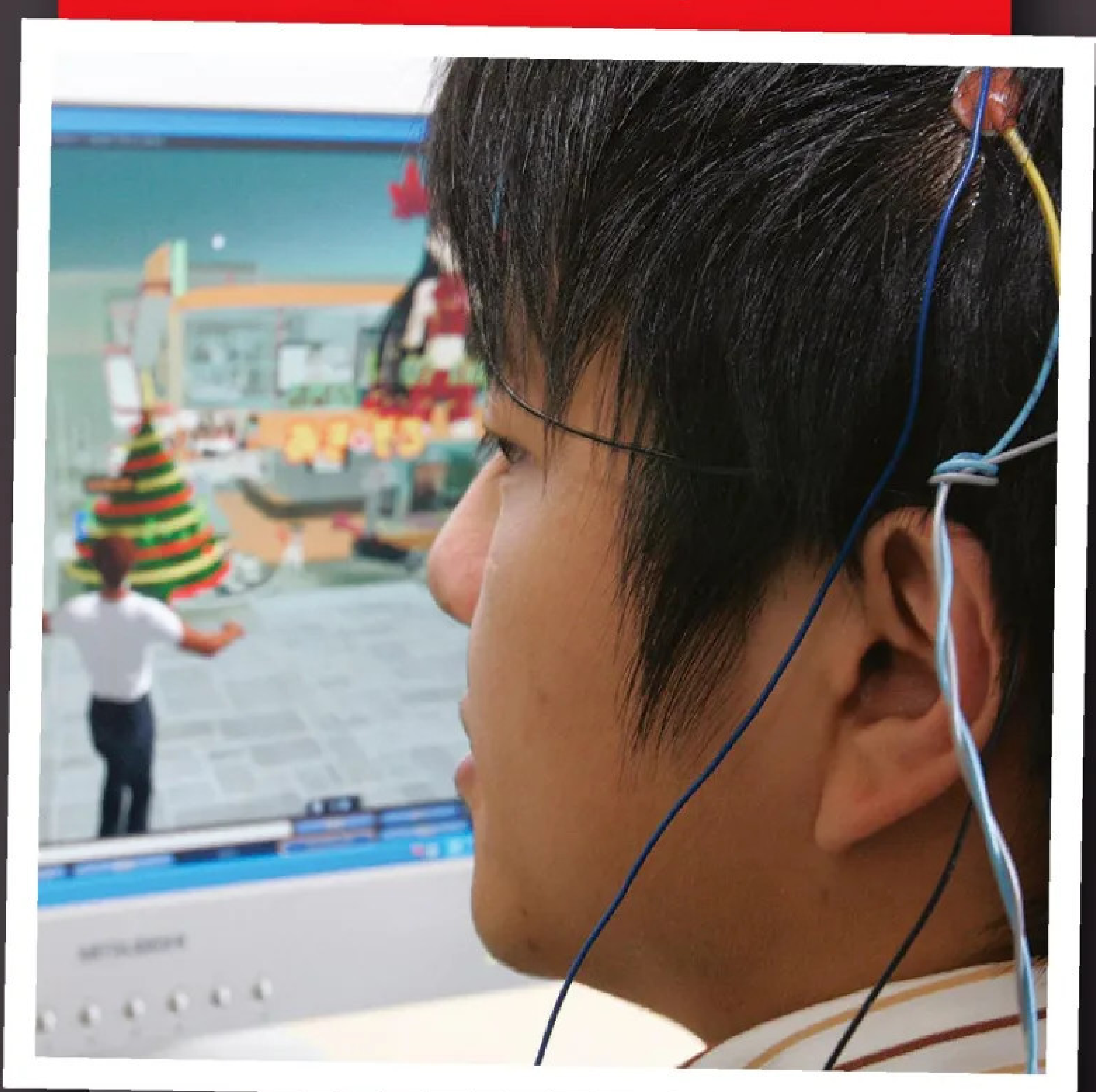
Community labs are popping up all over the world, providing amateur scientists with access to biotech equipment

Exoskeletons and virtual reality

At the 2014 World Cup in Brazil, Miguel Nicolelis from Duke University teamed up with 29-year-old Juliano Pinto to showcase exciting new technology. Pinto is paralysed from the chest down, but with the help of Nicolelis' mind-controlled exoskeleton and a cap to pick up his brainwaves, he was able to stand and kick the official ball.

The next step in Nicolelis' research has been focused on retraining the brain to move the legs – and this time he's using VR. After months of controlling the walking of a virtual avatar with their minds, eight people with spinal-cord injuries have actually regained some movement and feeling in their own limbs.

Electrodes can pick up neural impulses, so paralysed patients are able to control virtual characters with their brain activity



Exosuits can amplify your natural movement, while some models can even be controlled by your mind

BUILDING FUTURE YOU

A closer look at some of the emerging tech that will allow you to customise your body

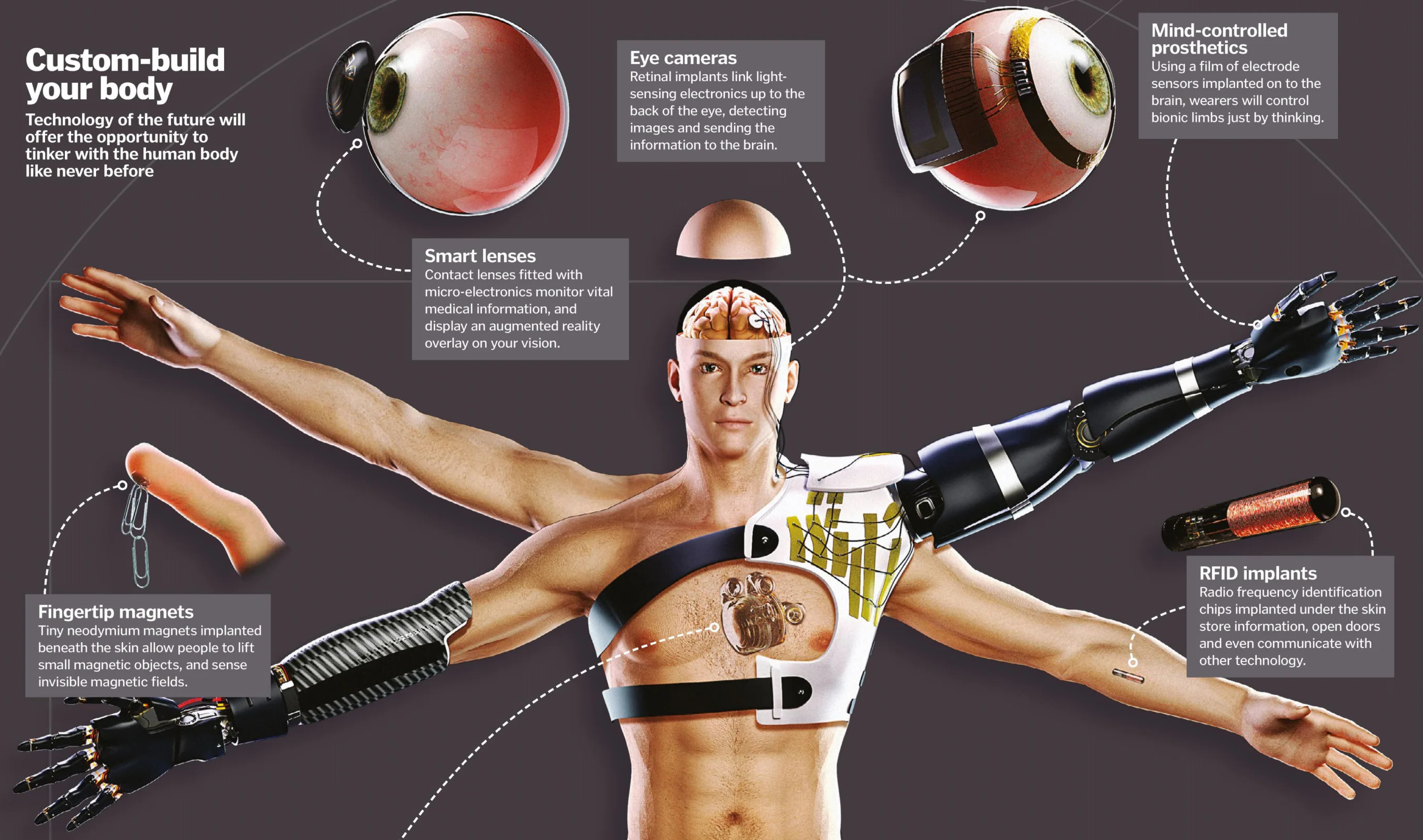
Self-improvement is part of human nature, and technology is bringing unprecedented possibilities into reach. Much of the development up until this point has had a medical purpose in mind, including prosthetic limbs for amputees, exoskeletons for paralysis, organs for transplant, and light sensors for the blind. However, with the advent of wearable technology, and a growing community of amateur and professional biotechnology tinkerers, there is increased interest in augmenting the healthy human body.

The first cyborgs already walk among us, fitted with magnetic senses, implanted with microchips, and talking to technology using their nervous systems. At the moment, many devices are experimental, sometimes even homemade and unlicensed. However, the field is opening up, and the possibilities are endless.

So, what does the future hold for a customisable you? Medical implants could monitor, strengthen, heal or replace our organs. We could add extra senses, or improve the ones we already have. And, one day, we might be able to tap straight into the internet with our minds.

Custom-build your body

Technology of the future will offer the opportunity to tinker with the human body like never before



Smart lenses
Contact lenses fitted with micro-electronics monitor vital medical information, and display an augmented reality overlay on your vision.

Eye cameras
Retinal implants link light-sensing electronics up to the back of the eye, detecting images and sending the information to the brain.

Mind-controlled prosthetics
Using a film of electrode sensors implanted on to the brain, wearers will control bionic limbs just by thinking.

Fingertip magnets
Tiny neodymium magnets implanted beneath the skin allow people to lift small magnetic objects, and sense invisible magnetic fields.

RFID implants
Radio frequency identification chips implanted under the skin store information, open doors and even communicate with other technology.

Bionic organs
Replacement organs will be grown from real human cells in the lab, or reconstructed using synthetic materials and electronics.

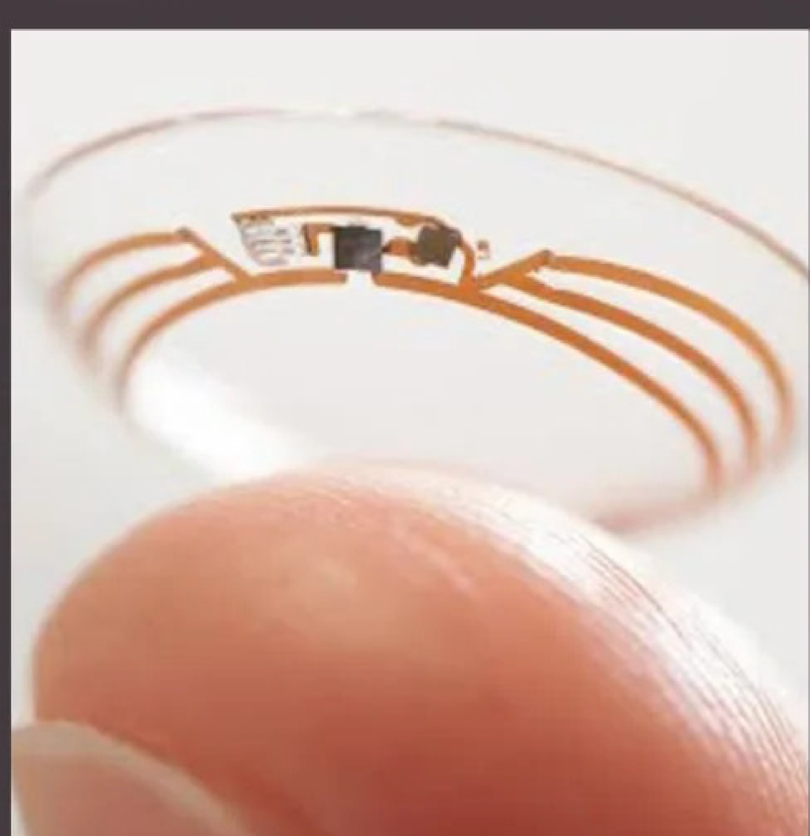
Exoskeleton support
Robotic exoskeletons support the wearer's limbs, using hydraulics in place of muscles, and hinges in place of joints.

Interchangeable limbs
Advanced prosthetics could give amputees superhuman abilities, and the option to switch between designs to suit the situation.

Smart bandages
Wound dressings will be equipped with sensors to monitor healing and flag up the first signs of infection by turning fluorescent green.

Electronic tattoos
Gold-leaf temporary tattoos can be used as touch sensors, colour-changing indicators, and for Wi-Fi communications.

> "Many devices are experimental, sometimes even homemade"


Google is developing a contact lens that senses blood sugar by analysing tears


This RFID chip shows the coiled copper antenna it uses to communicate


The Argus implant's camera and transmitter signal to the optic nerve


The i-limb hand can be moved by gestures, apps, muscle signals or proximity sensors


Ekso moves legs in response to upper body movement

HOW PET ID TAGS WORK

These smart devices reunite owners with their animal companions

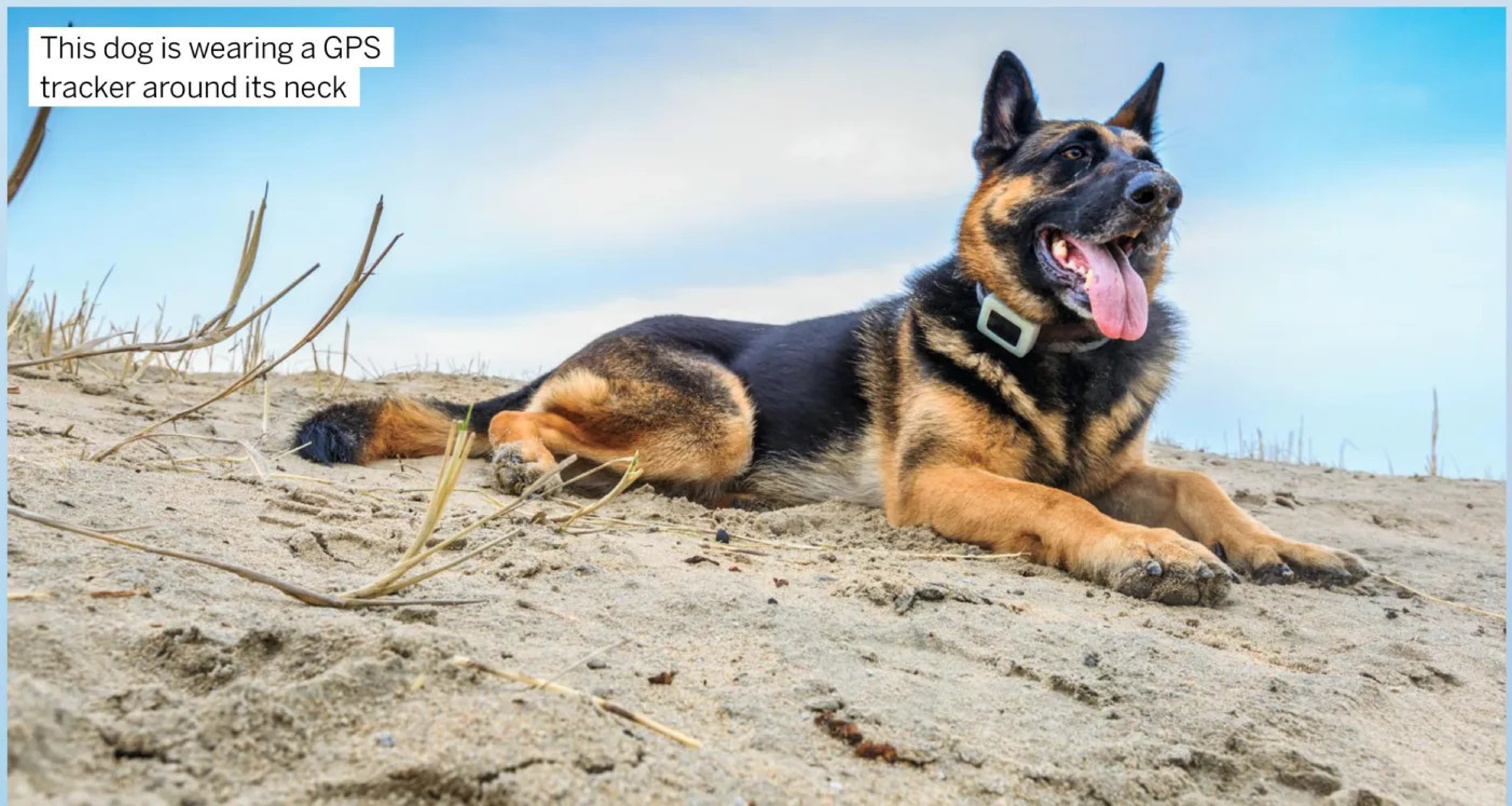
Small microchips implanted under a pet's skin can be scanned to display digital information about an animal and its owner

No matter how much an owner adores their pet and takes precautions to keep them safe, it's still very common for animals to go missing. When this happens, it can be distressing for both pet and owner. Some of the main reasons for a pet getting lost include fear or anxiety, curiosity, hunting and mating instincts.

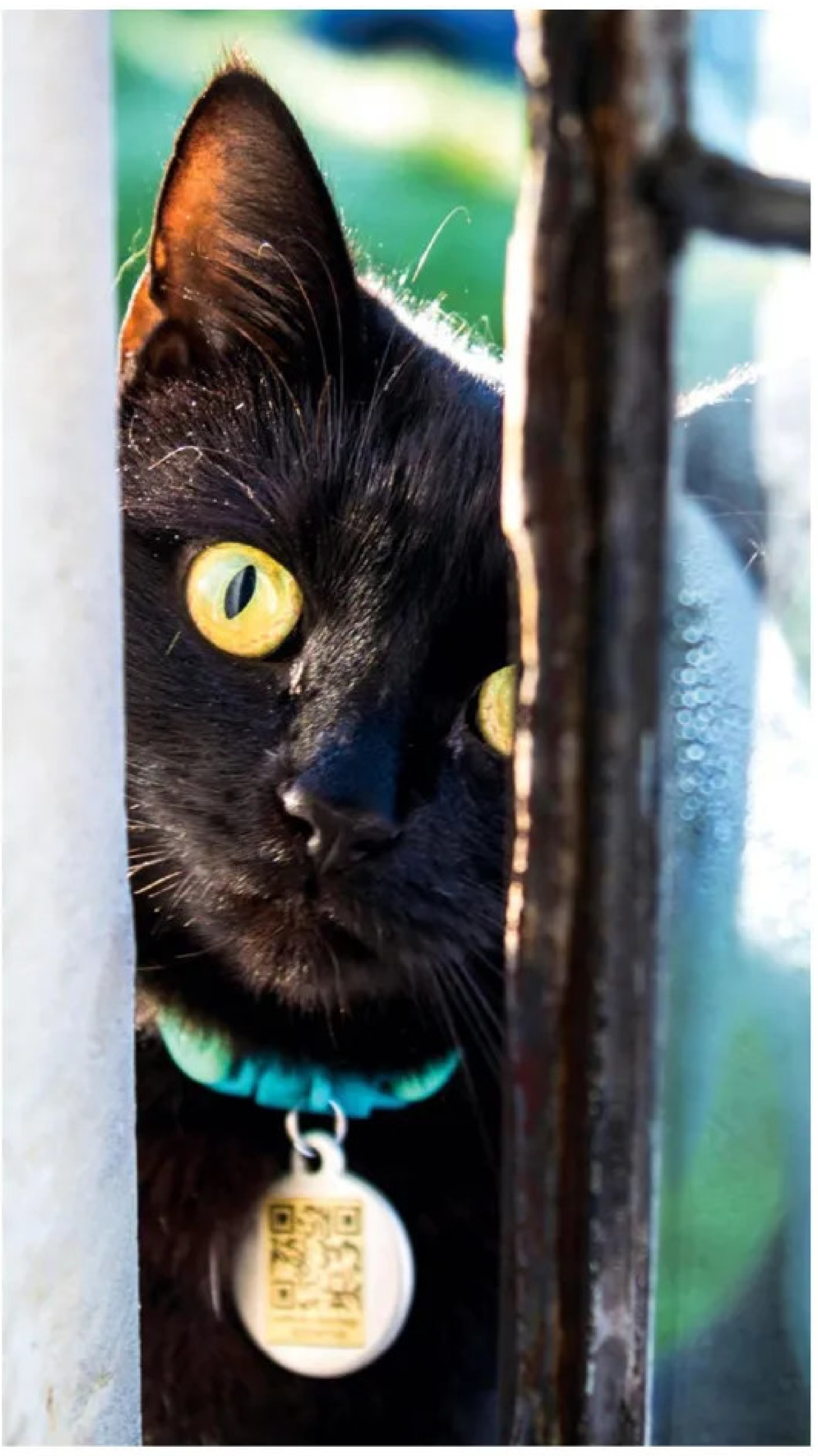
An owner only has to look away for a short time before completely losing track of their pet. Even if they spot them chasing something into the distance, dogs are often much faster than their owners, leaving them helpless. Meanwhile, cats, which don't require supervision and typically do their own thing, may leave an area they know well and struggle to return home.

Pet identification (ID) tags are worn by domestic animals to reunite lost pets with their owners. These tags display contact information and other important details about the animal. Without these, if a stranger finds a wandering animal, they have no way of knowing whether it's a loved and sought-after pet or a stray.

Keeping your pet's name and your contact information secured to your pet's collar enables others to inform you of your animal's whereabouts. But for those wanting to take a more active role in the search, tracking tags prevent owners from having to helplessly wait for news. These smart tags vary in range, but some can provide digital information about an animal's whereabouts and live tracking details as soon as a pet is lost.



This dog is wearing a GPS tracker around its neck



QR stands for 'quick response'

DIGITAL PROFILE

Some pet collars display a QR code instead of written information. These need to be scanned by a smartphone camera. Today many people carry their phones with them everywhere, so reporting sightings of animals that appear lost is quicker and easier than ever. Using QR codes means that more details about a pet – such as contact details, medical information and photographs – can be stored in a small space on the ID tag. As long as the person who finds the missing animal has a smartphone and access to the internet, when they scan the QR code, they will get instant access to this helpful information.

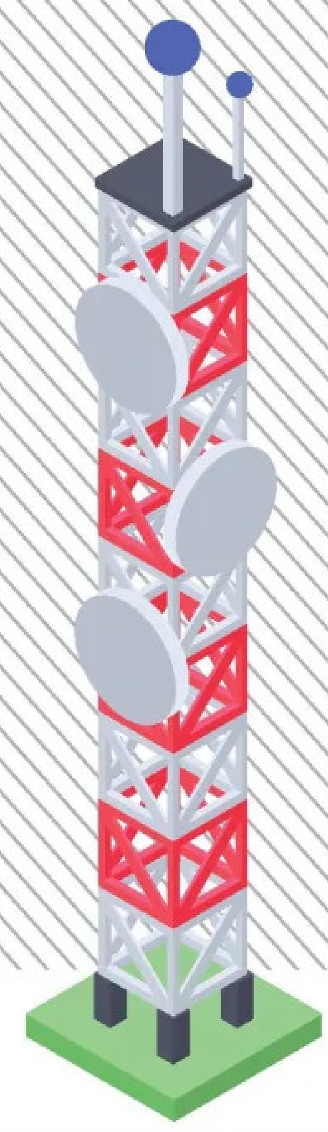
When the collar tag is scanned, the phone screen will display the animal's profile. This can store multiple emergency contact numbers in one place to ensure that the person who has found your pet will be able to get into contact with someone. Digital tags are also more flexible, as owners can change their details online. This feature means details can also be temporarily changed – to a pet sitter's, for example – when the owners are elsewhere. Without this flexibility, a lost or broken phone could reduce the chances of an owner seeing their pet again.

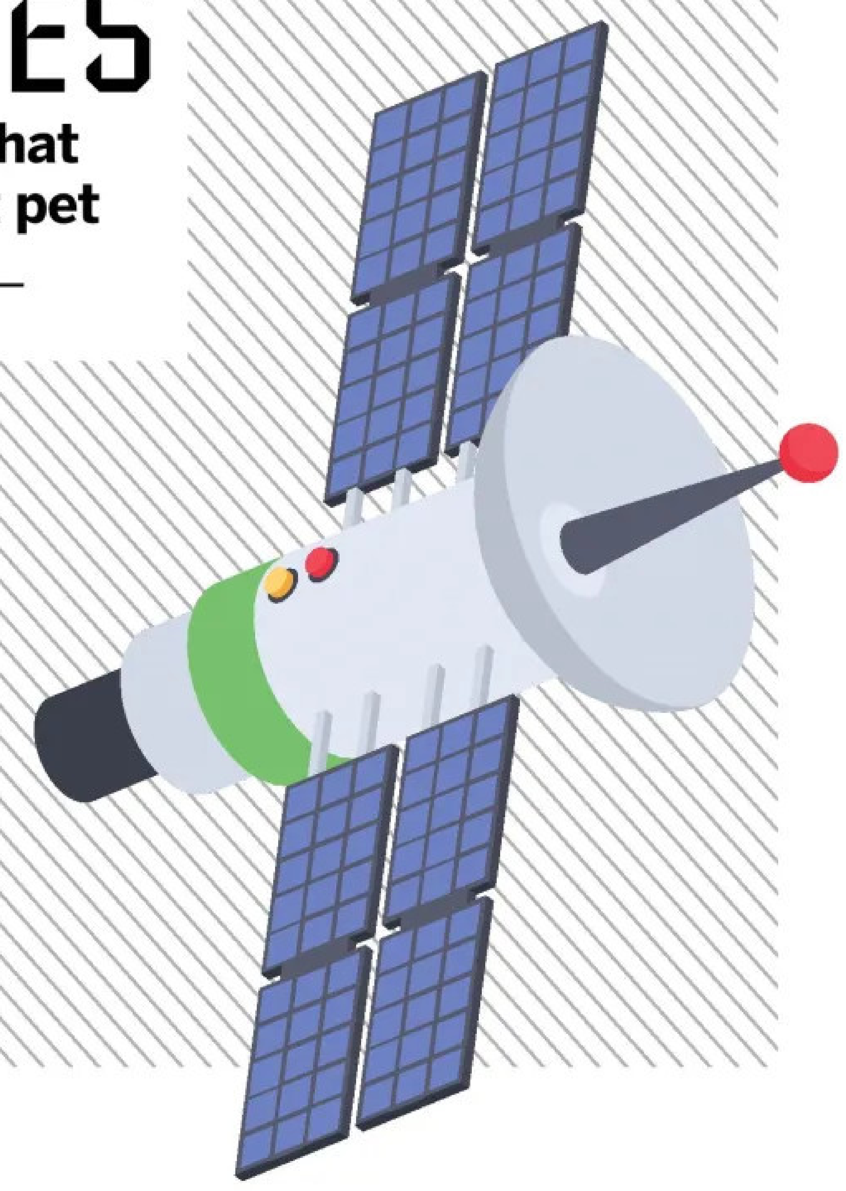
Did you know?

12 to 18 per cent of cats go missing at least once in a five-year period

TRACKER TYPES

There are three main systems that can be used to track down a lost pet





RADIO

Radio frequencies can be used to locate a missing pet. Signals are released from the animal's collar and picked up by the owner's transmitter. On the screen, the direction and distance are displayed. These trackers are relatively bulky, and so can't be used easily on small animals. They are used across short distances and require the owner to be able to travel to their pet.

CELLULAR

These use mobile phone masts to retrieve an animal's location. Cellular trackers are most beneficial in built-up areas with good mobile phone signals. They are accurate when a pet is lost within a few street blocks. As this uses mobile data, these trackers usually have an additional monthly cost.

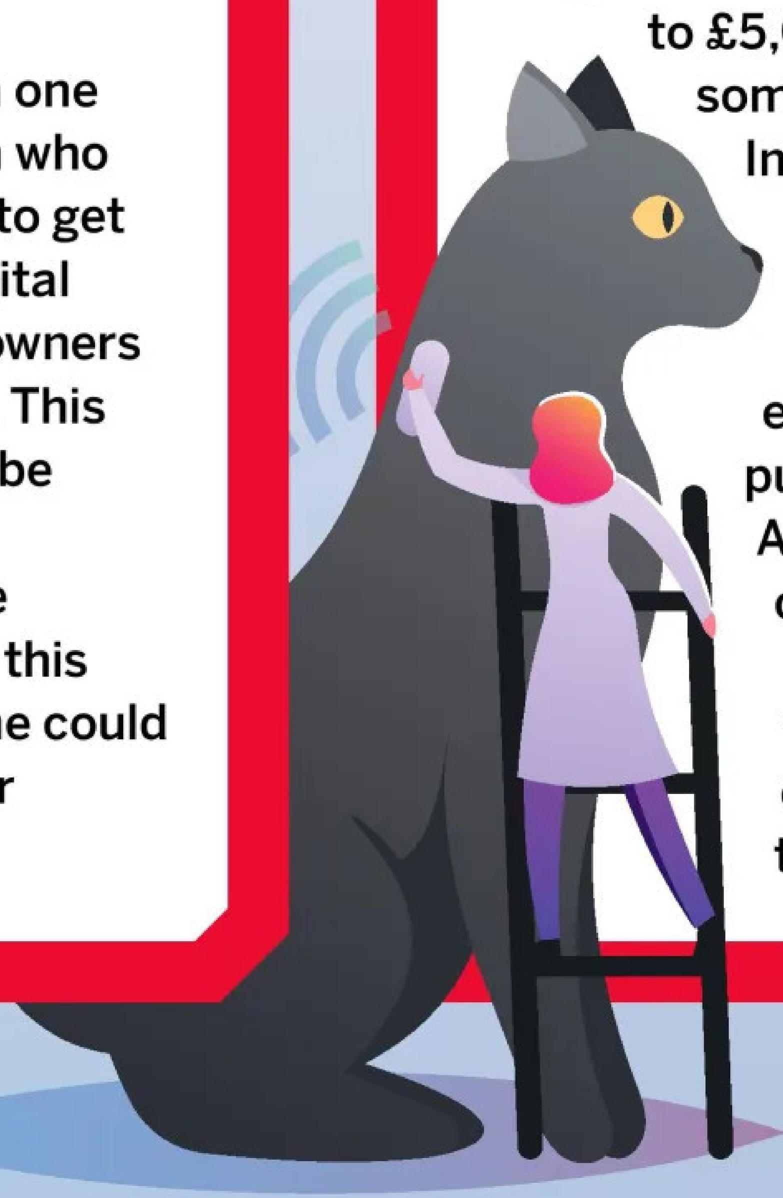
GPS

Using satellites to locate an animal's whereabouts, GPS trackers can show owners live tracking data on a digital map. For as long as a pet is wearing a working tracker, owners can see the location of their pet on their phone screen, even from the other side of the world.

DO ALL DOGS NEED TAGS?

It's illegal in many countries, such as the UK, US, Canada and Australia, for dogs to be walked in public without an ID tag on their collar. In the UK these tags must include at least a name and address, otherwise dog owners can receive a fine of up to £5,000 ($6,550). There are some exceptions to this law. In UK legislation, this includes dogs used for sport, to control cattle and sheep, for emergency or rescue purposes and guide dogs. All dog owners should check the law in their local area, because these laws can vary by country or regions of the same country.

Guide dogs don't always require ID tags, but many owners choose to take this precaution



WHAT IS A FIREWALL?

Discover how your computer filters out threats while allowing you access to everything you want to look at online

You can use a separate computer or buy a dedicated device to use as a physical firewall

The internet connects you to the world. You can use it to communicate with 4.9 billion people worldwide, accessing more knowledge than at any other time in history. The downside is that everybody also has access to you. This includes hackers and viruses that want to steal your data, take control of your computer or even destroy it. To stop this from happening, a firewall controls the data flowing between your computer and the internet. Think of this as a border guard checking your passport when you go on holiday. A firewall inspects data to make sure it has the right permissions. If it does, it can pass through. If it doesn't, it's instantly blocked.

A firewall works at your computer's ports. When we're talking about computer networking, a port isn't the same as a jack or socket. It's a virtual entry point where your computer exchanges information with other networks. Every computer has lots of ports, each of which handles different kinds of data. For instance, emails often go to port 25, while web pages go to port 80 – even though they both come through the same internet connection.

When a firewall checks if data can enter your network, it'll read a message that comes with it called 'metadata'. This will list a string of numbers indicating where the data has come from, known as 'the source address'; where it's going, the 'destination address', or your PC, and over which port. Whether the data has permission will all depend on a set of rules known as a protocol, which a computer's owner or an IT manager can adjust any way they want. As well as restricting what types of files you can download onto your computer, these rules can be set to prevent you – or any other particular user – from uploading certain files to the internet.

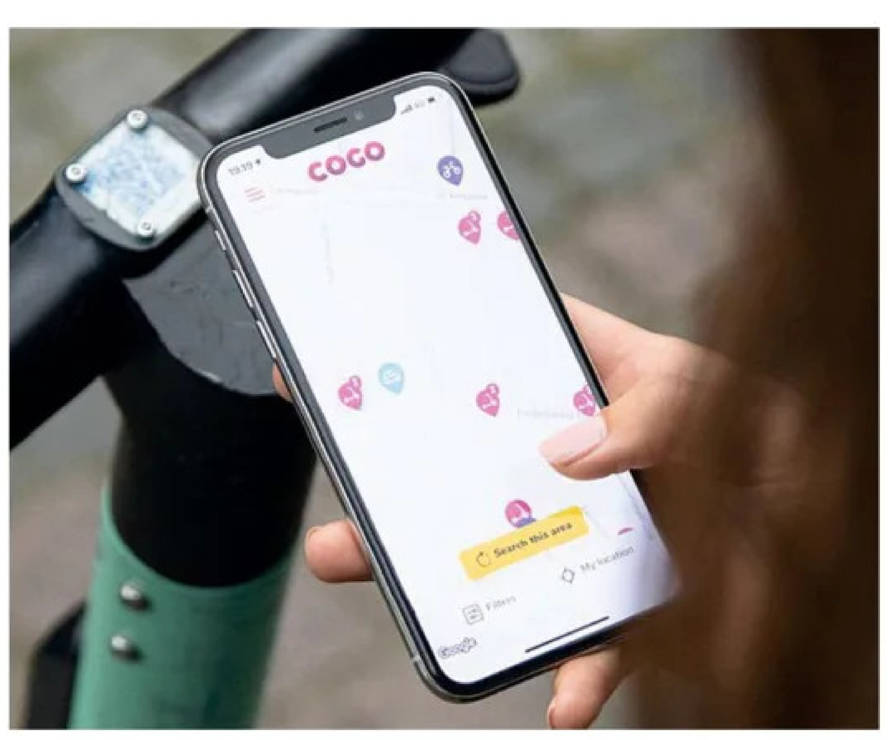
Your firewall is likely installed as a program on your computer. But there are also hardware firewalls that plug in between your computer and internet router. However, hardware firewalls still rely on software to monitor ports, so the only real difference between firewall software and firewall hardware is that one filters data on individual computers, while the other does it for whole computer networks. If you're extra concerned about your cybersecurity, you can use both software and hardware firewalls.

Did you know?

The first commercial firewall was DEC SEAL

PACKET CHECKING

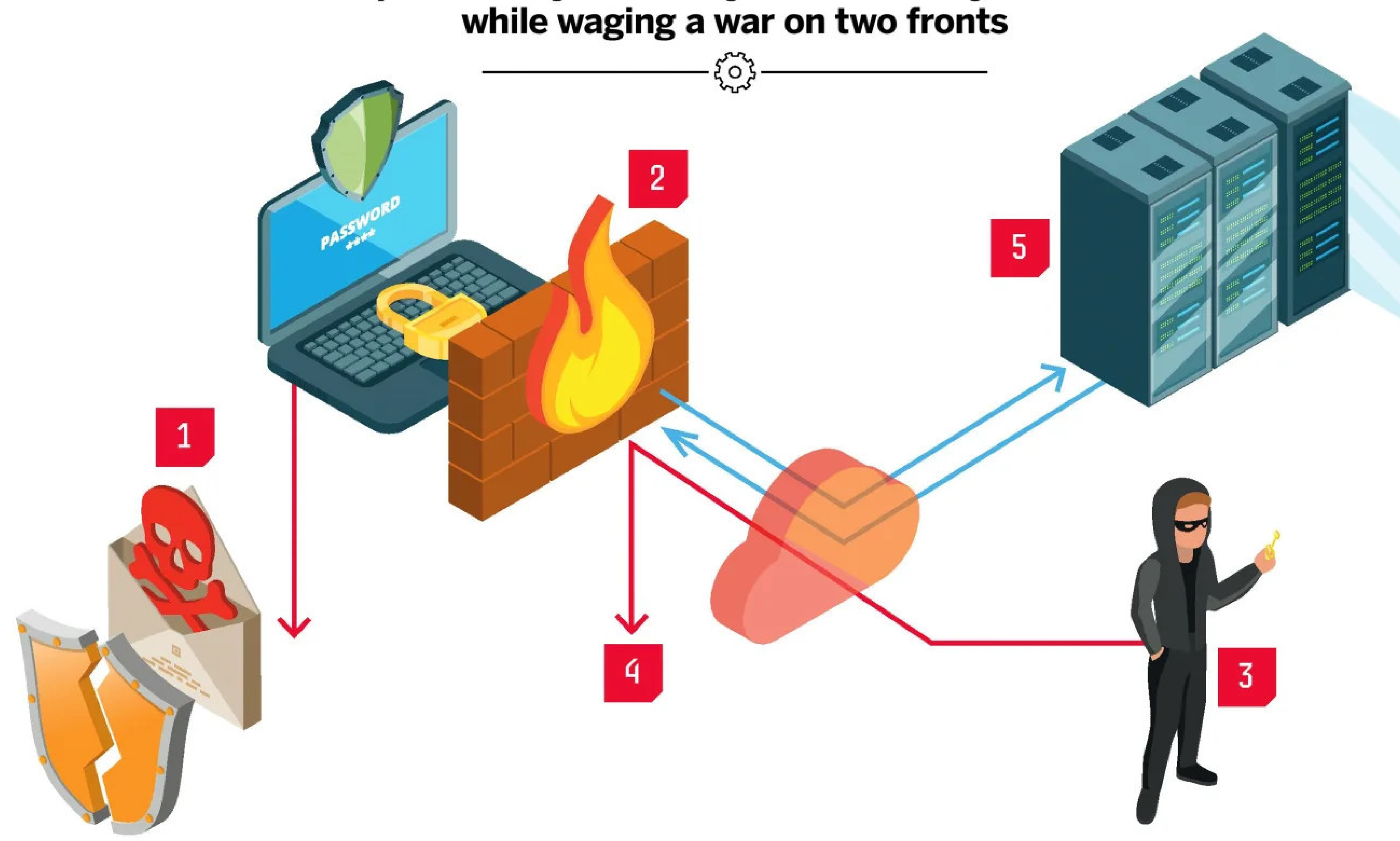
A video file isn't sent from YouTube to your computer as a single file. It's broken down into smaller pieces called 'data packets', which reassemble once you receive them. Packet-filtering firewalls check each data packet to make sure it has permission to pass through your network. Threats have become a lot more sophisticated, so new types of firewalls have emerged. Stateful packet inspection firewalls don't just assess each packet, also making sure they all come from the same network connection.



The rise of apps for smartphones has forced firewalls to get smarter too

HOW A PERSONAL FIREWALL KEEPS YOU SAFE

This simple security tool lets you view what you want online while waging a war on two fronts



1 THE THREAT WITHIN
A program you installed on your computer tries to send your precious files to a hacker.

2 STOPPED AT THE WALL
This program isn't authorised to access the internet, so the firewall instantly blocks it.

3 EXTERNAL HACKING ATTEMPT
A hacker tries to transfer a file to your computer, which contains a virus.

4 ACCESS DENIED
From reading the metadata, the firewall can tell the file wasn't requested by your computer and rejects it.

5 PERMISSION GRANTED
Your web browser is authorised to request web pages, so the firewall allows it to access the internet.

On board the Dream Chaser

With the Space Shuttle in retirement, NASA is looking to the next generation of space planes

Sierra Nevada's Dream Chaser is a smaller, more adaptable version of the Space Shuttle and will spend much of its time going on trips to resupply the International Space Station (ISS). Unlike the Space Shuttle, Dream Chaser can fly autonomously, without a human pilot. Crewed versions will also be developed, capable of carrying seven astronauts plus cargo.

Once in space, it will be powered by twin hybrid rocket engines, which use two propellants – one solid, the other gaseous or liquid. These are mixed together and tend to be less explosive than purely solid rocket fuel when they fail. In the case of Dream Chaser, the solid propellant is a rubbery material called 'hydroxyl-terminated polybutadiene', while the gas propellant is nitrous oxide. Its engines are so powerful that, when docked with the ISS, Dream Chaser can raise the Space Station's altitude, useful for avoiding pieces of space debris.

Dream Chaser is a fairly modest spacecraft in terms of size; its wingspan is seven metres, compared to the 23.8-metre wingspan of the Space Shuttle. It will be capable of carrying over five tons of cargo into space before returning to Earth hours later, landing like an airplane on a runway.

Expected to first launch some time in 2021, there will be two versions: the Dream Chaser Cargo System sports folding wings to allow it to fit into the cargo fairing rockets such as the Ariane 5, while the crewed Dream Chaser Space System will launch on an Atlas V rocket to carry astronauts to the ISS.

The Dream Chaser will be able to return from space and land like an airplane

Compared to the giant Space Shuttles, Dream Chaser is modest in size

Spacecraft design

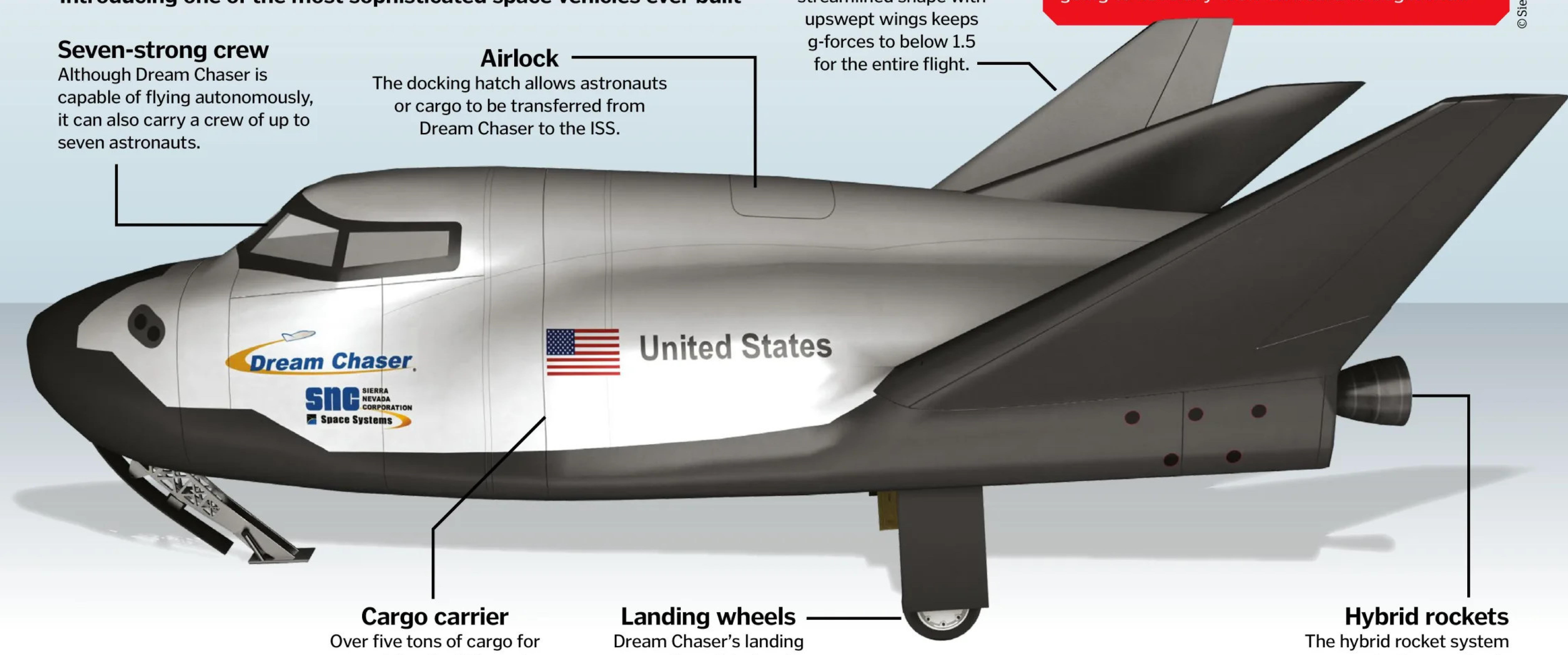
Mark Sirangelo, head of Sierra Nevada Corporation Space Systems, tells us more

"Dream Chaser is a pilot-automated space plane that has many similarities to the Space Shuttle. It is smaller in terms of overall size – it doesn't have the huge cargo compartment that the Shuttle did – but it has a similar sized pressurised crew compartment. This means that it can still take up the same number of astronauts (seven) and the same amount of protected cargo in the pressure hold as the Shuttle.

It's a highly reusable vehicle and, presuming that there's a mission and rocket, we can launch each Dream Chaser vehicle potentially five times a year. We're planning on having a fleet so that we can fly one while we're getting the next one ready to fly again. We are expecting our first orbital flight to be in 2018 but we're probably not going to have any crew on board to begin with."

What dreams are made of

Introducing one of the most sophisticated space vehicles ever built



The Dyson Supersonic has three different nozzles, which attach magnetically for easy adjustments

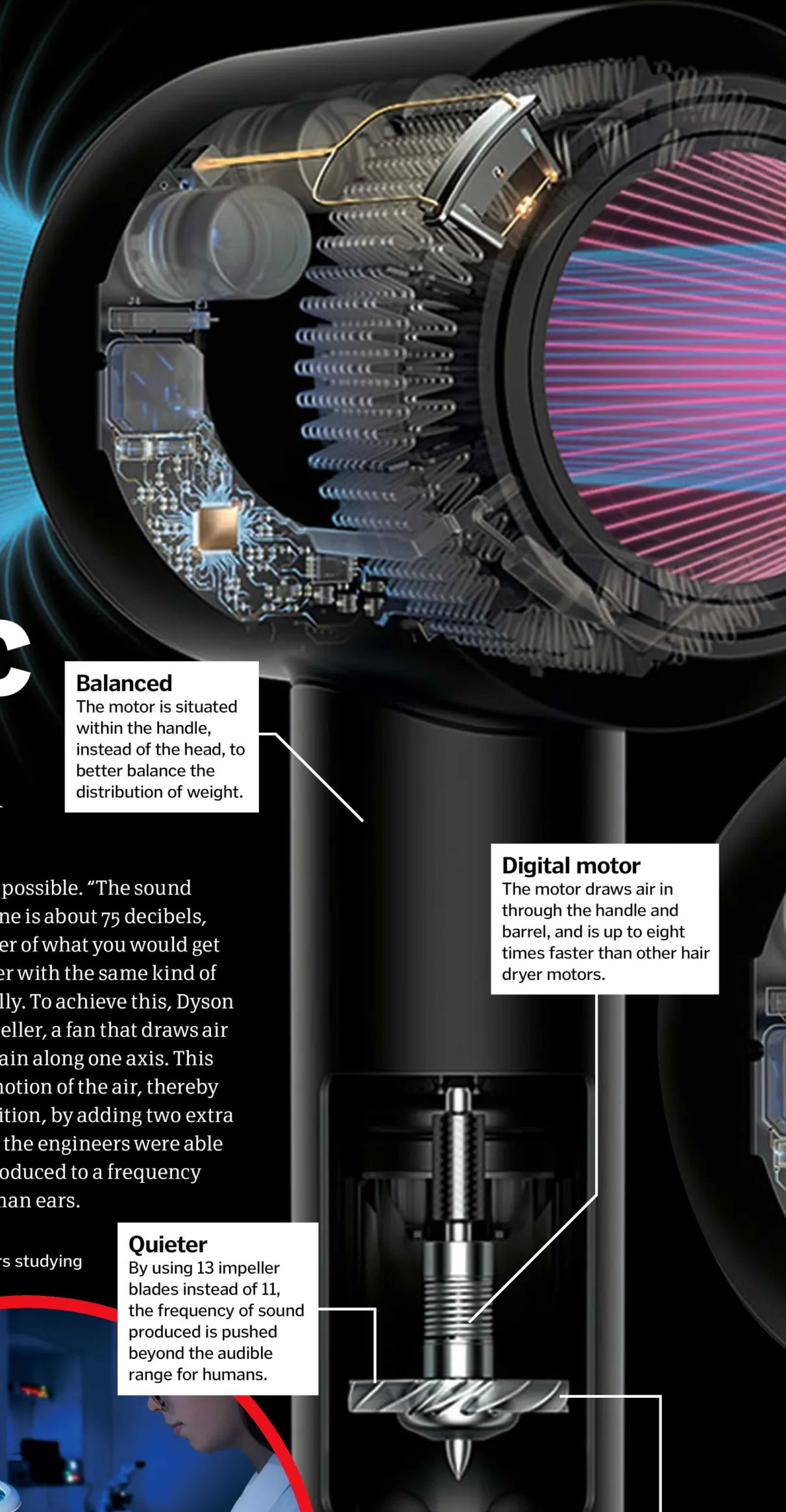
The Dyson Supersonic

From the vacuum cleaner company comes its first-ever hair dryer, designed to be quiet and lightweight

Dyson has applied its engineering know-how to reinvent the hair dryer, and the result is the Dyson Supersonic – a new type of device that is lighter, quieter and better for your hair. The company has invested £50 million ($72 million) into the development of the hair dryer, which was designed in a state-of-the-art laboratory dedicated to studying the science of hair.

"When your hair is heated above a certain temperature, it will start to change its structure in a way that can't be reversed," says Matt Kelly, a mechanical engineer at Dyson. "This happens above 150 degrees Celsius, but some hair dryers can get into the region of 200 degrees Celsius, which is far too hot." At these extreme temperatures, small holes can appear in the strands and cause light bouncing off of your hair to scatter, making it look dull. To protect your hair's natural shine, the Dyson Supersonic constantly measures the temperature of the air flowing out of the nozzle, and feeds this information to a microprocessor. This then controls the level of heat so that it never exceeds a certain limit.

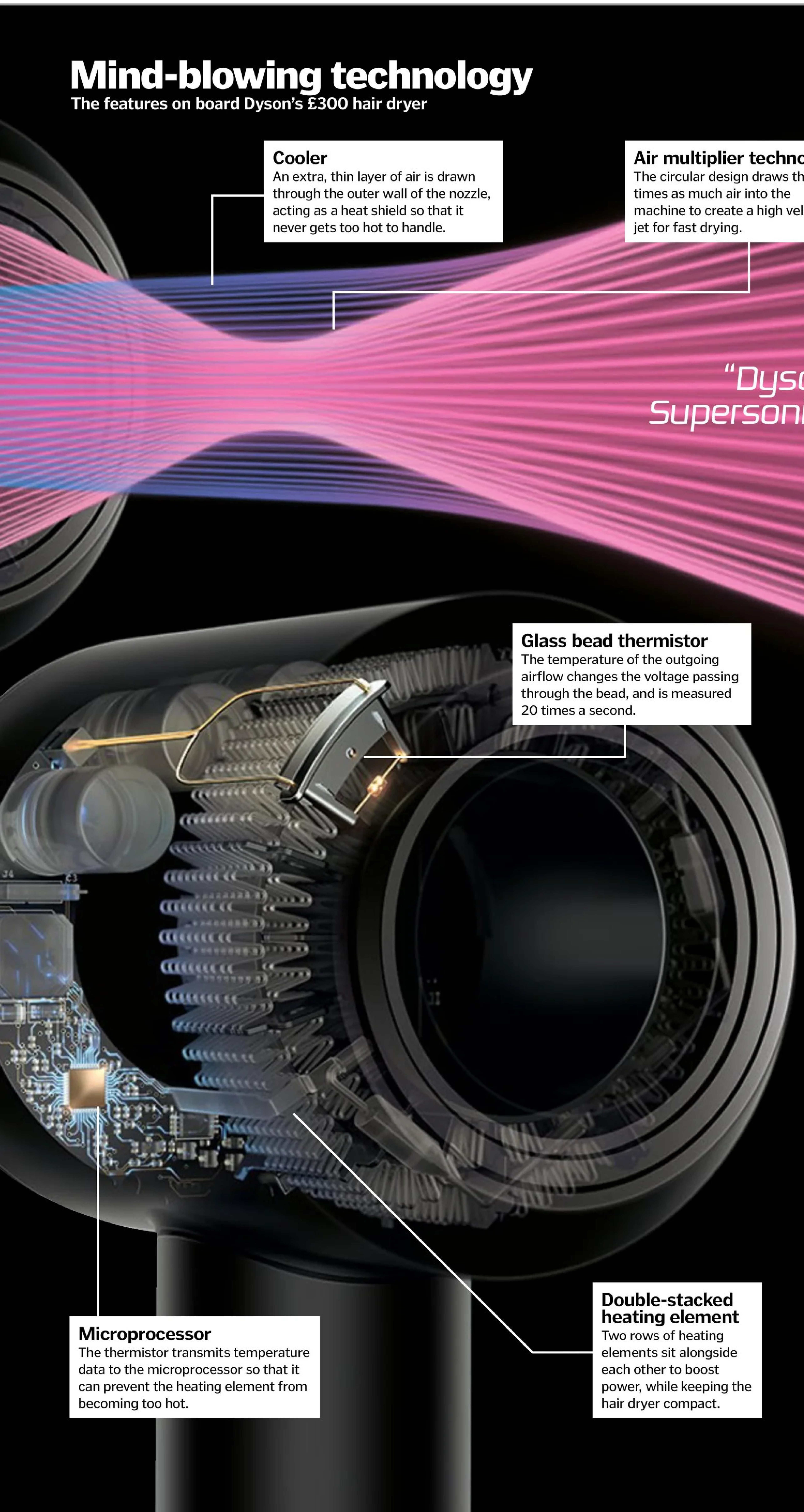
The other major problem with conventional hair dryers is the noise they produce, so Dyson set out to make the Supersonic as quiet as possible. "The sound power from the machine is about 75 decibels, which is about a quarter of what you would get from another hair dryer with the same kind of performance," says Kelly. To achieve this, Dyson used an axial flow impeller, a fan that draws air in and pushes it out again along one axis. This reduces the swirling motion of the air, thereby reducing noise. In addition, by adding two extra blades to the impeller, the engineers were able to push the sound it produced to a frequency that's inaudible to human ears.



Dyson's hair lab spent years studying the science of shiny locks

Mind-blowing technology

The features on board Dyson's £300 hair dryer

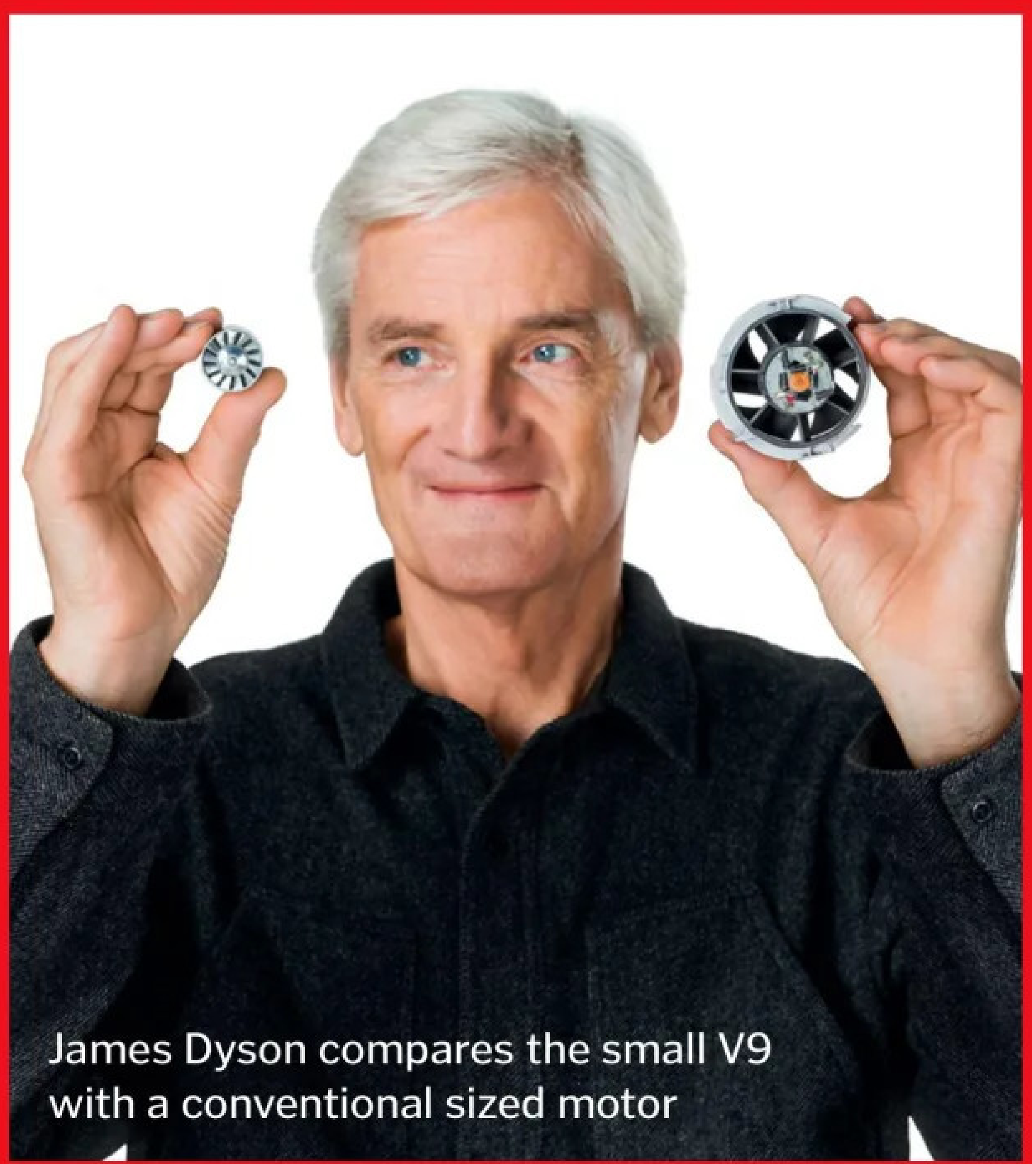


"Dyson set out to make the Supersonic as quiet as possible"

Motor magic

The reason most hair dryers are bulky and uncomfortable to use for long periods of time is because the motor is located in the head, making them top heavy. To solve this problem, Dyson has created its smallest, lightest digital motor yet, the V9. Created by a team of more than 15 motor engineers, the V9 is just 27 millimetres wide, and spins 110,000 times per minute, allowing it to draw in more air for a more powerful performance.

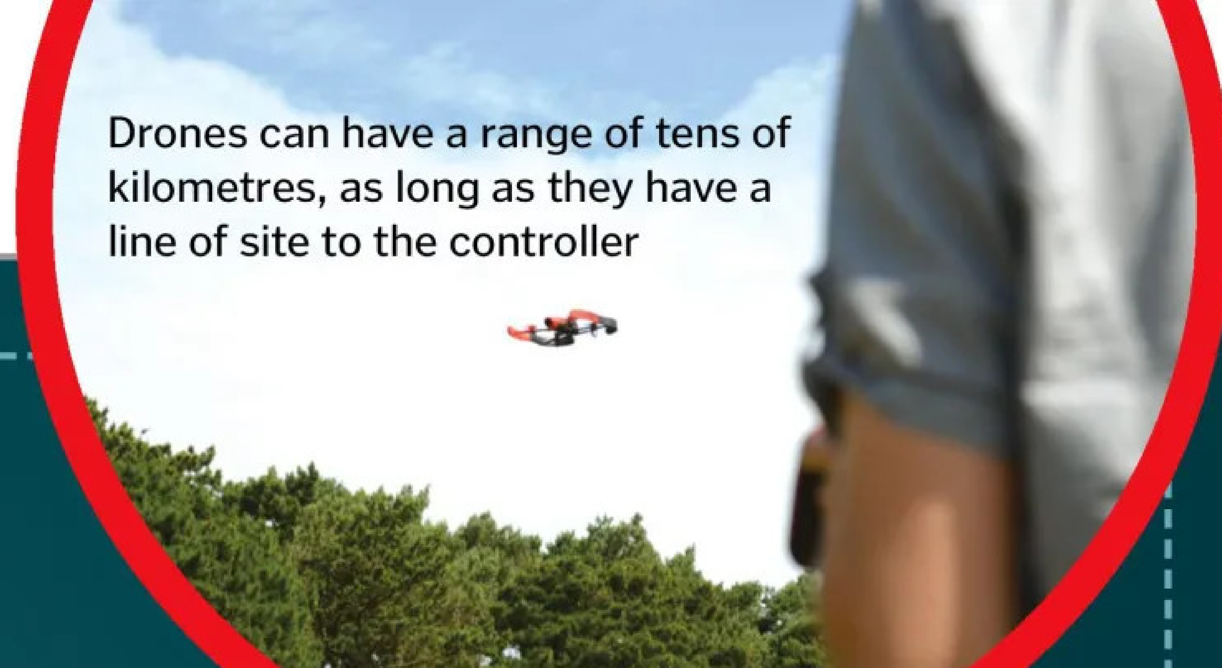
Its small size means that it can be fitted inside the handle of the hair dryer, bringing the centre of mass closer to your hand for a more balanced hold. This also means that Dyson has been able to make the barrel of the device shorter, enabling you to hold it closer to your head, putting less strain on your arm.



James Dyson compares the small V9 with a conventional sized motor

SUPER DRONES

MEET THE ROBOTS EXPLORING ALIEN WORLDS, UNCOVERING ANCIENT SECRETS & HELPING HUMANITY



Drones can have a range of tens of kilometres, as long as they have a line of site to the controller

DIGGING NOW STARTS IN THE SKIES

The Indiana Drones pushing archaeology into a new era

Archaeologists have used aerial photography to map dig sites for years. But where before they needed balloons, kites and airplanes to capture data, drones now make the process faster, cheaper and guarantee an image quality that couldn't be achieved before.

Drones can be piloted manually, or pre-programmed with a flight path over an area of archaeological interest, taking photos at regular intervals, and computer software can then piece these photos together to create an incredibly accurate topographical view of the area. The process is called photogrammetry, and it's changing the way archaeologists work.

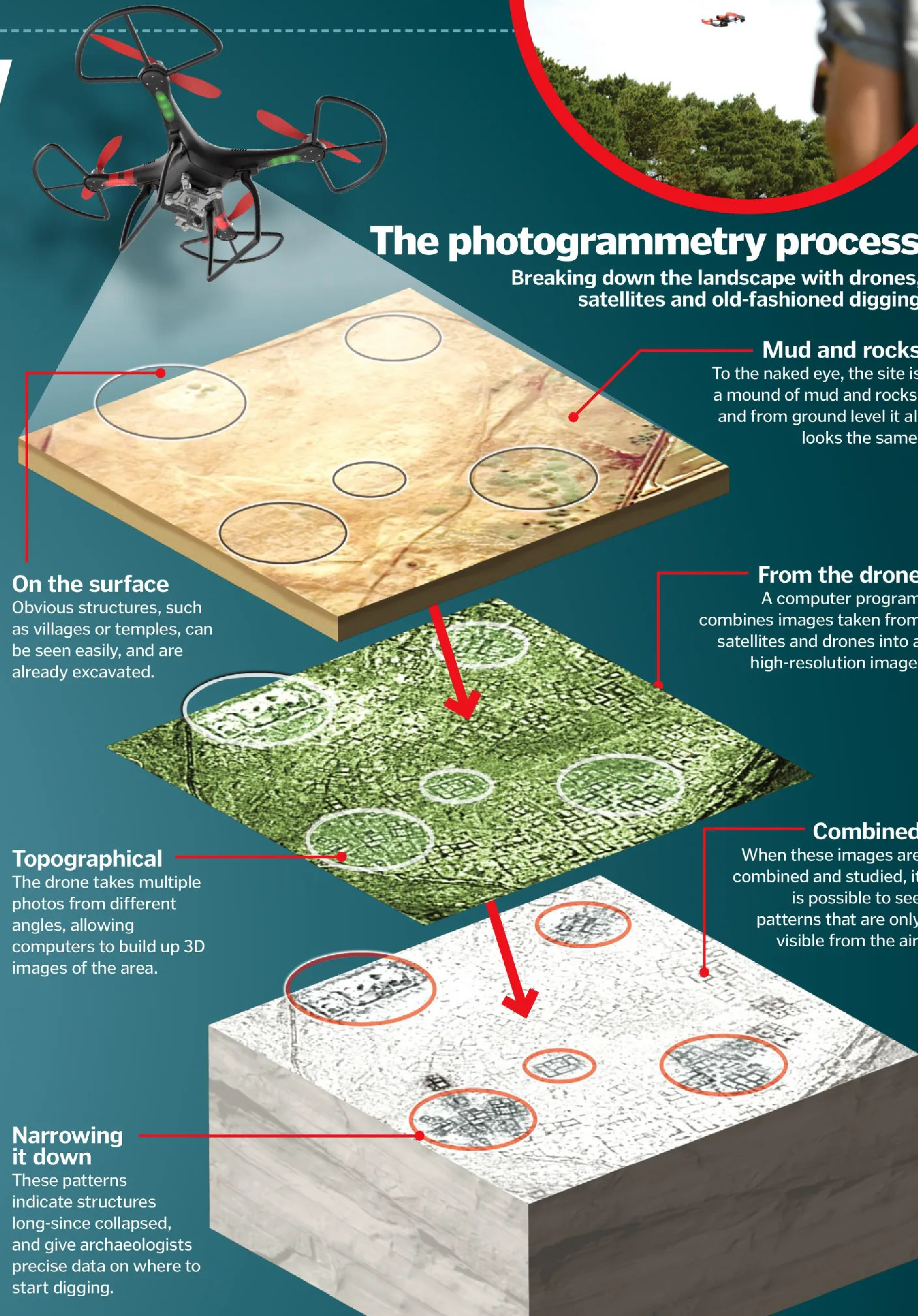
This detailed, three-dimensional map can be manipulated on-screen, allowing archaeologists to see tiny details just centimetres across without having even set foot near the site. Combined with satellite imagery, the scientists can extrapolate a great deal of data from these photos. Scholars can better understand how ancient communities were organised, and can even pick out rock carvings from the sky. Of course, the drones can only tell archaeologists so much – once they have acquired and analysed the data collected from the drones, they will still travel to the site and begin excavating the area. The benefit, however, is that they can more accurately choose the best places to dig before they get to the site, and make discoveries more quickly thanks to the information captured by the drone.

But drones aren't only used for picking excavation sites. They are also providing archaeologists with ongoing information that should help to curtail looting from these important historical sites. In remote areas of countries like Jordan, looting is a real problem, but it can be difficult for governments to track what is being taken and how much damage the looters are doing.

However, drones are able to survey an entire area in a matter of days, and at a resolution of one to two centimetres per pixel. This allows archaeologists to track the minute changes to the landscape, even when the looted area is larger than 50,000 square metres. Data is gathered over a number of years to determine just how much of a problem looting is in specific areas, which gives scholars and governments a better idea of the size of the problem.

The photogrammetry process

Breaking down the landscape with drones, satellites and old-fashioned digging



New discoveries in Petra

It seems strange that archaeologists are still finding new structures in a dig site as well-known as Petra, in Jordan, but thanks to the use of drones it is now possible for scholars to locate areas that previously remained hidden. In early 2016, archaeologists Sarah Parcak and Christopher Tuttle combined drone footage and satellite imagery to identify faint footprints of ancient buildings, which led to the discovery of a huge monument just 800 metres south of the ancient city's centre. This structure is roughly the size of two Olympic-sized swimming pools, but remained undiscovered for years.

Petra is already a huge archaeological wonder, but drones show there is more to find

DRONES IN CONSERVATION

Helping to save the natural world with flying machines

White rhino populations have increased in recent years, thanks to conservation work using drones

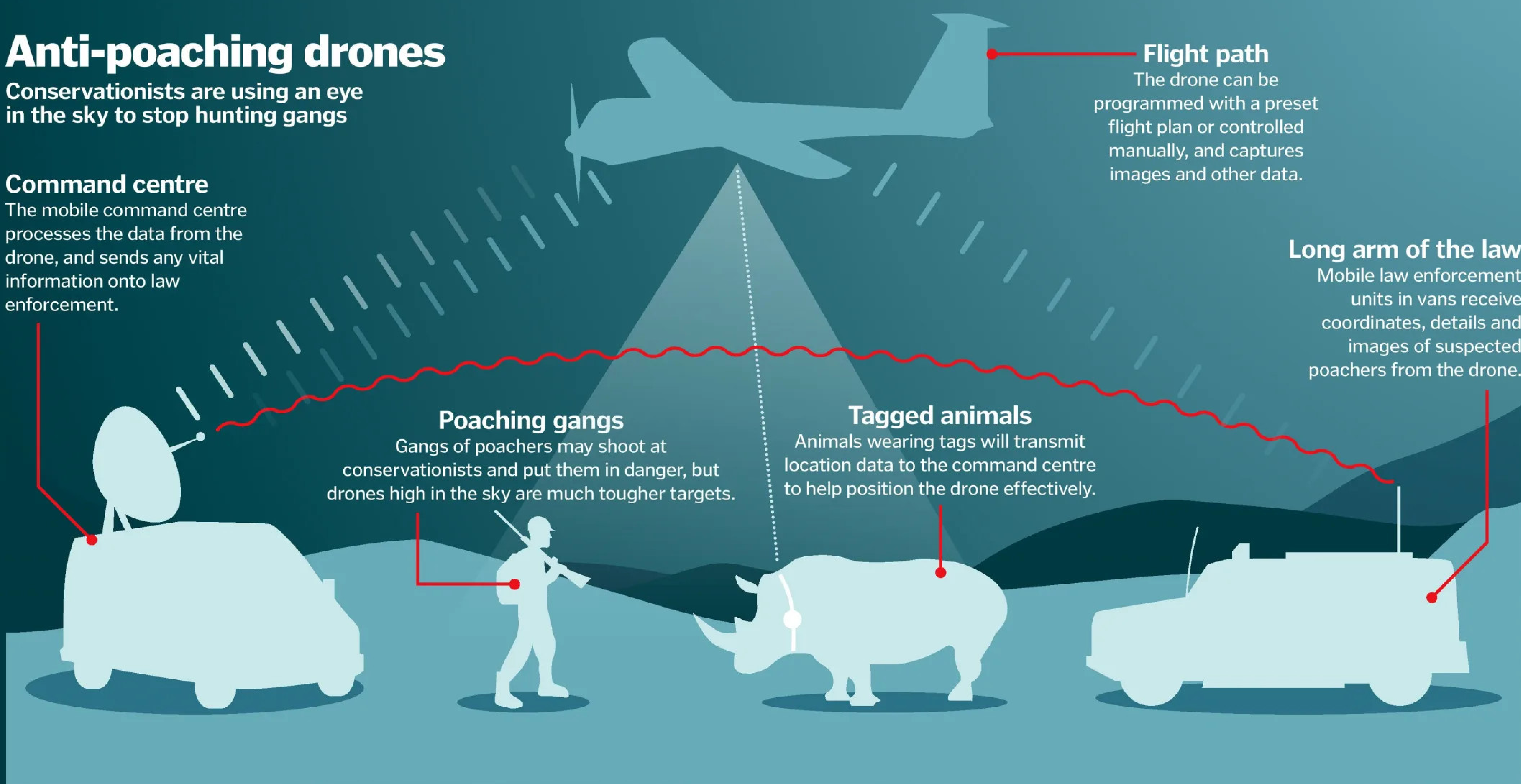
The white rhinoceros holds Near Threatened status due to devastatingly aggressive poaching, while the mountain gorilla and the orangutan are both classed as Endangered due to expansive deforestation and the broadening reach of humans. Without intervention, there is no doubt that these incredible creatures will be extinct before the end of the century. But scientists and conservationists are working hard to stop this terrible deterioration, and they're doing it with some pretty cool drone tech.

One of the biggest dangers to endangered animals in the modern day comes from poaching, which claims the lives of hundreds of white rhinos every year. However, while rangers and regular patrols can help in dissuading poachers from certain areas, they are often well-armed and unafraid to fire upon those hoping to protect the rhinos. This is where drones come in – if conservation researchers work in these areas there would be a real danger of coming into contact with the poachers, and their lives might well be at risk. By having drones collect data, movement patterns and numbers of animals, biologists are able to avoid many of these risks.

But drones aren't only used to collect information in dangerous areas – they can also be sent into the skies above difficult-to-reach areas to get data that would otherwise be tough to collect. Mountain gorillas and orangutans are usually found in dense jungle, and organising an expedition can be expensive, time-consuming, and require a great deal of bodies and planning. Instead, researches can send drones over the forest canopy to capture data about the habitat of the animals, and perhaps even capture high-quality images of an ape. This information can be incredibly valuable when it comes to an on-foot expedition, as researchers can get up-to-date information on the whereabouts of the animals as they move. In this situation, human-led surveys will still offer better results, but drones can play a huge part in the conservation process.

The downside currently is the cost, which can run into tens, if not thousands, of dollars. However, drone tech is still becoming a more feasible option in the fight against extinction.

Organisations like the WWF are using drones around the world to capture valuable data



Anti-drone technology

As drones become more common, limiting their movement is more important than ever

1 DroneDefender
This gun-like device uses radio pulses to disable drones within a 400-metre radius by interrupting their communications.

2 Drone on drone
Yes, drones can be used to capture drones. In this case, a large drone snags smaller flying machines in a hanging net.

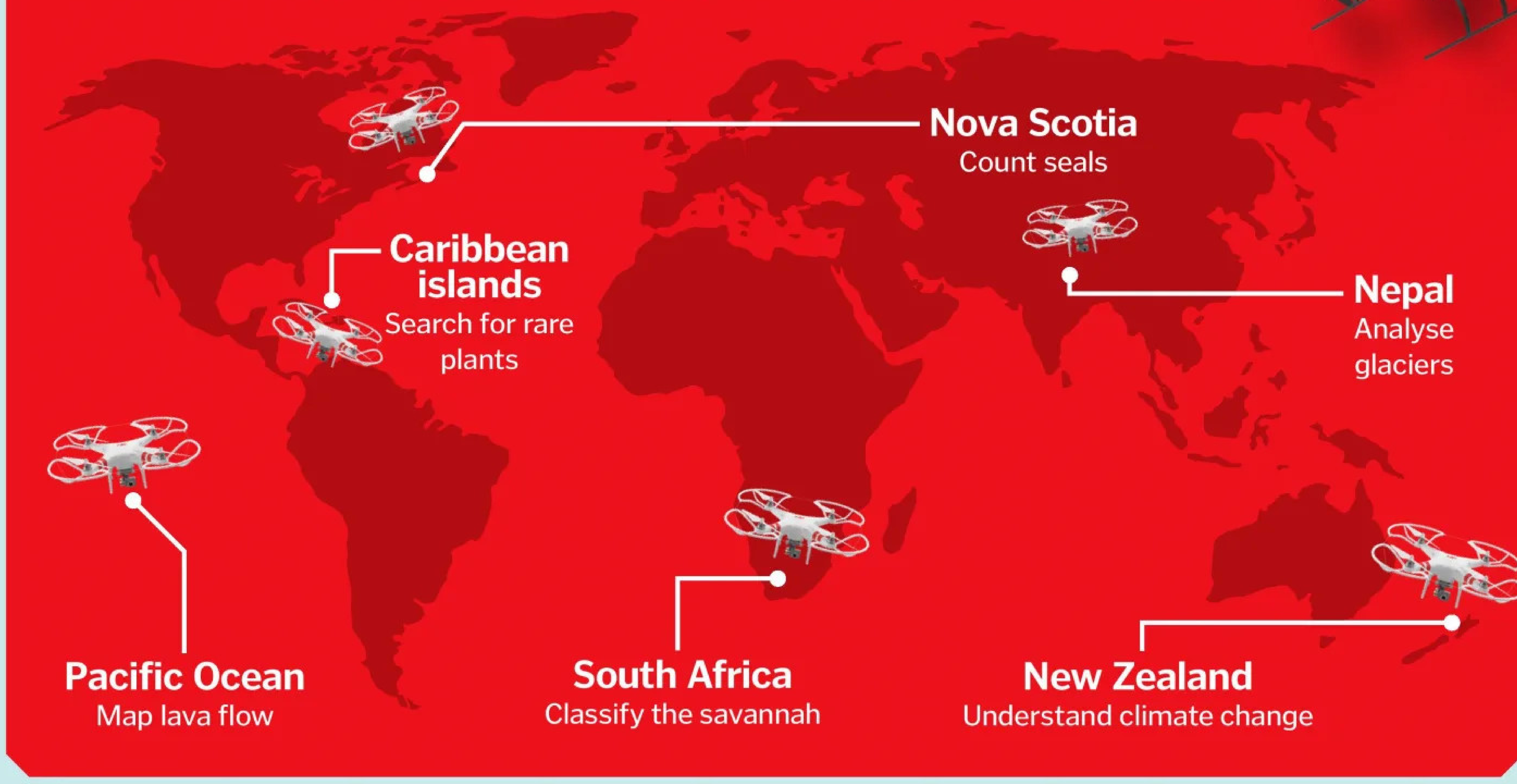
3 Boom!
Mobile weapon vehicles, armed with 50mm Bushmaster cannons, are being tested to eradicate drones in situations that may threaten soldiers.

4 Perimeter breached
Specially designed smart panels can be placed around an area, which send alerts via email if drones are detected.

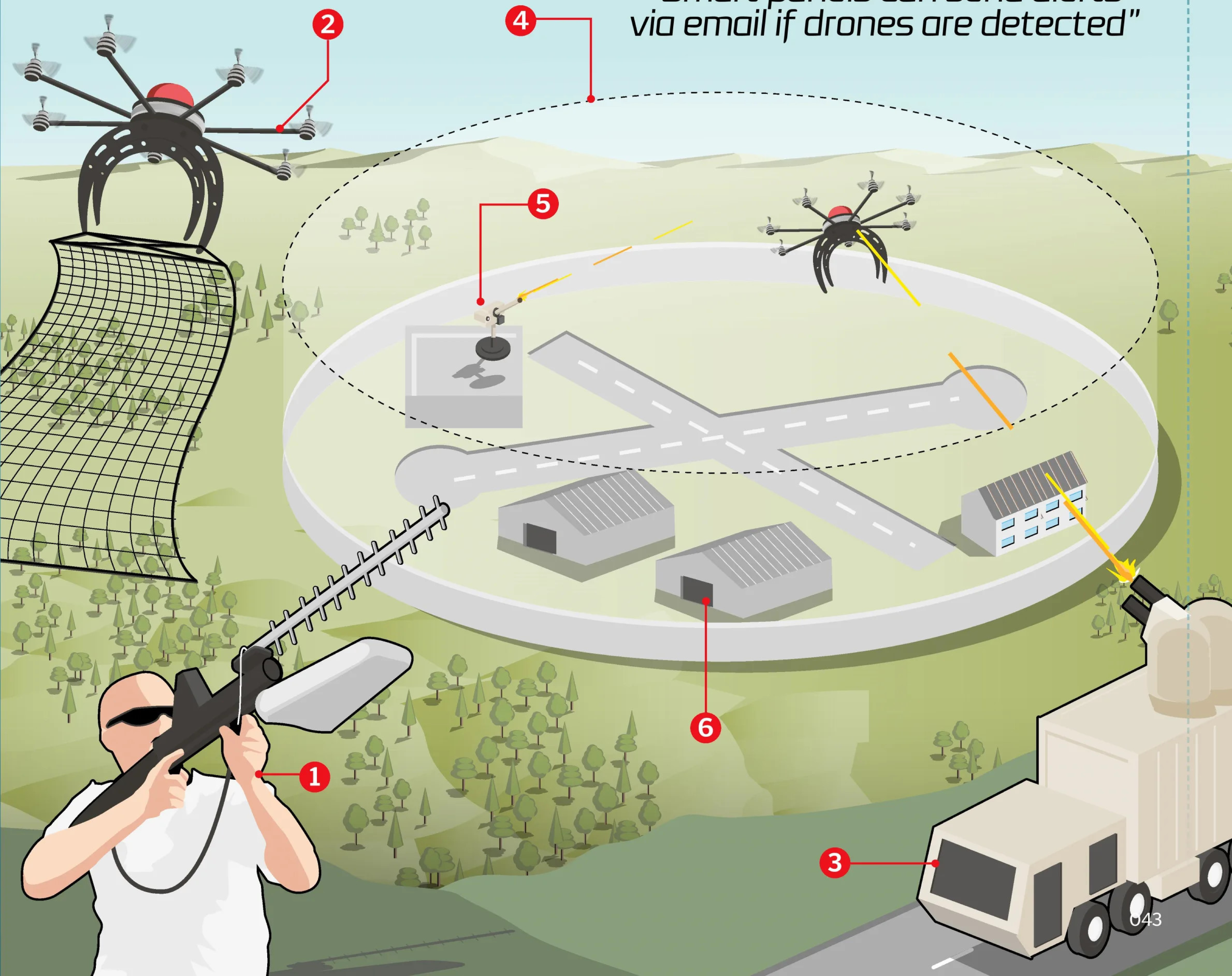
5 Gun placements
For prominent buildings, such as the White House, permanent gun placements may help to keep people safe from drone attacks.

6 Smart prison guards
Prisons are now implementing anti-drone tech to prevent prisoners receiving contraband deliveries from outside.

How drones are used worldwide

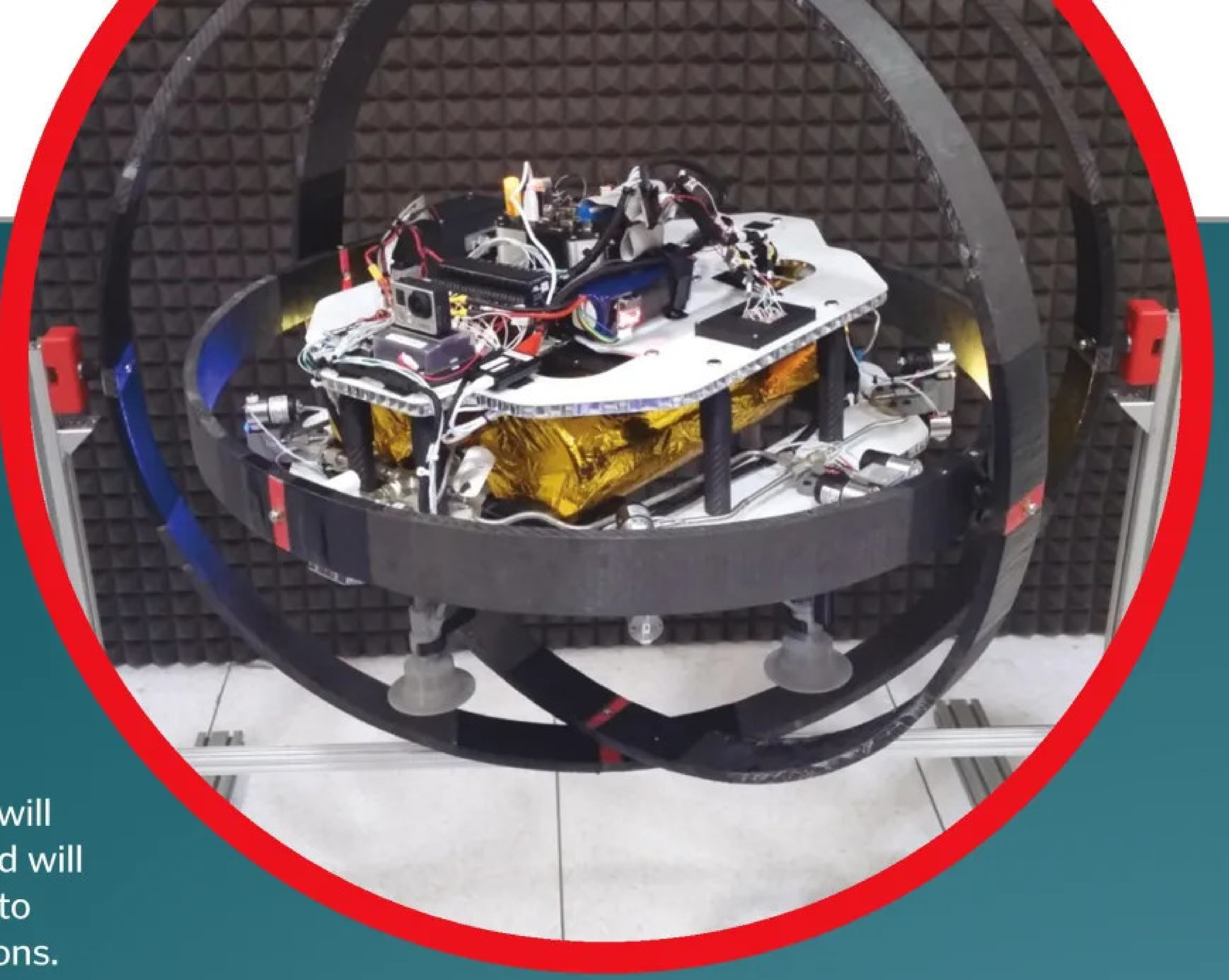


"Smart panels can send alerts via email if drones are detected"



STAR TREKKERS

How drones can be used in space exploration

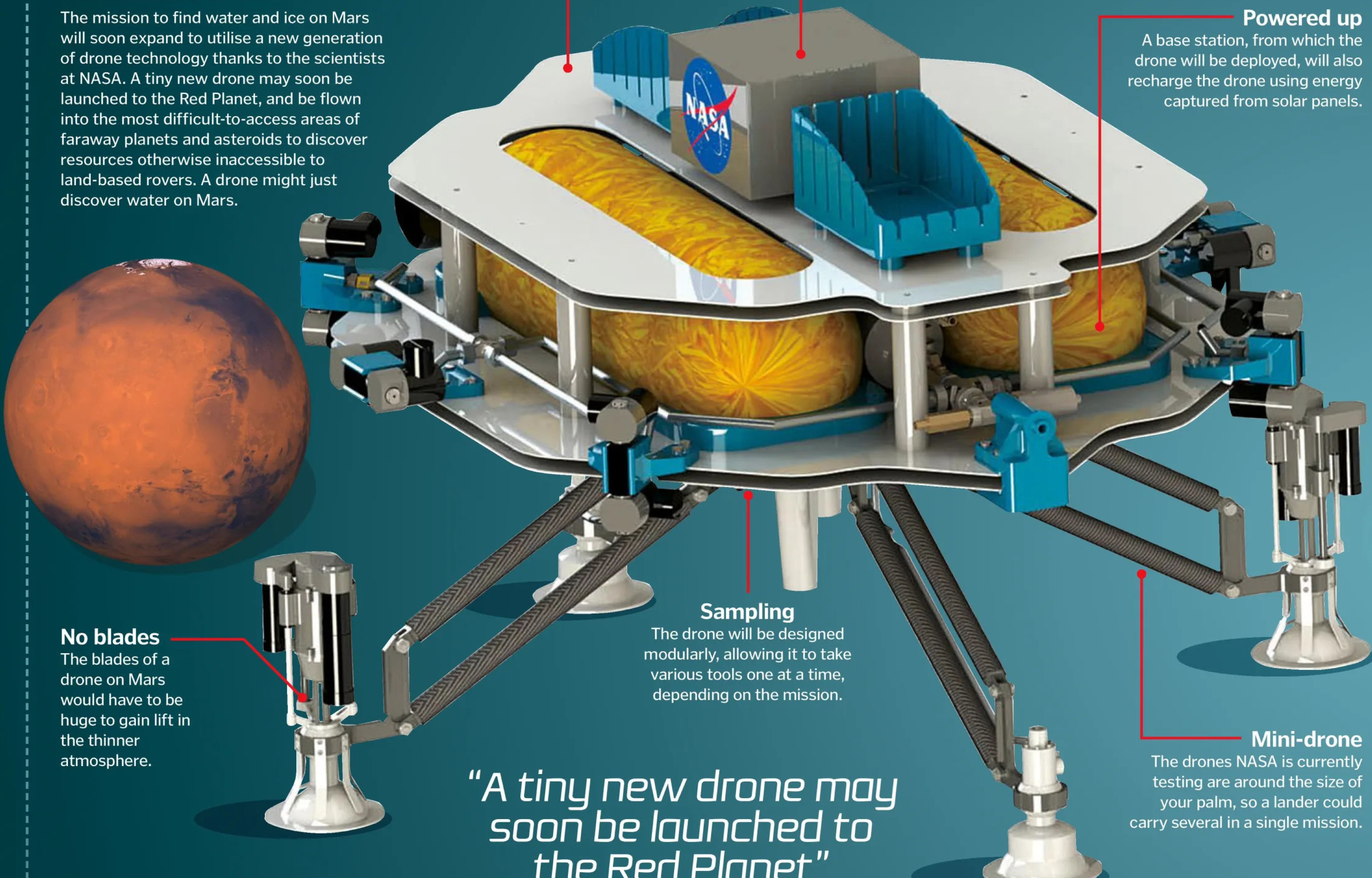


NASA's prototype drone is being tested in this gimbal to assess its low-gravity performance

Extreme Access Flyers

The next evolution of quadcopters will use fuels created on Mars

The mission to find water and ice on Mars will soon expand to utilise a new generation of drone technology thanks to the scientists at NASA. A tiny new drone may soon be launched to the Red Planet, and be flown into the most difficult-to-access areas of faraway planets and asteroids to discover resources otherwise inaccessible to land-based rovers. A drone might just discover water on Mars.



Cold-gas jets
Instead of rotors, jets will use oxygen or steam water vapour to handle the lifting and manoeuvring duties.

Navigation
The navigation system will recognise landscapes, and will be able to guide itself to pre-programmed locations.

Powered up
A base station, from which the drone will be deployed, will also recharge the drone using energy captured from solar panels.

No blades
The blades of a drone on Mars would have to be huge to gain lift in the thinner atmosphere.

Sampling
The drone will be designed modularly, allowing it to take various tools one at a time, depending on the mission.

Mini-drone
The drones NASA is currently testing are around the size of your palm, so a lander could carry several in a single mission.

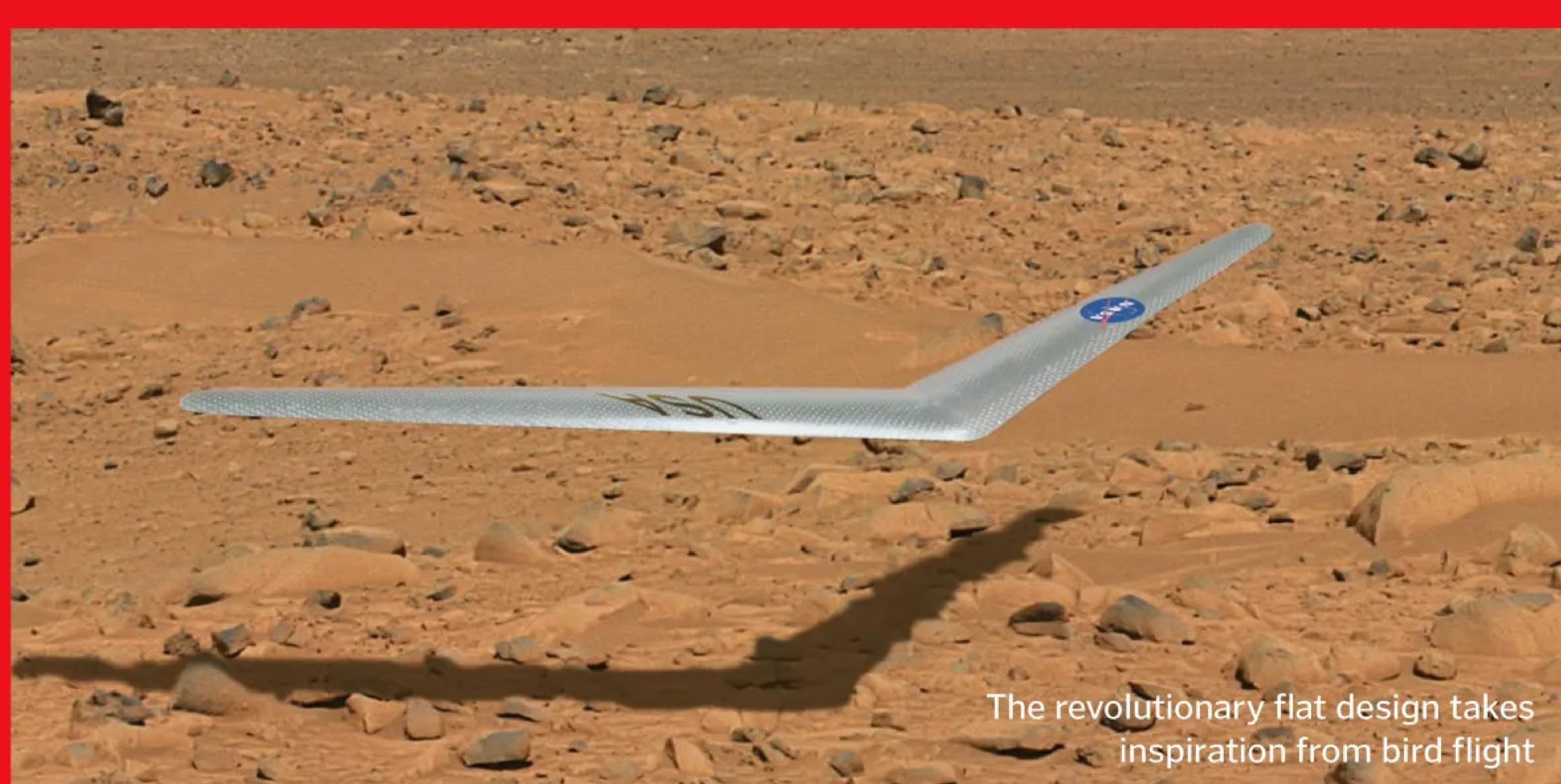
> "A tiny new drone may soon be launched to the Red Planet"

NASA's Prandtl-D

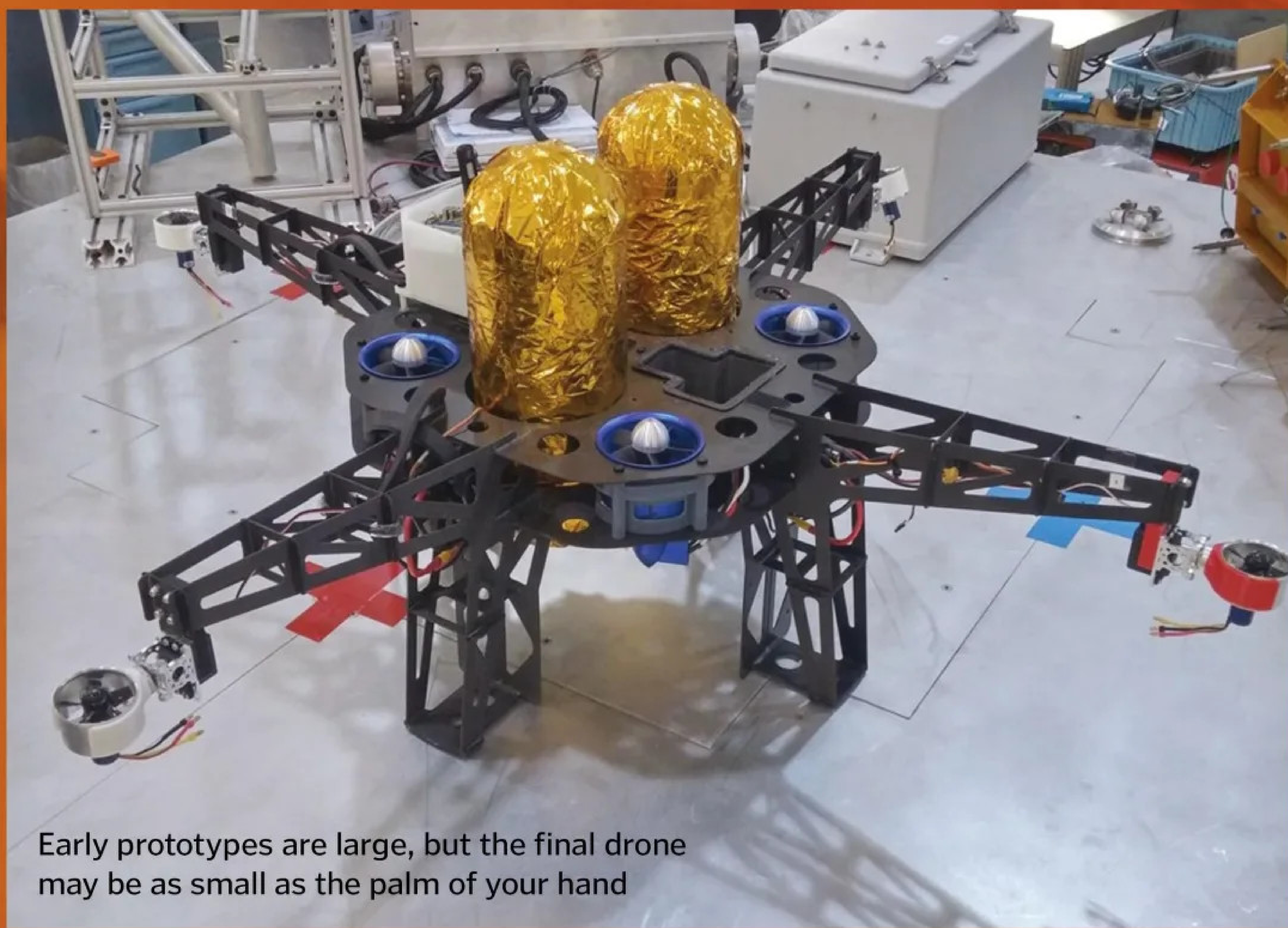
Drones are already used in space exploration – that is, if you count rovers and balloon-based scanners. But hundreds of thousands of miles away, drones may soon be used to scout new landscapes of planets using lightweight new designs like the Prandtl-D.

This aircraft, currently in development at NASA, may be the future of exploration thanks to a revolutionary design. The new wing is bell-shaped rather than a traditional elliptical shape, and the removal of a tail or flight control surfaces has dramatically reduced the craft's weight. Together, these features result in more than a 30 per cent increase in fuel economy.

The design began with the research of the early 20th-century aeronautical engineer Ludwig Prandtl, and also incorporates conclusions from several other engineers and aerodynamics pioneers. However, the craft's name, Prandtl-D, also stands for Preliminary Research Aerodynamic Design to Lower Drag – we wonder what Ludwig would think of that...



The revolutionary flat design takes inspiration from bird flight

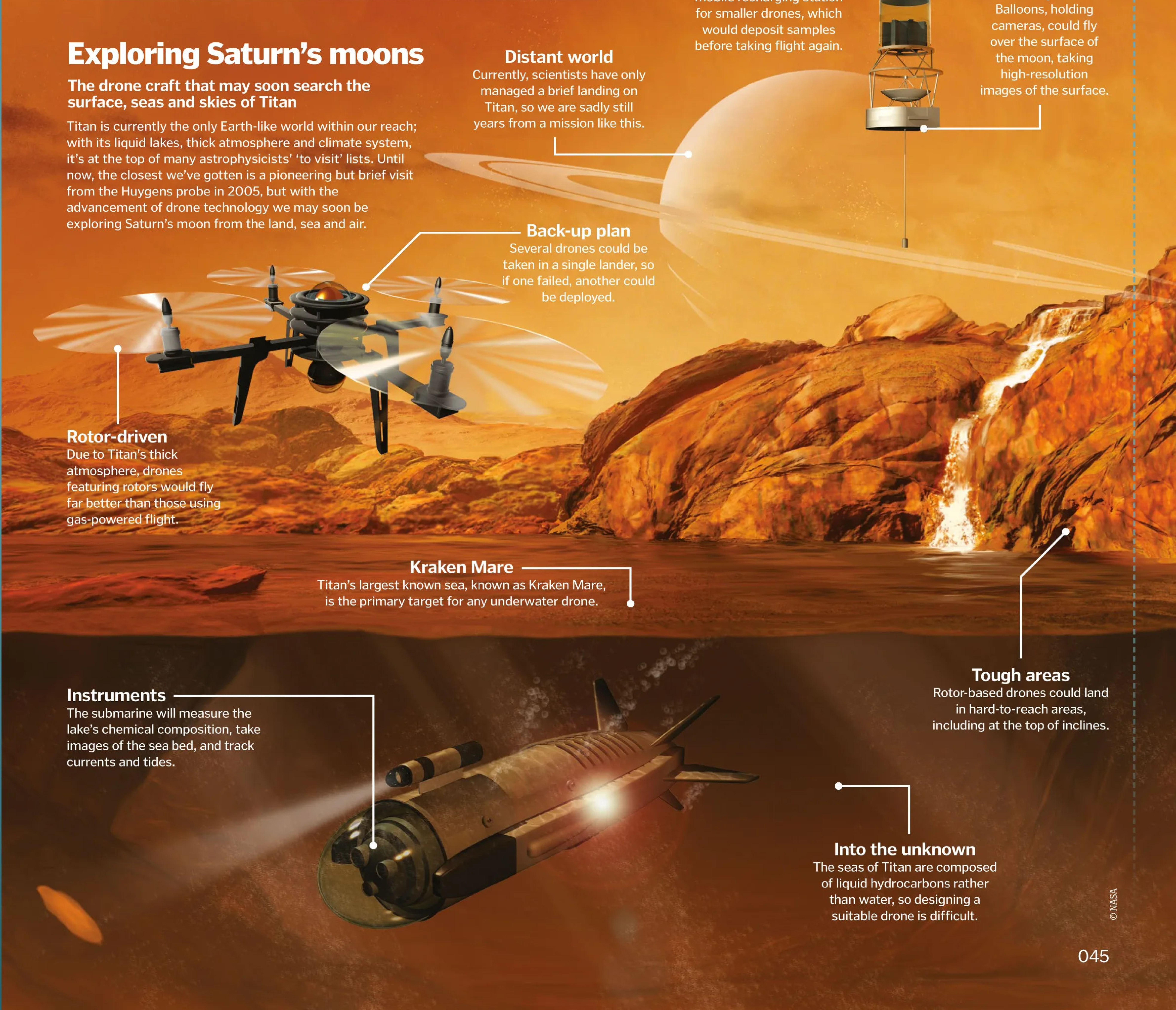


Early prototypes are large, but the final drone may be as small as the palm of your hand

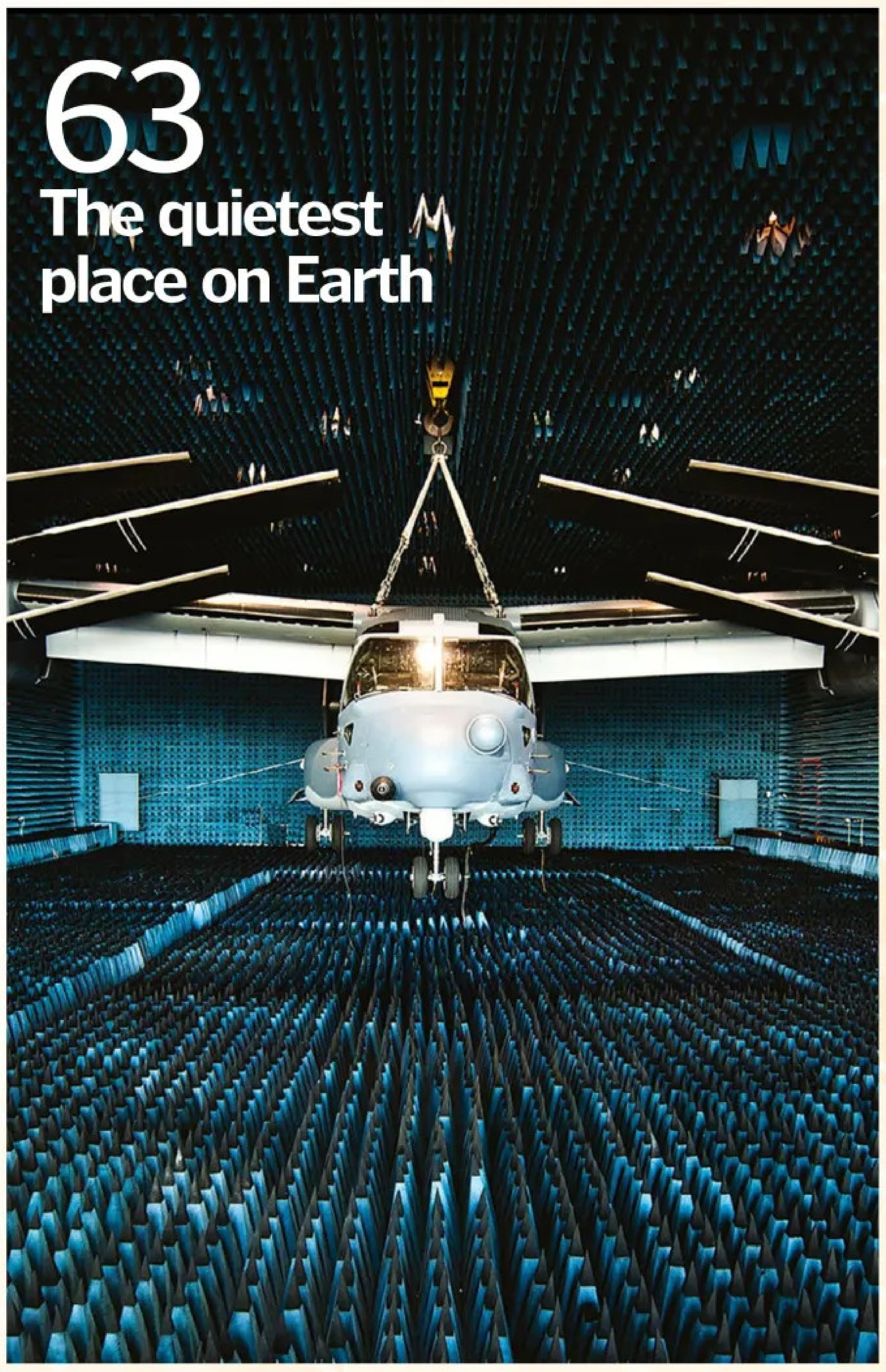
Exploring Saturn's moons

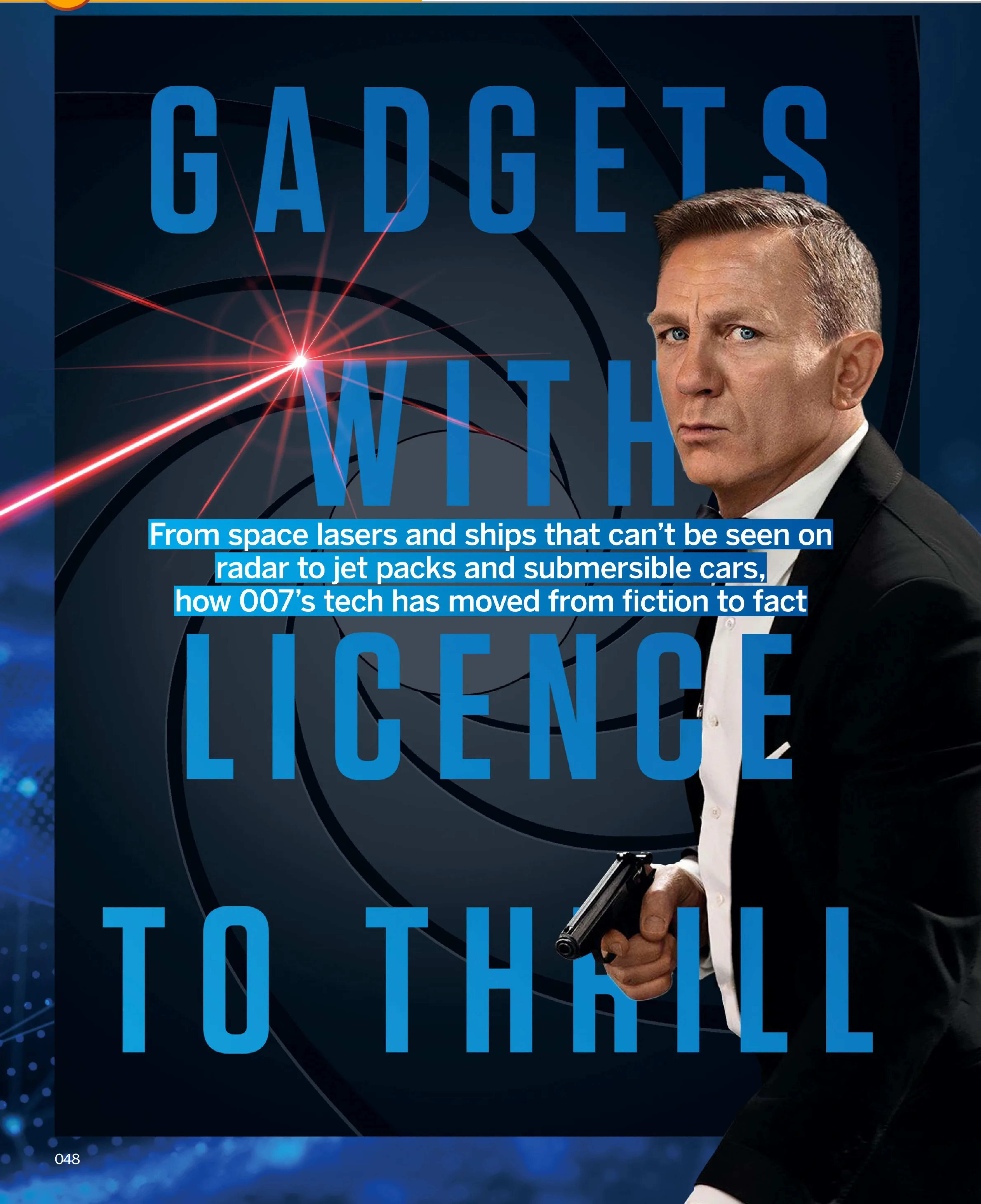
The drone craft that may soon search the surface, seas and skies of Titan

Titan is currently the only Earth-like world within our reach; with its liquid lakes, thick atmosphere and climate system, it's at the top of many astrophysicists' 'to visit' lists. Until now, the closest we've gotten is a pioneering but brief visit from the Huygens probe in 2005, but with the advancement of drone technology we may soon be exploring Saturn's moon from the land, sea and air.



LIFESTYLE





GADGETS WITH LICENCE TO THRILL

From space lasers and ships that can't be seen on radar to jet packs and submersible cars, how 007's tech has moved from fiction to fact

THE INVISIBLE SHIP

FROM: Tomorrow Never Dies

In his efforts to start a war between China and the UK so that he can make money from the resulting media coverage, dastardly media baron Elliot Carver uses a stealth ship, a vessel that's completely invisible to radar. But it looks uncannily like a ship that really existed. From 1985 to 2006, the US Navy developed the experimental Sea Shadow IX-529, which was designed to test stealth technology.

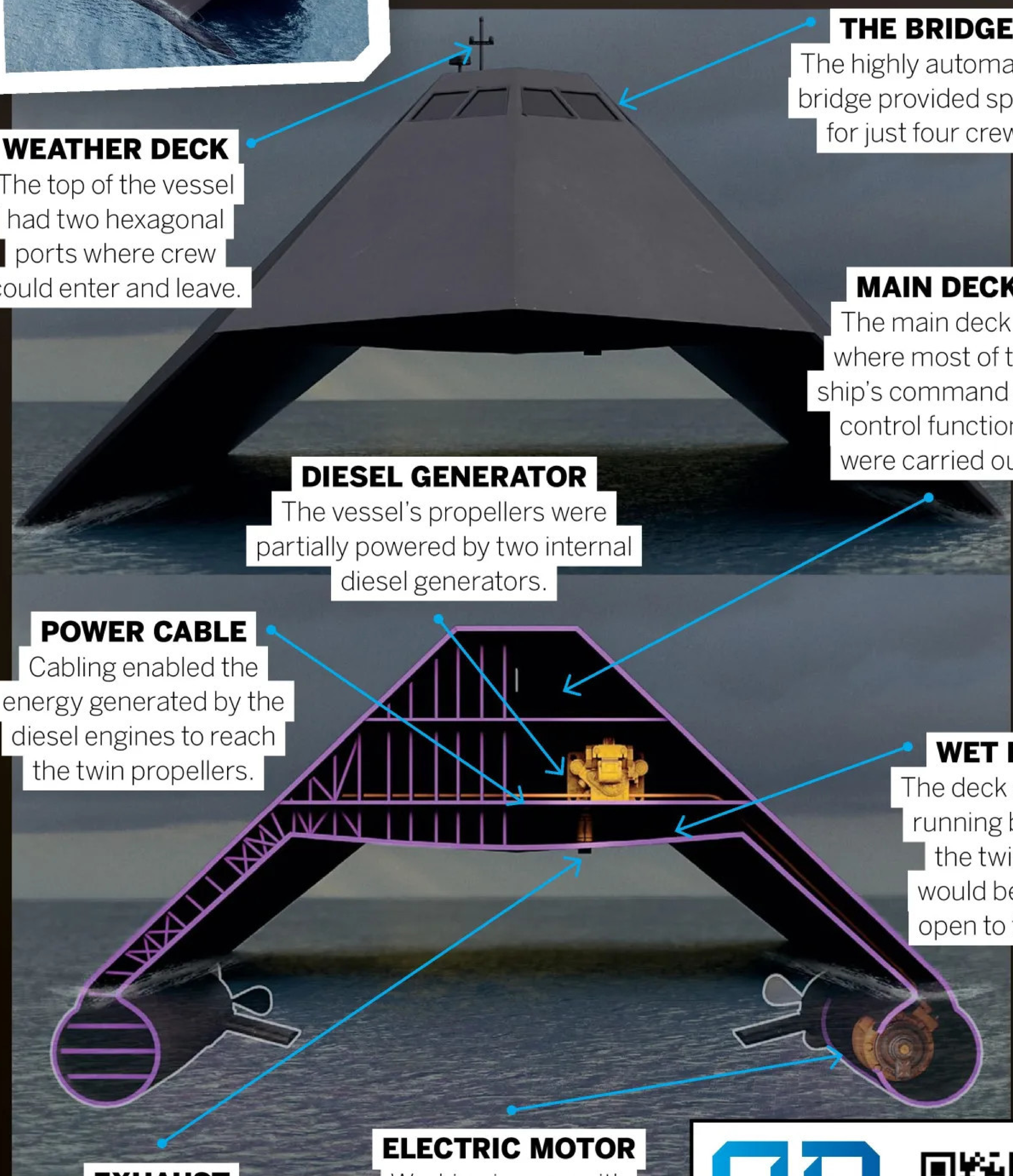
Both craft have a catamaran design and are made of black, radar-absorbing materials, much like the real-world stealth bomber and stealth fighter aircraft. Also known as the Sea Dolphin II, Carver's fictional craft had a 'sea drill', which it used to sink the HMS Devonshire in the film as a prelude to starting an armed conflict. It also had a range of missiles and a large crew complement. By contrast, the Sea Shadow only had a crew of four, and no weapons. It never saw action and was eventually sold for scrap!

The stealth craft Sea Shadow undergoes manoeuvres off the coast of San Francisco

Lockheed developed the sneaky sea vessel

INSIDE THE STEALTH CRAFT

Highly experimental, the Sea Shadow had a number of unusual design features



AR zone SCAN HERE

Did you know? Daniel Craig is younger than Bond itself

UNDERSEA PROBE

FROM: Tomorrow Never Dies

Carver's stealth ship launches the sea drill – or 'sea vac' – to sink a Royal Navy frigate in order to start a war. It's a wire-guided underwater drone with rotary cutters that can slice through a steel hull in just a matter of seconds. In the real world, autonomous underwater vehicles (AUVs) are being used for much less nefarious purposes, such as the Artemis, deployed in the search-and-rescue operation to try and track down the missing Malaysia Airlines Flight MH370. AUVs are also being increasingly used by the energy sector to scout oil and gas deposits, as well as for scientific research.

Drones like this sea drill are being used for a range of undersea operations

A NEW WAY TO FLY?

Richard Browning's jet suit could usher in a new era of flight

ROCKET MAN

FROM: Thunderball

In one of the most iconic Bond moments of the entire franchise, Sean Connery takes to the sky in a jet pack. The pack was actually a functioning Bell Rocket Belt that had been designed for the US army, but was rejected because of its short flying time of 21 to 22 seconds. Ever since, others have tried to come up with a more practical version. One of those is Gravity Industries, whose founder Richard Browning developed a jet suit reminiscent of the one used in the Bond film and, a few decades later, Marvel's *Iron Man* films. With more thruster jets, it's able to stay airborne longer than Bond's version – his Daedalus Flight Pack has a top speed of 85 miles per hour, can fly for about five minutes at up to 80 miles per hour and climb to 365 metres.

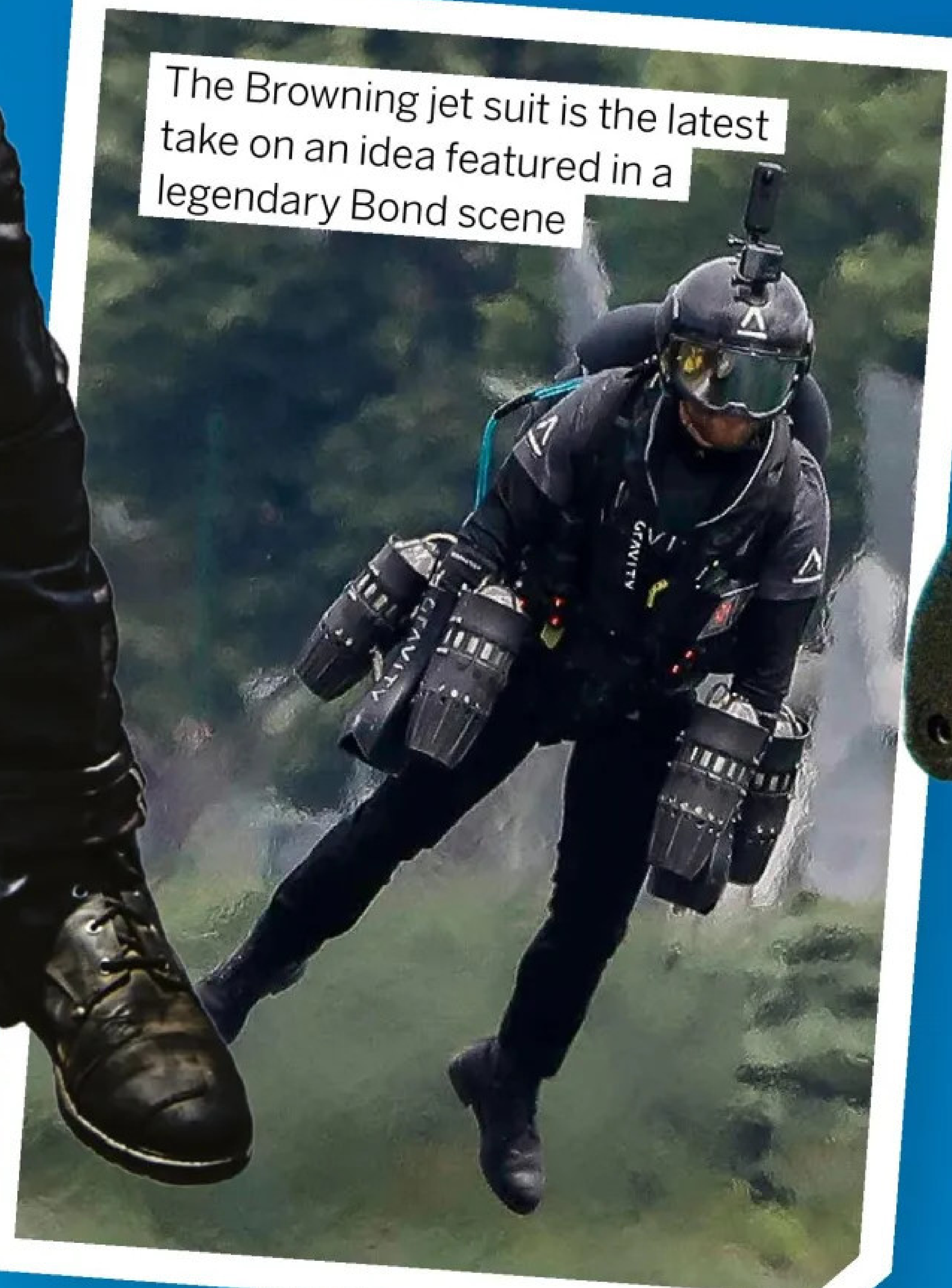
DIGITAL DISPLAY
The helmet displays all the flight information the pilot needs to control the suit.

THRUSTER PACK
A fifth thruster is fitted inside the backpack worn by the pilot.

METAL FRAME
A metal frame is used to secure the thruster and power pack to the wearer.

LIGHTWEIGHT FOOTWEAR
The boots are designed to be protective while not weighing the pilot down.

IRON MAN THRUSTERS
The suit has two miniature jet engines on each arm to allow for changes in direction and altitude.

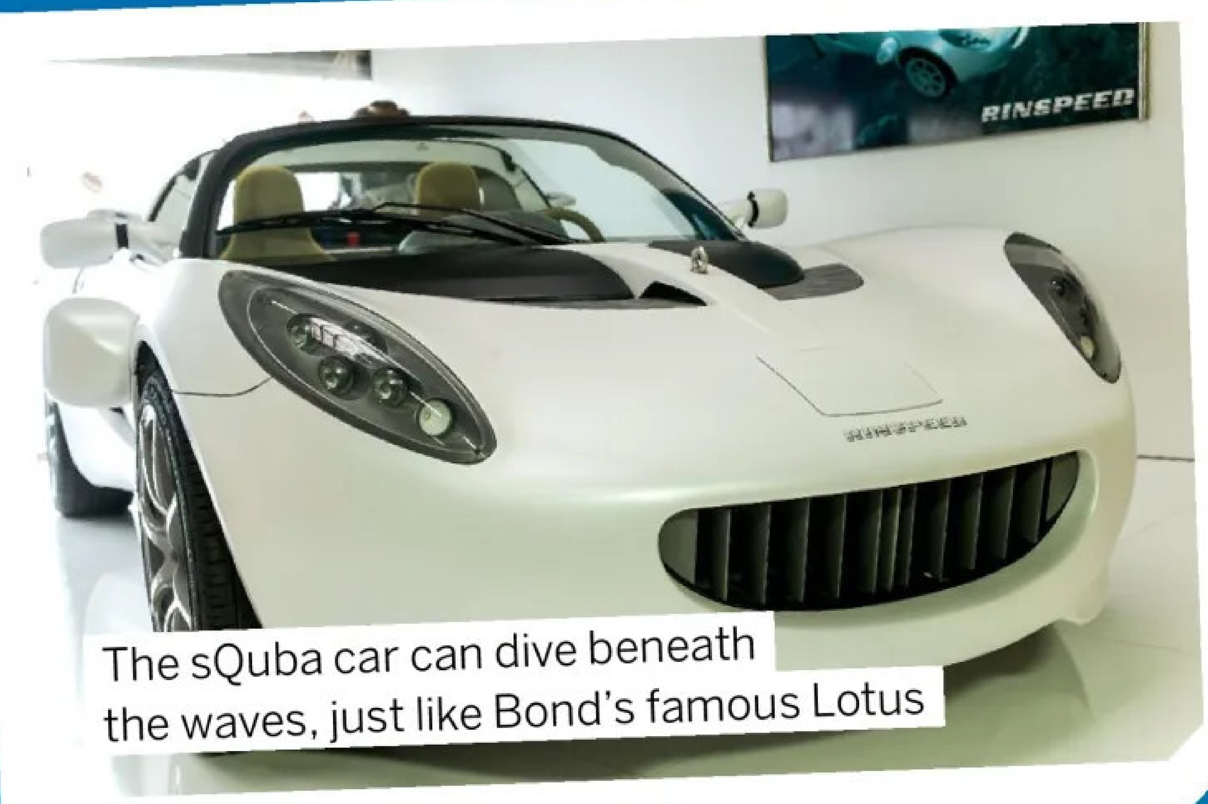


The Browning jet suit is the latest take on an idea featured in a legendary Bond scene

DRIVING BENEATH THE WAVES

FROM: The Spy Who Loved Me

Nothing sums up the magic of a Bond film quite like driving a car into the ocean, with it carrying on the journey by turning into a submarine. Dubbed Wet Nellie, the production version was a submarine built specially for the film in the shape of a Lotus Esprit S1 sports car. In 2008, the Rinspeed sQuba became the first car to be able to travel underwater. Unlike Bond's Lotus, which was pressurised, allowing the driver to stay dry, sQuba is open to the water, with those inside having to don scuba gear. But with its ability to travel submerged, just like Bond's car, it's about as close to his Lotus submarine as it's possible to get.



The sQuba car can dive beneath the waves, just like Bond's famous Lotus

A BRUSH WITH DANGER

FROM: License to Kill

One concoction that was guaranteed to remove plaque – along with the rest of your head – was Bond's 'Dentonite' toothpaste. The explosive putty was a creation conjured up by Q Branch, consisting of explosive paste mixed with regular toothpaste as a disguise, so Bond could slip it past any airport's – or henchman's – searches. Of course, we're not likely to find much of a market for exploding toothpaste, but using everyday items for deadly purposes is something real-life spies have attempted. In fact, one alleged plot had the CIA attempt to assassinate the leader of the Democratic Republic of Congo Patrice Lumumba with poisoned toothpaste in 1961.

It wasn't the first time something so innocuous was used as a weapon

The robotic dogs currently being trialled by police forces are far more sophisticated than the one seen in *A View to a Kill*

Did you know?
Seven actors have portrayed Bond in films

ROBOTIC CANINES

FROM: A View to a Kill

Snooper didn't look too canine

What better way to gather information on unsuspecting rivals than with a pet pooch that's wired for sound? In *A View to a Kill*, the Snooper is a remote-operated surveillance robot developed by Q Branch for gathering information.

In 2021, the New York Police Department started deploying its own robotic dog, dubbed the Digidog. Developed by Boston Dynamics, it's far more sophisticated than Bond's version. Whereas Bond's was remotely controlled by an operator and had wheels, Digidog has legs and can make its own decisions thanks to artificial intelligence.

After briefly being deployed in the Big Apple, it was quickly taken off the streets after backlash from the public. But other police departments in Massachusetts and Hawaii are also testing the digital dog device.

5 FACTS ABOUT BOND WATCHES AND WEAPONS

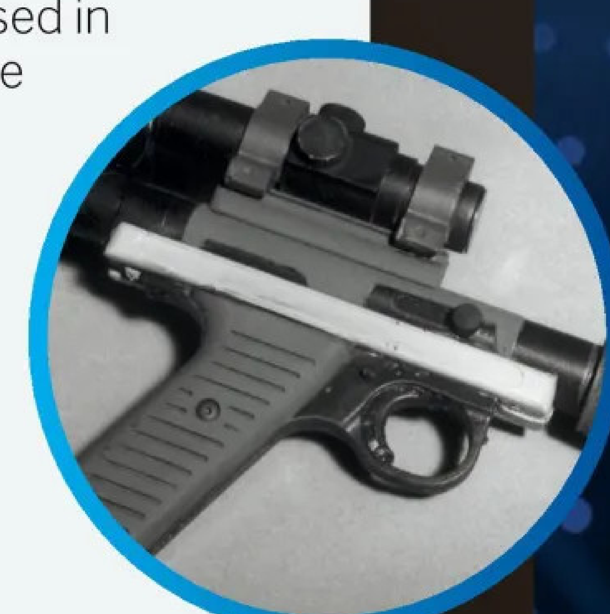
1 THE GOLDEN GUN
The iconic weapon used by flashy hitman Francisco Scaramanga comprises everyday objects: a cufflink (the trigger), a gas lighter (bullet chamber), a fountain pen (the barrel) and a cigarette case (the handle).

2 LASER WATCH
Bond wears an Omega Seamaster in *Goldeneye* which can fire a laser, which he uses to cut a hole in a train. German laser enthusiast Patrick Priebe built his own working version.

3 WRIST DART GUN
In *Moonraker*, Bond uses a dart gun strapped under his wrist like a watch, capable of firing small darts. Dart guns are widely used, particularly for tranquillising large animals.

4 THE EXPLODING OMEGA WATCH
In *Spectre*, Daniel Craig's Bond manages to get himself out of a tight spot by triggering his exploding Omega watch.

5 LASER GUN
The laser pistols used in *Moonraker* befit the film's setting in space. Chinese researchers have apparently developed an actual laser gun that can ignite a target from half a mile away.



ONE TOUGH AUTOMOBILE

FROM: Goldfinger

BOND'S MOST FAMOUS RIDE

Bond loves his motors, and nothing is as quintessentially 007 as the Aston Martin DB5

UNWELCOME GUESTS
An ejector seat could be activated to deter any backseat driving from passengers.

CONTROL PANEL
Bond's control panel featured a radar screen – today you'd most likely find a satnav.

PROTECTIVE COVER
Bond got extra cover when driving away from danger, with a shield that stopped bullets in their tracks.

SLICK DRIVING
The tail lights could eject hot oil onto the road, providing a slippery surface for any pursuing vehicles.

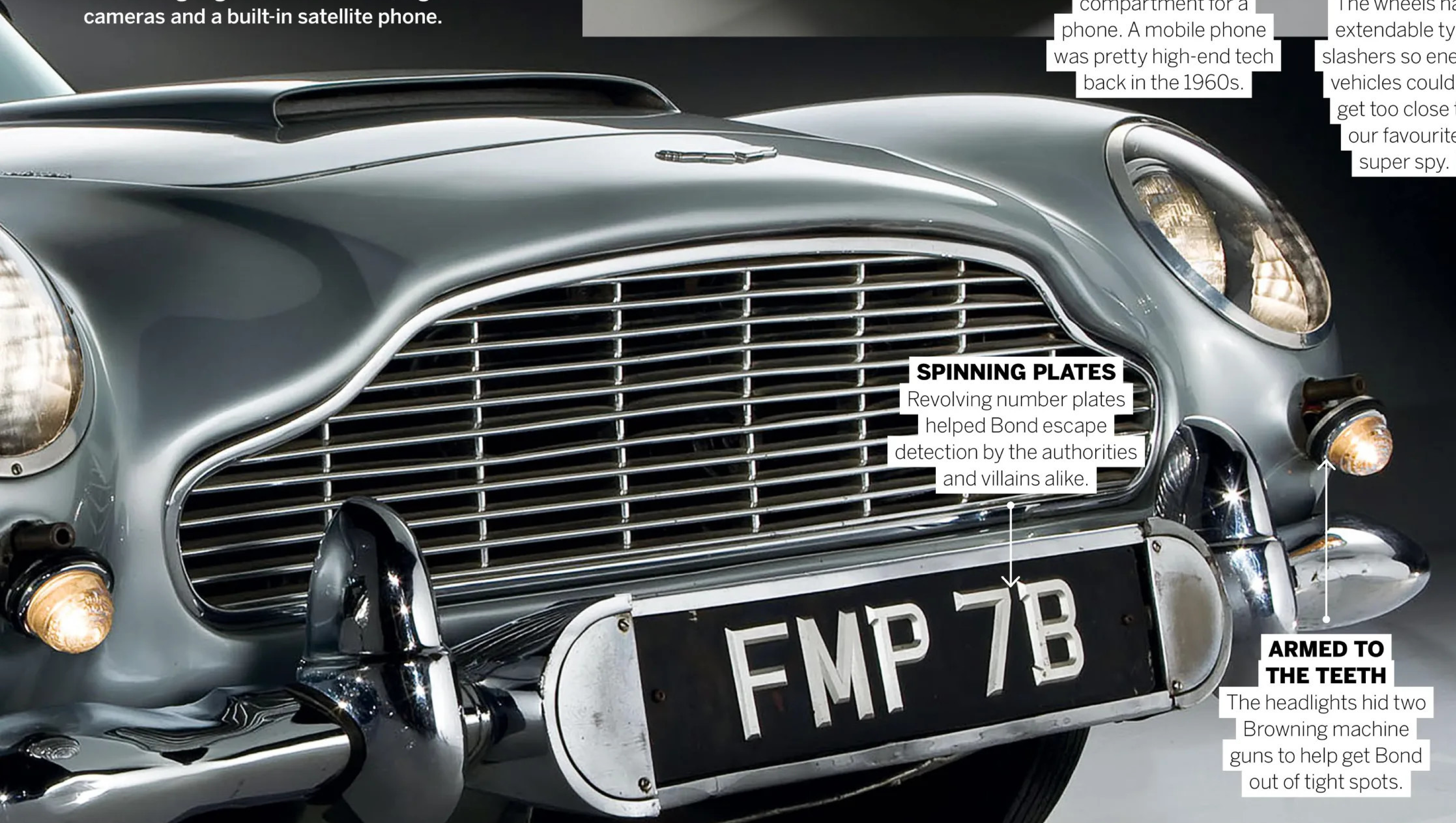
BULLETPROOF BODY
The body was bulletproof, much like many cars used by dignitaries and the military today.

The US President's ride features similar technology to that used on Bond's Aston Martin

Did you know?
'007' was the bus route used by Ian Fleming

Without a doubt, the most memorable vehicle in the Bond franchise – and one of the most memorable in pop culture history – is this silver beauty. The model did exist in the real world, but unlike Bond's version, it didn't come with a range of advanced offensive and defensive weapons.

That's not to say in the real world vehicles don't have that type of technology when it comes to cars used by the military or to protect important people. The serving US president, for instance, travels in Cadillac One, an enhanced limousine dubbed 'the Beast' which features armour plating, foam around the fuel tank and bulletproof glass. Nowhere near as nimble as Bond's car – you're unlikely to see it undertake any hot pursuits – it weighs in at about nine tonnes and is reported to have tear gas grenade launchers, night-vision cameras and a built-in satellite phone.



THE MINI-AIRCRAFT FROM: You Only Live Twice

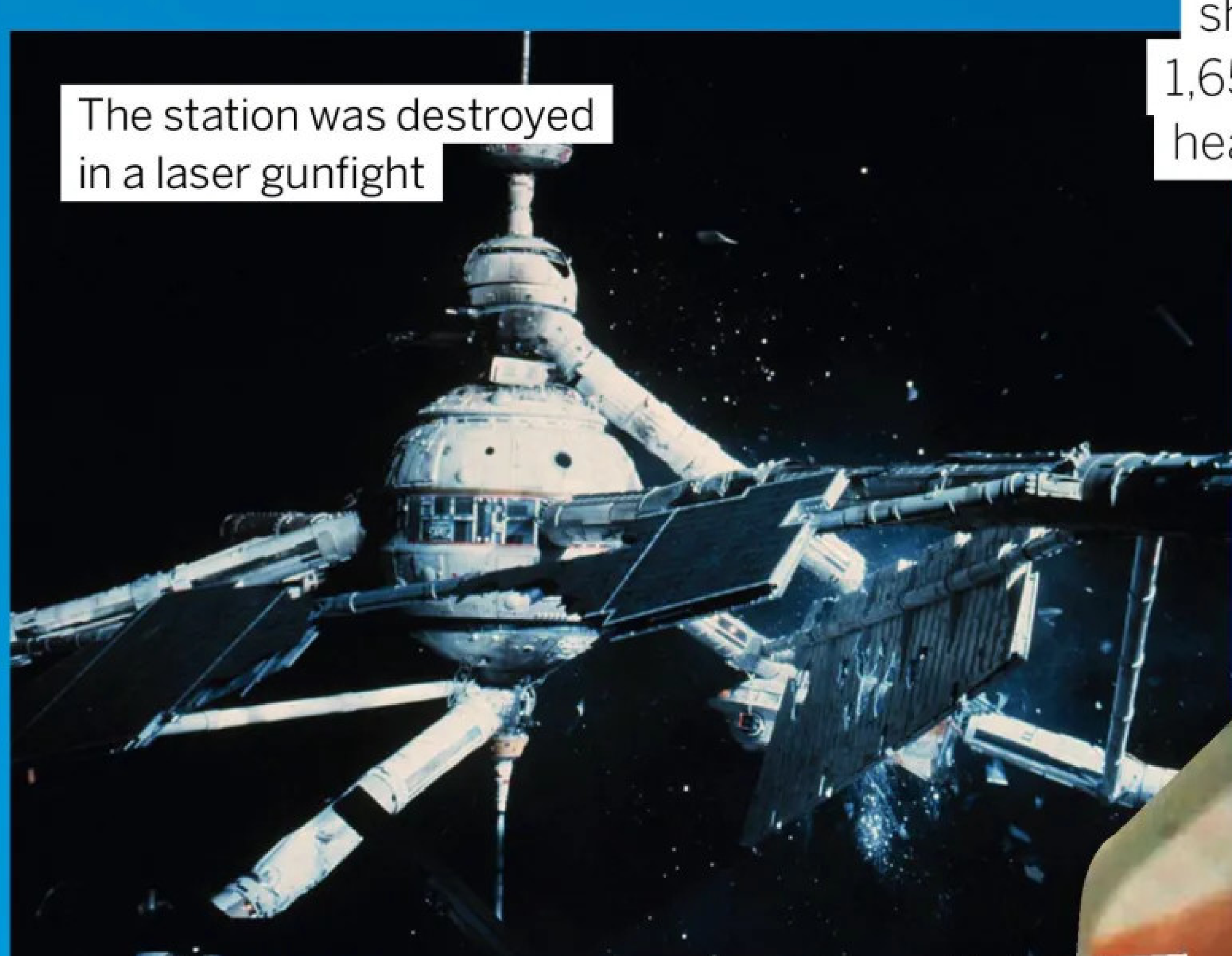
In *You Only Live Twice*, Bond takes to the skies in a special one-person aircraft to track down Ernst Stavro Blofeld's secret base. Dubbed 'Little Nellie', the aircraft is neither a plane nor a helicopter. It's actually an autogyro, which looks a bit like a small helicopter. But where it differs from a regular chopper is that it has no power to its rotor blades, which move via the momentum created by the aircraft's rear motor instead. Little Nellie was a cut-down version of the Wallis WA-116 Agile, developed in the early 1960s by former Royal Air Force Wing Commander Ken Wallis. The version we see on screen is the real one, although Bond's was heavily armed and was equipped with – among other things – rockets and flamethrowers. Bond's was also highly portable, being brought to him by Q Branch folded up in four cases.


Bond took to the skies in Ken Wallis' Little Nelly – although his didn't have missiles

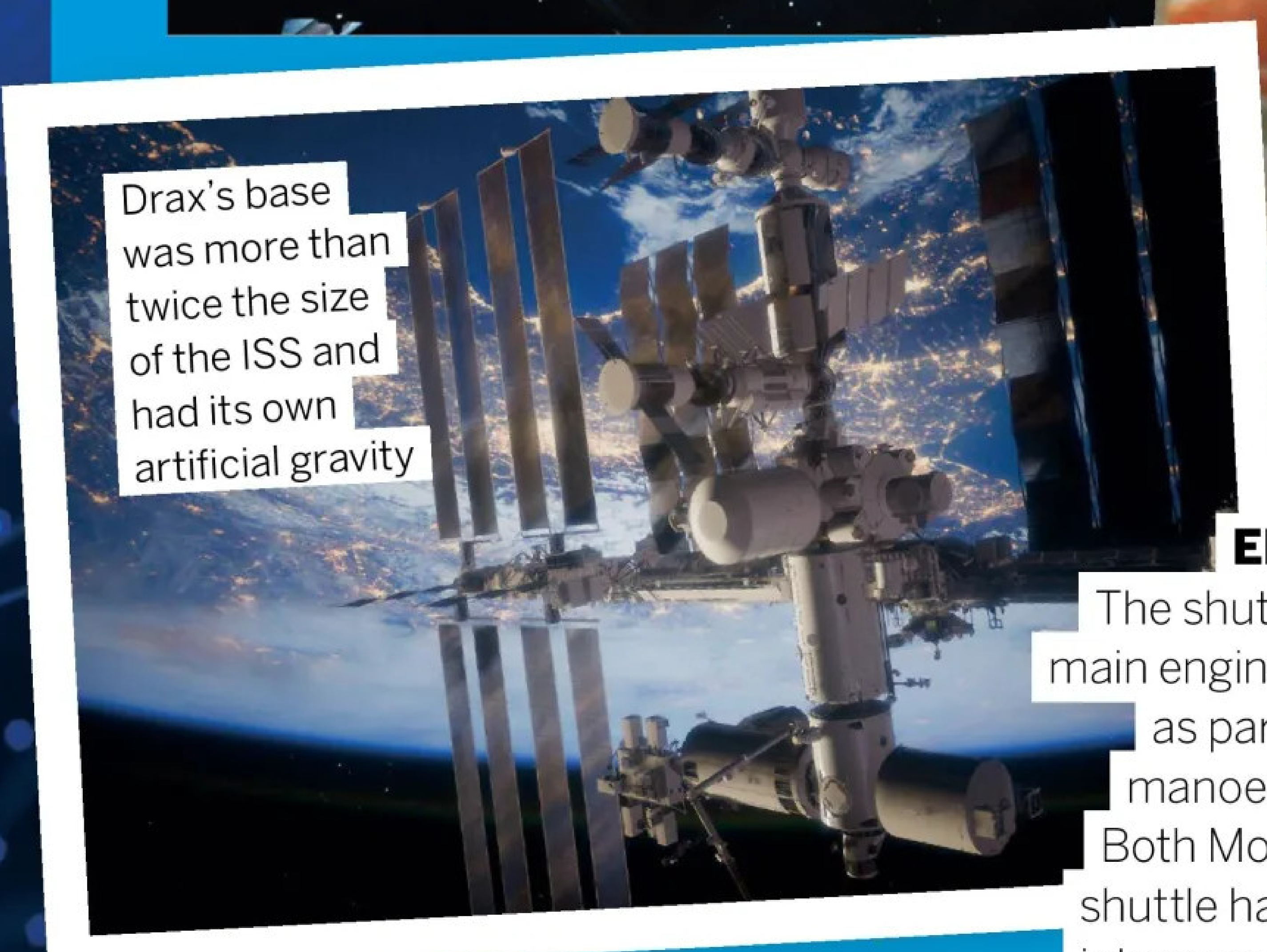
GOING ORBITAL

FROM: Moonraker

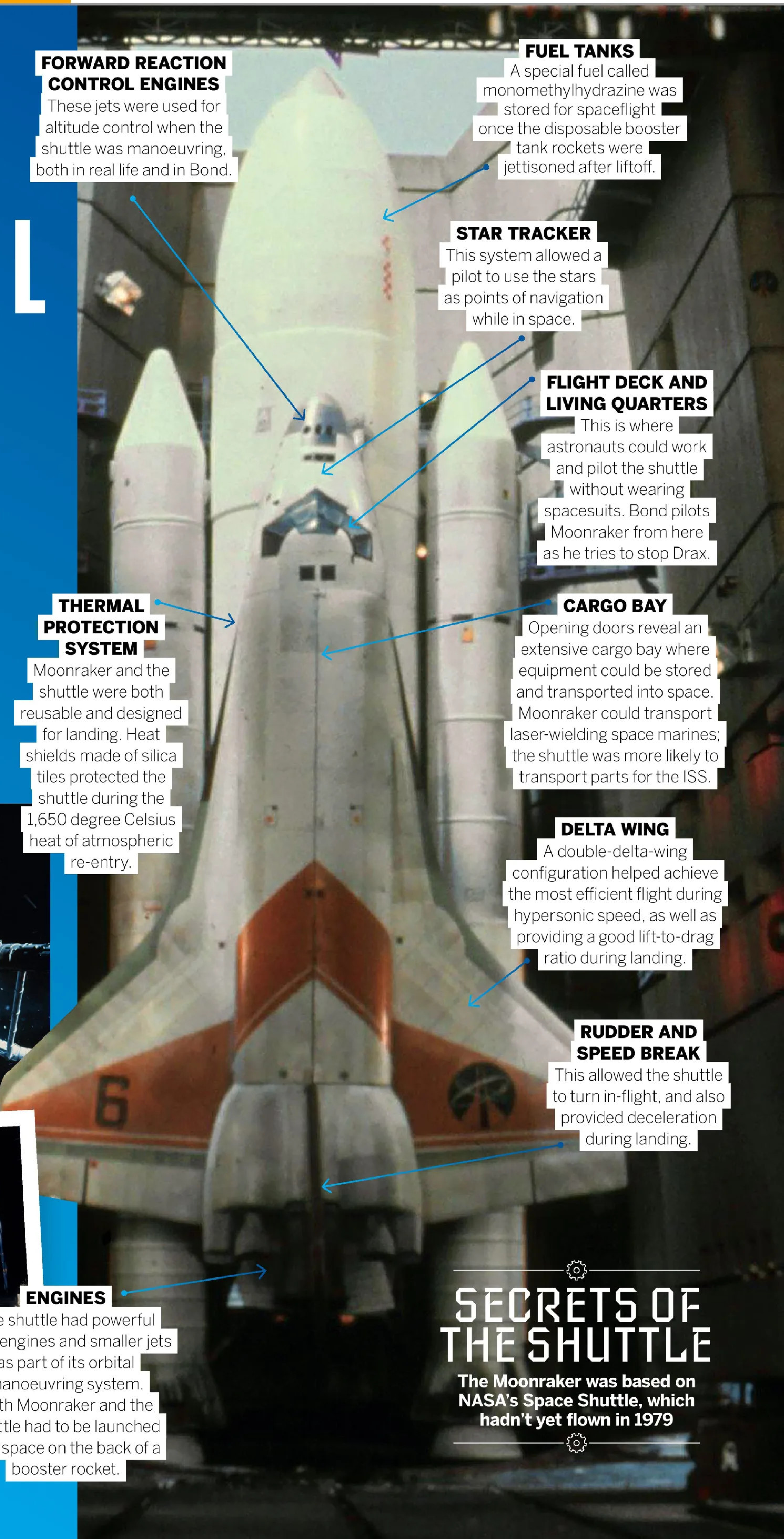
Drax's space station was the stuff of science fiction when *Moonraker* was released in 1979, but since then we've seen the launch of Mir and the International Space Station (ISS). Mad billionaire industrialist Hugo Drax built the station in Earth orbit to house his master race. It was 260 metres wide and had artificial gravity, as well as a large hangar bay for space shuttles, and also had a powerful laser weapon. By contrast, the ISS is unarmed and isn't big enough to house spacecraft, instead having to dock with them. It also doesn't have gravity, with its crew having to train in a zero-gravity environment before they're posted up there. At 110 metres in diameter, it's also less than half the width of the fictional Bond station.



The station was destroyed in a laser gunfight



Drax's base was more than twice the size of the ISS and had its own artificial gravity



SECRETS OF THE SHUTTLE

The Moonraker was based on NASA's Space Shuttle, which hadn't yet flown in 1979

NO, MR BOND… I EXPECT YOU TO DIE

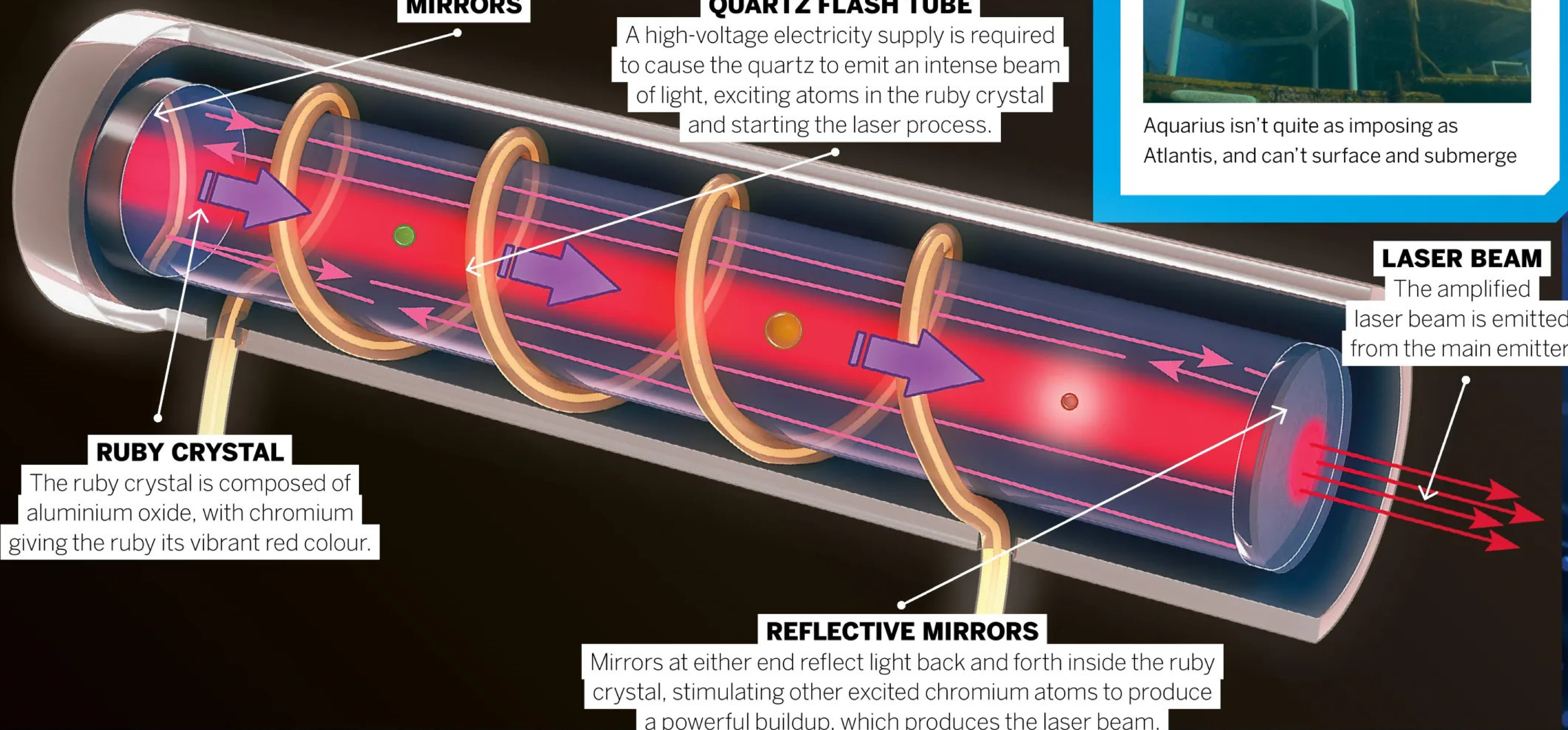
FROM: Goldfinger

Bond has found himself in innumerable scrapes over the years, but arguably none as harrowing as the prospect of being sliced in half by a laser beam – with the first parts to go being his privates. An industrial laser designed to slice through the vault doors of Fort Knox was the piece of tech which Goldfinger used to try and bring an end to 007's snooping around. In the real world, lasers have been deployed for industrial and military use for decades. From precision cutting in factories to now even being mounted on military vehicles, lasers are no longer the stuff of science fiction.

Laser cutters like the one in *Goldfinger* are widely used in industry

COMPONENTS OF A LASER

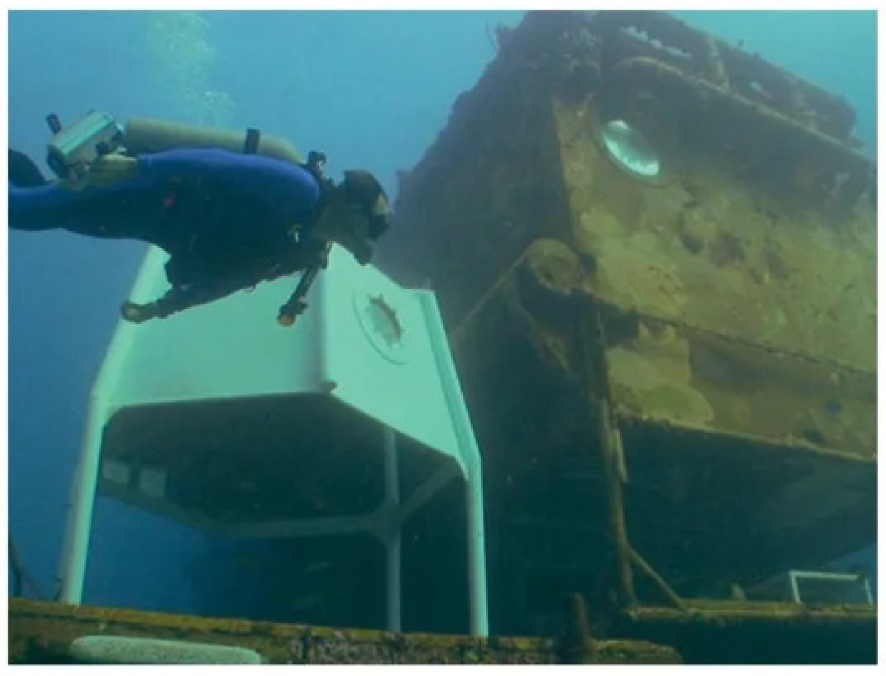
The first ruby laser meant such devices were no longer confined to science fiction



OCEANS OF TROUBLE

FROM: The Spy Who Loved Me

Atlantis was a base and research lab built by criminal mastermind Karl Stromberg. Located off the coast of Italy, it was a 200-metre, four-legged structure that could submerge. There are a number of undersea labs in the world, although none on the scale of Atlantis. Aquarius Reef Base sits 5.4 miles off the coast of Florida at a depth of 19 metres. At 37 square metres, it's much smaller than Stromberg's habitat, and it can't surface and submerge, but is instead fixed in position beneath the surface of the ocean. Whereas Atlantis was designed to be essentially a floating base and research lab, Aquarius is designed purely for research, with its depth allowing divers to travel short distances from inside to the ocean floor to carry out their work.



Aquarius isn't quite as imposing as Atlantis, and can't surface and submerge

Food blenders

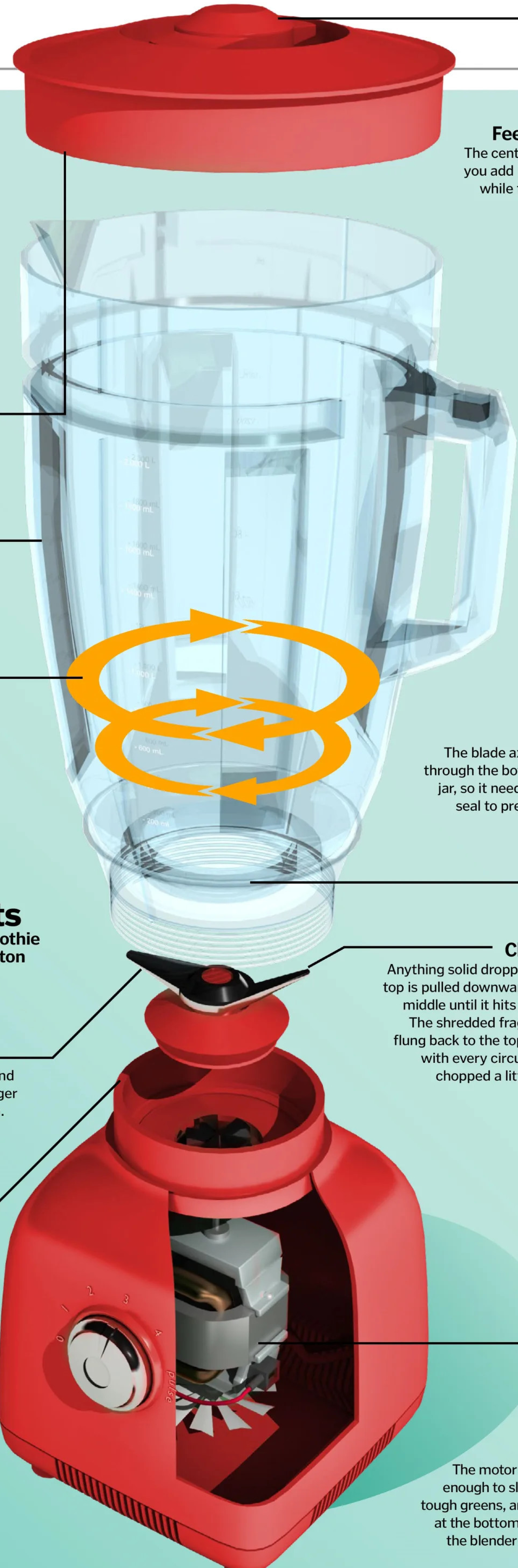
Turn fruit salad into smoothie with a tornado in a jar

A smoothie blender is a compact fluid dynamics laboratory. Friction at the surface of the blades accelerates the liquid, centrifugal force pushes it outwards, atmospheric pressure creates an air-filled vortex in the centre, and turbulence keeps everything churning and mixing. Within seconds, your placid pint of milk and fruit chunks is transformed into a chaotic, churning maelstrom.

The vortex in the centre of a blender looks like a tornado but it acts in quite a different way. A tornado is powered by a thermal updraft in its centre that pulls everything into the middle and flings it up to the sky. In a blender, the spinning blades at the bottom are constantly pushing the liquid away from the middle to the edges of the jar and this creates a suction that pulls material downwards in the centre.

The cutting blades do most of the initial work of chopping up the solid chunks, but once the size of the pieces drops below a certain point, the blades can't hit hard enough to slice them up any smaller. Amazingly, the blender uses implosion shock waves to finish the job. The blades are spinning so fast that they create a vacuum on their trailing edge. The water caught in their wake effectively boils, and as the tiny steam bubbles condense and collapse again, they send out a cascade of shock waves that shatter the food particles even further.

Don't forget to put the lid on!



Feeder cap
The centre hole lets you add ingredients while the blender is running.

Lid
The vortex forces the liquid up the sides of the jar, so a tightly sealed lid is vital.

Jar
The funnel shape helps pull the liquid up from the bottom with no stagnant spots.

Rotating
The spinning blades drag the liquid round with them and centrifugal force tends to push it out towards the edge and up the sides of the jar. This pushes the surface up at the edges and down in the middle.

Seal
The blade axle extends through the bottom of the jar, so it needs a reliable seal to prevent leaks.

Blender bits
From chunky to smoothie at the touch of a button

Chopping
Anything solid dropped in at the top is pulled downwards into the middle until it hits the blades. The shredded fragments are flung back to the top again and with every circuit, they are chopped a little bit finer.

Blades
Angling some blades up and others down creates a larger slicing zone at the bottom.

Coupling
A cog arrangement connects to the blade axle and locks the jar in place.

Motor
The motor is powerful enough to slice through tough greens, and a weight at the bottom helps keep the blender steady too.

DID YOU KNOW? *People with CVD see only 5-10% of the 1 million distinct shades of colour that people with normal vision see*

Glasses for the colour blind

EnChroma glasses help people with CVD distinguish between colours

Discover the optical tech that can restore normal colour vision

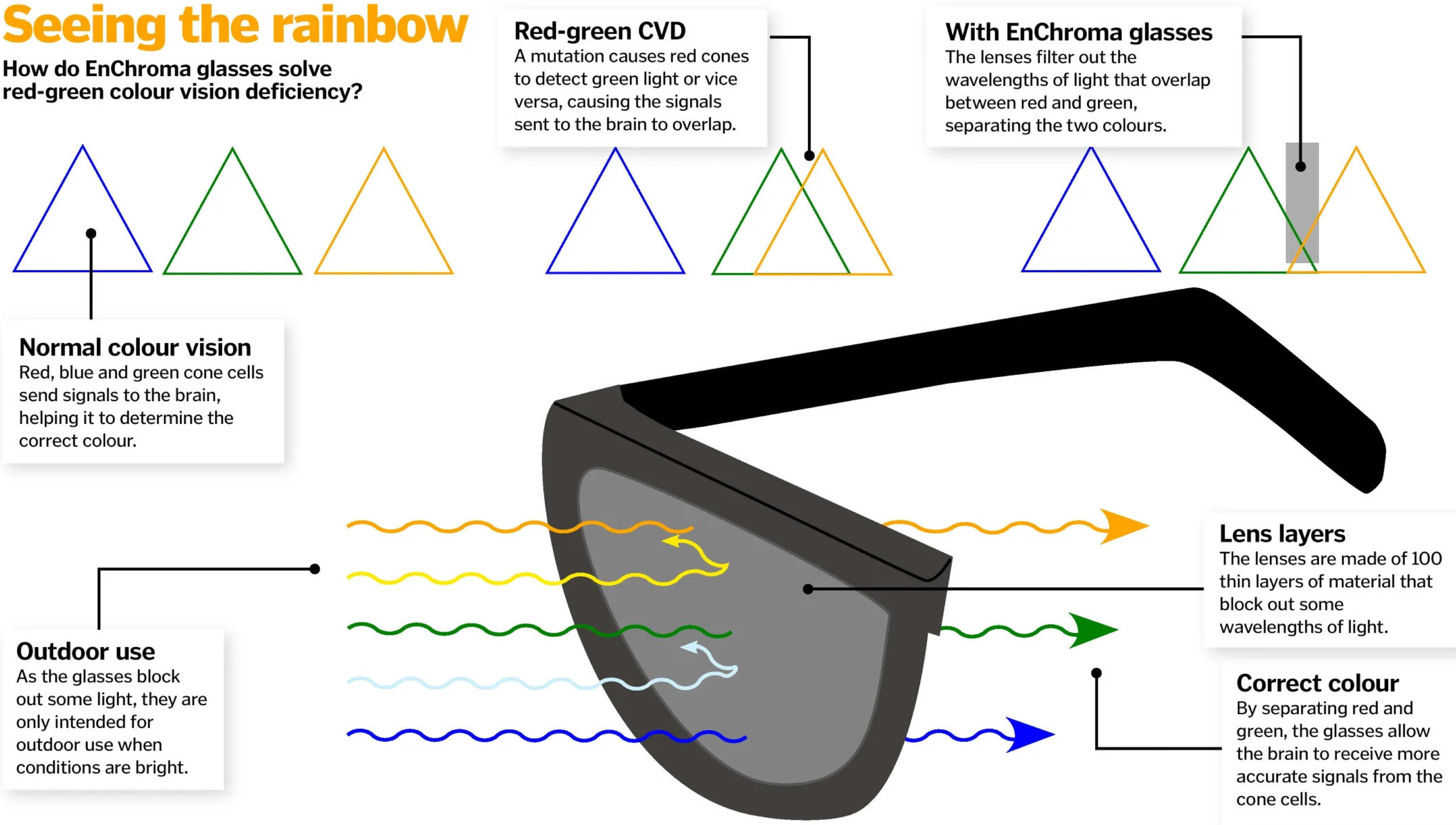
Millions of people around the world experience colour blindness, with one in 12 men, and one in 200 women affected by the condition. Men are more susceptible because most cases are inherited through the X chromosome, of which men have one and women have two. Therefore, men have a decreased chance of inheriting one normal copy of the gene.

Although commonly referred to as colour blindness, those affected are not actually blind to colour. The more accurate term is colour vision deficiency (CVD), as those with the condition have difficulty distinguishing between certain shades. This is caused when one type of cone cell at the back of the eye is missing or mutated, affecting the signals received by the brain that help it determine colour. The most common form of the condition is known as red-green CVD, which occurs when the red and green cone cells overlap more than normal. This alters the strength of the signals sent to the brain, causing green to appear more brown, and red to appear more yellow.

While there is no cure for CVD, EnChroma has developed a pair of glasses that can improve colour vision. They were originally used as safety glasses by surgeons performing laser eye surgery, but when a person with red-green CVD put them on, they noticed that they could see more colours than they were able to before.

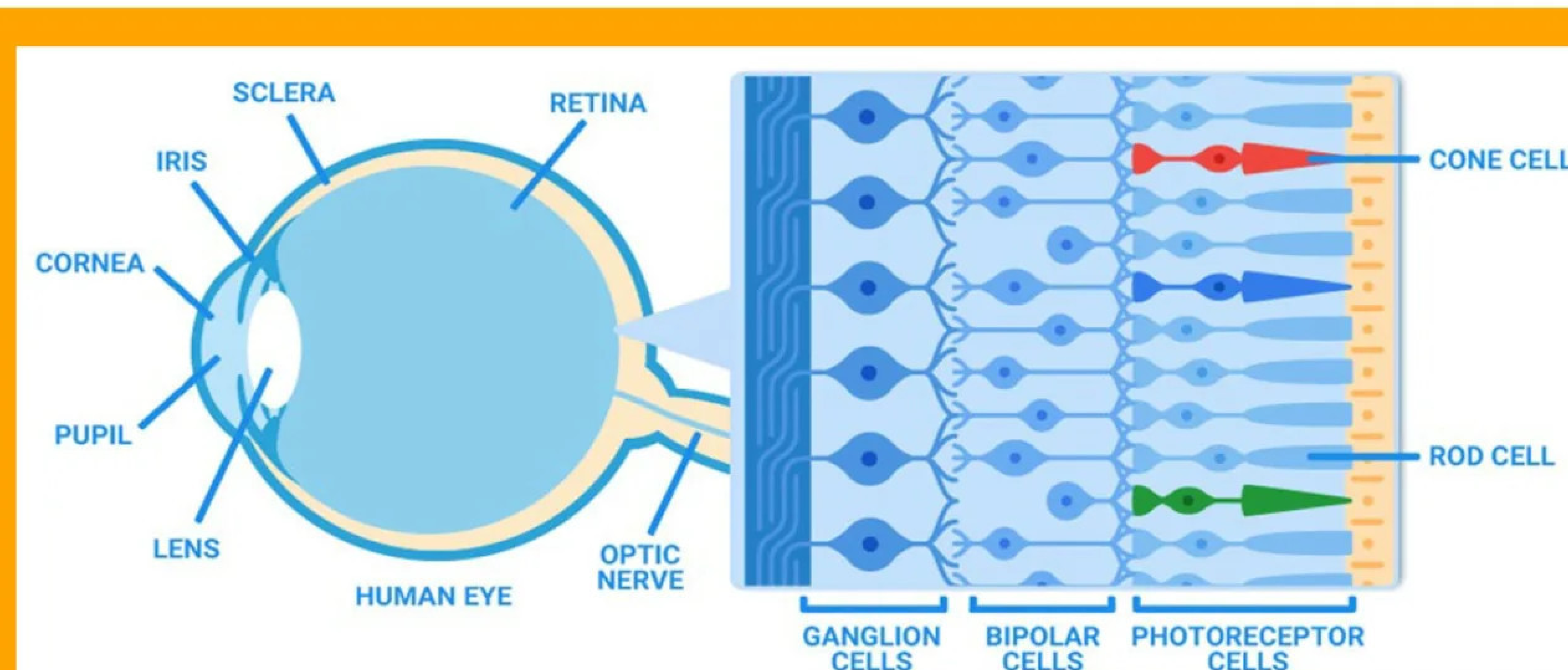
Seeing the rainbow

How do EnChroma glasses solve red-green colour vision deficiency?



How we see colour

When light reaches our eyes, it is detected by photoreceptor cells in the retina called rods and cones. Rods detect the brightness of the light, while cones detect the colour. Humans have three different types of cone cell, each able to detect all of the visible wavelengths, or colours, of light. However, some respond more strongly to certain wavelengths than others. Red cone cells respond more strongly to long wavelengths, blue cone cells to short wavelengths and green cone cells to the wavelengths in the middle of the spectrum. To determine the colour of the object you are seeing, your brain compares the strength of the signal coming from each cone cell, and mixes them together to create the right shade.



How are products tested?

The checks put in place to make sure your gadgets are safe


A variety of machines are used to test products to the limits

Before any new product can hit the shelves, it is put through rigorous tests to ensure it is robust and safe enough to be used by the public. These tests are carried out by professional product testers, who must determine whether the product complies with the international standards set by industry experts from all over the world.

"These standards are considered state of the art when it comes to product safety," says Greg Childs, product tester in the Consumer Products and Electrical department at the British Standards Institution (BSI). "For electrical products they focus on things like protection against electric shocks and resistance to fire, making sure plastics won't catch fire very easily."

The job involves testing the products in extreme conditions, such as very hot and cold climates, as well as pushing them to their usage limits. "We test for faults that could foreseeably happen in normal use, and check that if they do happen, the product is still going to be safe to use," says Childs. "For things like washing machines, we test the product with abnormal loads. I'm sure everyone's shoved too much washing in the machine at some point. We make sure that it wouldn't cause an issue."

The huge range of products that pass through the lab means that life as a product tester is extremely varied. From smartphones and drones to fridges and ovens, each product has its own set of tests to pass. "The standards are fairly generic for a product category, but every product is slightly different, so the most challenging bit is applying tests when they're not made specifically for the bit of kit that you're testing," he explains. "Plus, attitudes to what we consider safe change, so the standards are reviewed and reissued all the time."

As well as determining the safety of the products, the testers must also ensure they keep themselves safe should a fault be discovered. "The nature of what we do means there's always a possibility that something might go wrong, because that's what we're testing for," he says. "It's important to have the right controls in place, wear the correct safety clothing and know general electrical safety. We always make sure we have fire extinguishers nearby."

Three typical tests your home products must pass

1 Environmental extremes
Products are often tested in climatic chambers. These are rooms where the temperature and humidity can be carefully controlled, to ensure the products will function safely in hot and cold climates.

2 Predicting mistakes
One test for microwaves involves sticking a metal spike through a potato and cooking it to check that it would be safe if someone did accidentally put metal in the device.

3 Pushing the limits
High-voltage dielectric strength testers are used to apply thousands of volts to a product to make sure that it can withstand a surge to the mains electricity supply.


Electrical products are overloaded with thousands of volts to check their safety


Cooking metal in the microwave is one of the more bizarre tasks of a product tester

Real-time traffic data

How modern sat navs keep you up to date with the latest traffic news

When sat navs first came onto the market they functioned only to get you from one place to another. Modern varieties are a whole other matter; they now offer live traffic data, to keep you aware of developments on the roads as they happen in real time.

The bulk of this information is actually provided by the drivers' journeys as they're undertaken. A small mobile device, similar to a SIM card, is built into the sat nav, which sends data on the speed it's travelling at and its precise geographical location back to the manufacturer's headquarters.

Along with this data, live information is gathered from mobile phone networks, radio reports and government organisations, which have access to traffic data through a multitude of cameras and road sensors. These detect the volume and speed of vehicles, using either radar or active infrared, and then wirelessly transmit the results to a server. By combining these various data sources, it's possible to show where the most congestion is and where traffic is flowing freely.

Live traffic data can also be used to create faster, alternative routes for drivers who are already part way through their journey. Once these have been compiled they are sent directly to sat nav systems; drivers can then choose to change their route to save some time or continue on their original path.

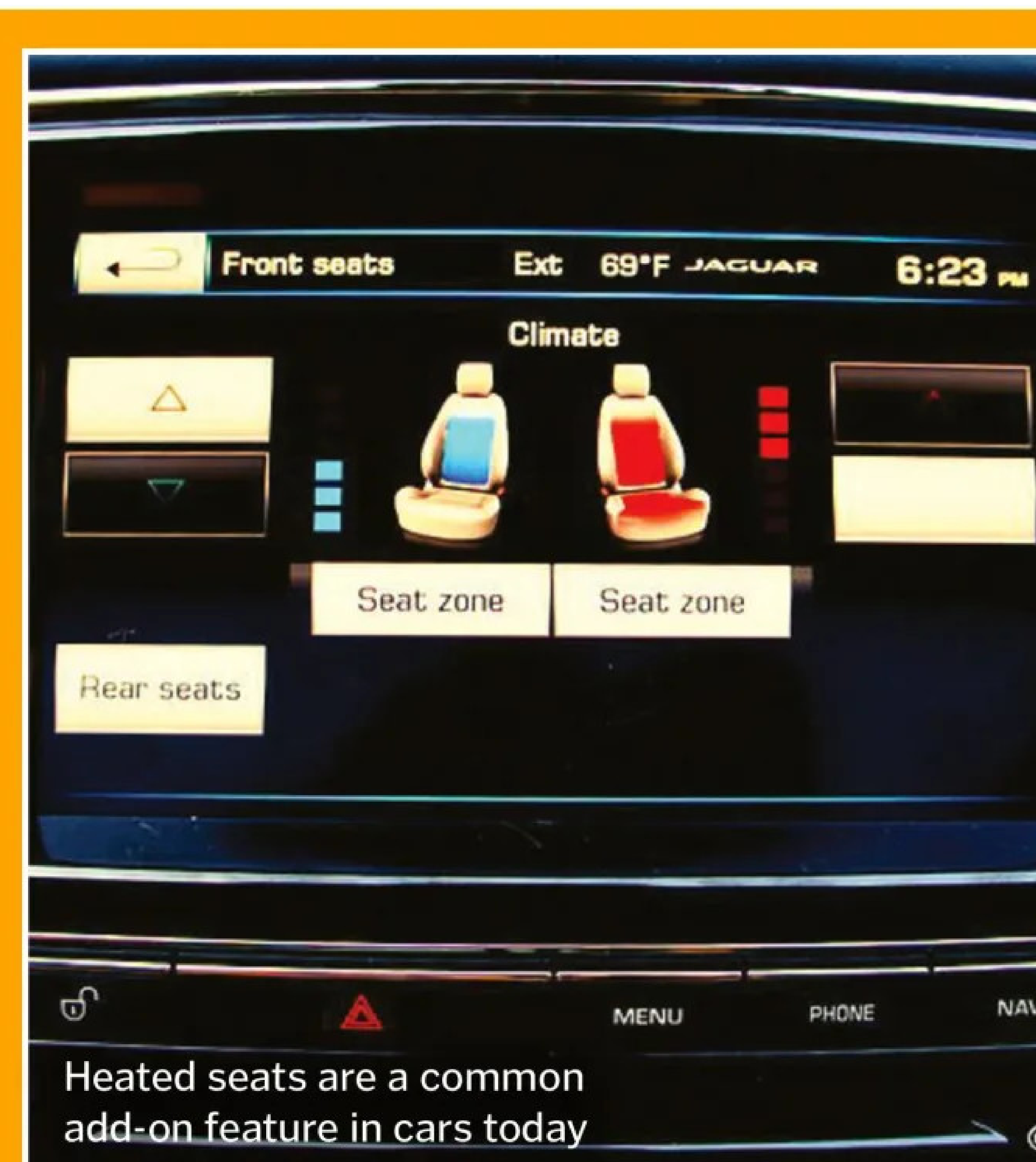
Live traffic data can be used to offer alternative routes to delayed drivers

How heated car seats work

The tech that keeps you warm on a freezing winter morning

Swedish manufacturer Saab was the first company to offer electronically heated car seats in the early 1970s. They're now available on hundreds of car models and lend an extra bit of comfort on chilly days. Depending on the manufacturer, the seat can work in two different ways. Some are essentially like a heated blanket, meaning that a heating coil running under the seat is connected to a switch. A thermostat, usually located on the side of the seat or the steering wheel, allows the occupant to regulate the level of heat as the coil receives power directly from the car's battery. If the car has both heated and cooling seats, a thermoelectric device is used instead. The seats are made with a more porous material or even have perforations. Fans within the seat circulate either warm or cold air, depending on the direction of the electrical current.

Heated seats do come with a caveat: don't keep them on full blast for too long. Some users have experienced 'toasted skin syndrome' with discoloured skin on the rear, thighs, and backs of the legs, and some have even suffered burns.



Heated seats are a common add-on feature in cars today

Inkjet printers

How these devices produce documents and photos with microscopic precision

An inkjet printer is really just a collection of motors, rollers and drive belts that move the paper around. Almost all of the complicated technology is in the print heads. These can either be fixed within the printer, or incorporated in the replaceable ink cartridge. A single print head contains hundreds or even thousands of microscopic nozzles, each one about ten times thinner than a human hair.

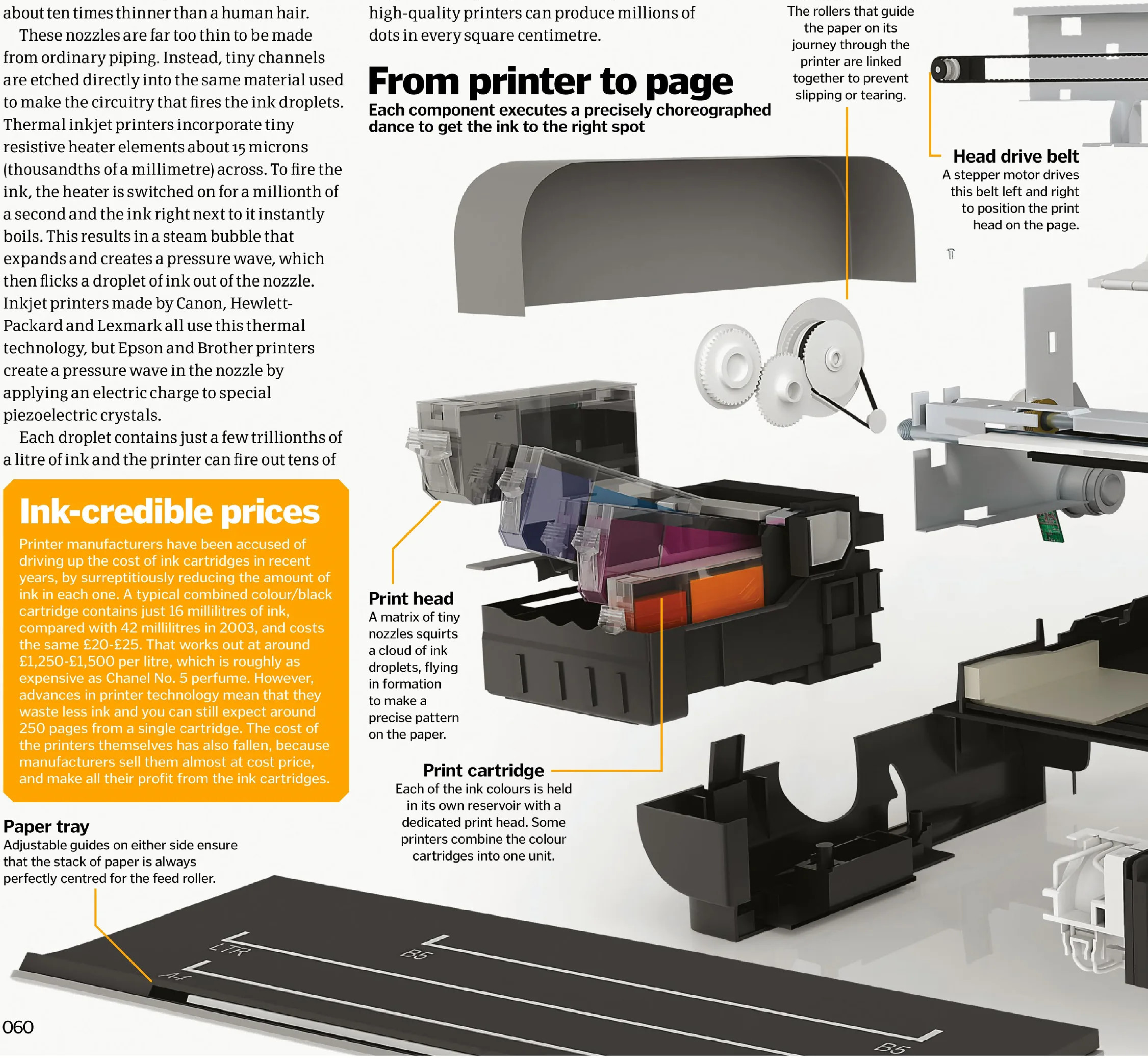
These nozzles are far too thin to be made from ordinary piping. Instead, tiny channels are etched directly into the same material used to make the circuitry that fires the ink droplets. Thermal inkjet printers incorporate tiny resistive heater elements about 15 microns (thousandths of a millimetre) across. To fire the ink, the heater is switched on for a millionth of a second and the ink right next to it instantly boils. This results in a steam bubble that expands and creates a pressure wave, which then flicks a droplet of ink out of the nozzle. Inkjet printers made by Canon, Hewlett-Packard and Lexmark all use this thermal technology, but Epson and Brother printers create a pressure wave in the nozzle by applying an electric charge to special piezoelectric crystals.

Each droplet contains just a few trillionths of a litre of ink and the printer can fire out tens of thousands of droplets per second. Most printers have four different colour inks: black, cyan, magenta and yellow, and some models also have cartridges for light cyan, light magenta, light yellow and light grey. These colours are layered on top of each other to create every possible shade. A single colour dot on the page might contain 32 separate ink droplets and high-quality printers can produce millions of dots in every square centimetre.

Heavy-duty commercial inkjet printers can produce 75,000 pages from a single cartridge

From printer to page

Each component executes a precisely choreographed dance to get the ink to the right spot



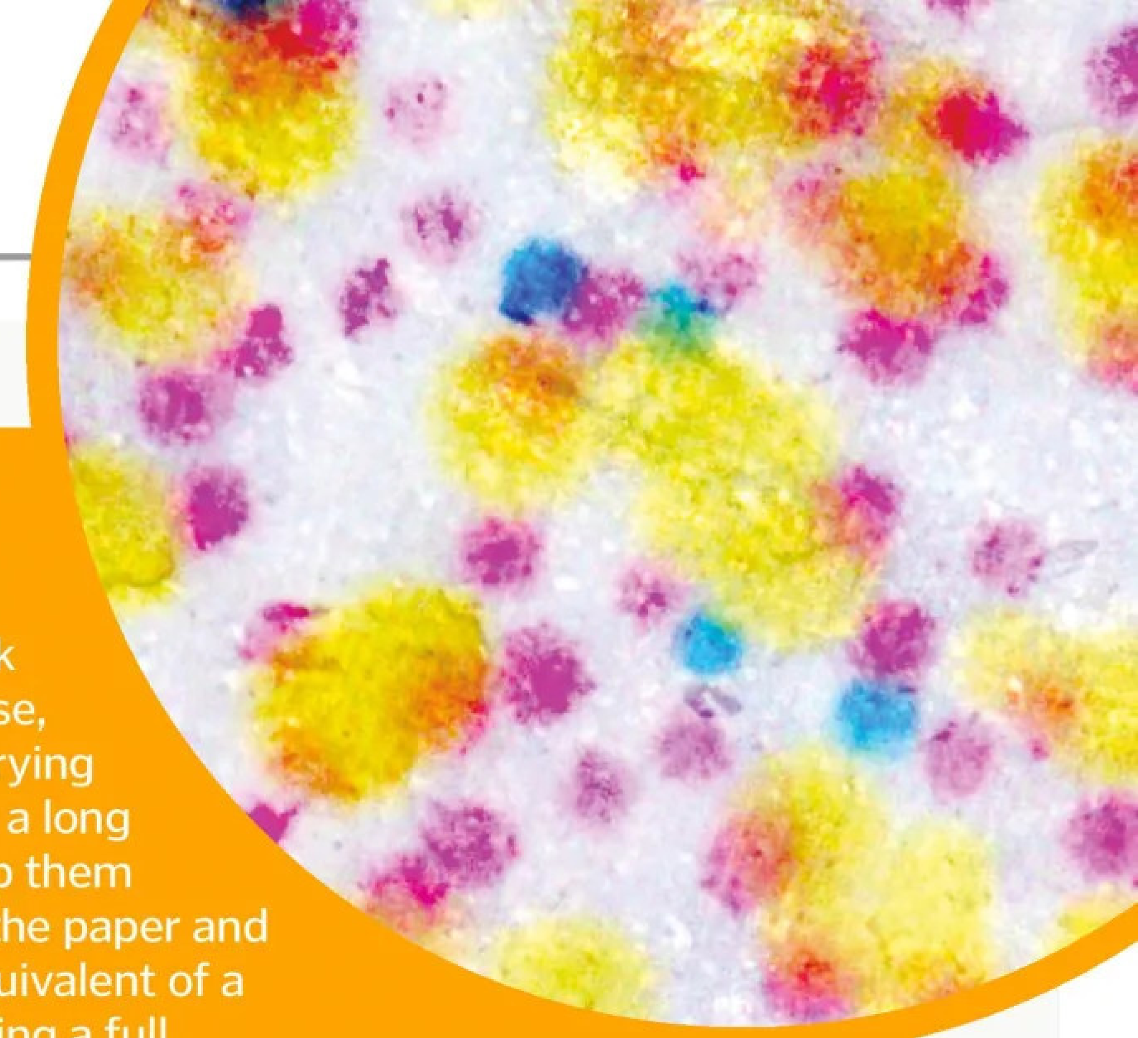
Ink-credible prices

Printer manufacturers have been accused of driving up the cost of ink cartridges in recent years, by surreptitiously reducing the amount of ink in each one. A typical combined colour/black cartridge contains just 16 millilitres of ink, compared with 42 millilitres in 2003, and costs the same £20-£25. That works out at around £1,250-£1,500 per litre, which is roughly as expensive as Chanel No. 5 perfume. However, advances in printer technology mean that they waste less ink and you can still expect around 250 pages from a single cartridge. The cost of the printers themselves has also fallen, because manufacturers sell them almost at cost price, and make all their profit from the ink cartridges.

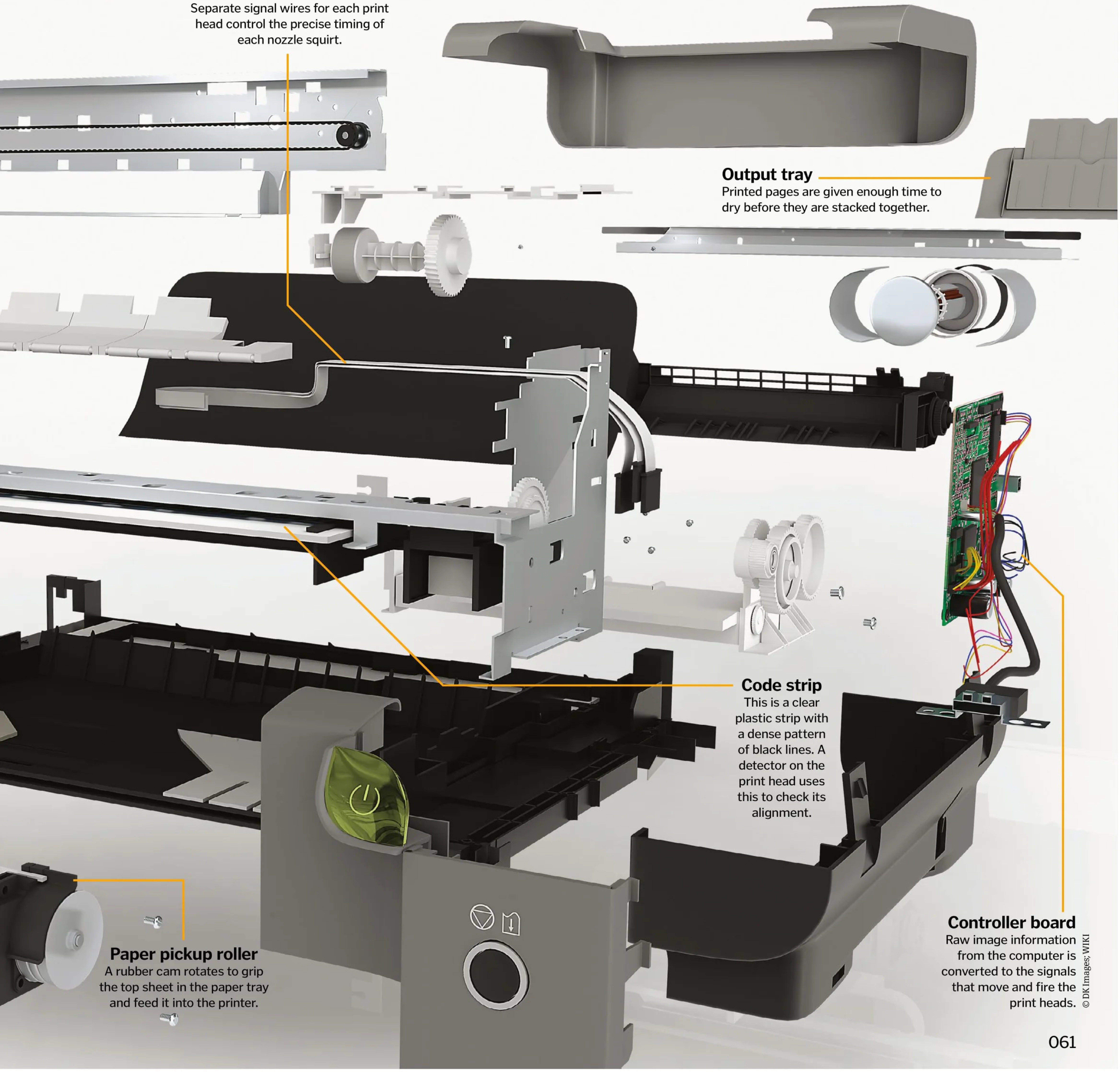
"A single print head contains hundreds of microscopic nozzles, each one about ten-times thinner than a human hair"

Clog-free colours

Printer ink needs to dry quickly once it hits the paper, but if the ink dries in the nozzles then they will clog. When the printer isn't in use, the print heads are sealed with a rubber cap to keep them from drying out but during printing, individual nozzles might be uncovered for a long time, even though that particular colour isn't needed. To help keep them flowing freely, the print head deliberately scans past the edge of the paper and fires the unused nozzles into a small chamber, like the printing equivalent of a Wild West spittoon. It wastes a little ink, but much less than running a full cleaning cycle. Some printers will pause to wipe the print head against a rubber squeegee to clean off any crusted ink. This is often what is happening if the printer makes those strange clanking and whirring sounds when idle.



The individual ink dots on a page are visible under high magnification



The mechanics of mountain bikes

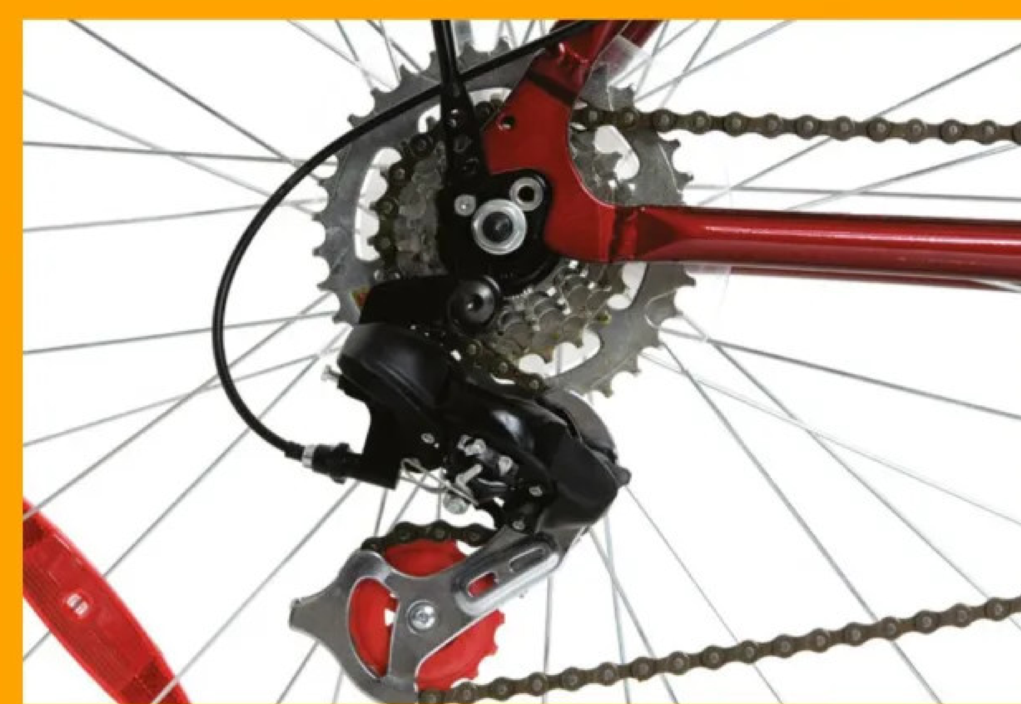
The incredible tech powering your off-road adventures

Bicycles are remarkably efficient modes of transport. Just look at a typical car, which converts petrol into motion via combustion: only around 20 to 25 per cent of that fuel will be transformed into useful kinetic energy, while the rest ends up as waste heat and pollutants. Compare that to the 90 per cent efficiency that a typical bike derives from the driving force of your legs. But just like motorised vehicles, a bike specialised for a Tour De France-style road race or cruising along a flat promenade, will be very different from those designed for a rough, off-road track.

The rigours of off-roading – which include uneven terrain, wet and slippery mud and wild inclines – mean that mountain bikes need to be much more robust than other types of bike. It's easy to spot the differences when a mountain bike and a road bike, for example, are side by side. Mountain bikes will have much wider tyres – three or four times the width of a road bike – with a more pronounced grip. The bike will feature front and sometimes rear suspension, often twice the number of gears, a thicker frame and a disc brake system. Even a bad cyclist on a road bike could outpace a person riding a mountain bike on flat, even terrain because road bikes are so much lighter and their tyres are smoother. But in unforgiving, off-road conditions, a mountain bike is in its element.

Gear up to go

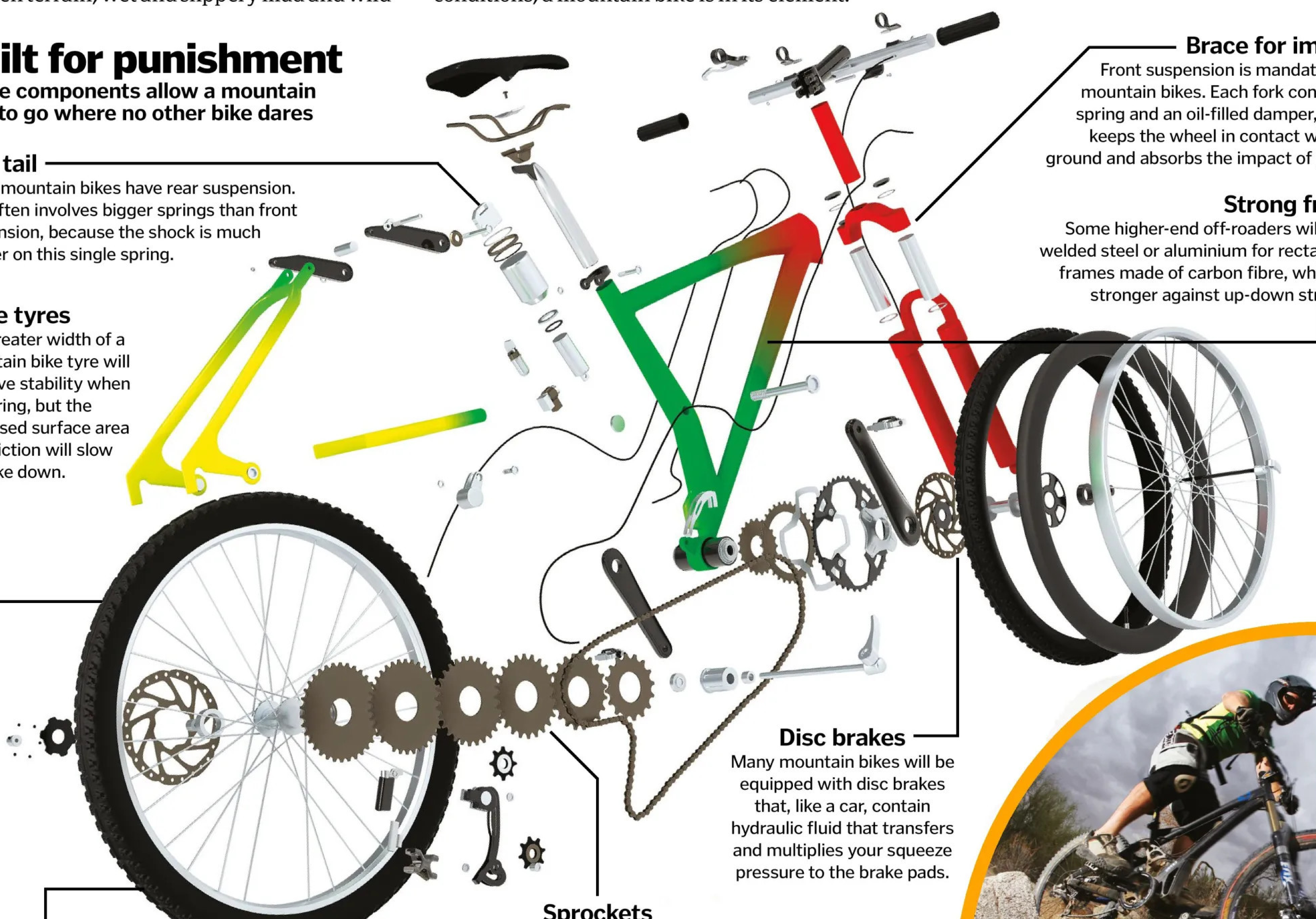
The pace at which you can turn the pedals will be dictated by the incline your bike is on. Obviously, this is going to be a lot more difficult cycling uphill than on a flat surface, so mountain bikes incorporate a number of different-sized sprockets – or cogs – to produce a gear ratio that will allow you to ride more comfortably. A 27-speed gearing system, for example, will incorporate three chainrings at the front and nine sprockets at the back. Changing the gear ratio will allow you to cover more or less ground while maintaining the same pace, so tackling a steep incline or taking advantage of a downhill is never out of the question.



Mountain bikes typically have 21, 24 or 27 gears, compared to the 11 of a road bike

Built for punishment

These components allow a mountain bike to go where no other bike dares



Soft tail
Some mountain bikes have rear suspension. This often involves bigger springs than front suspension, because the shock is much greater on this single spring.

Wide tyres
The greater width of a mountain bike tyre will improve stability when cornering, but the increased surface area and friction will slow the bike down.

Lugging weight
The knobs on a tyre, or 'lugs', dig into loose dirt and mud to provide extra grip.

Sprockets
The number of cogs, or sprockets, determines the number of gears a bike has and thus, the variety of terrain it can tackle.

Disc brakes
Many mountain bikes will be equipped with disc brakes that, like a car, contain hydraulic fluid that transfers and multiplies your squeeze pressure to the brake pads.

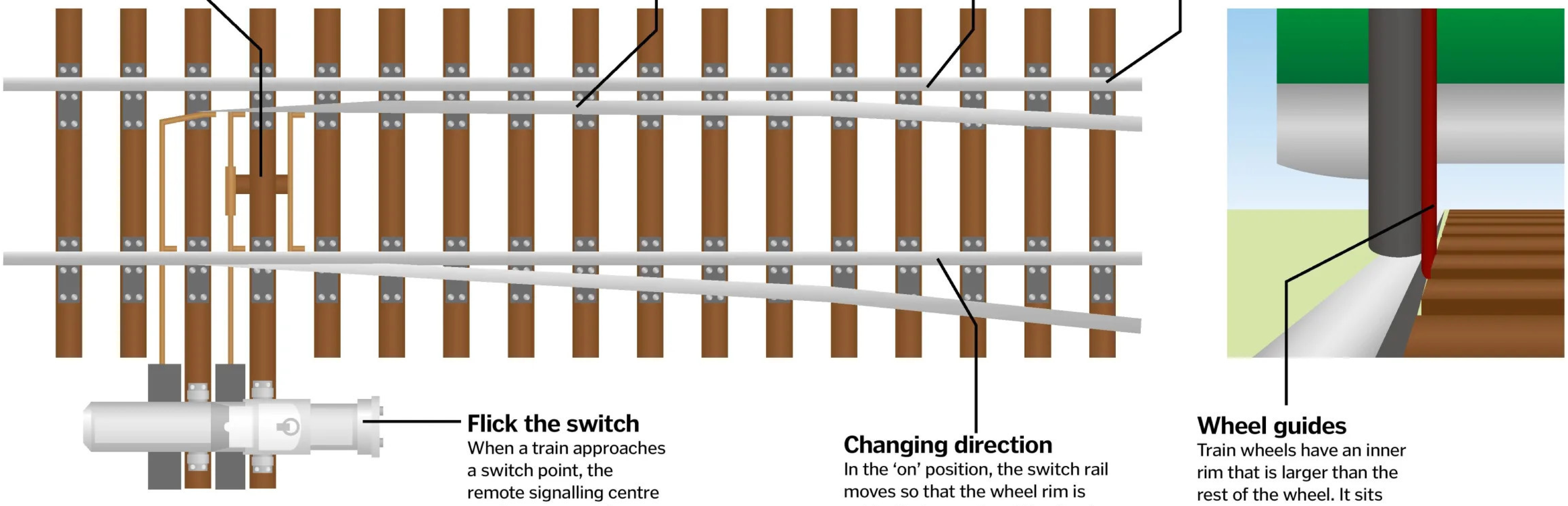
Brace for impact
Front suspension is mandatory for mountain bikes. Each fork contains a spring and an oil-filled damper, which keeps the wheel in contact with the ground and absorbs the impact of jumps.

Strong frame
Some higher-end off-roaders will forgo welded steel or aluminium for rectangular frames made of carbon fibre, which are stronger against up-down stresses.

Mountain bikes with full suspension are ideal for rough terrain, as they help to absorb impact

How do trains change tracks?

The simple switches that let trains reach different destinations



The quietest place on Earth

The extraordinary rooms that make it possible to hear your own heartbeat

You haven't truly experienced silence until you've been in an anechoic chamber. These rooms are made from heavy concrete with rubber-sealed doors to prevent any sound at all from getting in. Inside, the walls are covered in foam wedges to absorb internal noise, and the floor is a suspended mesh to eliminate the sound of footsteps. Every inch is designed to absorb reflections of sound waves, so you hear absolutely nothing.

These chambers are mainly used to test the performance of speakers, microphones and other products, but they also help astronauts to prepare for the eerie silence of space. The longest anyone has been able to bear the quiet for is 45 minutes. Orfield Laboratories, which is in the US, currently holds the Guinness World Record for the quietest place on Earth, as the walls can absorb 99.9 per cent of sound.

In this environment, all a person can hear is the thumping of their heart, which can quickly drive them crazy, and with no perceptual cues to help them balance, it's also incredibly disorientating and difficult to stand or move. So next time you wish for a bit of peace and quiet, think again.

Anechoic chambers absorb all sound so there are no echoes

How smoke detectors work

They may annoy us when toast burns, but these ear-piercing devices save lives

There are two main types of smoke detector: optical and ionisation. Optical detectors contain an infrared light beam pointing toward a photocell, which generates electricity when light falls on it (like on solar panels). When there is no smoke, the light reaches the photocell unobstructed. This is registered by the internal circuitry so the alarm is not triggered. When there is a fire, smoke enters the detector and blocks the beam of light, so the photocell can no longer produce an electric current. This change is picked up by the circuitry, triggering the alarm and alerting people to danger.

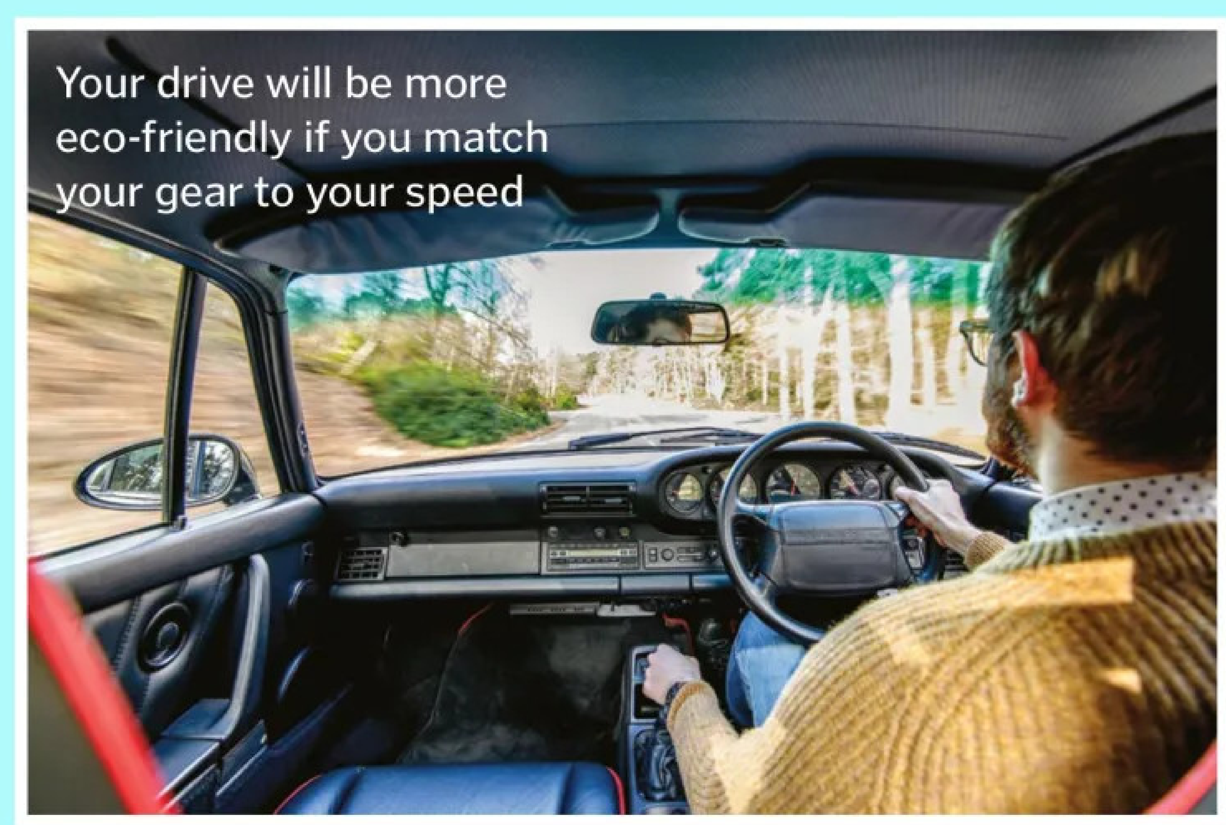
Ionisation detectors contain a small sample of a radioactive substance, typically americium. This element constantly emits alpha particles (positively-charged helium nuclei), which pass between two charged metal plates called electrodes. The alpha particles collide with air molecules and split them into positive ions and negative electrons. These charged particles are then attracted to opposite electrodes, causing a current to flow. Smoke particles can attach to ions and neutralise them, so they are no longer attracted to the electrodes. A sensor detects the drop in current and the alarm is triggered.

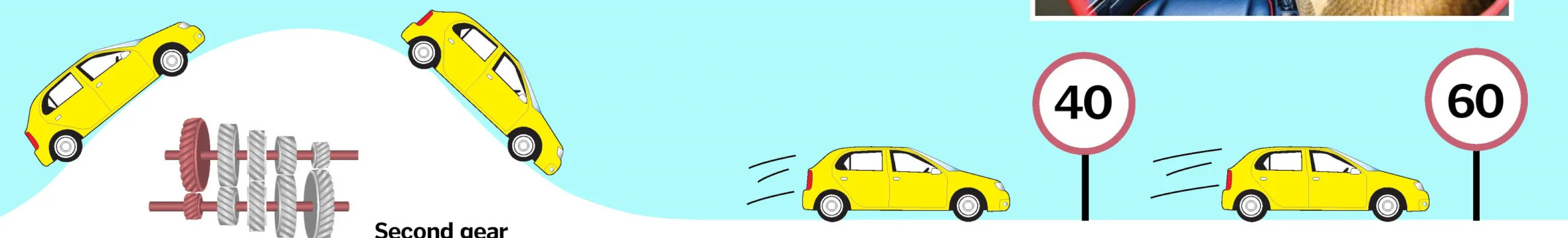
Detectors are placed high up because hot smoke is less dense than air, so it rises

Gearboxes explained

How a gearbox transfers power from the engine to the wheels

A gearbox is attached to a car's engine, and power generated from the engine flows through it before being passed on to a car's wheels. The pistons in the engine have to pump constantly – with a minimum speed of 1,000RPM – to stop the engine cutting out. To stop the car flying off at top speeds, the gearbox controls how much of this power gets to the wheels. Cogs and shafts inside the gearbox create different ratios of speed and torque, which are known as gears. Each gear works best in a different situation, depending on the speed of the car and the incline of the road.


Your drive will be more eco-friendly if you match your gear to your speed



First gear

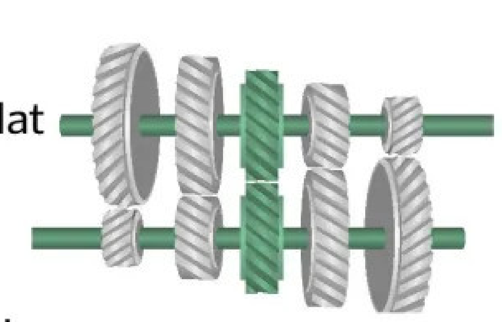
First gear uses lots of torque and is commonly used to get the mass of a vehicle moving from standstill, or to propel a car slowly up a very steep slope.

Second gear

Second gear is commonly used when traveling down hills with steep inclines. This is because gravity is pulling the car down the hill, so no or little torque is needed from the engine to move the car.

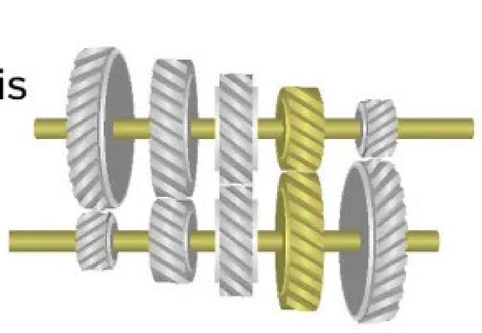
Third gear

Accelerating on a flat surface is likely to require third gear, which sends more torque to the wheels to get them – and the car – moving faster.



Fourth gear

The fourth or 'top gear' is used for high speeds where low amounts of torque are needed. It is usually more fuel-efficient to be in a higher gear at high speeds.




This cement kiln is fuelled by burning old car tyres

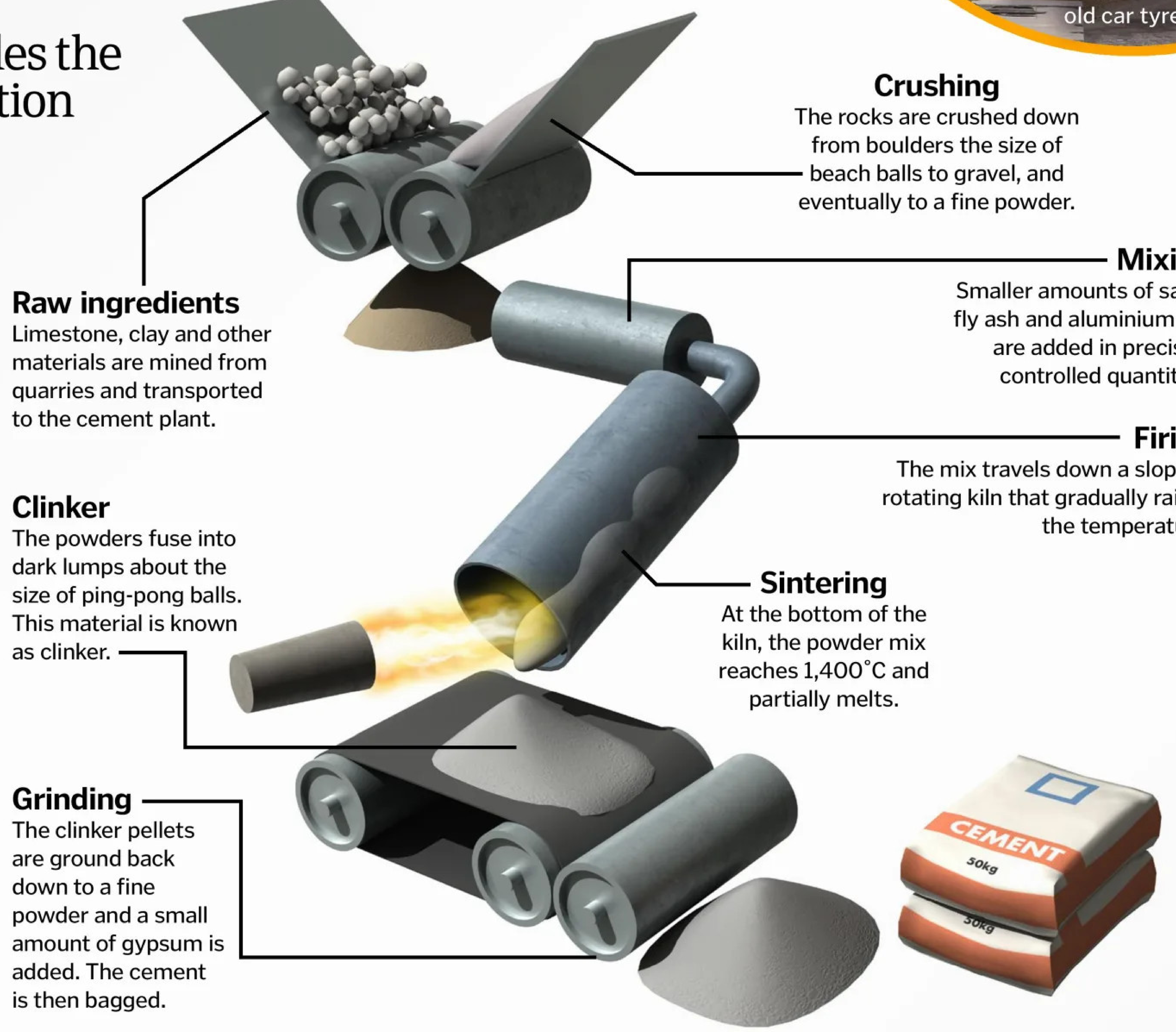
Concrete vs cement

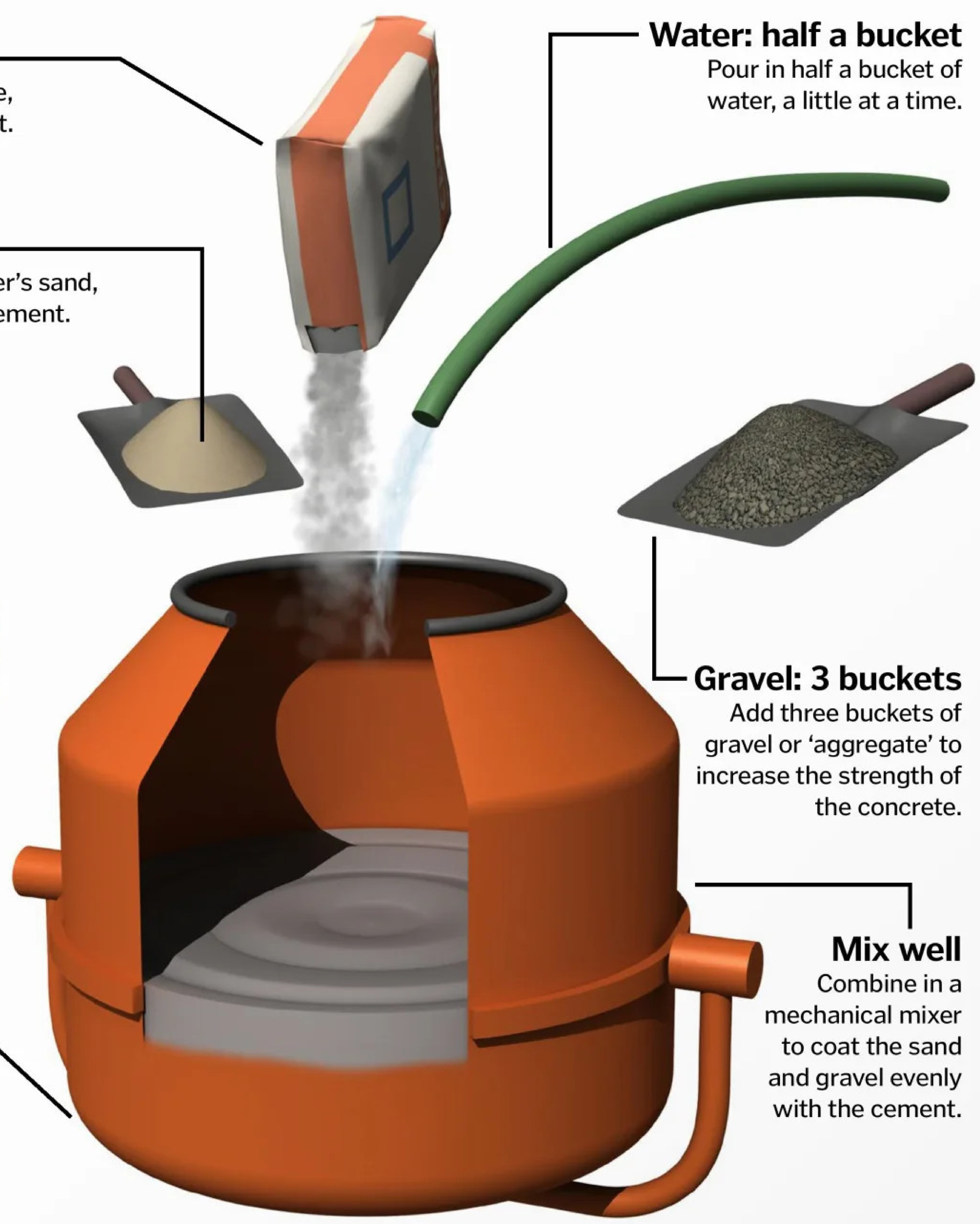
CEMENT

This ancient technology provides the foundations of modern civilisation

Cement is made from a mixture of calcium, silicon, aluminium and other ingredients, which are heated and ground into a fine powder. When this mixture is combined with water, it forms a complex, interlocking crystal structure that is incredibly strong. In other words, cement hardens by reacting with water, rather than by drying out in the air as many other binding materials do. This means that it will even set underwater!

Cement was first used by the Ancient Macedonians and, three centuries later, by the Romans. Their recipe used limestone, with volcanic ash from Mount Vesuvius to provide the crucial silica and aluminium minerals. Modern cement uses clay instead of volcanic ash, but fly ash from coal-fired power stations is also added. The most widely used kind is called Portland cement because it has the same colour as Portland stone from Dorset, UK. The exact recipe for Portland cement was worked out by trial and error in the 19th century but the precise chemical reactions are still not fully understood.






Steel reinforcing bars or 'rebar' are usually embedded in concrete to make it even stronger

CONCRETE

Powdered cement can be turned into super-sturdy concrete with just a few added ingredients

Concrete is stone, sand and gravel held together by a key ingredient: cement. The stones in the concrete are stronger than the cement itself, so this is a way of transforming the mixture into a durable building material.

The chemical reaction that hardens the cement only requires about one part water for every five parts cement, by volume. However, a concrete mix this dry would be unworkably stiff and would leave air gaps that would weaken the structure overall. This is the reason why concrete is normally made with one part water for every two parts cement.

Modern high-performance concrete also has 'silica fume' added to it. This is an incredibly fine silicon dioxide powder, which is a by-product of industrial silicon production. The huge surface area of the tiny silica particles traps the water within the concrete and helps prevent cracking.

Casino technology

The ingenious innovations casinos use to catch criminals and boost profits

With their sprawling floors of gambling tables and row upon row of slot machines, casinos can cash in millions of pounds every day. However, with so much money at stake, they also find themselves vulnerable to the dark side of the gambling world – the professional crooks out to cheat their way to the jackpot. With such a vested interest and an enormous budget to play with, it's no wonder then that casinos are behind some of the biggest developments in surveillance technology. They have the funds to employ some of the best security experts in the business, and the tech they've developed has gone on to be used by many other sectors, including government agencies.

Of course, all this new technology is not just there to prevent big money scams. It can also help increase the casino's profits, and even benefit the customers too. Gamblers are willing to sacrifice a great deal of personal information when they register to play at casinos, which the establishment can use to encourage them to spend more money. In return, the customers are rewarded for their big bets with deals and perks that keep them coming back for more.

RFID chips help casinos keep track of profits and catch cheats

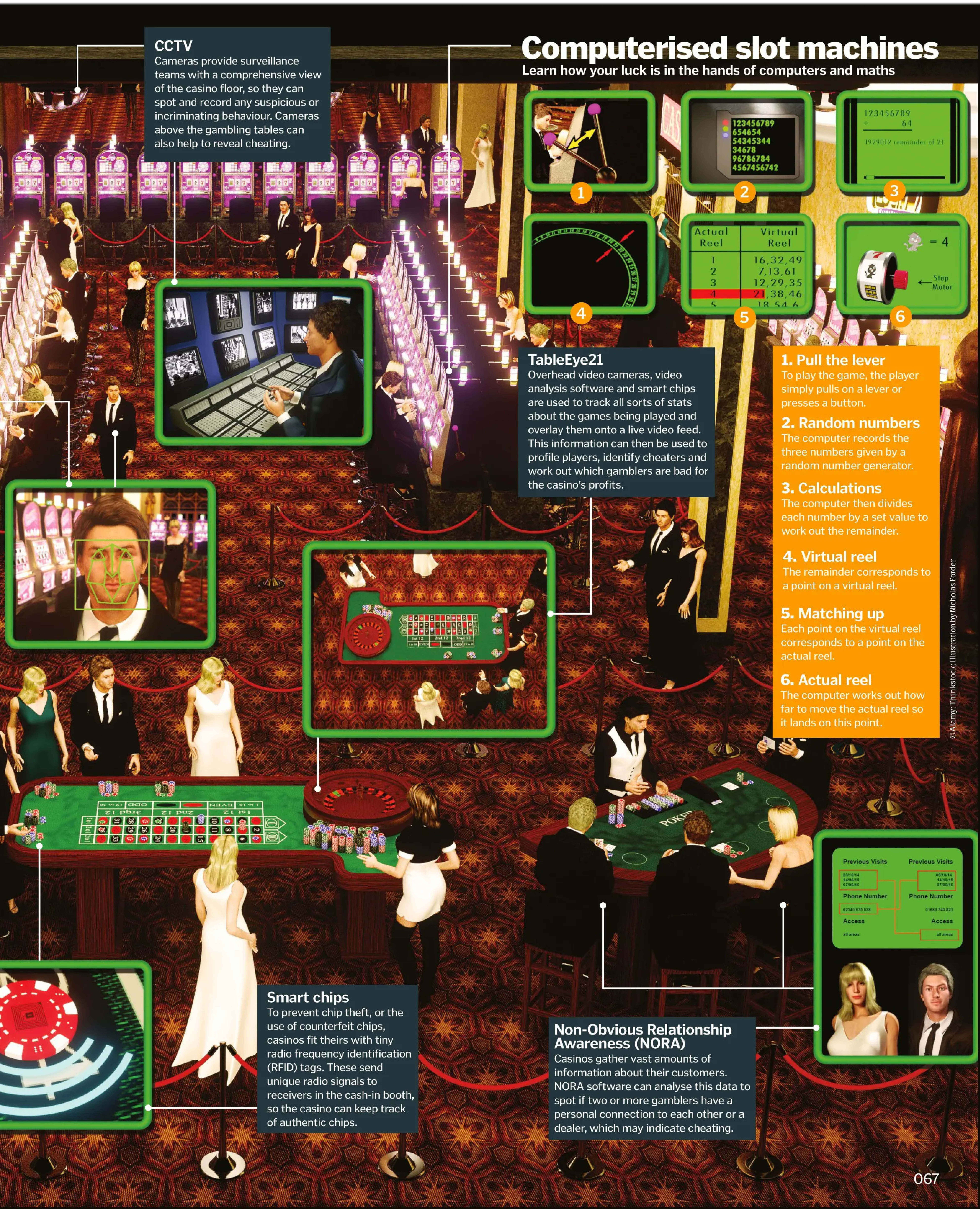
Gambling gadgets

Discover what tech can be found on the casino floor

"Casinos are behind some of the biggest developments in surveillance technology"

Computerised slot machines

Learn how your luck is in the hands of computers and maths



CCTV

Cameras provide surveillance teams with a comprehensive view of the casino floor, so they can spot and record any suspicious or incriminating behaviour. Cameras above the gambling tables can also help to reveal cheating.

TableEye21

Overhead video cameras, video analysis software and smart chips are used to track all sorts of stats about the games being played and overlay them onto a live video feed. This information can then be used to profile players, identify cheaters and work out which gamblers are bad for the casino's profits.

1. Pull the lever
To play the game, the player simply pulls on a lever or presses a button.

2. Random numbers
The computer records the three numbers given by a random number generator.

3. Calculations
The computer then divides each number by a set value to work out the remainder.

4. Virtual reel
The remainder corresponds to a point on a virtual reel.

5. Matching up
Each point on the virtual reel corresponds to a point on the actual reel.

6. Actual reel
The computer works out how far to move the actual reel so it lands on this point.

Smart chips

To prevent chip theft, or the use of counterfeit chips, casinos fit theirs with tiny radio frequency identification (RFID) tags. These send unique radio signals to receivers in the cash-in booth, so the casino can keep track of authentic chips.

Non-Obvious Relationship Awareness (NORA)

Casinos gather vast amounts of information about their customers. NORA software can analyse this data to spot if two or more gamblers have a personal connection to each other or a dealer, which may indicate cheating.

Camera tech

Exposing the inner working of your digital camera

Compact system cameras are a cross between a compact and a DSLR

Digital cameras are incredibly complex gadgets, able to capture and process an image in just a fraction of a second.

There are three main types of digital camera. The most basic are compacts, which are usually pocketable, more budget-friendly and feature automatic modes, so all you need to do is point and shoot. However, the smaller size means a smaller sensor, which affects image quality. The reduced number of pixels means less information is recorded. To combat this, small sensors need to be more sensitive, which leads to grainy images.

Digital single-lens reflex (DSLR) cameras, on the other hand, are much bigger, so they can accommodate much larger sensors for crisp, clear images. They also enable you to change the lens, so you're not restricted to the focal lengths of a fixed-lens compact. Another big difference is the optical viewfinder, usually positioned on top of the camera. When framing shots with a compact camera, light enters the lens and travels straight to the sensor, which then displays a digital image on an electronic viewfinder, or LCD. In DSLRs, the light hits an angled mirror in front of the sensor, which bounces it up to an optical viewfinder. Then when you take the photo, the mirror flips up, letting the light pass through to the sensor so it can be recorded.

The third type of digital camera is the compact system camera, which is a cross between a compact and DSLR. These models don't have optical viewfinders, which is why they are also referred to as mirrorless cameras, but they do have an interchangeable lens. With larger sensors than most compacts, and more manual controls, they offer many of the advantages of a DSLR but in a smaller, lighter camera.

Controlling exposure

Photography is all about recording light. If your camera's sensor is exposed to too much light, your photo will be too bright, or overexposed, but if it is not exposed enough, it will be too dark, or underexposed. To control the amount of light that reaches the sensor, you can adjust the three main exposure settings. In auto mode, the camera will do this for you.

Aperture

There is an opening inside a lens called an aperture, the size of which can be tweaked. A large f-number (such as f22) makes the opening smaller, allowing less light into the lens, whereas a small f-number (such as f2.8) will widen it, allowing more light in. This also controls how much is in focus. Large numbers keep everything sharp, and small numbers will blur backgrounds.

f1.8; small f-numbers blur the background to make your subject stand out

f13; large f-numbers keep both the background and foreground in focus

Shutter speed

The time a camera's shutter stays open for can be adjusted with the shutter speed. A fast shutter speed (such as 1/250sec) will keep the shutter open for just a fraction of a second, only letting a bit of light in, whereas a slow shutter speed (such as 30sec) will keep it open longer. Fast speeds are great for sharp action shots, and slow speeds let you blur any movement in a scene.

1sec; use a tripod when using slow shutter speeds to avoid blurring stationary subjects

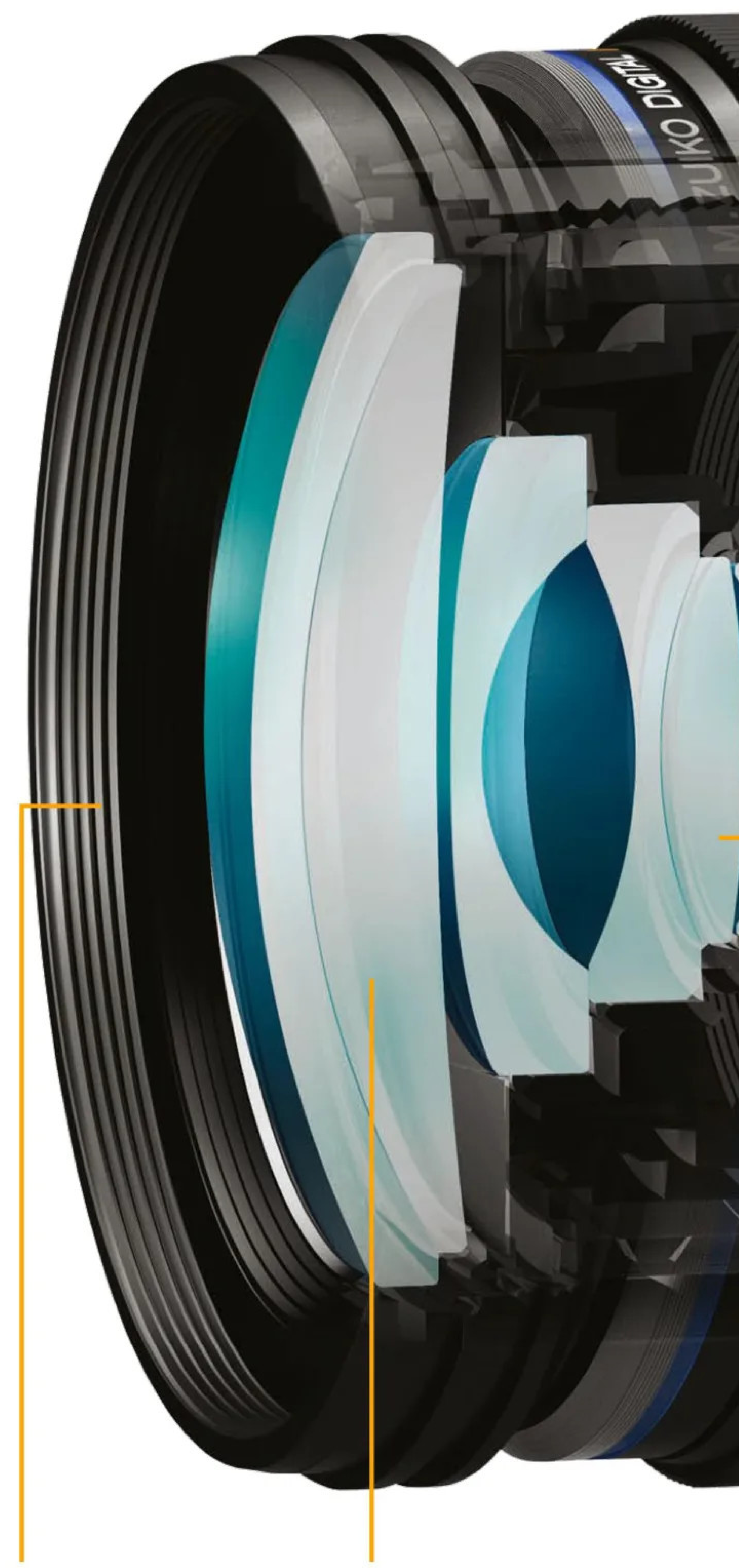
1/1600sec; fast shutter speeds freeze any movement to capture a split second in time

ISO

By adjusting your camera's ISO setting, you can control how sensitive the sensor is to light. A high ISO (such as 1600) will boost the sensitivity, making the final photo brighter, but can also create digital noise, making your photo appear grainy. It's best to only increase the ISO as a last resort and adjust the aperture and shutter speed to brighten the shot instead if you can.

ISO 100; a low ISO will make sure you keep your photo crisp and clear

ISO 1600; a high ISO will brighten your shot but can make it grainy



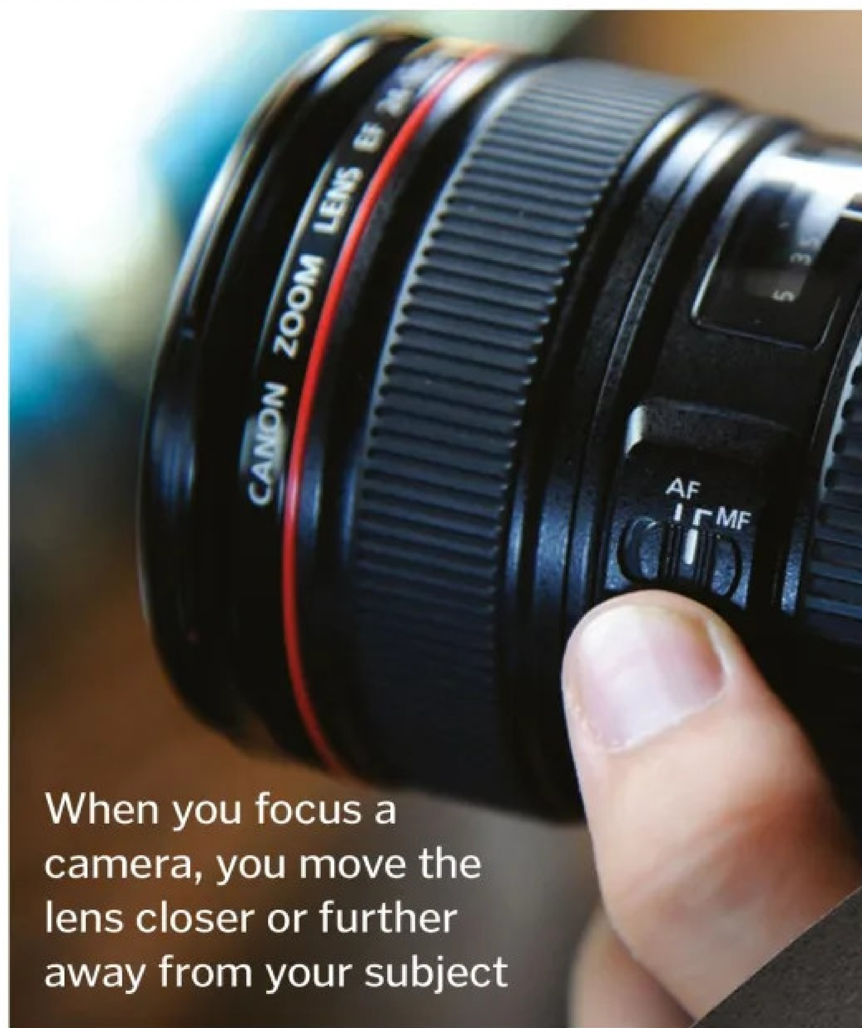
Into the lens
Light bounces off the subject or scene you are shooting and enters the camera lens.

Focus the light
The curved glass of the lens bends all of the light rays onto one single point – the image sensor.

Stay focused

When rays of light bounce off of an object and pass through the lens, they bend at a certain angle and then converge on the sensor to create an image. If they converge too far in front of the sensor, or don't converge by the time they reach it, the image will be out of focus.

To keep the image in focus, you can adjust the distance between the lens and the object to control where the rays meet. The closer the lens is to the object, the smaller the angle at which the rays will bend and the further away the point at which they will converge.



When you focus a camera, you move the lens closer or further away from your subject

Picture perfect

What happens inside your camera when you take a photo?

Record the colour

In front of the sensor, a colour filter array ensures red, blue and green light only reaches certain pixels.

Making the final image

The microprocessor uses the available data from the sensor to recreate the image and save the digital file onto a memory card.

Accurate colours

The lens bends different wavelengths of light at different angles, so a further series of lenses helps to realign the colours.

Capture the light

A mechanical shutter in front of the sensor opens briefly, letting light through. The time that it remains open for is known as the shutter speed.

To the sensor

The sensor is made up of millions of light sensitive cells called pixels, which convert the light into electric signals.

Process the data

The electrical charge of each pixel provides the camera's microprocessor with information about the colour and brightness of the light.

Your car's air con explained

This cool tech relies on a chemical refrigerant to work

The subtle engineering that is sure to keep you cool behind the wheel

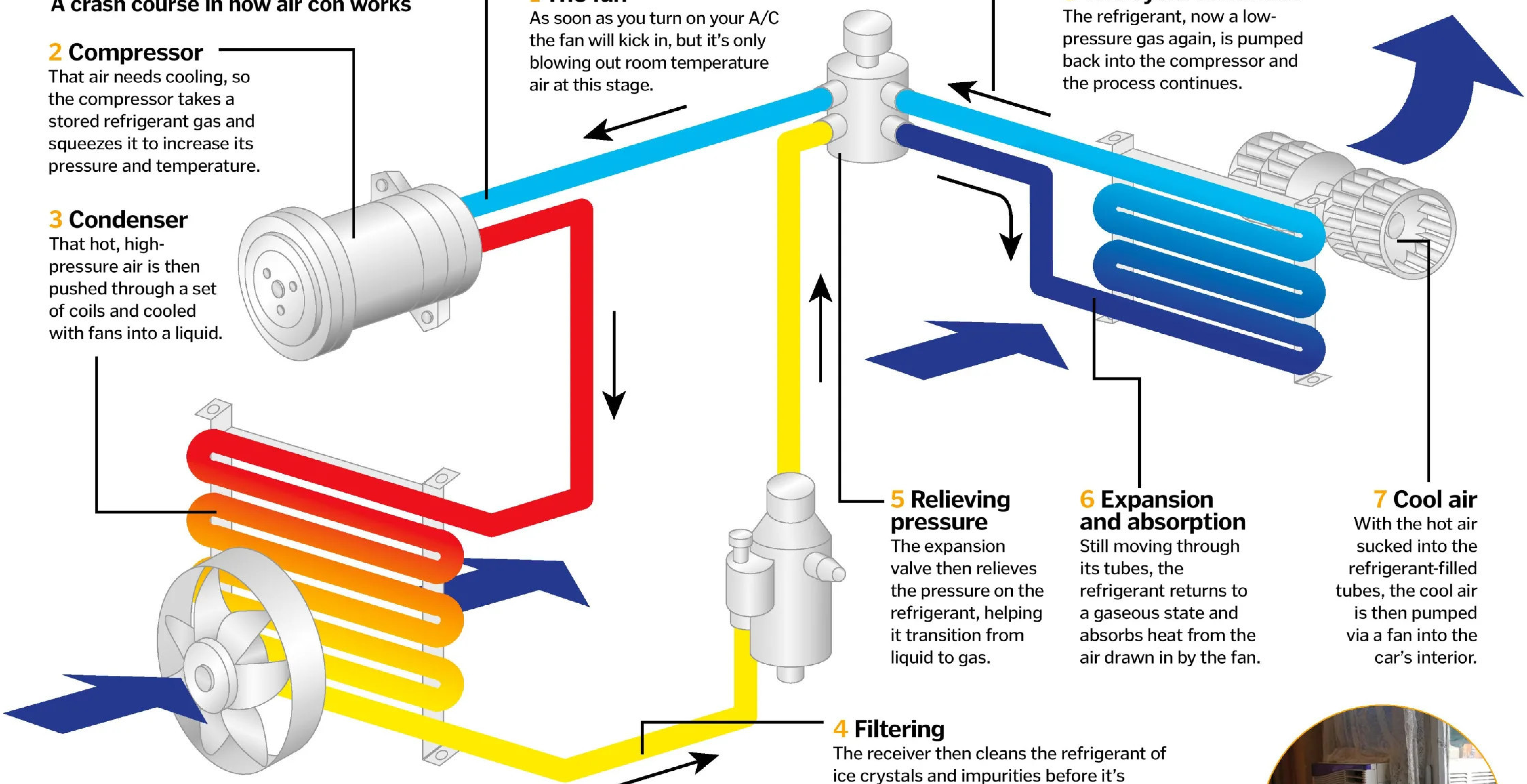
Like its stationary counterparts, the air conditioning unit in a car works on much the same principle. The process is broken down into four main stages – evaporation, condensation, compression and expansion – with each playing a vital role. It all starts when you press the A/C button on your dashboard. First off, a refrigerant gas (usually Puron or Freon) is pumped through a series of tubes by a compressor. Acting as the heart of the process, the compressor forces the vapour into a high-pressure state, causing its temperature to rise.

This hot air passes through a condenser, which uses fans to cool the refrigerant gas into a liquid. The cool liquid is then pumped into a receiver, which removes any moisture or ice crystals that could damage the circuit. Finally, it is pumped into an expansion valve that reduces its overall pressure, allowing it to pass into the evaporator.

The refrigerant has a very low boiling point and so becomes a gas again, even at the temperature of the car cabin. Heat from the air drawn in by the fans on the dashboard is then absorbed by the refrigerant, and the cool air that remains is pumped into the car's interior.

Riding in comfort

A crash course in how air con works



1 The fan
As soon as you turn on your A/C the fan will kick in, but it's only blowing out room temperature air at this stage.

2 Compressor
That air needs cooling, so the compressor takes a stored refrigerant gas and squeezes it to increase its pressure and temperature.

3 Condenser
That hot, high-pressure air is then pushed through a set of coils and cooled with fans into a liquid.

4 Filtering
The receiver then cleans the refrigerant of ice crystals and impurities before it's pushed into the expansion valve.

5 Relieving pressure
The expansion valve then relieves the pressure on the refrigerant, helping it transition from liquid to gas.

6 Expansion and absorption
Still moving through its tubes, the refrigerant returns to a gaseous state and absorbs heat from the air drawn in by the fan.

7 Cool air
With the hot air sucked into the refrigerant-filled tubes, the cool air is then pumped via a fan into the car's interior.

8 The cycle continues
The refrigerant, now a low-pressure gas again, is pumped back into the compressor and the process continues.

A brief history of A/C

1758
Humble beginnings
An early A/C is constructed by Benjamin Franklin and British chemist John Hadley as they discover alcohol can be used to freeze water.

1902
First commercial unit
US engineer Willis Carrier invents a unit that blows air over sets of cold coils to cool the warehouse of a publishing company.

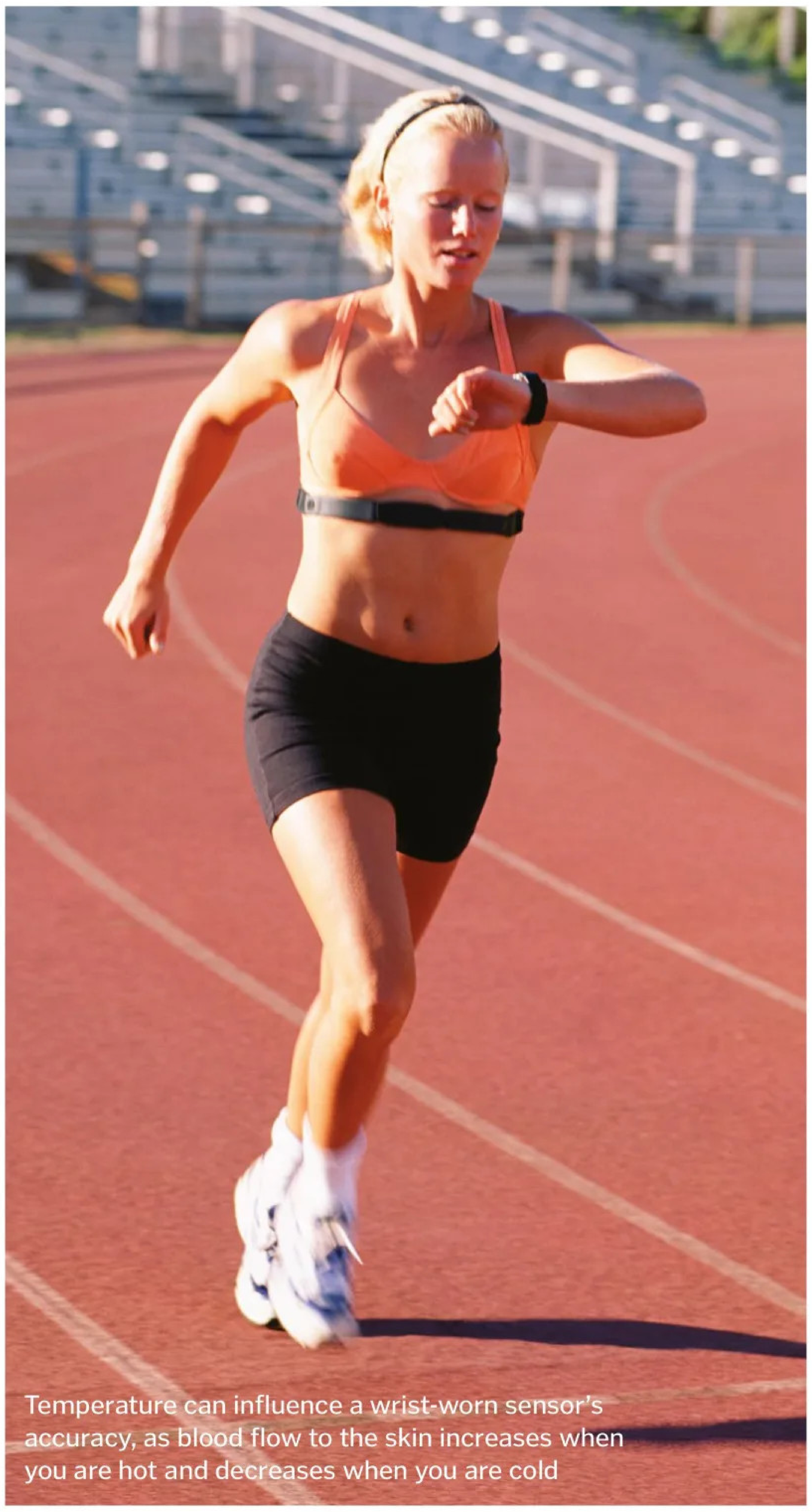
1931
In the home
HH Schultz and JQ Sherman invent the first home-based air con unit, built outside of the house. This design is still used.

1939
Going mobile
The first air con unit is installed in a car by luxury company Packard, but they were already used in limousines from 1933.

1953
Air con takes off
After the US housing boom, air con units become a mainstay in suburbs across the nation. In 1953 alone, one million units are sold.

Heart rate monitors

How these fitness gadgets use light to detect your pulse


Temperature can influence a wrist-worn sensor's accuracy, as blood flow to the skin increases when you are hot and decreases when you are cold

1. Flashing light
A green LED flashes hundreds of times every second, while a light sensor detects how much is reflected.

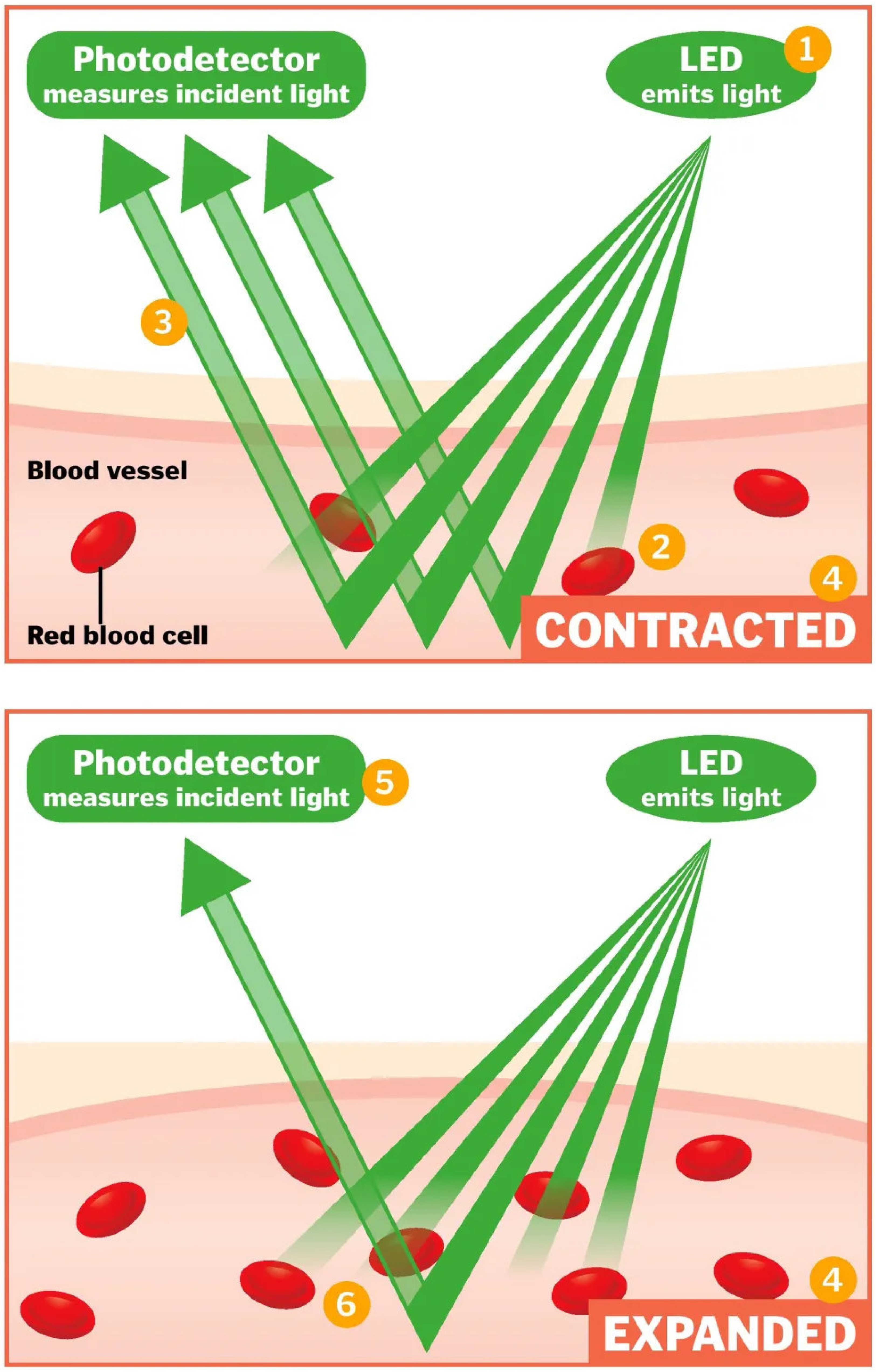
2. Simple principle
Red blood cells reflect red light and absorb green light.

3. Reflection
Some of the light that isn't absorbed is reflected back to the light sensor.

4. Blood flow indicator
Your blood flow is highest when your heart pumps and arteries expand, and is reduced between beats when arteries contract.

5. Change in light
By detecting fluctuations in the amount of light being absorbed, the monitor can calculate how many times your heart beats each minute.

6. Absorption
The green light travels through the skin and some is absorbed by the red blood cells. When your heart beats, blood flow is greater, so absorption increases.



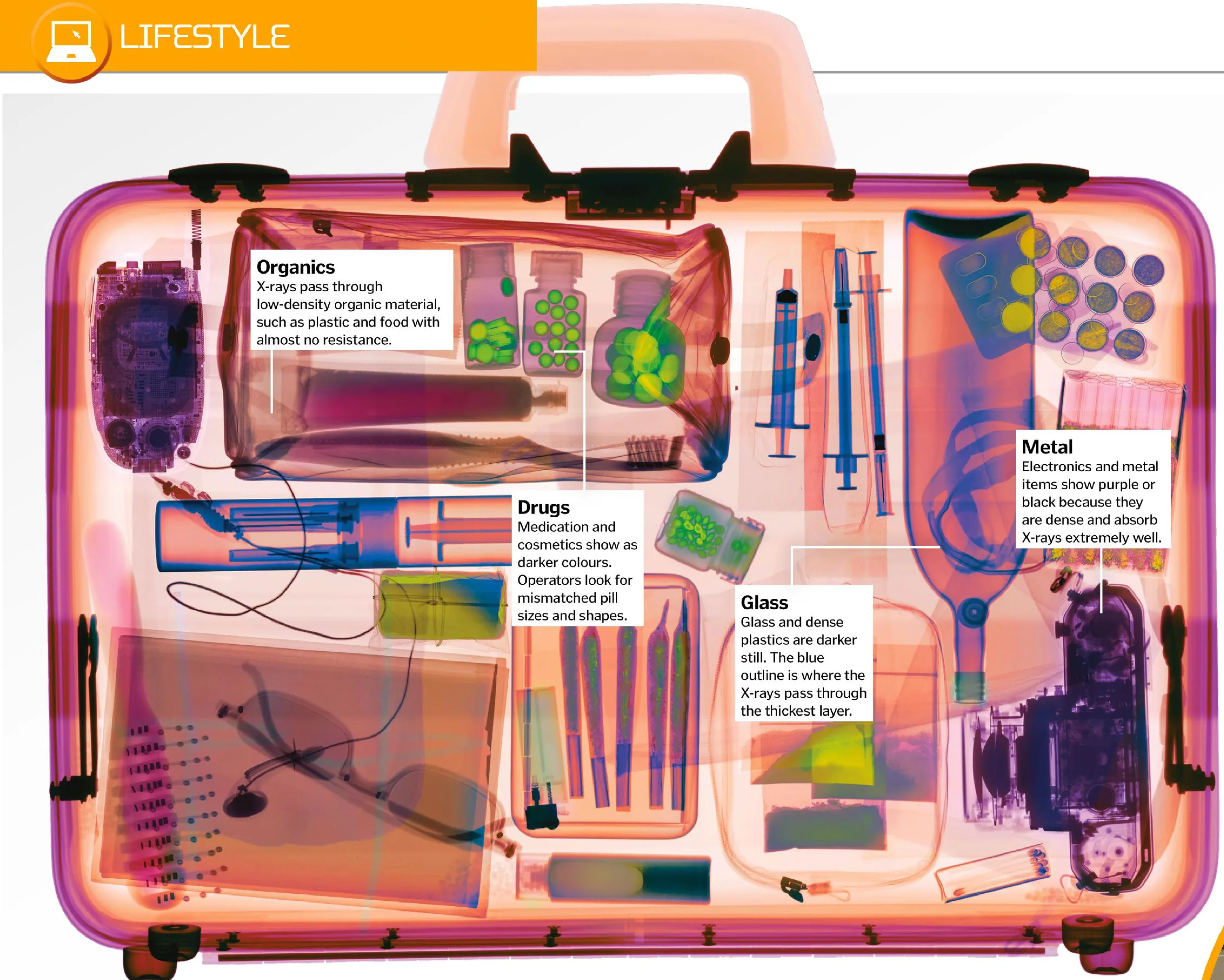
Photoelectric cells explained

How do automatic doors and taps know you're there?

There's no magic involved in these everyday gadgets that can sense your presence. Both work with the help of photoelectric cells, which use light's photons (its elementary particles) to generate electricity. One type of this cell contains 'photoconductive' materials, which means their ability to conduct electricity changes when they are subjected to light. Each cell features a small lens fitted over a piece of light-sensitive calcium sulphide. When light shines through the lens, the electrons become more mobile, reducing the overall resistance in the cell. This allows current to flow through the circuit freely.

Some automatic doors and taps work using light-dependent resistors (LDRs) – a type of photoconductive cell. A beam of infrared light is shone in front of the door or tap and received by an LDR, enabling a steady flow of current to pass through it. When something blocks the beam of infrared, such as a person, it can no longer be detected by the LDR. This causes an increase in the cell's electrical resistance and a reduction in the flow of current. A separate circuit detects this change and triggers the door to open or the tap to switch on. A few seconds after the beam of light is restored, both will reset to their default closed position.


As soon as the sensor beam is disrupted, the tap turns on



Airport security

What happens to your luggage when it passes through the scanner?

The scanner that checks your hand luggage provides security staff with an instant view of the contents, automatically colour-coded according to the material each item is made from. It works by shining an X-ray beam through the bag from two directions. As each beam strikes your luggage, some of the X-ray energy is absorbed or scattered by the contents. The X-rays hit a detector on the other side, which makes an initial measurement of their position and energy. The beam then passes through a filter that absorbs low-energy X-rays, but allows high-energy X-rays to pass through and strike a second detector. This helps to reveal low-density items that don't absorb X-rays well.

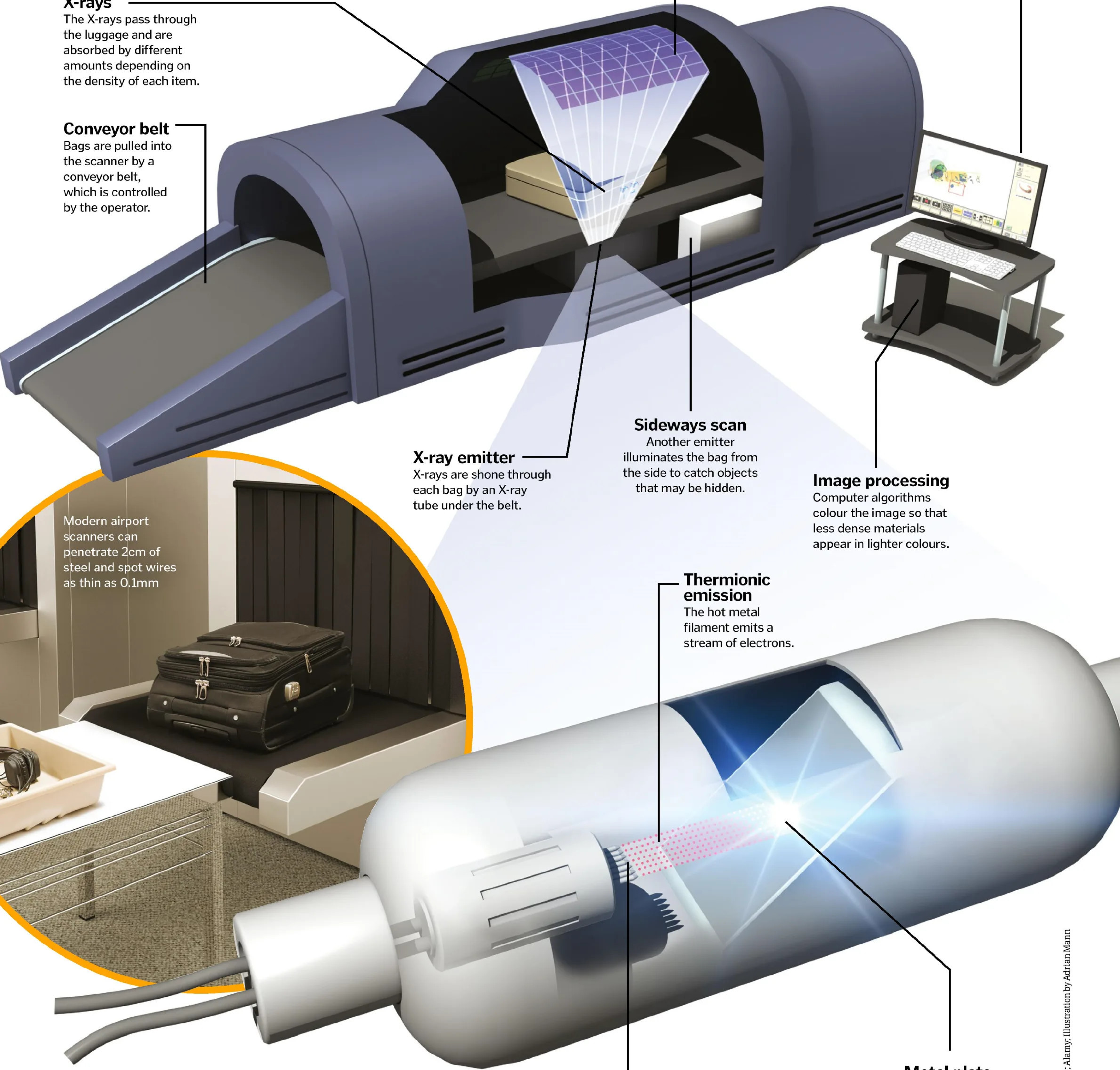
Computer algorithms use the pattern of X-ray absorption to determine the effective atomic mass of the material being scanned, as well as its density. Cross-referencing these values against a database of known substances allows the scanner to tell the difference between face cream and a plastic explosive, or cocaine and sugar, for example. Image-processing software then colours each item in the scan according to its material, and highlights any likely threats. To keep operators alert and focused, the software will occasionally insert a fake digital image of a suspicious item to check it is identified correctly.

Check-in baggage has to be scanned as well, and the automated X-ray machines used at UK airports can handle 1,800 bags an hour. If one of these spots something suspicious, it is automatically rechecked by a more sophisticated scanner that takes virtual slices all the way through the bag, like a hospital CT scan. This takes 16 seconds per bag and if the results from this are still flagged as a threat, a human operator will review the results of both scans, and determine if the bag needs to be opened.


145,000 bags pass through Heathrow airport every day, and they are all scanned

Inside a baggage scanner

How invisible X-rays can create a coloured image of your luggage



X-rays
The X-rays pass through the luggage and are absorbed by different amounts depending on the density of each item.

Detector
The X-rays that make it through are detected by a two-pass filter, which provides maximum contrast.

Display
The operator can pause the display and enlarge or enhance the image.

Conveyor belt
Bags are pulled into the scanner by a conveyor belt, which is controlled by the operator.

X-ray emitter
X-rays are shone through each bag by an X-ray tube under the belt.

Sideways scan
Another emitter illuminates the bag from the side to catch objects that may be hidden.

Image processing
Computer algorithms colour the image so that less dense materials appear in lighter colours.

Modern airport scanners can penetrate 2cm of steel and spot wires as thin as 0.1mm

Thermionic emission
The hot metal filament emits a stream of electrons.

Filament
An electric current heats a wire until it glows like a light-bulb filament.

Metal plate
When the high-speed electrons strike a metal plate, the collisions generate X-rays.

How automatic door mechanisms work

How do these doors know to open when you approach?

As the most popular supermarket door choice, automation supports daily crowds that often leave with full hands

There's nothing more welcoming than a door opening for you. Without the need to be touched to open or close, automatic doors are essential in improving disabled access to buildings, facilitating hygiene in required areas and helping provide general convenience to commercial buildings.

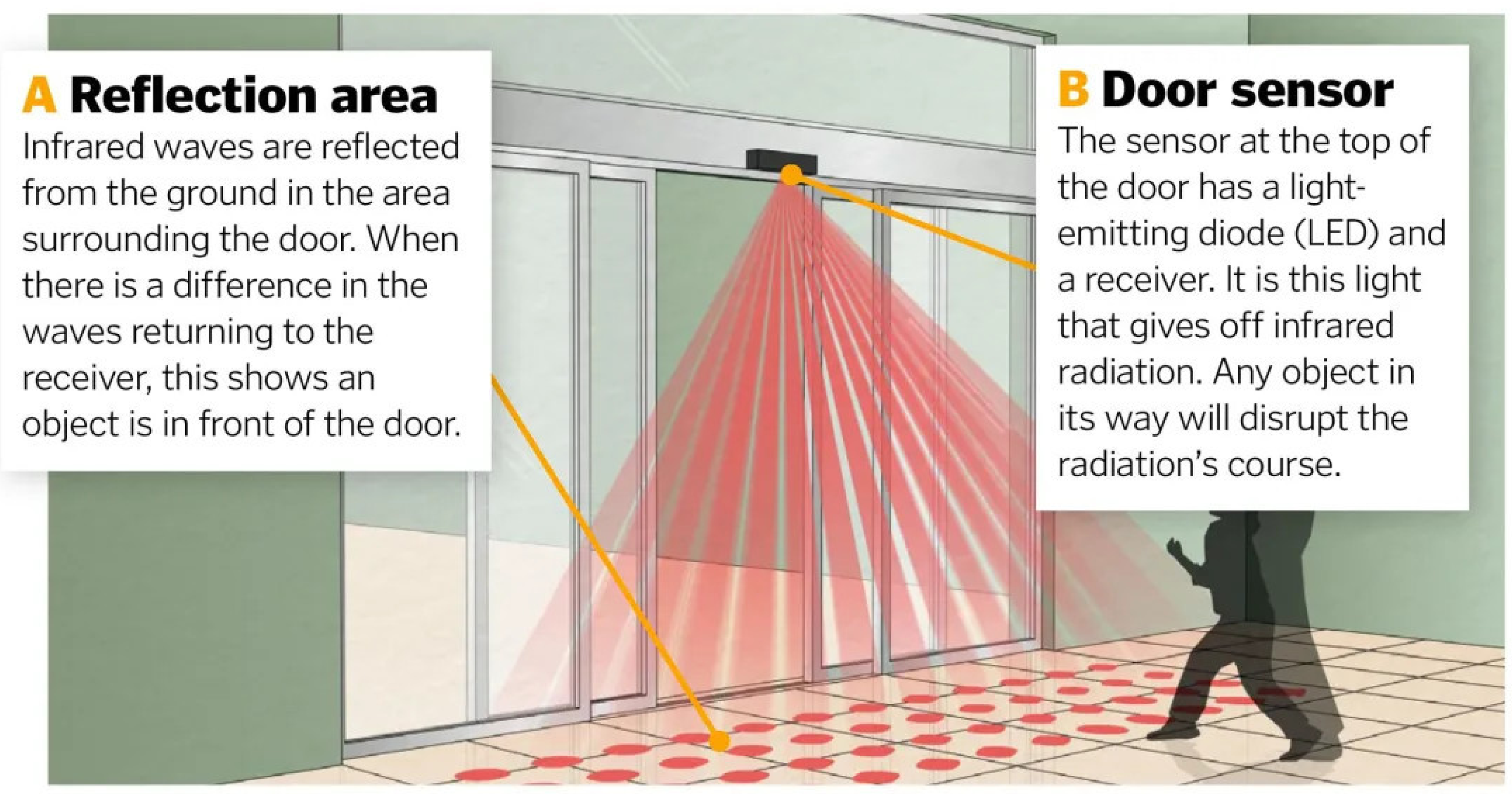
Self-sliding doors began to emerge as a commercial product in 1960 after being invented six years previously by Americans Dee Horton and Lew Hewitt. They started out as a novelty feature, but as their use has grown their benefits have extended within our technologically advanced world. Particularly useful in busy locations or during times of emergency, the doors act as crowd management by reducing the obstacles put in peoples' way. They give us one less thing to tackle during daily life and the occasional quick escape.

As well as making access both in and out of buildings easier for people, the difference in the way many of these doors open helps reduce the total area occupied by them. Automatic doors often open to the side, with the panels sliding across one another. Replacing swing doors, these allow smaller buildings to maximise the usable space inside without the need to clear the way for a large, protruding door.

There are many different types of automatic door, with each relying on specific signals to tell them when to open. Although these methods differ, the main principles remain the same. Each automatic door system analyses the light, sound, weight or movement in their vicinity as a signal to open. Sensor types are chosen to complement the different environments they are needed in. For example, a busy street might not suit a motion-sensored door, as it would constantly be opening for passers-by. A pressure-sensitive mat would be more appropriate to limit the surveyed area.

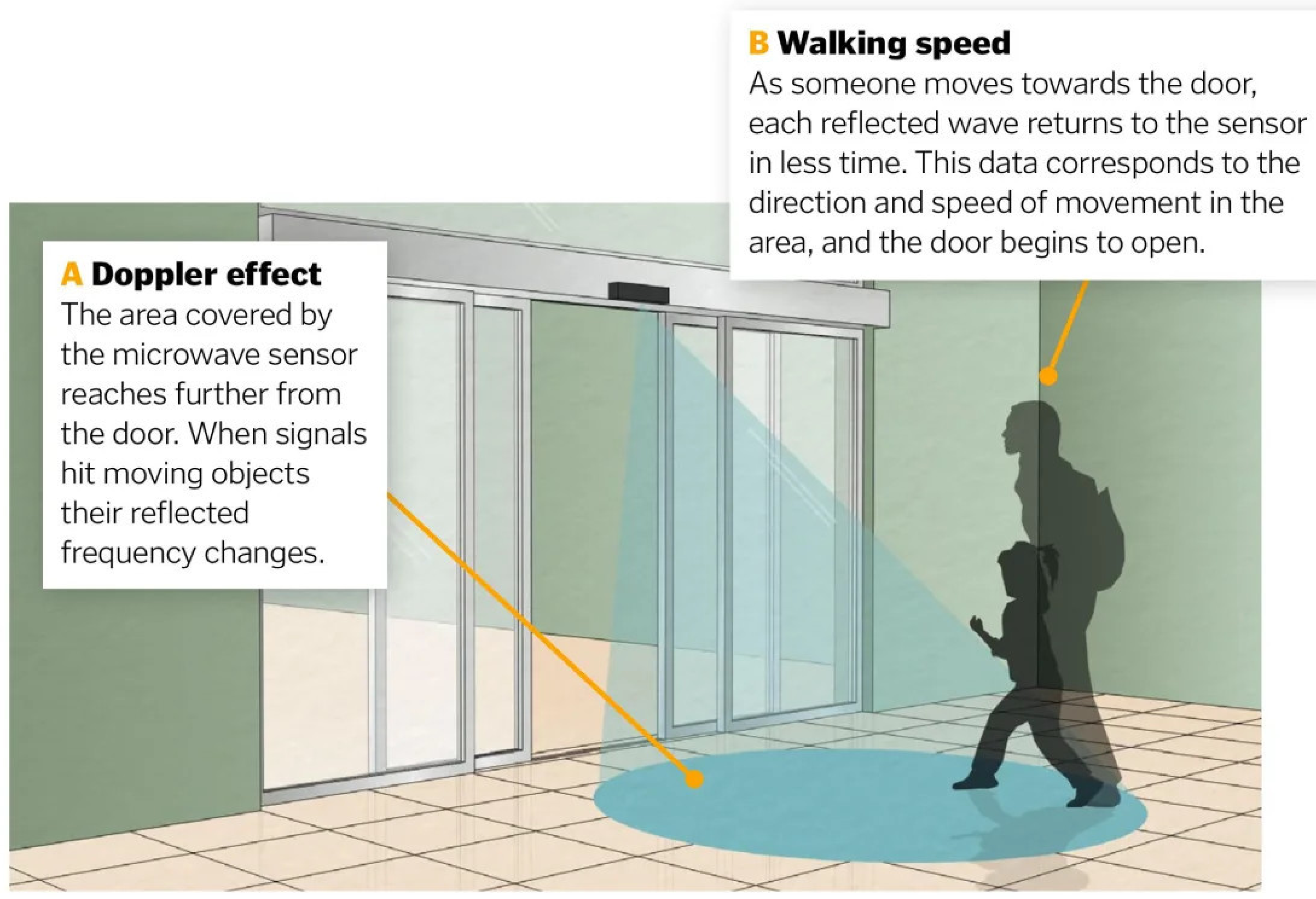
How different sensors work

In what ways can a door detect your presence?



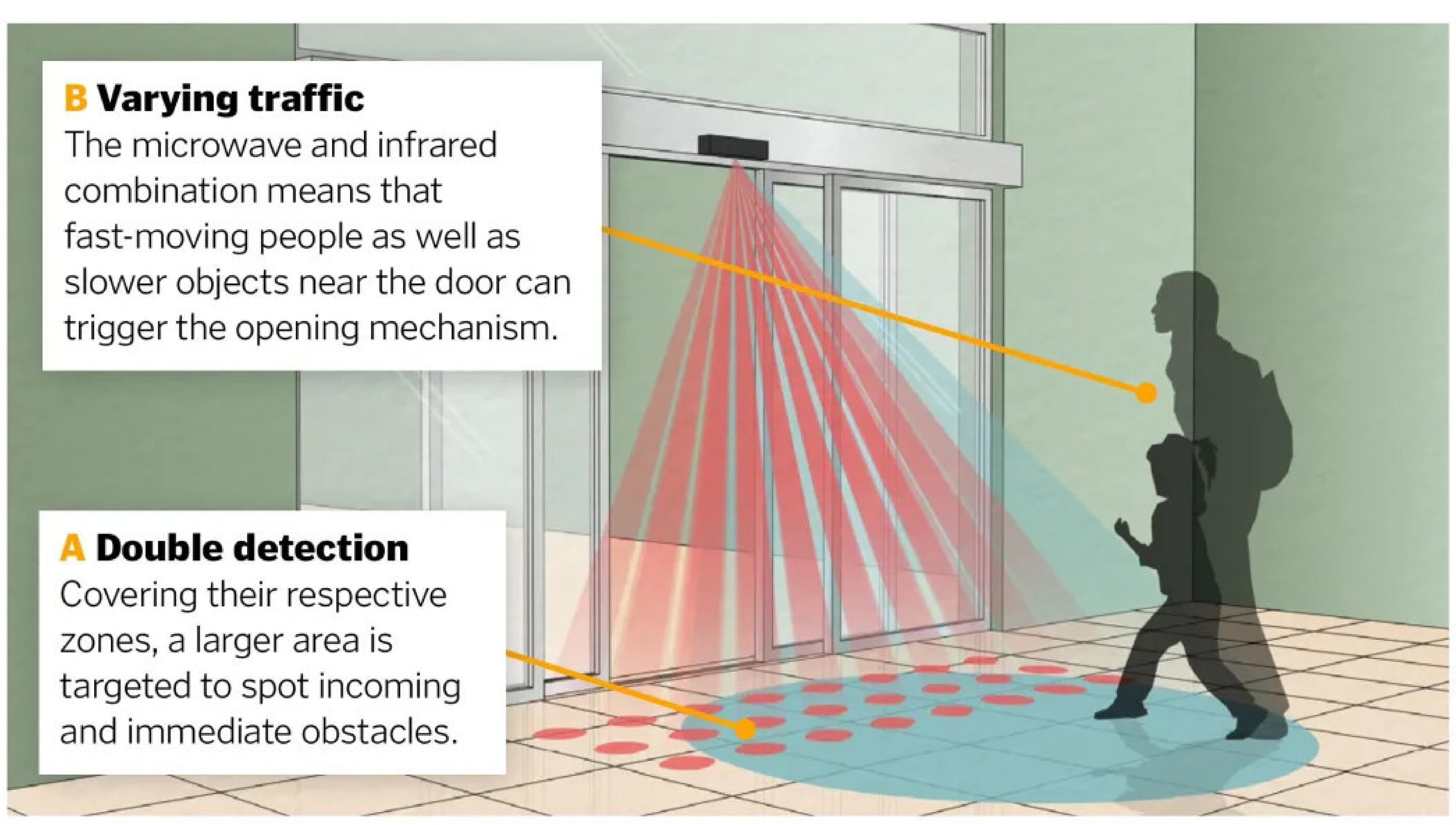
Active infrared

Everything that emits heat gives off infrared radiation, and it is the job of these sensors to detect it. Using infrared rather than movement makes the system suitable for detecting the heat of human bodies over other objects. Active systems give off and receive the wavelengths, differing from passive systems, which only receive.



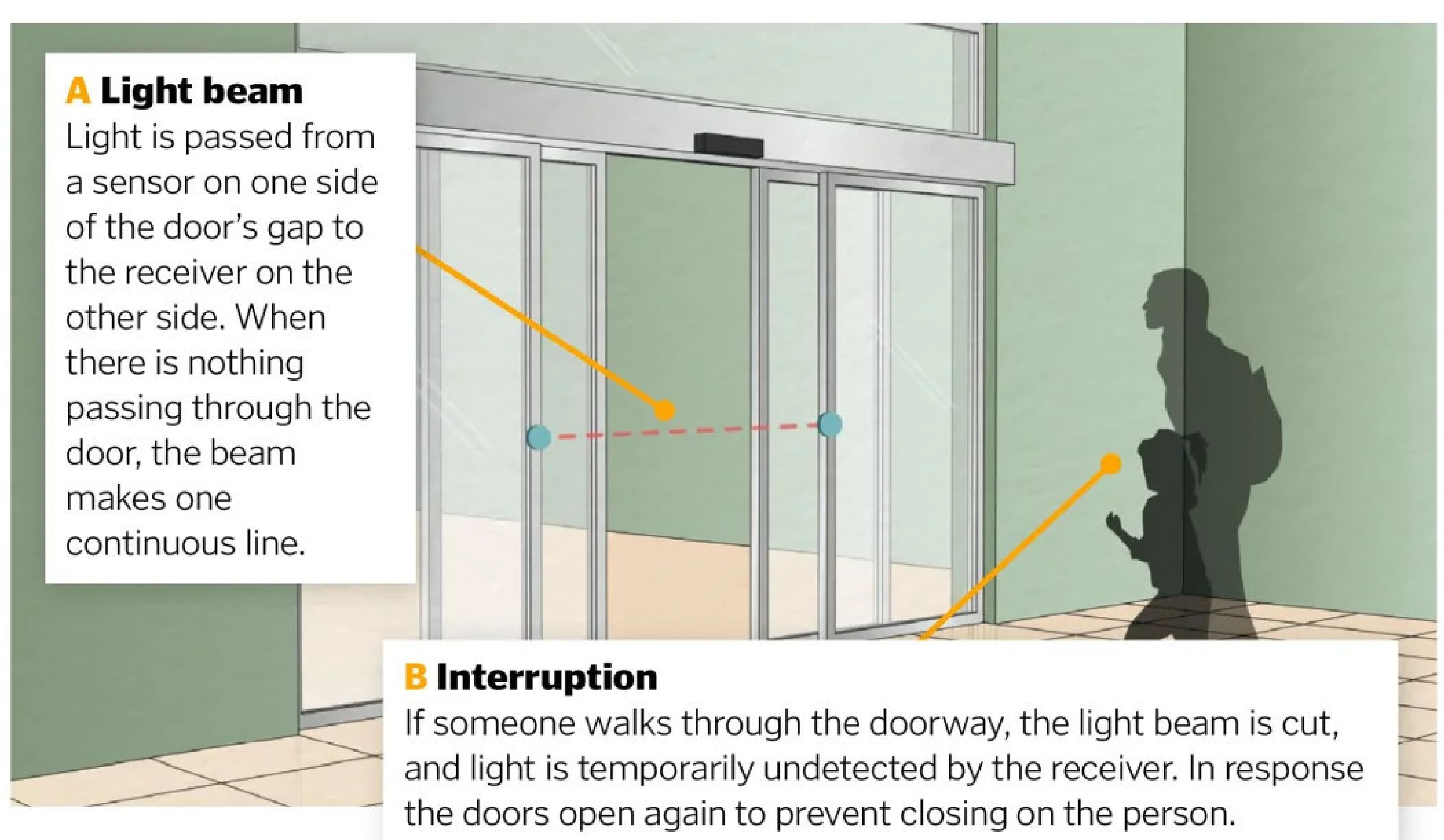
Microwave

Microwave sensors use electromagnetic radiation to detect any moving objects. Not only can they open when they sense movement, using microwaves means that the direction of travel can be pinpointed for improved accuracy.



Combined

Using both infrared and microwave technology increases the volume of data captured by the door. The combination of the two systems helps to improve accuracy and effectiveness, limiting the chances of standing in front of a door that won't budge.



Beam

This is one of the simpler automatic door mechanisms. Consisting of a beam of light, this acts as a safety feature, ensuring that the coast is clear when the door begins to return to its closed position.

How bass guitars work

The secret to those chest-pumping sounds is good vibrations

You might not always be able to hear it, but the bass guitar is one of the most important instruments in modern music. It usually tunes to the same scale as the double bass, but produces sound through an amplifier and a speaker because it lacks any natural amplification of its own.

The key to this electric amplification is a device called a magnetic pick-up. Mounted under the guitar's strings, the pick-up is able to detect their vibrations and send the information electronically to an amplifier and a speaker. In order to do this, the pick-up contains an electromagnet – a magnet wrapped in thousands of turns of fine wire – which can turn the tiny movements of the strings' vibrations into electrical energy. There are many different types of pick-up, and they can be located at various places on the bass guitar's body to give a distinctive combination of sounds.

The electrical signal that comes out of the pick-up would not be audible over the screaming fans, so it needs to be boosted by an amplifier and then driven into a speaker. If the signal is too powerful for the amp, the sound will become distorted in this process, but many musicians use this deliberately to add flair to their playing.

Plucking it apart

Peer inside a bass guitar and discover the origins of its rhythm-driving sound

Tuning up

Bass guitars usually come tuned in the EADG configuration, but that can be changed by tightening or loosening the strings with tuning nuts at the head of the guitar.

Vibrations

A pick-up contains a magnet wrapped thousands of times in fine wire. This coil can 'pick up' vibrations in the guitar string and translate the motion into an electrical signal.

Boost the sound

The signal can be adjusted by dials, and travels from the pick-up, through a power cord and into an amplifier, which massively increases its strength.

Don't fret

By placing fingers over the strings, you effectively shorten their length, and therefore change the vibrations they produce. The further down the neck you play, the higher the resulting notes will be.

Thick strings

Bass guitars work a lot like electric guitars, except their strings are a lot thicker. This means the vibrations are slower, which produces a deeper sound.

Size matters

The shape or depth of a guitar's body can alter the sound it makes – most guitars are solid, but hollow-bodied models can slightly amplify the sound made by the vibrating strings.

Resistance isn't futile

Plucking a bass guitar causes a series of barely-visible vibrations in the string that get passed through an electromagnetic field and amplified by a closed circuit. But that's not the only control you have over the sound you make; even the most basic models of bass have something else to let you produce a range of different effects.

Electric bass guitars come with at least two dials on their body: one for volume and one for tone. The volume dial is typically attached to a 500-kilo-ohm resistor that controls the signal's amplitude: the higher the resistance, the lower the volume. The tone dial (which is also usually a 500-kilo-ohm device) controls which frequencies get cut out – it allows you to make the sound 'sharper' or 'deeper' depending on what passes through it.

Depending on the settings you use for each dial, you can produce incredibly different sounds

Industrial robots

Inside the factories where no one gets tired, sick or even paid

Ninety per cent of all the robots in the world live in factories. The availability of cheap human labour in China and the Far East hasn't slowed down the march of machines, and sales of industrial robots are in fact growing faster in China than anywhere else in the world.

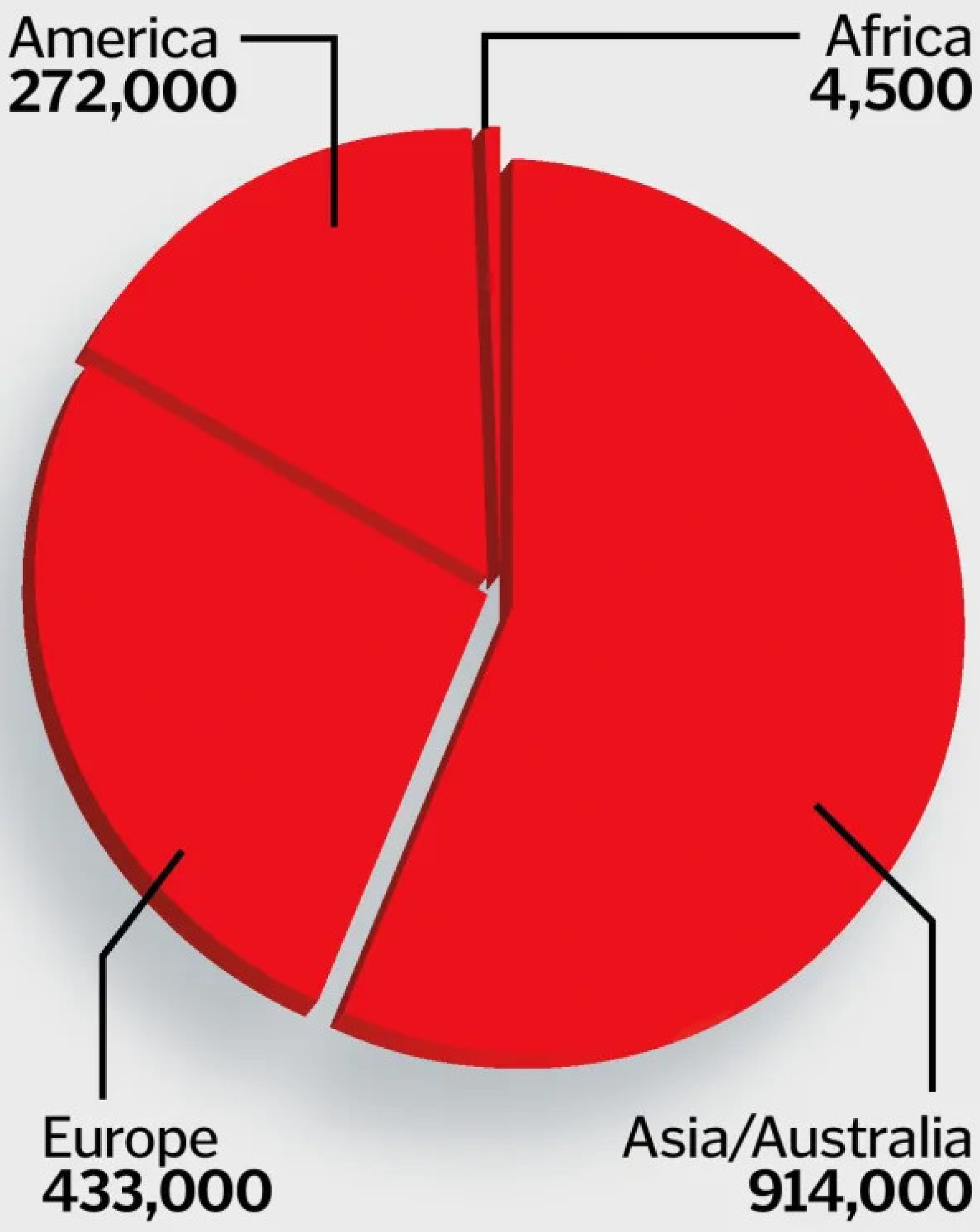
Robots were first put to work in 1961, when General Motors installed Unimate. This was a 1.8-ton, die-cast robot arm that dealt with red-hot, metal car door handles and other parts – dangerous and unpleasant work for humans. Unimate followed instructions stored on a magnetic drum (the forerunner of today's computer hard disks), and could be reprogrammed to do other jobs. When Unimate robots took over the job of welding car bodies in 1969, the GM plant in Ohio was able to build 110 cars an hour – twice as fast as any factory in the world at that time.

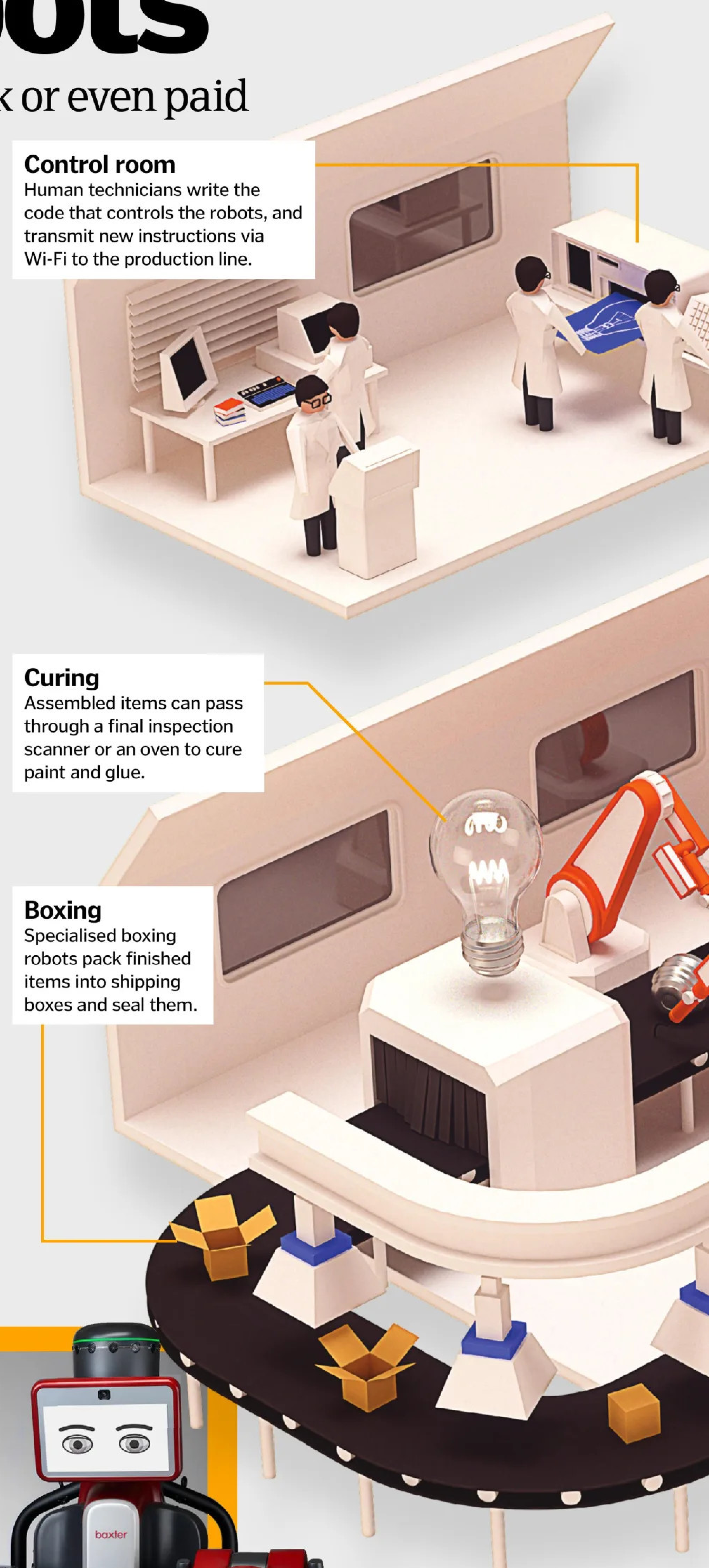
Modern industrial robots have evolved from using clumsy hydraulic pistons to much more precise electric motors for each joint. Sensors on each one detect an LED light shining through a disc with slots cut into it. As the slots interrupt the light beam, they send a series of pulses to the robot's CPU that tells it precisely how far the arm has moved. Cameras mounted on the end of each arm use sophisticated image-processing software that allows them to identify objects, even if they are upside down or rotated on the conveyor belt, while ultrasound proximity sensors prevent the robots from striking obstacles in their path.

Even with all this sophistication, industrial robots are so strong and move so quickly that it has always been dangerous for humans to share an assembly line with them. But the latest machines have joints driven by springs, which are tensioned by motors, instead of motors driving the arm joints directly. This absorbs the force from an accidental knock, and enables the robot to react in time to avoid an injury.

Where do industrial robots live?

Number of robots (as of 2015)





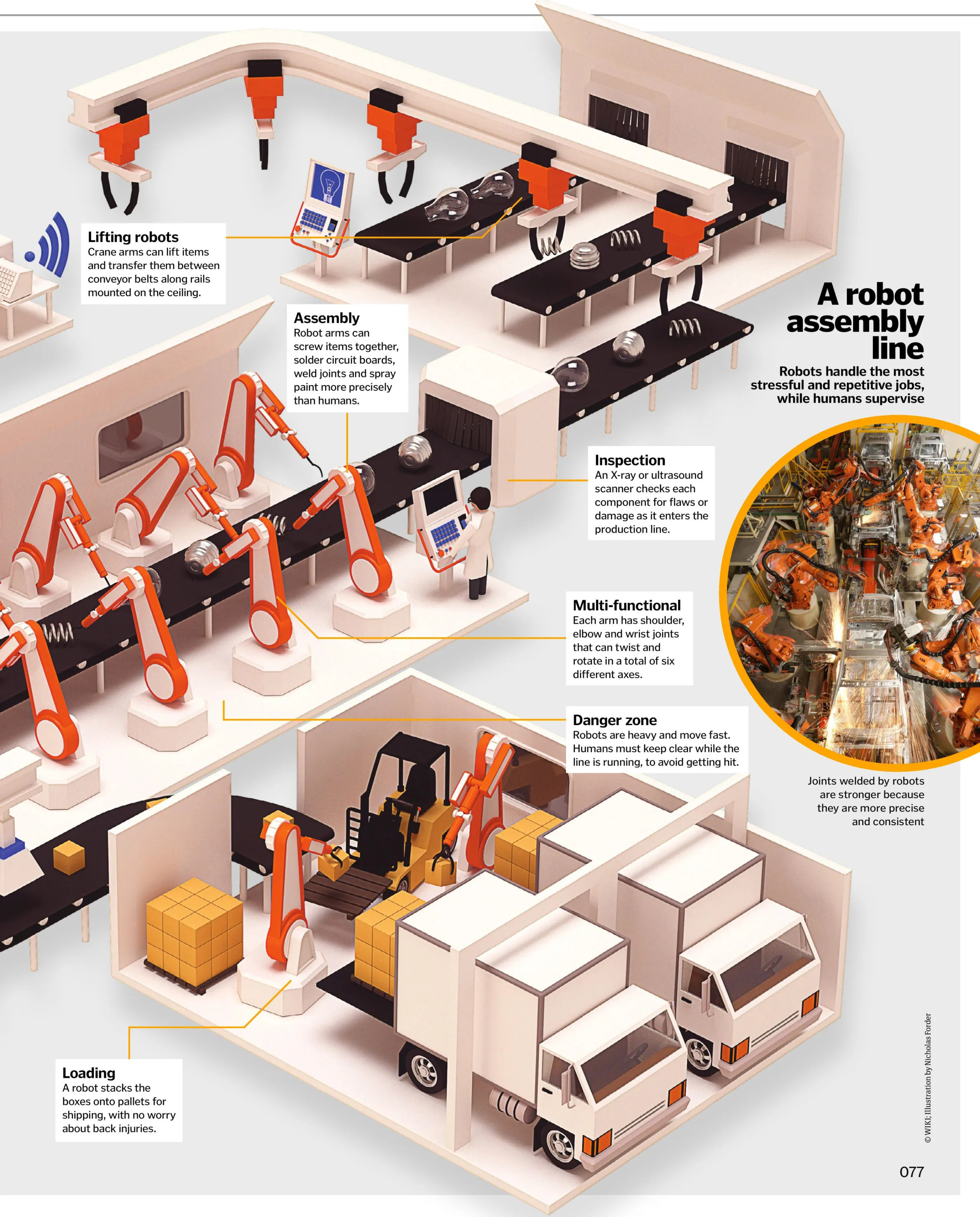
Learning by example

Most industrial robots need programmers to write the complex code that controls their movements, and reprogramming them can involve expensive stoppages. Baxter and Sawyer are a new generation of robots from Rethink Robotics in Boston, US. They can be taught what to do by moving their arms to the right position and then clicking a button to tell them 'this is the thing you need to pick up', or 'place the object in this box'. The face on the display screen allows humans to tell whether the robots are concentrating on learning a new task, working happily or have encountered a problem.

Sawyer (left) can manipulate objects with 0.1mm precision. Baxter (right) has two arms for heavier loads

A robot assembly line

Robots handle the most stressful and repetitive jobs, while humans supervise



Joints welded by robots are stronger because they are more precise and consistent

How barcode scanners work

Wait for the beep – find out how these all too familiar scanners function

Head to a supermarket, take your groceries to the checkout and watch as the assistant passes your weekly shop through that little red scanner to tot up the total. As the tin of beans whizzes past, a laser hits the barcode, interpreting the information. This super-quick action is enough to calculate your receipt and also add the sale of the tin of beans to the store's database of stock.

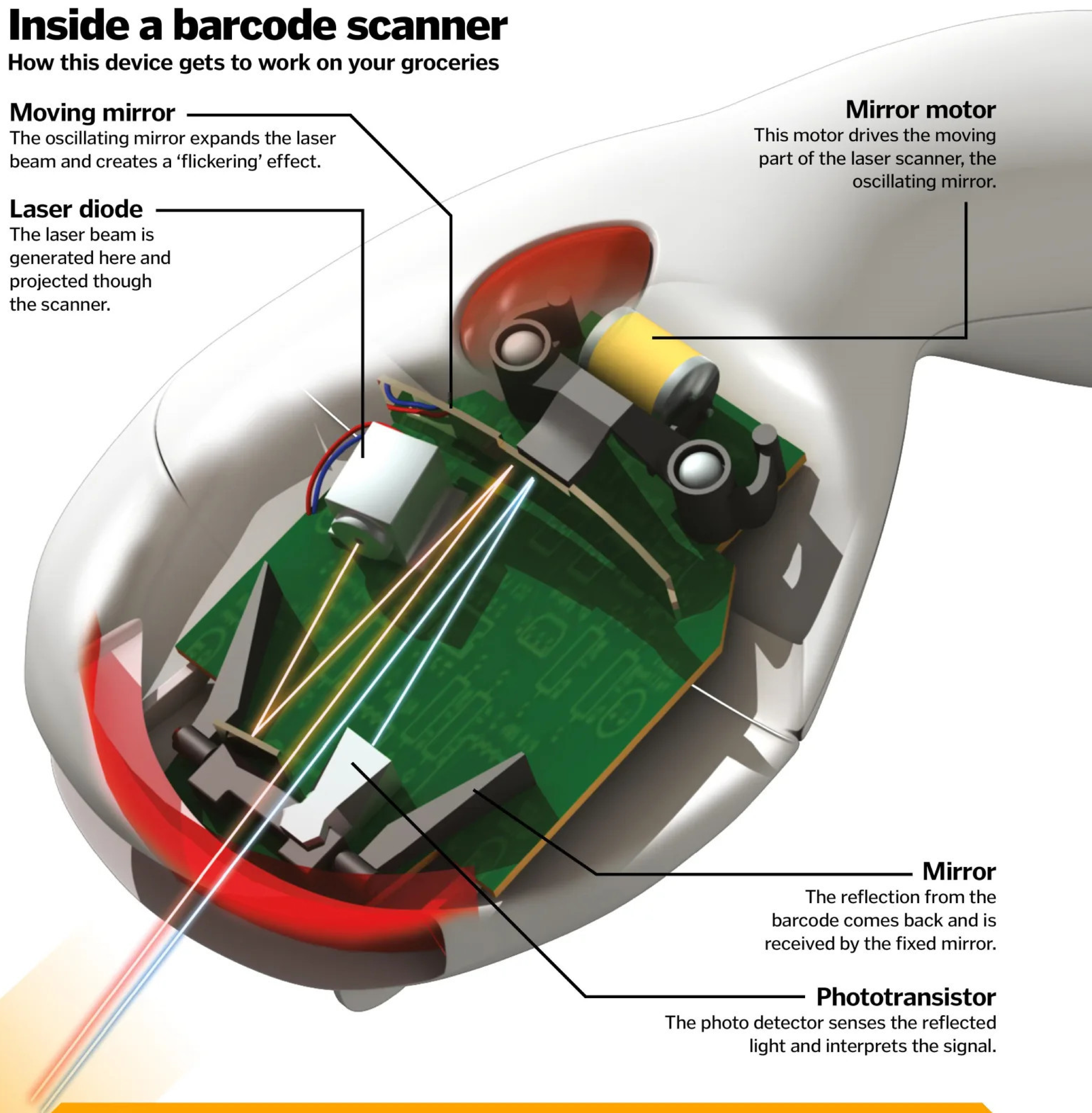
The scanners that large supermarkets use are complex omni-directional readers that can decode barcodes even when they are crumpled, torn or plastered on odd shaped items. There are many other types of barcode readers such as CCD readers, but the principal of these is the same.

There are three key parts to a barcode scanner: the illumination system, the sensor/converter and the decoder. A light source illuminates the barcode, which creates a reflection that can be read by the scanner and then interpreted.

A laser scanner uses a laser beam, which is expanded into a line using a mirror that oscillates back and forth, causing a blinking effect. The reflected light from the white spaces of the barcode is picked up by a fixed mirror, which is then processed to create the digital and analogue signals that relay the information back to a central database.

Inside a barcode scanner

How this device gets to work on your groceries

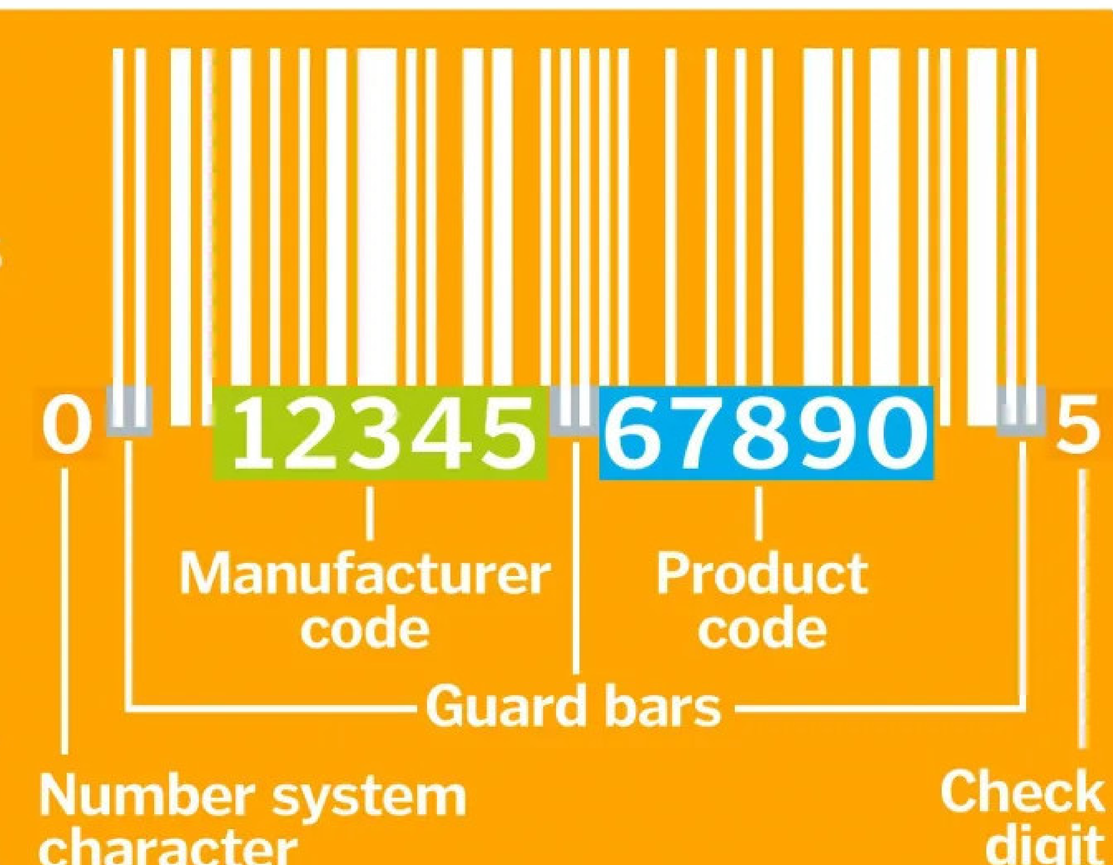


Barcode reading
Light from the scanner hits the barcode. Black lines absorb the red light and white lines reflect it back.

How barcodes work

One of the most widely used barcodes is the Universal Product Code (UPC). This is a series of 95 evenly spaced columns of black and white. When scanned, the computer creates a 95-digit code, grouped into 15 sections. The first, last and middle sections are 'guards' so that the computer can tell if the barcode is read left to right, or upside down.

The left-hand number at the bottom of the barcode represents the type of barcode, the first set of five numbers is the manufacturer's code, and the second set refers to the produce code. The last number on the right is the check digit, so the computer can verify that it has been read correctly.



Energy-efficient lighting

What makes LEDs different to traditional bulbs?

Traditional light bulbs have illuminated our homes for over 100 years. Inefficient and costly, they work by passing electricity through a small filament, making it incredibly hot. This produces light but a large proportion of the energy is lost as heat. That's why more and more people are choosing to switch to light-emitting diode (LED) lamps. These cost less to run, as they require less electricity, and the bulbs can last up to 25 times longer than conventional ones.

LEDs are semiconductor devices that carry electrical current in one direction. Semiconductors are naturally insulators, but can be turned into conductors by adding atoms of another element, a process called 'doping'. When an electric charge passes through the semiconductor, it activates the flow of electrons across it. This generates energy, which is released as photons – units of light.

LED lamps waste relatively little energy as heat, and as such have the advantage of being much more energy-efficient than their incandescent counterparts.

Some LED bulbs are reported to last for over 50,000 hours of use

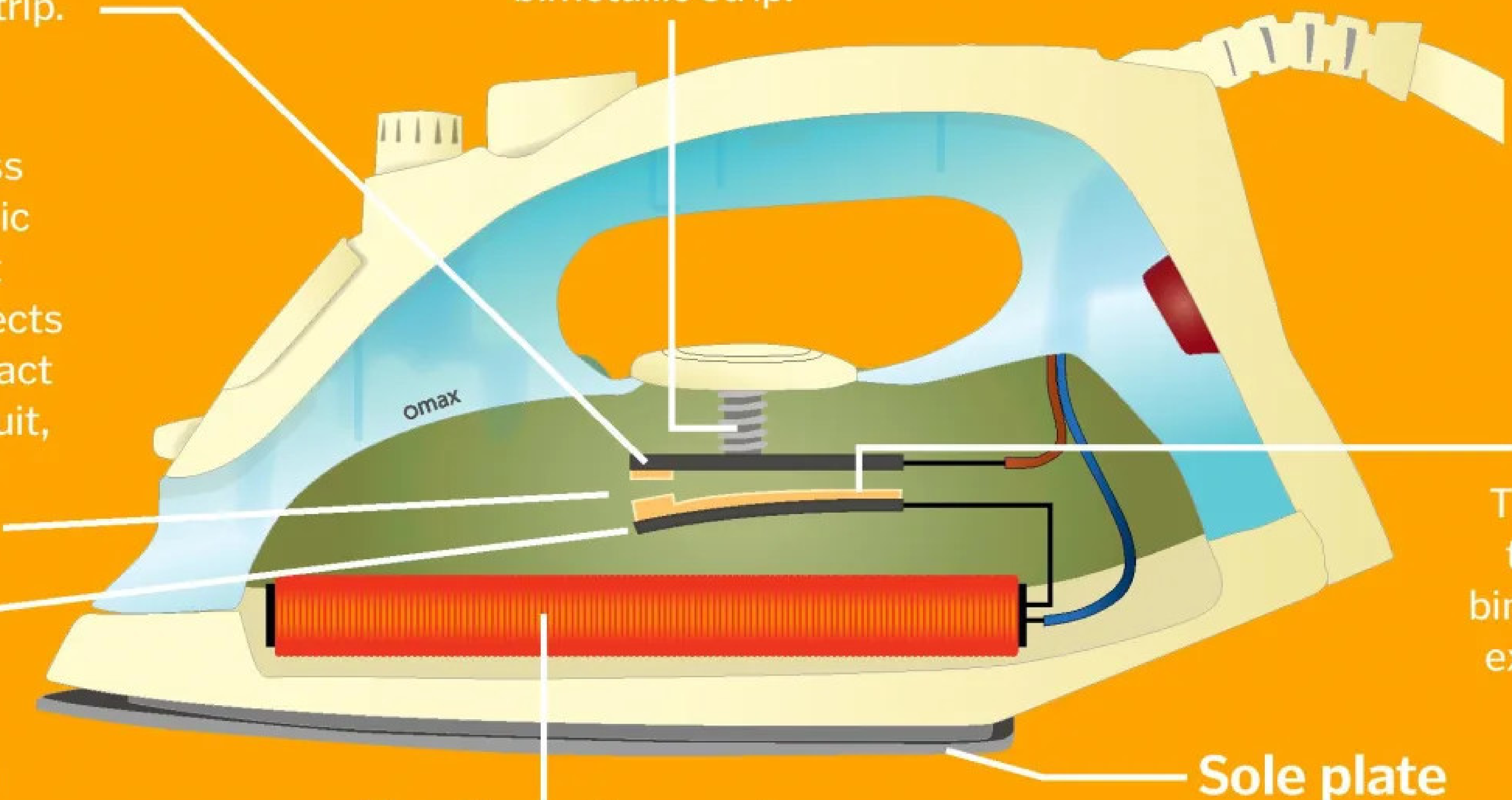
The inner workings of an iron

Discover the clever technology that keeps your clothes crease-free

Applying heat to creased clothes weakens the molecular bonds in the fabric's fibres so they can move into new positions before cooling. The temperature of an iron is controlled by a thermostat. This consists of a bimetallic strip – two different metals fitted close to the heating element. As they are heated, the metals expand by different amounts, bending into a curve. The current flows through the bimetallic strip to the heating element, which turns electricity into heat and warms up the base of the iron (known as the sole plate). When the thermostat reaches the desired temperature, the components of the strip will curve enough to pull away from each other and break the circuit. This mechanism also prevents the iron from overheating. Some irons also use steam to remove creases. Water from an internal tank is released into the hot sole plate, where it vaporises and helps to remove wrinkles.

Iron engineering

How do irons give off just the right amount of heat?



Fixed contact
An electric current from the mains supply travels through a fixed strip of iron that sits on top of a bimetallic strip.

Thermostat screw
The position of the fixed contact can be adjusted to control the temperature at which it disconnects from the bimetallic strip.

Bending
The expanding brass causes the bimetallic strip to bend until it eventually disconnects from the fixed contact and breaks the circuit, preventing the iron from overheating.

Expansion
The heat causes the brass in the bimetallic strip to expand, more so than the iron.

Bimetallic strip
Consisting of strips of iron and brass, this stays flat when cool, connecting with the fixed contact to complete the circuit.

Heating element
The current is passed from the bimetallic strip to a heating element, which converts the electricity into heat.

Sole plate
The heating element heats up the sole plate through conduction, allowing it to transfer the heat to your clothes.

Capturing a digital image

How a camera converts light into photo files on a memory card

All you have to do is point and say "CMOS sensor"!

With the simple click of a button, a digital camera turns light into data. This process starts with the image sensor, which is a silicon chip known as a CCD or CMOS. When light enters the camera lens, it is focused onto the sensor and dislodges some of the electrons in a tiny area of the silicon (known as a pixel), which creates an electrical charge. The brighter the light in that part of the image, the stronger the electrical charge that is created at that spot on the sensor.

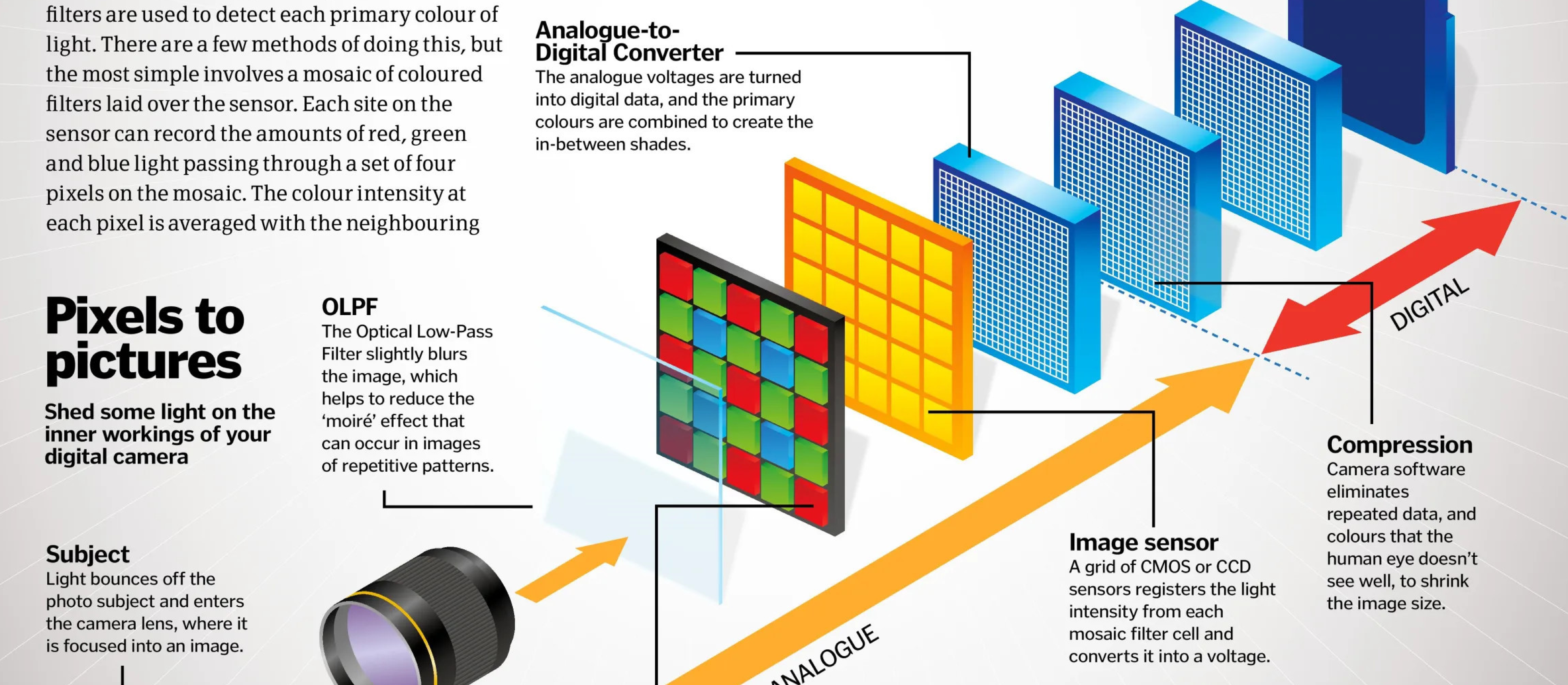
On its own, the sensor is colour-blind. To produce a colour image, red, green and blue filters are used to detect each primary colour of light. There are a few methods of doing this, but the most simple involves a mosaic of coloured filters laid over the sensor. Each site on the sensor can record the amounts of red, green and blue light passing through a set of four pixels on the mosaic. The colour intensity at each pixel is averaged with the neighbouring pixels to recreate the true colours of the image using special algorithms that run on the camera's Central Processing Unit.

Each pixel also needs some circuitry around it to allow the electrical charges to be amplified and read. The light that falls on this part of the sensor chip is lost, so some cameras use a grid of microscopic lenses that funnel more light to the centre of each pixel and away from the support circuitry.

The basic image data is then further processed to remove digital noise, correct for shadows cast by the camera lenses, and eliminate the flicker caused by artificial lighting. This data is then assembled into a format that can be read by other computers and written to the SD card as a JPEG file.

Pixels to pictures

Shed some light on the inner workings of your digital camera



The rolling shutter effect

The signals recorded on a CCD sensor are sent one row at a time to the Analogue-to-Digital Converter. This row-by-row recording of the image is known as a 'rolling shutter', and although it happens very quickly, a fast-moving image might still have changed in the time it takes to scan from the top to the bottom of the sensor. This is why propellers and helicopter rotor blades often look strangely bent in digital photos.

The rotor blade turned 90 degrees while the camera captured this scene

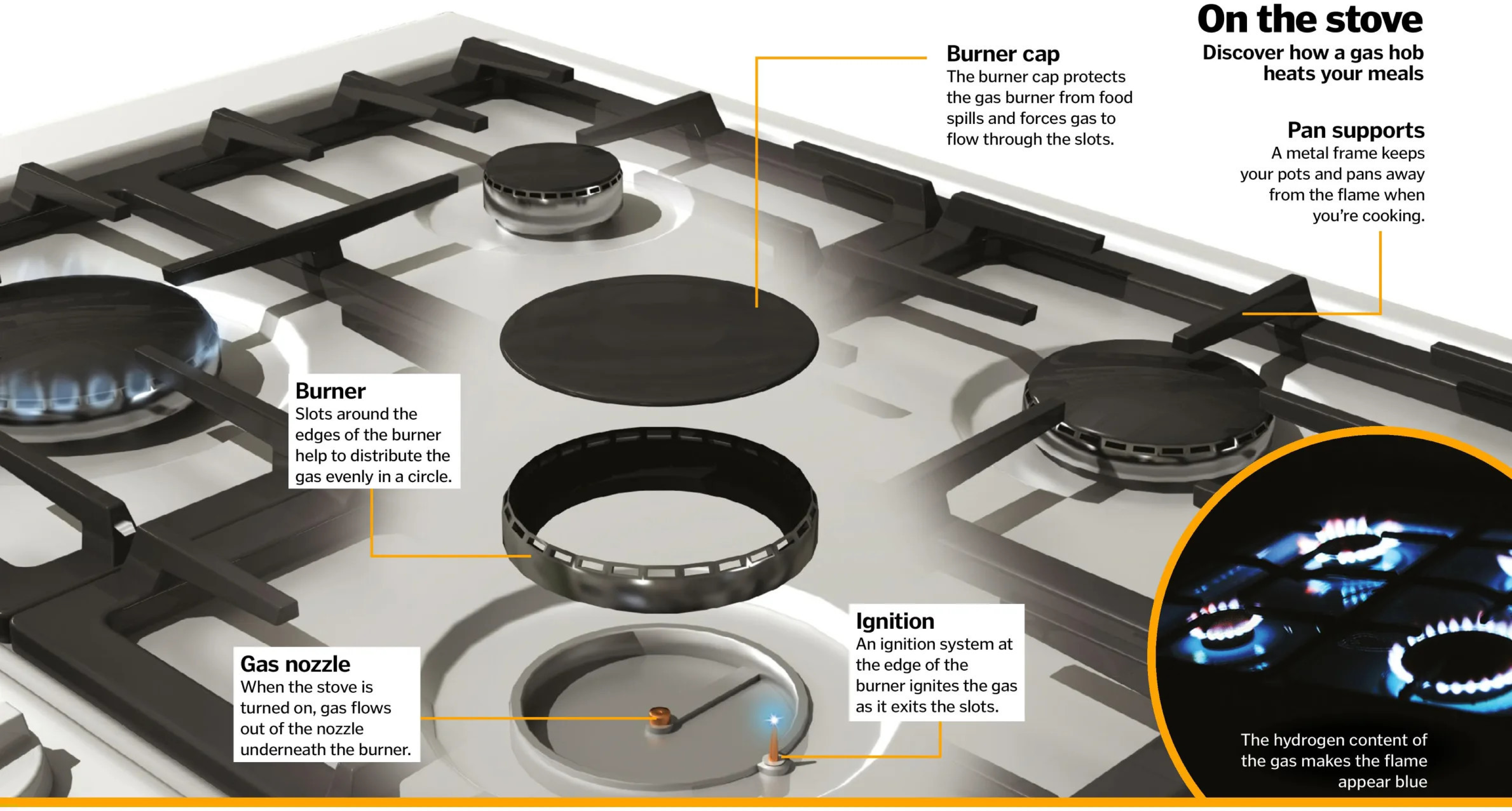
How does a gas stove work?

Get the dinner on and find out how it cooks using gas

Gas stoves may seem like simple contraptions, but there is a lot of science going on behind the scenes. It begins with the natural gas or propane that flows through the main gas line to your house and is carried to a valve inside the stove.

When the stove is turned on, the valve opens, sending the gas through a Venturi tube, which narrows in the middle. When the gas enters the narrowed section, it flows quicker and the pressure drops, creating a vacuum. To fill this vacuum, air will then start rushing through an inlet in the pipe and combines with the gas to make it combustible.

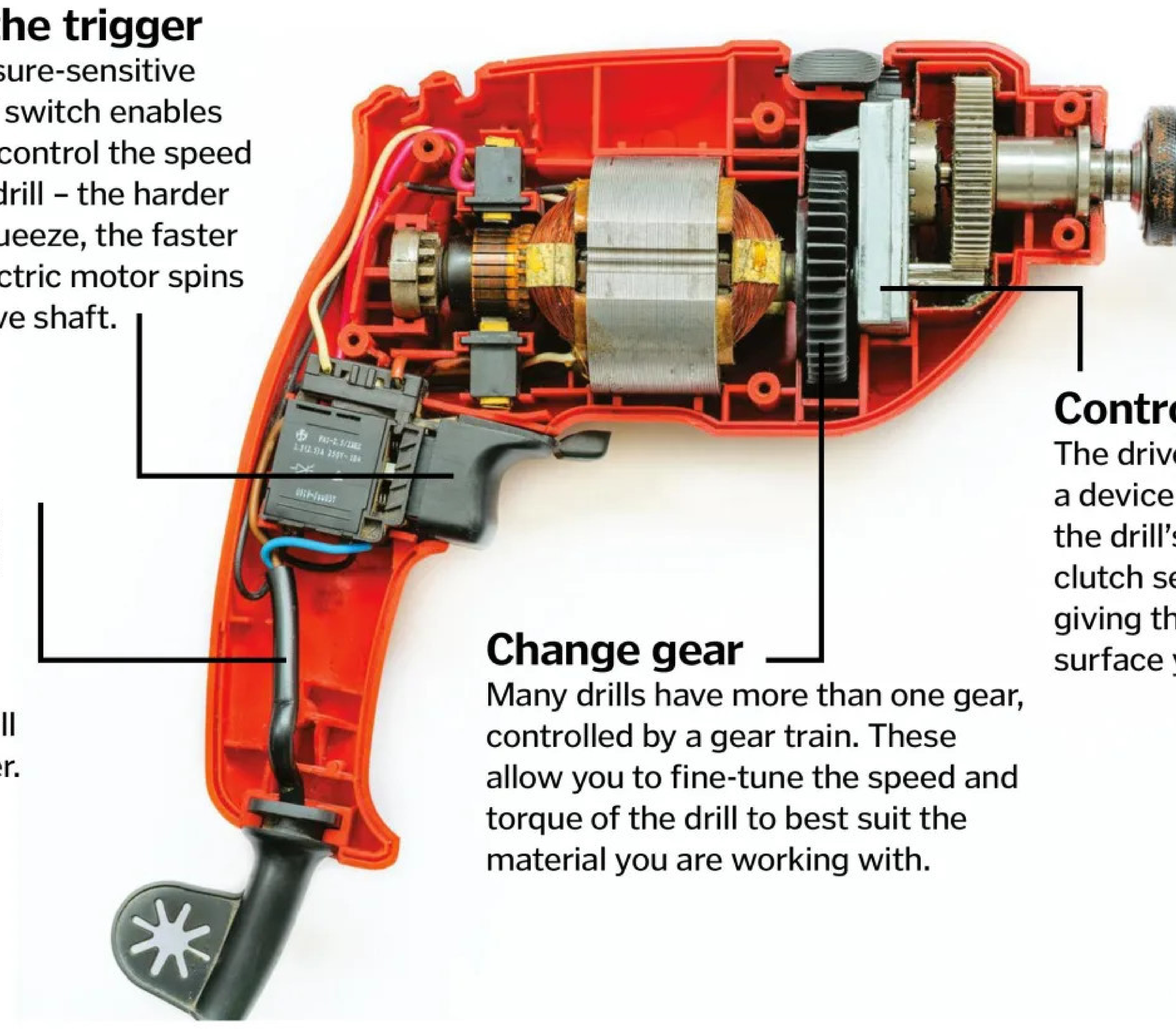
This mixture of gas and oxygen is then released through the gas nozzle and ignited by either a pilot light or an electric ignition system. A pilot light is a burning blue flame fuelled by its own separate gas nozzle and is constantly on. An electric ignition system, on the other hand, is only activated when you press the ignition switch, and creates a spark that jumps to the burner and ignites the gas so you can start cooking.



The hydrogen content of the gas makes the flame appear blue

Inside an electric drill

How this toolbox essential powers through your DIY project in no time



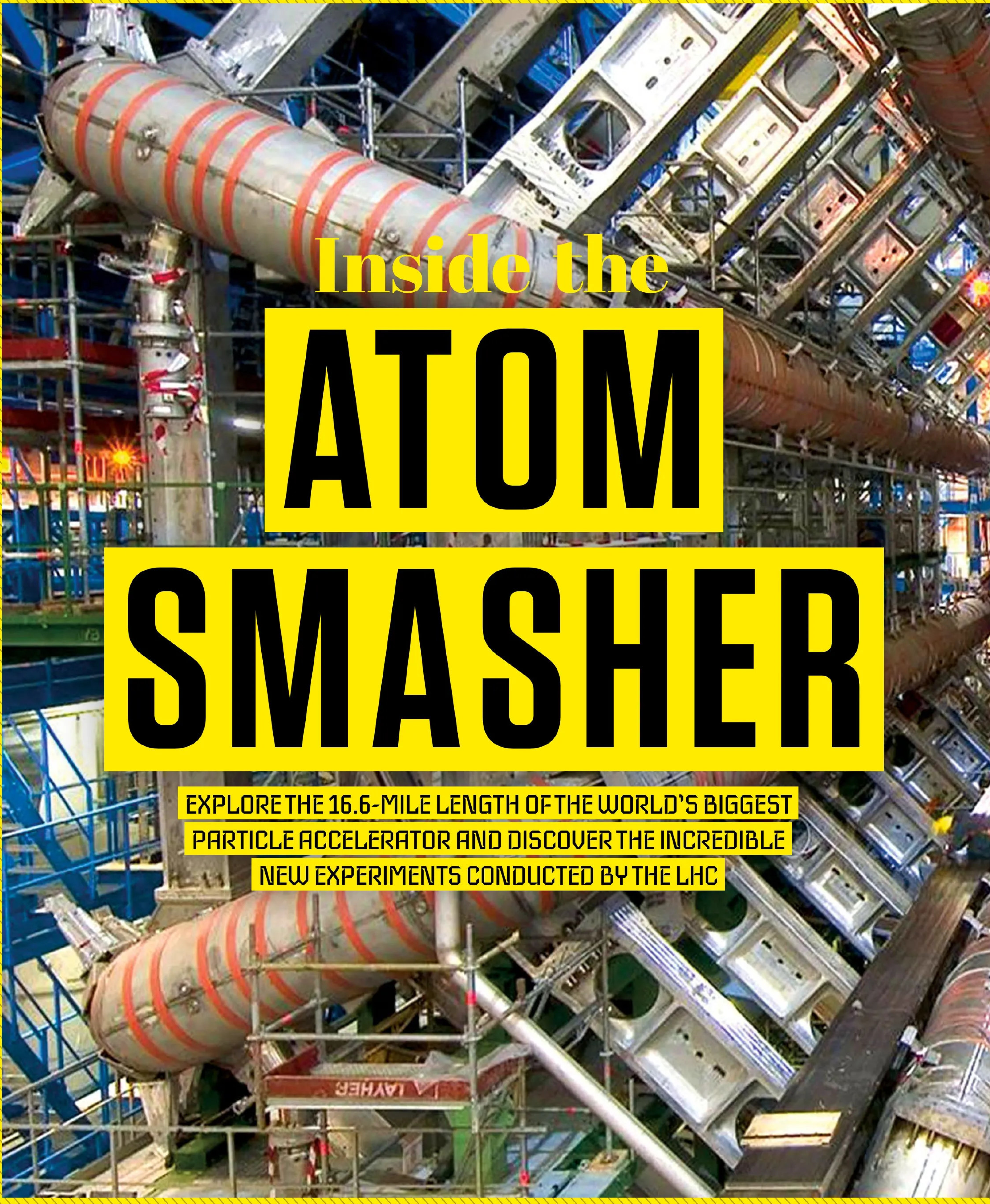
ENGINEERING

113
Inside a loud speaker


125
Journey
to Jupiter

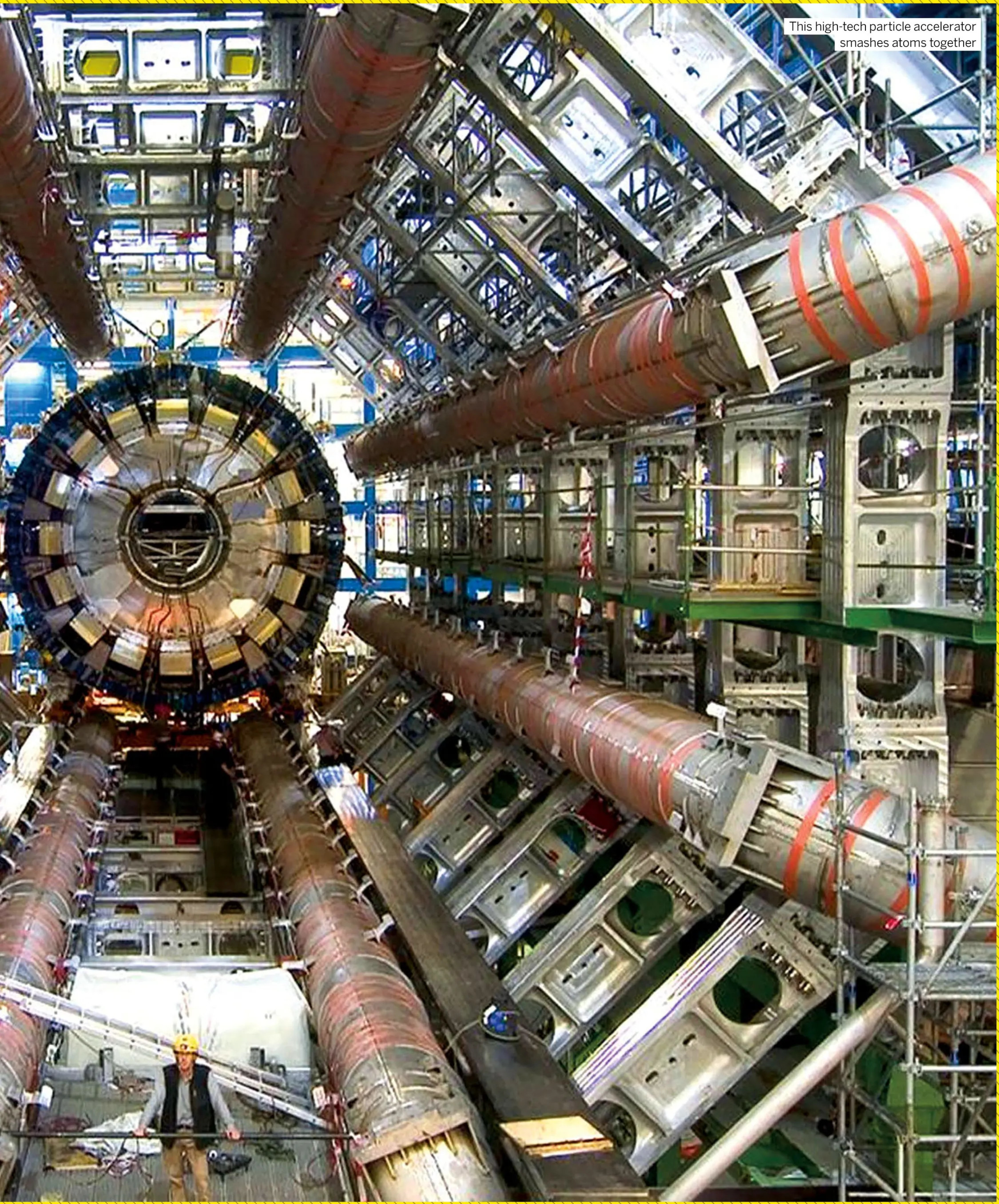

124
Firing torpedoes


98
Formula 1



Inside the ATOM SMASHER

EXPLORE THE 16.6-MILE LENGTH OF THE WORLD'S BIGGEST PARTICLE ACCELERATOR AND DISCOVER THE INCREDIBLE NEW EXPERIMENTS CONDUCTED BY THE LHC



This high-tech particle accelerator smashes atoms together

If you see a news headline about exotic new subatomic particles, the chances are the discovery was made at CERN, the European Organization for Nuclear Research, located near Geneva in Switzerland. A recent example occurred in January 2022, when CERN scientists announced "evidence of X particles in the quark-gluon plasma produced in the Large Hadron Collider (LHC)". Hiding behind that technospeak is the eye-popping fact that CERN succeeded in recreating a situation that hasn't occurred naturally since a few microseconds after the Big Bang. That particular study drew on pre-existing data from the LHC, the world's biggest particle accelerator, which has been undergoing a major upgrade since 2018. When it restarted in 2022 after a three-year hiatus, we can expect a whole new spate of discoveries, so it's a good time to take a closer look at what makes the LHC – and the rest of CERN – so unique.

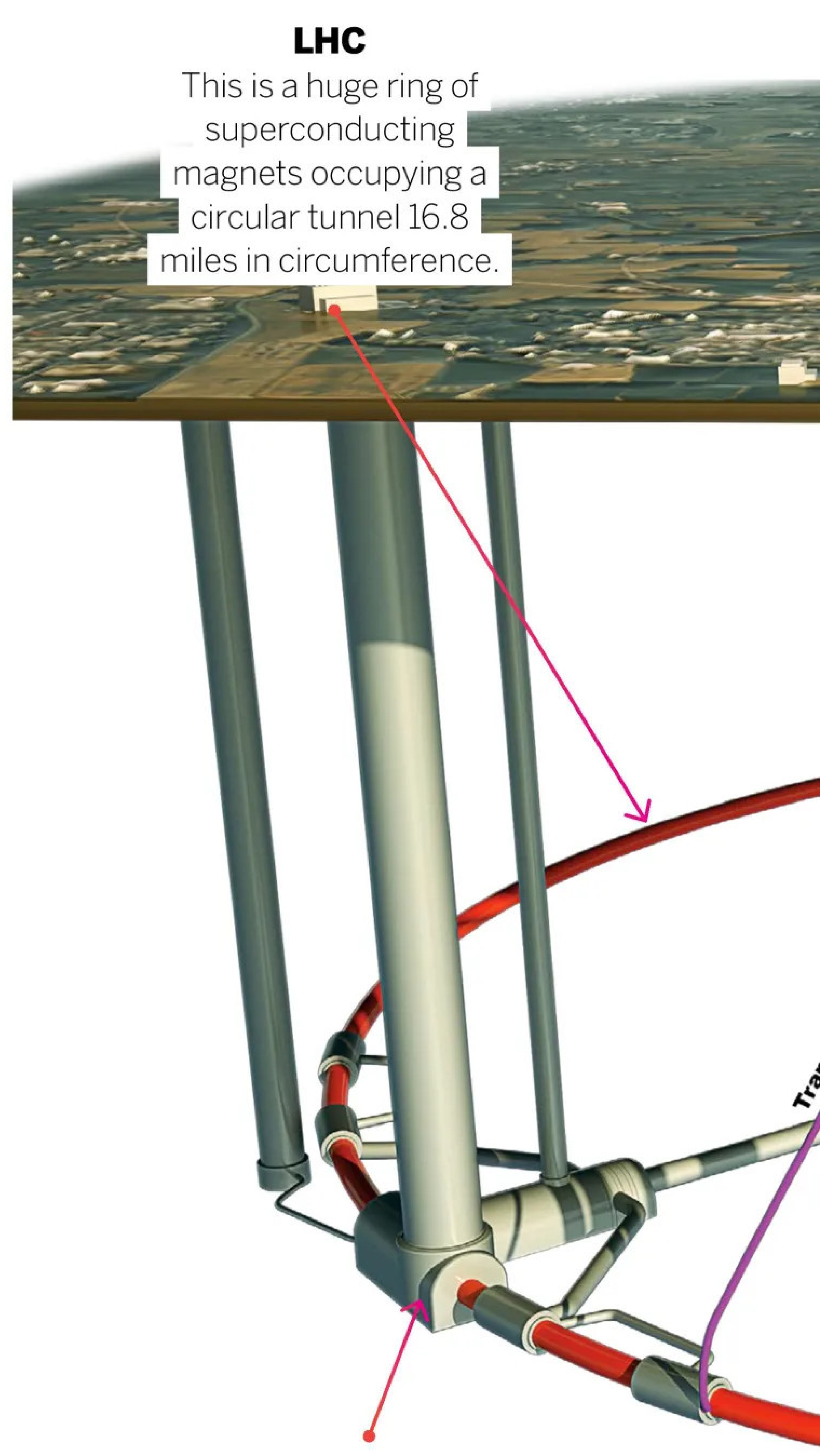
The LHC is a particle accelerator – a device that boosts subatomic particles to enormous energies in a controlled way so that scientists can study the resulting interactions. The 'large' that the L stands for is an understatement; the LHC is by far the biggest accelerator in the world right now, occupying a circular tunnel nearly 17 miles in circumference. The middle letter, H, stands for 'hadron', the generic name for composite particles such as protons that are made up of smaller particles called quarks. Finally, the C stands for 'collider' – the LHC accelerates two particle beams in opposite directions, and all the action takes place when the beams collide.

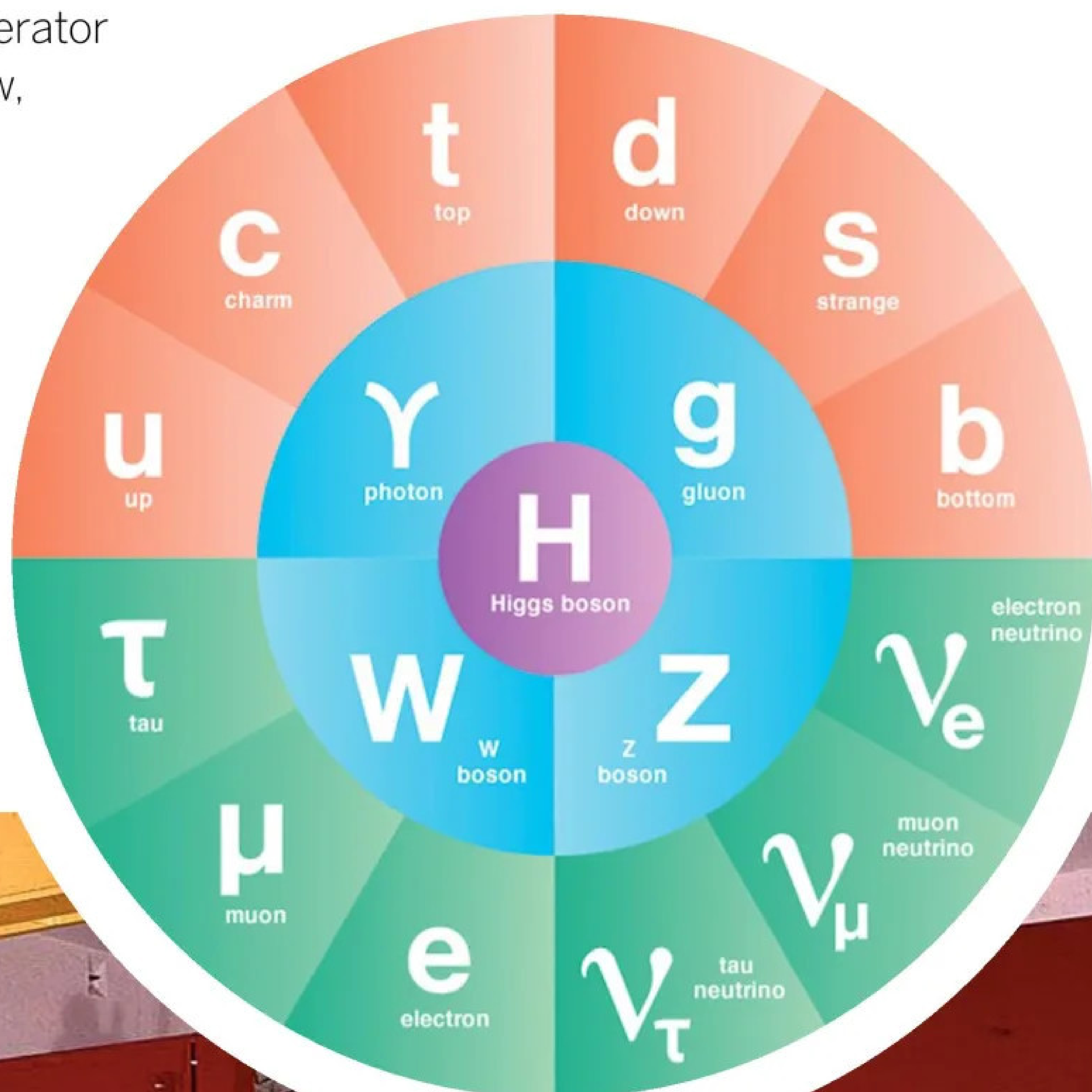
Like all physics experiments, the LHC's aim is to test theoretical predictions – in this case, the so-called Standard Model of particle physics – and see if there are any holes in them. As strange as it sounds, physicists are itching to find a few holes in the Standard Model because there are some things, such as dark matter and dark energy, that can't be explained until they do.

The LHC's biggest moment came in 2012 with the discovery of the Higgs boson. Although widely referred to as the 'God particle', it's not really as awesome in itself as that name might suggest. Its huge significance came from the fact that it was the last prediction of the Standard Model that hadn't yet been proven.

But the Higgs boson is far from being the LHC's only discovery. It's also found around 60 previously unknown hadrons, which are complex particles made up of various combinations of quarks. Even so, all those new particles still lie within the bounds of the Standard Model, which the LHC has struggled to move beyond, much to the disappointment of the numerous scientists who have spent their careers working on alternative theories. The first tantalising hints that a breakthrough might be just around the corner came last year, when analysis of LHC data revealed patterns of behaviour that indicated small but definite departures from the Standard Model.

The LHC opened for business in 2009, but CERN's history goes back much further than that. The organisation was established in 1954 following a recommendation by the European Council for Nuclear Research – or Conseil Européen pour la Recherche Nucléaire in French, from which it gets its name. Between its creation and the opening of the LHC, CERN was responsible for a series of groundbreaking discoveries, including weak neutral currents, light neutrinos and the W and Z bosons. As soon as the LHC is back up and running, we can expect discoveries to continue.





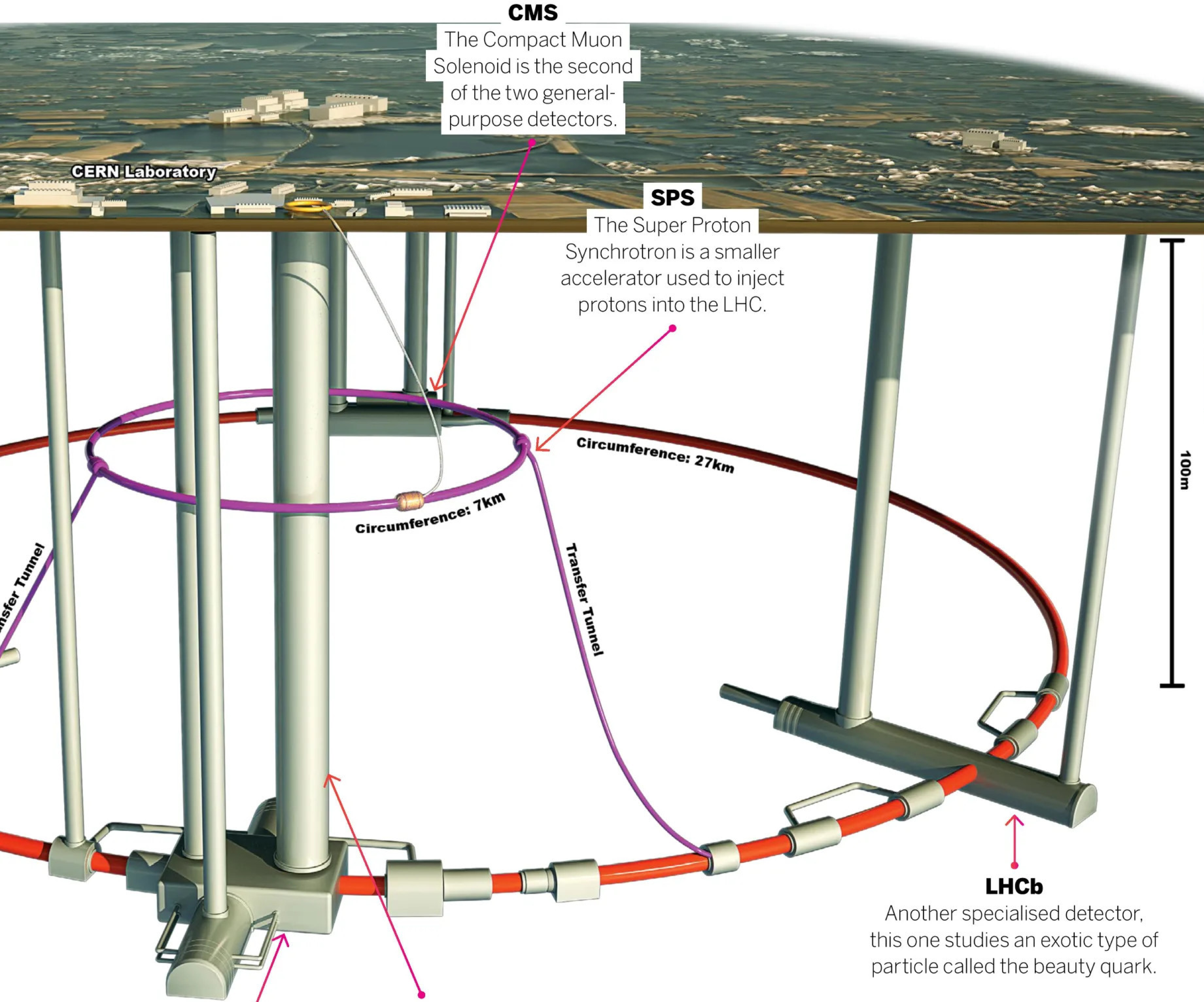
Left: The Standard Model of particle physics consists of 17 elementary particles

Below: CERN's first accelerator, the Synchrocyclotron, began operation in 1957

Did you know?
CERN has 23 member states, including the UK

GIANT UNDERGROUND LABORATORY

The Large Hadron Collider is located deep beneath the Franco-Swiss border near Geneva



CMS
The Compact Muon Solenoid is the second of the two general-purpose detectors.

SPS
The Super Proton Synchrotron is a smaller accelerator used to inject protons into the LHC.

LHCb
Another specialised detector, this one studies an exotic type of particle called the beauty quark.

ATLAS
This is one of the LHC's two principal general-purpose detectors.

ACCESS SHAFTS
Vertical shafts link the underground facilities to buildings on the surface 100 metres above.

5 FACTS ABOUT CERN

1 A WORLD-BEATER
CERN is the largest scientific laboratory in the world, boasting record-breaking facilities. The Large Hadron Collider, for example, is seven times as powerful as any previous particle accelerator.

2 A LOT OF DATA
CERN's data centre accumulates over 30 million gigabytes of data every year. That's the same as 250 years of HD video – enough to fill over a million Blu-ray discs.

3 COLDER THAN SPACE
The LHC's superconducting magnets are cryogenically cooled to just 1.9 degrees above absolute zero, or 271.25 Celsius. That's even lower than the 2.7 degrees Kelvin of outer space.

4 ATOMS OF ANTIMATTER
Particle accelerators have always been able to create individual antiparticles, but CERN was first to combine these into atoms of antimatter in the form of antihydrogen.

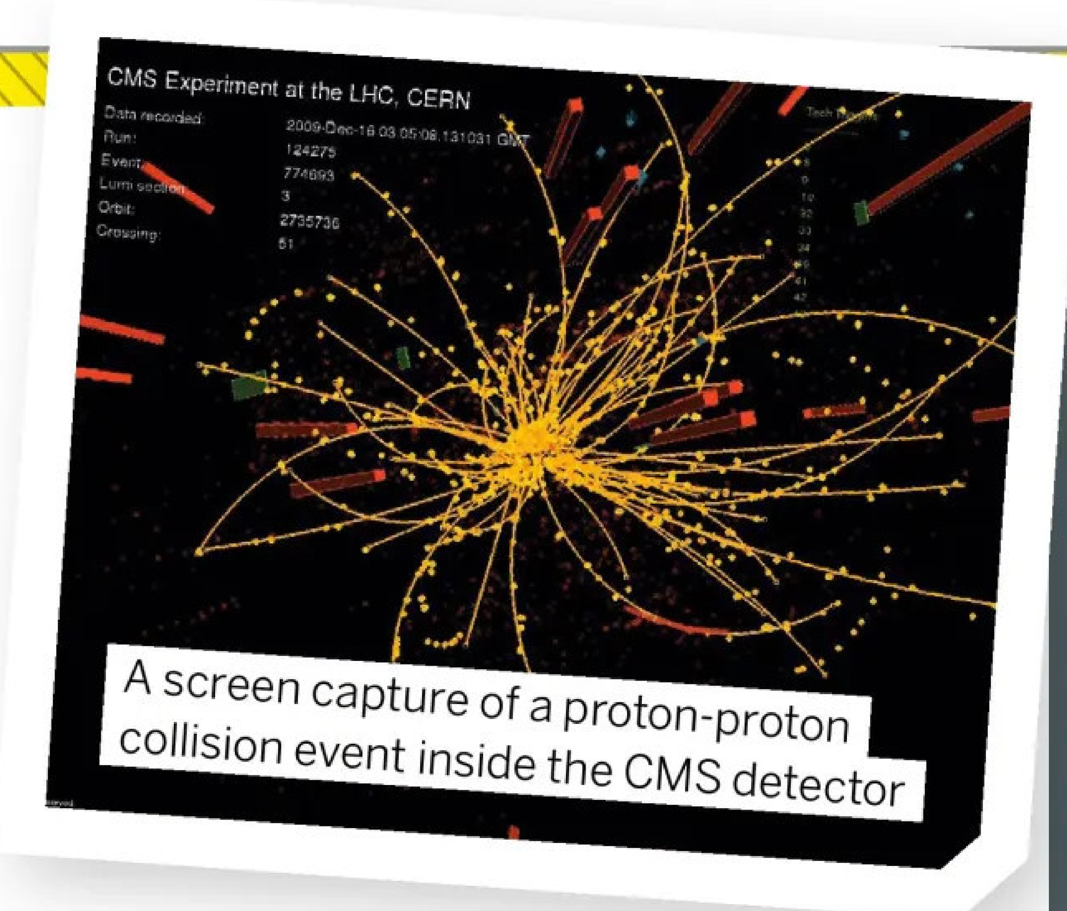
5 CERN'S GREATEST INVENTION?
Despite its specialised research, CERN has made a major impact on ordinary life through its creation of the World Wide Web, originally as a way for scientists to share information.

IS CERN DANGEROUS?

People have speculated that experiments at CERN might pose a danger. Take the N in CERN, which stands for nuclear. This has nothing to do with the reactions that take place inside nuclear weapons, which involve swapping protons and neutrons inside nuclei. CERN's research is at a lower level, in the constituents of the protons and neutrons themselves. It's sometimes referred to as 'high-energy' physics, but the energies are only high when viewed on a subatomic scale. Particles inside the LHC typically only have the energy of a mosquito. People have also worried that the LHC might produce a 'mini black hole', but even in the unlikely case this happened, it would be unbelievably tiny and so unstable that it would vanish within a fraction of a second.


There's no danger that CERN would ever explode like a nuclear bomb

HOW THE LHC WORKS



A screen capture of a proton-proton collision event inside the CMS detector

As huge as it is, the LHC can't function without the help of other machines around it. Before particles, which are usually protons but for some experiments are much heavier lead ions, are injected into it, they're passed through a chain of smaller accelerators that progressively boost their speed. Smaller is just a relative term; the last step in the injector chain, the Super Proton Synchrotron, is almost 4.3 miles in circumference. The end result is two beams travelling in opposite directions around the LHC at virtually the speed of light. The beams are kept on their circular trajectories by a strong magnetic field, which has the effect of bending the path of electrically charged particles. At four points around the LHC's vast ring, the opposing beams are brought together and made to collide, and that's where all the science happens.

Particles are smashed together with such enormous energies that the collisions create a cascade of new particles – most of them extremely short-lived. The important thing for scientists is to work out what all these particles are, and that's not an easy task. The LHC has an array of sophisticated particle detectors for this purpose, each made up of layers of subdetectors designed to measure certain particle properties or to look for specific types of particles. For example, calorimeters measure a particle's energy, while the curving track of a particle in a magnetic field reveals information about its electric charge and momentum.

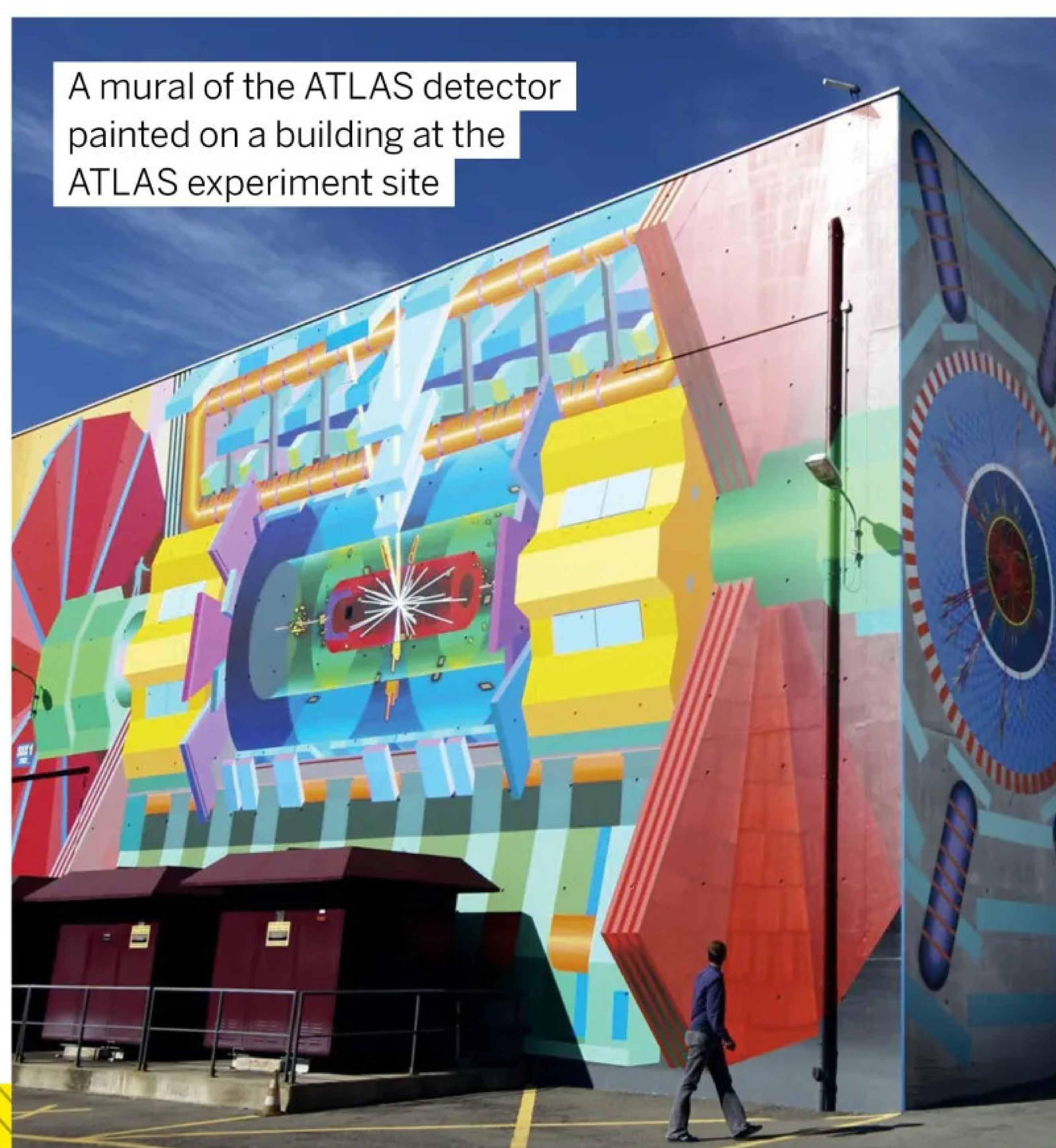
Two of the four collision points around the circumference of the LHC are occupied by large general-purpose detectors. These include the Compact Muon Solenoid (CMS), which can be thought of as a giant 3D camera, snapping images of particles up to 40 million times per second. The paths of the particles inside the detector are controlled by a gigantic electromagnet called a solenoid. Despite weighing 12,500 tonnes, it's actually quite compact, as the detector's name suggests. That middle word, muon, refers to an elusive particle similar to the electron but much more massive, which requires its own array of subdetectors wrapped around the solenoid. The LHC's other general-purpose detector, ATLAS (A Toroidal LHC ApparatuS), has an identical purpose to CMS, but differs in the design of its detection subsystems and magnets. It's also less compact than CMS, occupying a greater volume than any other particle detector ever built.

Many of the LHC's most important experiments, including the discovery of the Higgs boson, utilise the general-purpose detectors ATLAS and CMS. But it also has several other more specialised detectors that can be used in specific types of experiments.

The LHC forward (LHCf) detector, located close to the ATLAS interaction point, uses particles thrown forward in collisions as a means of simulating cosmic rays under laboratory conditions. Further along the beam trajectory is the ForwArd Search ExpeRiment (FASER), designed to look for light, weakly interacting particles that are likely to elude the larger detectors. A third experiment optimised for the forward direction is TOTal Elastic and diffractive cross-section Measurement (TOTEM), located near the CMS interaction point, which focuses on the physics of the high-energy protons themselves.

Away from ATLAS and CMS, the LHC has two other interaction points. One is occupied by A Large Ion Collider Experiment (ALICE), a specialised detector for heavy-ion physics. The final interaction point is home to two experiments on the very cutting edge of physics: LHCb, devoted to the physics of the exotic 'beauty quark', and MoEDAL – the Monopole and Exotics Detector at the LHC.

Did you know?
LHC particles complete 11,000 circuits per second


A mural of the ATLAS detector painted on a building at the ATLAS experiment site

THE MAIN DETECTORS

The LHC has two large general-purpose particle detectors, known as ATLAS and CMS

1 COMPACT MUON SOLENOID
Weighing around 14,000 tonnes, the CMS is 28 metres in length and 15 metres in diameter.

2 SUPERCONDUCTING COIL
Essentially a giant electromagnet, this generates a magnetic field 100,000 times as strong as Earth's.

3 COLLISION CHAMBER
The actual particle collisions occur here, in a vacuum chamber at the centre of the detector.

4 CALORIMETERS
Wrapped around the collision chamber, these absorb particles in order to measure their energy.

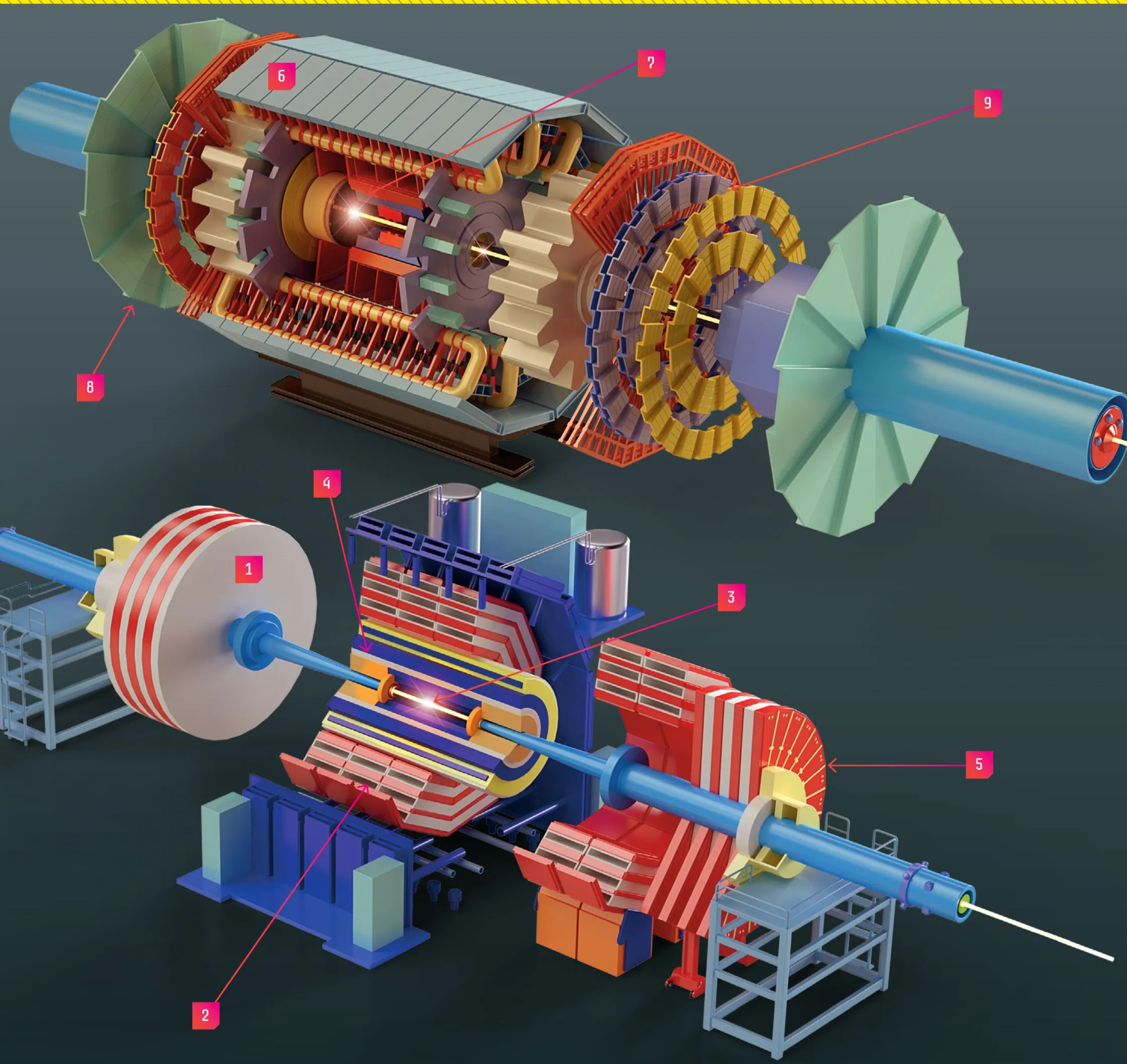
5 MUON CHAMBERS
Surrounding the collision chamber at a greater distance, these detect muons created by the collisions.

6 ATLAS
At 15 tonnes, this is lighter than the CMS, but it's physically larger: 44 metres long and 22 metres in diameter.

7 INNER DETECTOR
This takes the form of a cylinder 2.4 metres in diameter, wrapped around the central collision chamber.

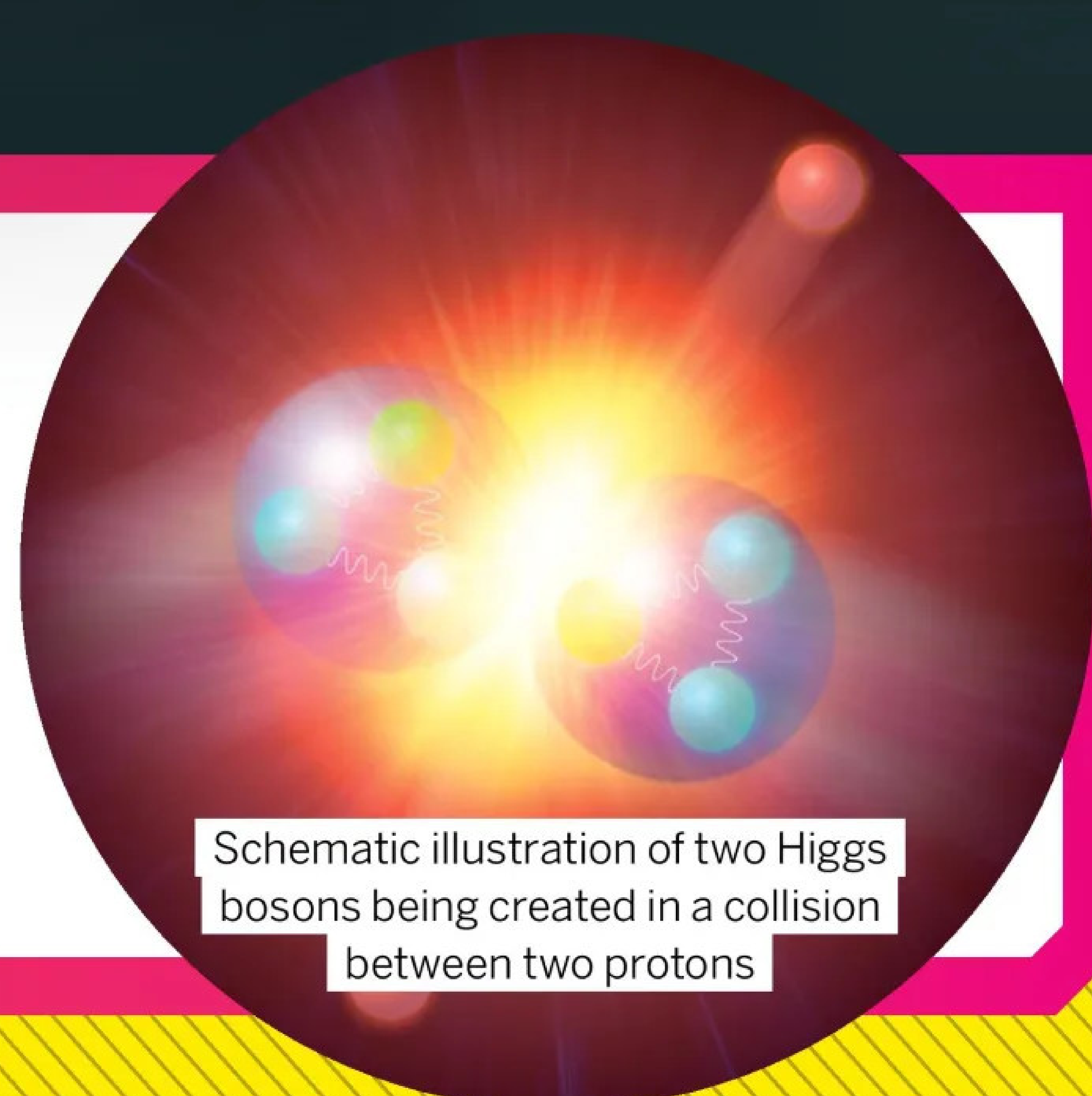
8 MUON SPECTROMETERS
Like the CMS, ATLAS has several detectors designed to study muons produced in particle collisions.

9 TOROIDAL MAGNETS
These create the strong magnetic field needed to produce curved particle tracks.



THE HIGGS BOSON

When physicists come up with new theories, they always try to make sure they can be tested experimentally. That happened in the early 1960s, when Peter Higgs and others developed a theory to explain why certain force-carrier particles have non-zero mass. The theory predicted the existence of a previously unsuspected particle, dubbed the Higgs boson. The next step was to find the Higgs boson, thus validating the theory. As simple as that sounds, it led to a decades-long hunt around the world. The end finally came in 2012, when data from a combination of ATLAS and CMS measurements proved beyond doubt that the Higgs boson had been discovered.



Schematic illustration of two Higgs bosons being created in a collision between two protons

AR zone

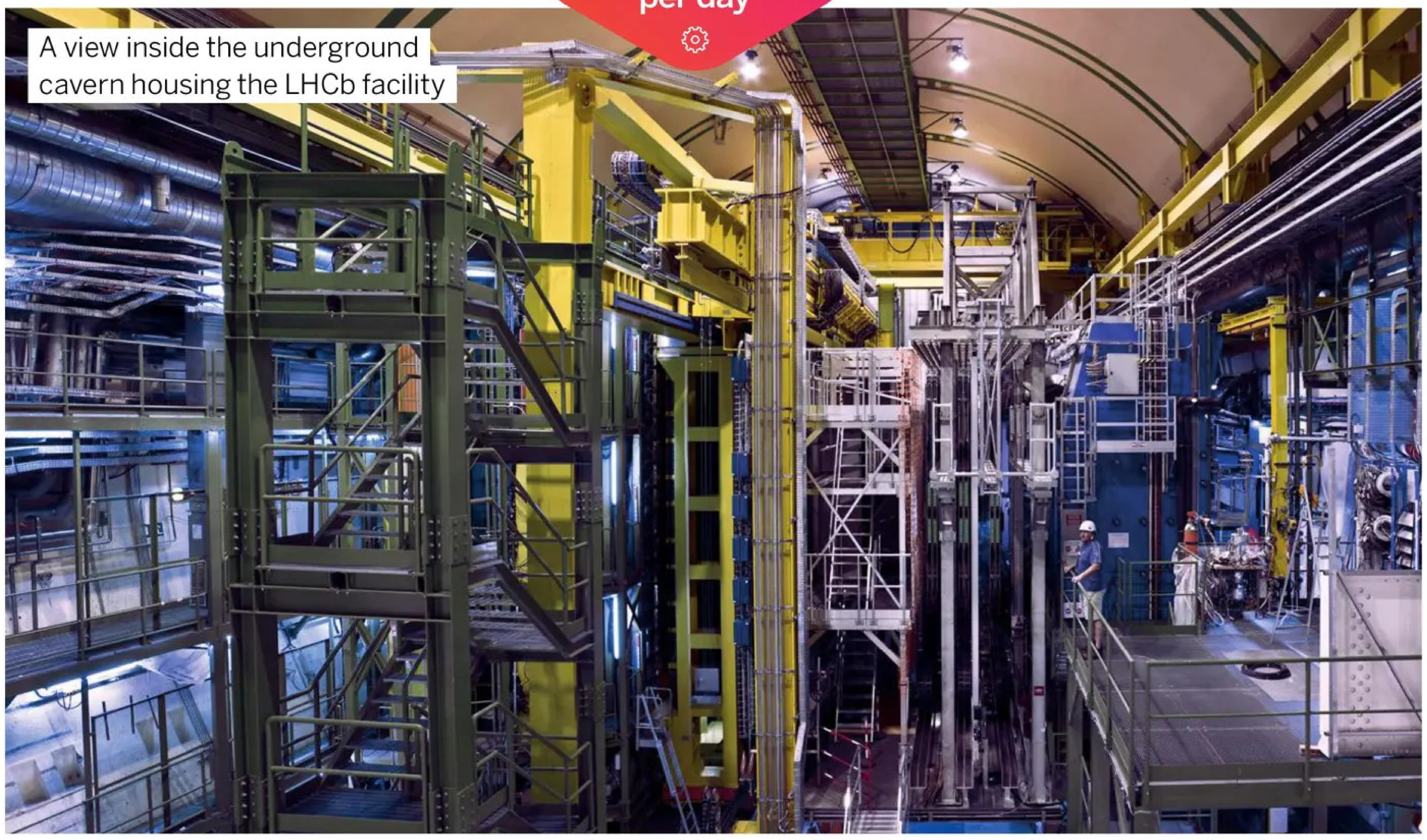
SCAN HERE

CERN'S MANY EXPERIMENTS

One of the key mysteries of the universe is the striking asymmetry between matter and antimatter – why it contains so much more of the former than the latter. According to the Big Bang theory, the universe must have started out with equal amounts of both. Yet very early on, probably within the first second, virtually all the antimatter had disappeared, and only the normal matter we see today was left. This asymmetry has been given the technical name 'CP violation', and studying it is one of the main aims of the Large Hadron Collider's LHCb experiment. All hadrons are made up of quarks, but LHCb is designed to detect particles that include a particularly rare type of quark known as 'beauty'. Studying CP violation in beauty-containing particles is one of the most promising ways to shed light on the emergence of matter-antimatter asymmetry in the early universe.

Did you know?

CERN can make 0.1 picograms of antimatter per day



A view inside the underground cavern housing the LHCb facility

One of the project scientists inside the CLOUD experiment chamber

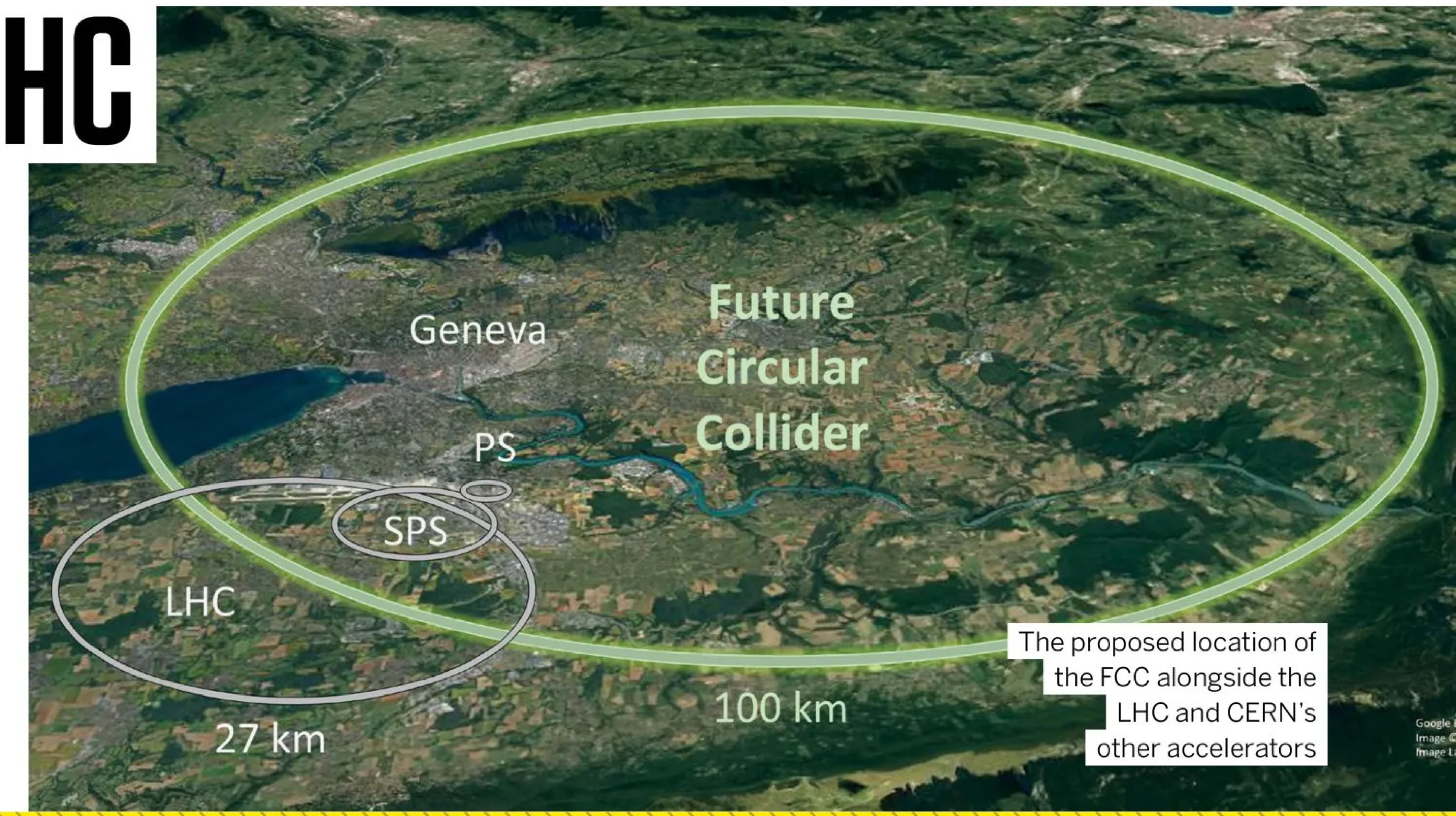
CLIMATE SCIENCE

Away from the LHC, there are other facilities at CERN that are doing equally important research. Linking particle physics to climate science may not be an obvious step, yet that's what one experiment is doing at CERN's Proton Synchrotron.

This is a smaller and less sophisticated accelerator than the LHC, but it's still capable of doing useful work. The climate experiment is called CLOUD, which gives a strong hint of what it's about, although the name actually stands for Cosmics Leaving Outdoor Droplets. Earth is under constant bombardment by cosmic rays, and it's been theorised that these play a role in cloud formation by seeding tiny water droplets. It isn't an easy process to study in the real atmosphere with real cosmic rays, so CERN is creating its own cosmic rays with the accelerator. These are then fired into an artificial atmosphere, where their effects can be studied much more closely.

BEYOND THE LHC

Over 13 years after it entered service, the LHC is still the world's biggest and most powerful particle accelerator. But it won't hold that record forever. Several countries have plans to go a step further, including China's Circular Electron Positron Collider and the International Linear Collider in Japan. Europe's own proposal is the Future Circular Collider (FCC), to be built near the LHC at CERN but dwarfing it in size. Though not yet financially approved – the estimated cost is £20 billion ($27 billion) – the design is well advanced. The FCC would be 62 miles in circumference and sit alongside the LHC, which it would use as a particle injector, ultimately achieving energies seven times greater than its predecessor.

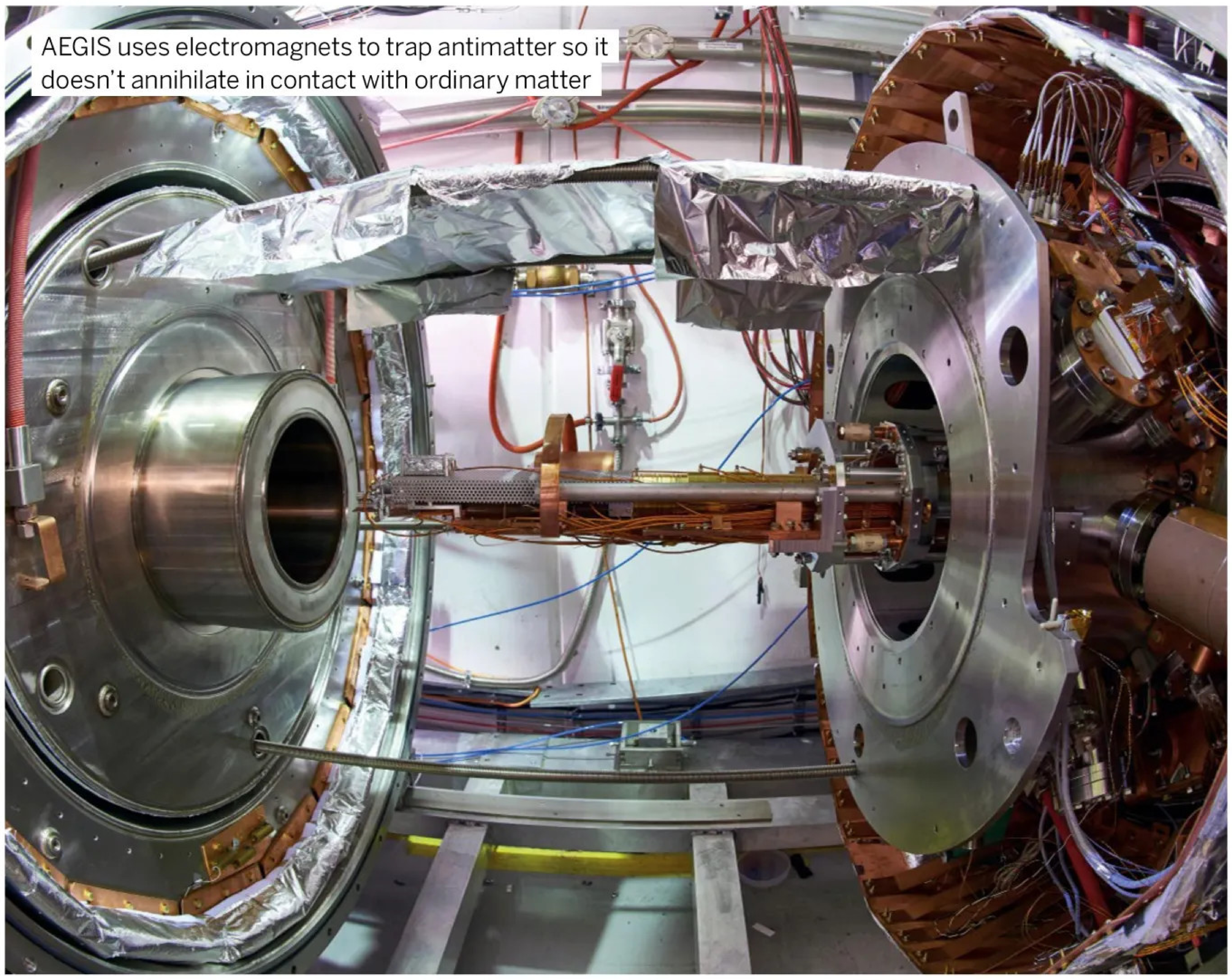


The proposed location of the FCC alongside the LHC and CERN's other accelerators

MAKING ANTIMATTER

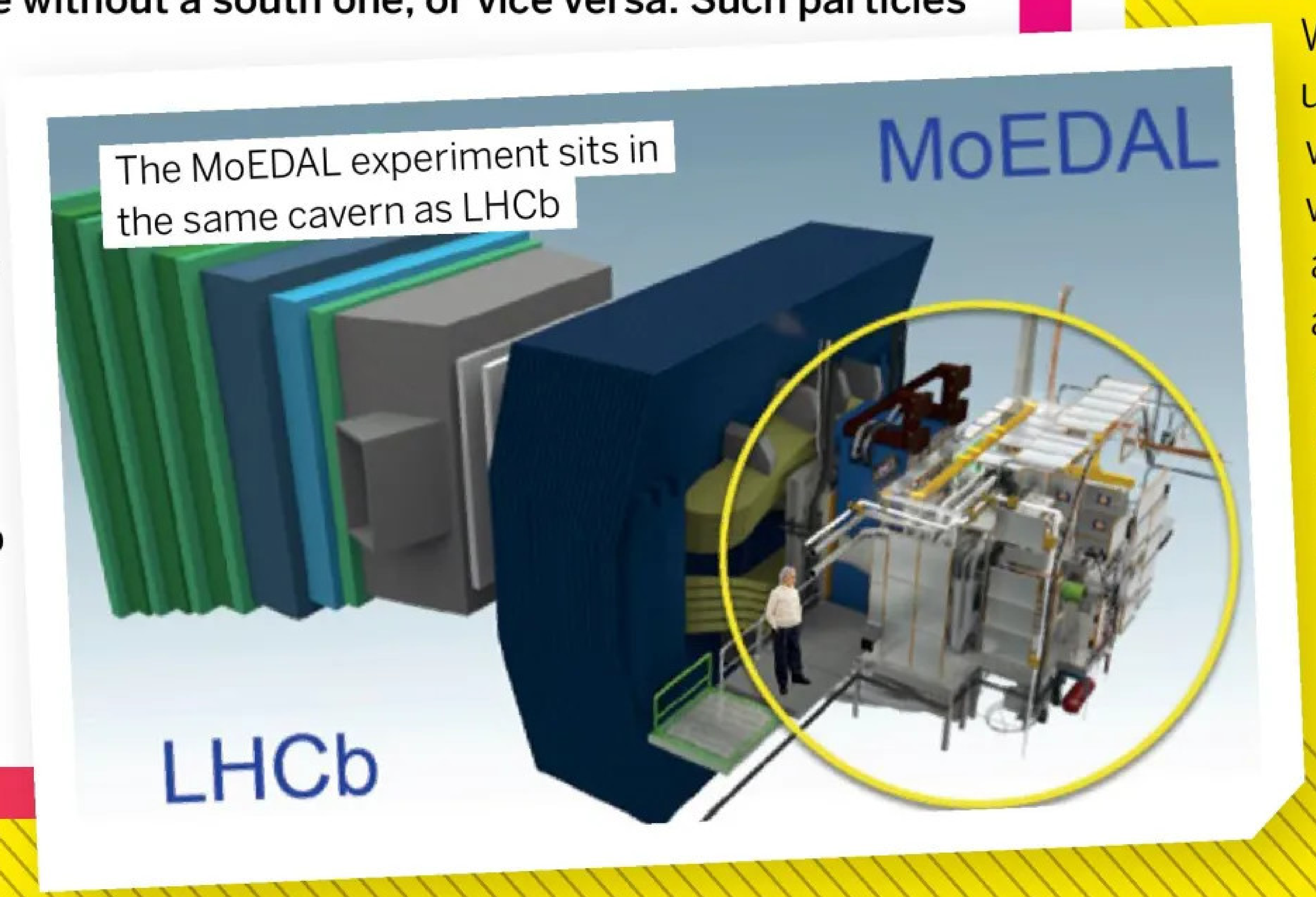
Antimatter often pops into existence inside CERN's high-energy accelerators as one half of a particle-antiparticle pair. But in the usual course of events, the antiparticles don't last long before they're annihilated in collisions with ordinary particles. If you want to create antimatter that stays around long enough for detailed study, you need more than just an accelerator. This is where CERN's unique 'antimatter factory' comes in.

It takes antiparticles created in the Proton Synchrotron and slows them down to manageable speeds in what is effectively the exact opposite of a particle accelerator: the Antiproton Decelerator. The resulting 'antiatoms' can then be studied by a range of instruments, such as AEGIS (Antihydrogen Experiment: Gravity, Interferometry and Spectroscopy). One question that AEGIS should be able to answer soon is the fascinating one of whether antimatter falls downwards in a gravitational field, like ordinary matter, or upwards in the opposite direction.


AEGIS uses electromagnets to trap antimatter so it doesn't annihilate in contact with ordinary matter

HUNTING EXOTIC PARTICLES

Sharing the same cavern as LHCb is a smaller instrument called MoEDAL, which stands for Monopole and Exotics Detector at the LHC. While most CERN experiments are designed to study known particles, this one is aimed at discovering unknown ones that lie outside the Standard Model. A monopole, for example, would be a magnetised particle consisting only of a north pole without a south one, or vice versa. Such particles have long been hypothesised, but never observed. The purpose of MoEDAL is to look out for any monopoles that might be created in collisions inside the LHC. It could also potentially detect certain 'stable massive particles' that are predicted by theories beyond the Standard Model. If it's successful in finding any of these particles, MoEDAL could help resolve fundamental questions such as the existence of other dimensions or the nature of dark matter.



The MoEDAL experiment sits in the same cavern as LHCb

WORKING WITH THE LHC

We speak to CERN scientist Clara Nellist about her work with the LHC's ATLAS detector

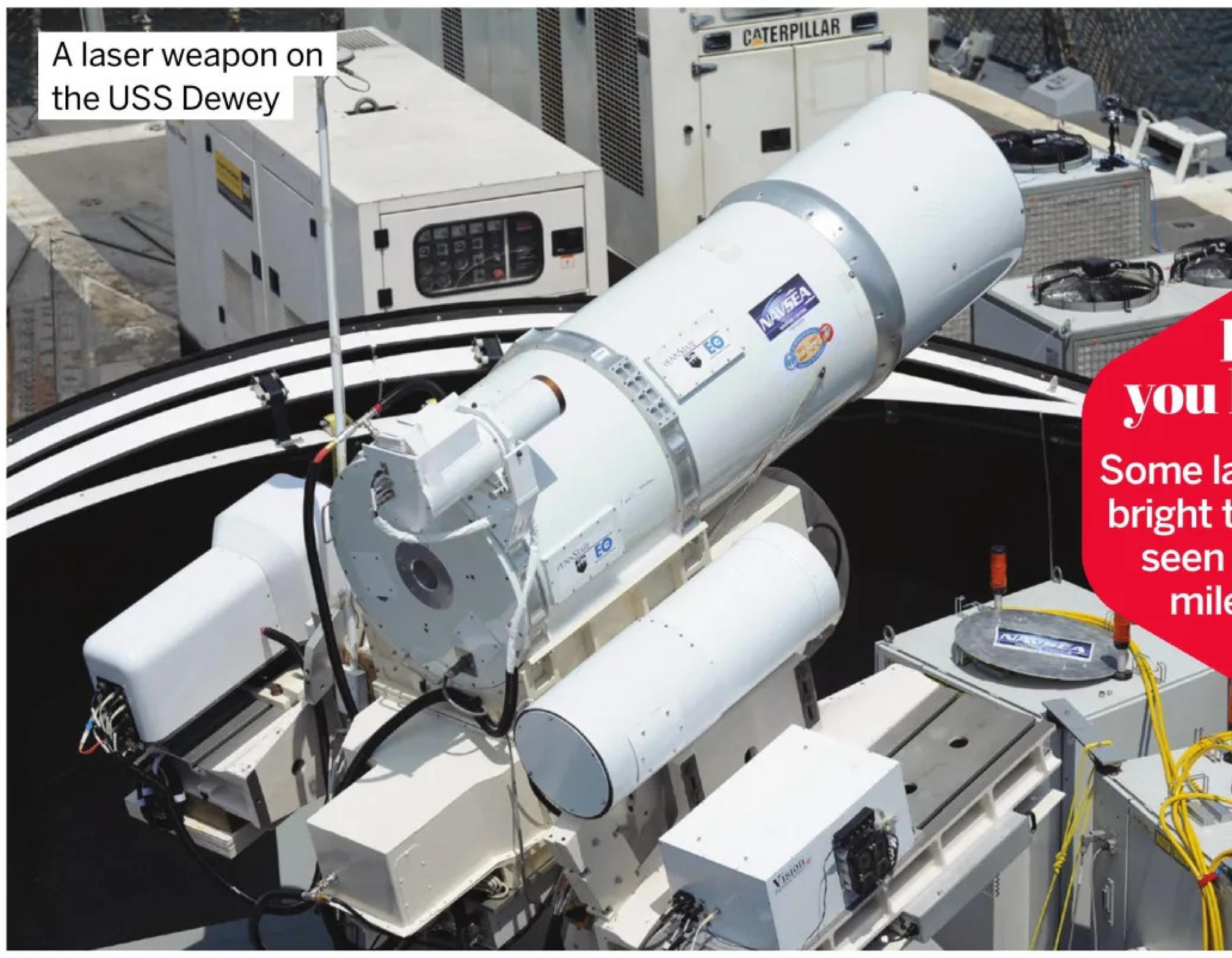
How did you come to be involved with the ATLAS experiment?
I started on ATLAS for my PhD research. I was developing new pixel sensors to improve the measurement of particles as they pass through our detector. It's really important to make them resistant to radiation damage, which is a big concern when you put the sensors close to the particle collisions. Since then, I've had the opportunity to work on a number of different projects, such as understanding how the Higgs boson and the top quark interact with each other. Now I'm applying machine learning algorithms to our data to look for hints of dark matter. One of the biggest mysteries in physics right now is, what is 85 per cent of the matter in our universe? We call it dark matter, but we don't actually know much about it!

What's it like working with such a unique and powerful machine?
It's really amazing to be able to work on this incredibly complicated machine with people from all over the world. No one person can run it all, so each team becomes an expert on their specific part. When we all work together, we can make discoveries about the smallest building blocks of our universe.

Are there any exciting new developments you're particularly looking forward to?
We're starting the Large Hadron Collider up again, so I'm really excited to see what we might find with it. Part of our work is to understand the particles we already know about in as much detail as possible to check that our theories match what we measure. But we're also looking for brand-new particles that we've never seen before. If we find something new, it could be a candidate for dark matter, or it could be something completely unexpected.

HOW LASERS ARE RESHAPING MODERN WARFARE

Whether it's navy ships or armoured vehicles, militaries all around the globe are taking lasers from the pages of fiction and turning them into the weapons of today



A laser weapon on the USS Dewey

The USS Ponce is equipped with laser weapon systems

Did you know?

Some lasers are so bright they can be seen up to 0.6 miles away

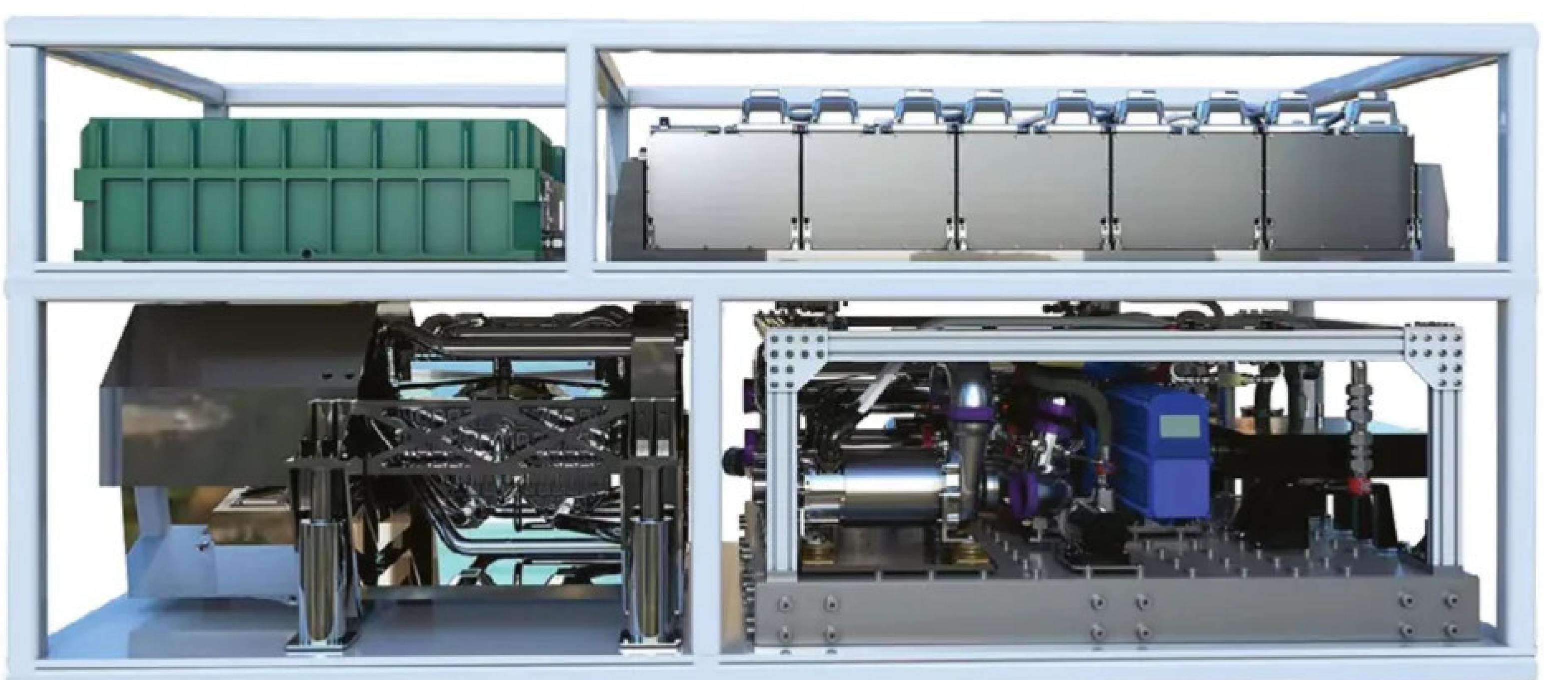
From James Bond to *Star Wars*, lasers have always been some of the coolest bits of technology found in the most fantastical stories. Whether it was the Death Star pulverising Alderaan or Goldfinger trying to get Sean Connery to talk, they've always seemed like a science fiction device found purely in the imagination of writers, directors and special-effects gurus. But lasers are a real-world technology that's already used widely in electronics and things like hair removal and cataract operations. The time is fast approaching, too, where they'll be used on the battlefield just as much as bombs, missiles and bullets.

The fascination with laser weapons, made famous by books such as H. G. Wells' *The War of the Worlds*, saw the British Ministry of Defence in the 1930s offer a cash prize for anyone who could invent a 'death ray' that could destroy a sheep at 100 yards. While that work never came to fruition, the research was taken in a different direction and sowed the seeds for what would eventually become radar.

Lasers entered industrial use in the 1960s, but putting them to military use still proved to be tough. President Ronald Reagan envisaged an orbital platform of laser-firing satellites that could wipe out incoming nuclear missiles. Nicknamed the Star Wars program, the tech was never up to the job, and the program was scrapped in the 1990s. But the research continued.

Thanks to the advent of fibre laser technology, systems shrunk to a level where they could be

General Atomics Electromagnetic Systems (GA-EMS) can target unmanned vehicles, missiles, rockets, artillery and mortars

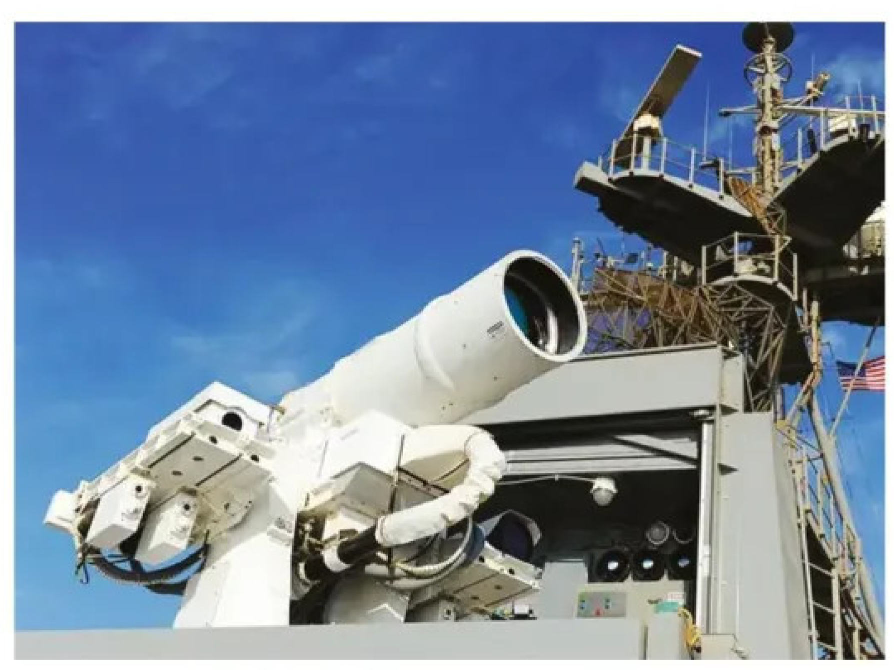


A French military vehicle used a laser to destroy a small drone, the first such success in Europe

HOW HIGH-POWER LASERS WORK

At its most basic level, a laser is a supercharged beam of light particles called photons. The key to getting these particles to do what you want is by 'exciting' the photons, which means giving them lots of energy so that they gain enough power to be aimed and fired at a target.

Laser itself stands for 'light amplification by stimulated emission of radiation' and consists of four basic parts. The first is a source of atoms in what is called a 'lasing medium' – it can be a gas, solid or liquid. The second is an energy source, which is needed to get the atoms 'excited'. The third is mirrors, usually a full mirror and a half-silvered mirror. These are used to allow the emitted light to bounce back and forth in the lasing medium while they build up energy. The fourth component is a lens, which focuses the beam of now-excited photons and allows it to be aimed at a target.



The LaWS weapons system mounted on a US Navy vessel fitted on vehicles, aircraft and ships. This leap forward resulted in a number of breakthrough tests, such as in 2016 when Lockheed Martin's 30-kilowatt Advanced Test High Energy Asset (ATHENA) was used to disable a vehicle's engine from more than a mile away.

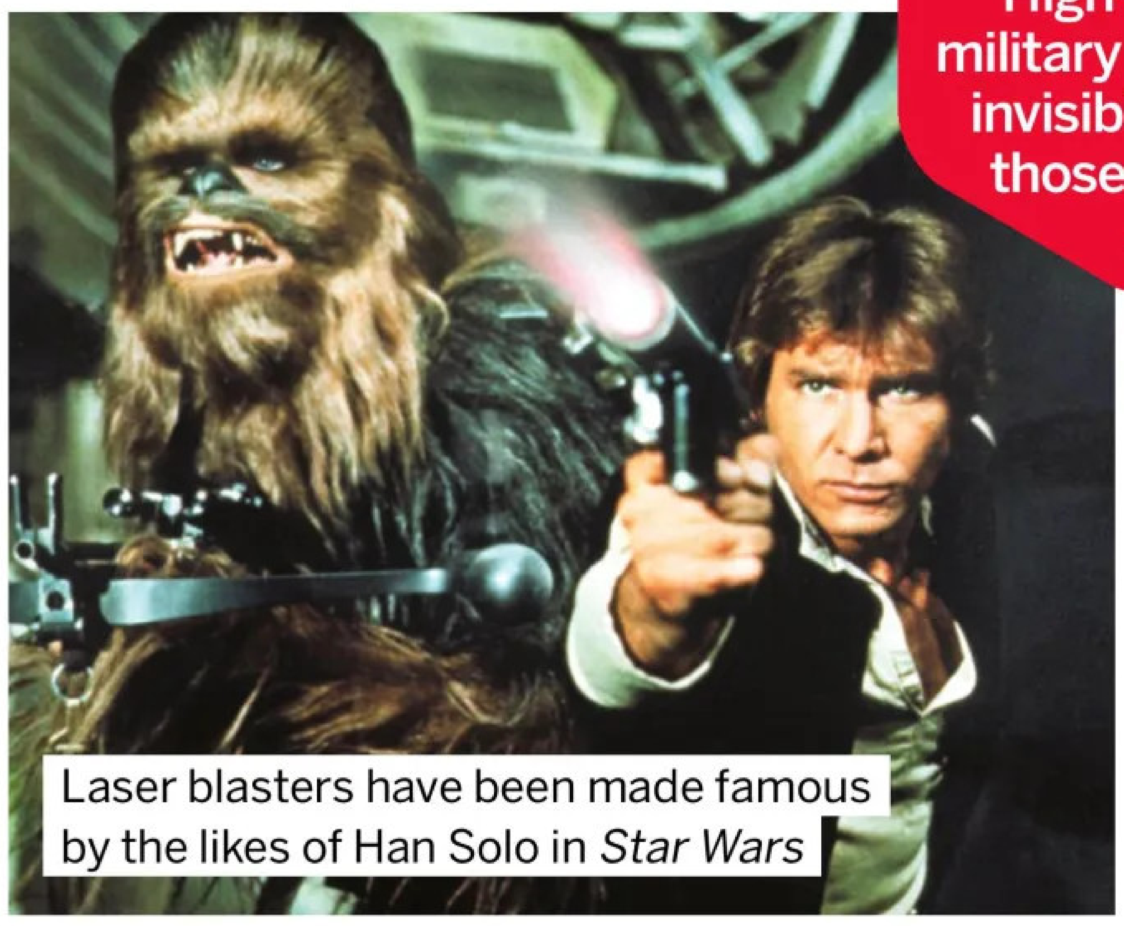
While their use as a weapon has always seemed a long way off, lasers have been used for other military purposes with great success. Weapon system guidance – where a laser is reflected from a target so a missile or bomb can more accurately home in – is one such use. But developing a solid-state laser weapon has remained difficult. Not only do they not need to be replenished with ammunition, in theory they would also have huge destructive power. Because of the size and huge power requirements of lasers, it has been naval vessels that have had the bulk of the early trials. The US Navy deployed the first high-energy laser weapon system, known as LaWS, on the USS Ponce in 2014, with a reported 30-kilowatt output.

Ground and air forces have also been developing laser weapons. The US Army has been working on the High Energy Laser Tactical Vehicle Demonstrator (HEL TVD), a truck-mounted 100-kilowatt-plus laser weapon that is designed to defend infrastructure such as airfields. In 2020, the US Air Force deployed the service's first high-energy laser – Raytheon's High Energy Laser Weapon System (HELWS) – for battlefield use against drones. In 2022, the US Army deployed 50-kilowatt lasers mounted to Stryker armoured vehicles. These are designed to defend against drones, artillery and rockets. The US government has also awarded a team a contract to build a prototype 300-kilowatt laser weapon.

Despite these advances, the expense of developing the technology and the huge power requirements for generating an effective laser mean the days of a soldier being able to fit a laser pistol into his holster are still some way off. Until then, we'll have to stick to games of laser tag.

Did you know?

High-energy military lasers are invisible, unlike those in films



Laser blasters have been made famous by the likes of Han Solo in *Star Wars*

"Not only do they not need to be replenished with ammunition, they would also have huge destructive power"

Boeing's HEL MD can take down multiple targets

LASER ON WHEELS

One example of battlefield laser technology that the industry has high hopes for is the High Energy Laser Mobile Demonstrator (HEL MD). Essentially a giant truck with a laser on its back, it has been in development since 2011. In 2013 it shot down several unmanned aerial vehicles (UAVs) in flight as well as more than 90 mortar rounds at the High Energy Laser Systems Test Facility located at White Sands Missile Range, New Mexico. It fired a ten-kilowatt laser in that test, but future plans include tests with a 50 and then 100-kilowatt laser – this means it could engage cruise missiles, rockets and even artillery.

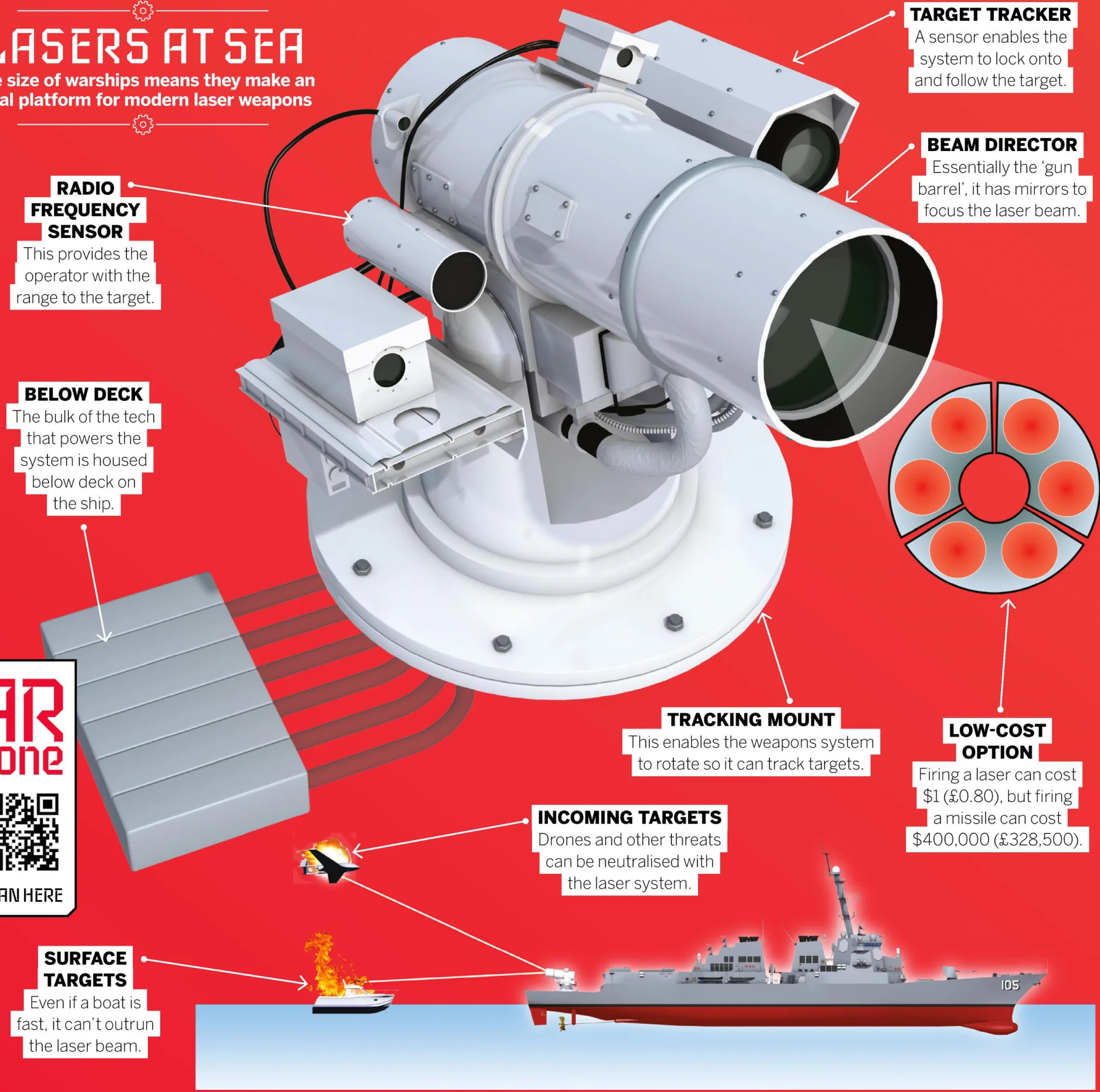
CHINA'S NEW LASER RIFLE

Mystery surrounds one piece of intriguing technology purported to be a Chinese 'laser rifle'. In 2018 the Communist country's military claimed to have created a revolutionary new type of laser rifle straight from the movies. Branded the ZKZM-500, it's supposedly capable of burning a hole in an enemy soldier from half a mile away.

Manufactured by ZKZM Laser, it supposedly weighs around 2.7 kilograms and was claimed to have a range of 800 metres. China said the rifle consists of two important components, the laser and its lithium battery, which account for most of its weight. But many industry experts in the West were heavily sceptical of the claims.

LASERS AT SEA

The size of warships means they make an ideal platform for modern laser weapons




A USS Ponce weapons test in 2014


Operators control the laser weapons


A Northrop Grumman laser weapon ready for transport

Testing the limits of spacecraft

Take a look inside the European Space Agency's high-tech testing facility

The European Space Agency (ESA) brings more than 20 countries together in pursuit of space travel, and its largest facility can be found at Noordwijk, on the west coast of the Netherlands. The European Space Research and Technology Centre (ESTEC) is the high-tech hub of the operation, responsible for making sure that all spacecraft and their payloads are fit to fly.

Travelling to space is a challenge. Spacecraft are exposed to extreme speeds, extreme temperatures, and extreme vibration. They will enter a vacuum, undergo weightlessness, and be pummelled with radiation, so before the spacecraft set off into these unforgiving conditions, the ESA team needs to make sure that they are ready.

More than 2,500 people work at ESTEC, designing the blueprints for new missions, developing new technology, and checking every spacecraft before launch. Each new item needs to be tested, and the facility is equipped to mimic the stresses of outer space as closely as possible.

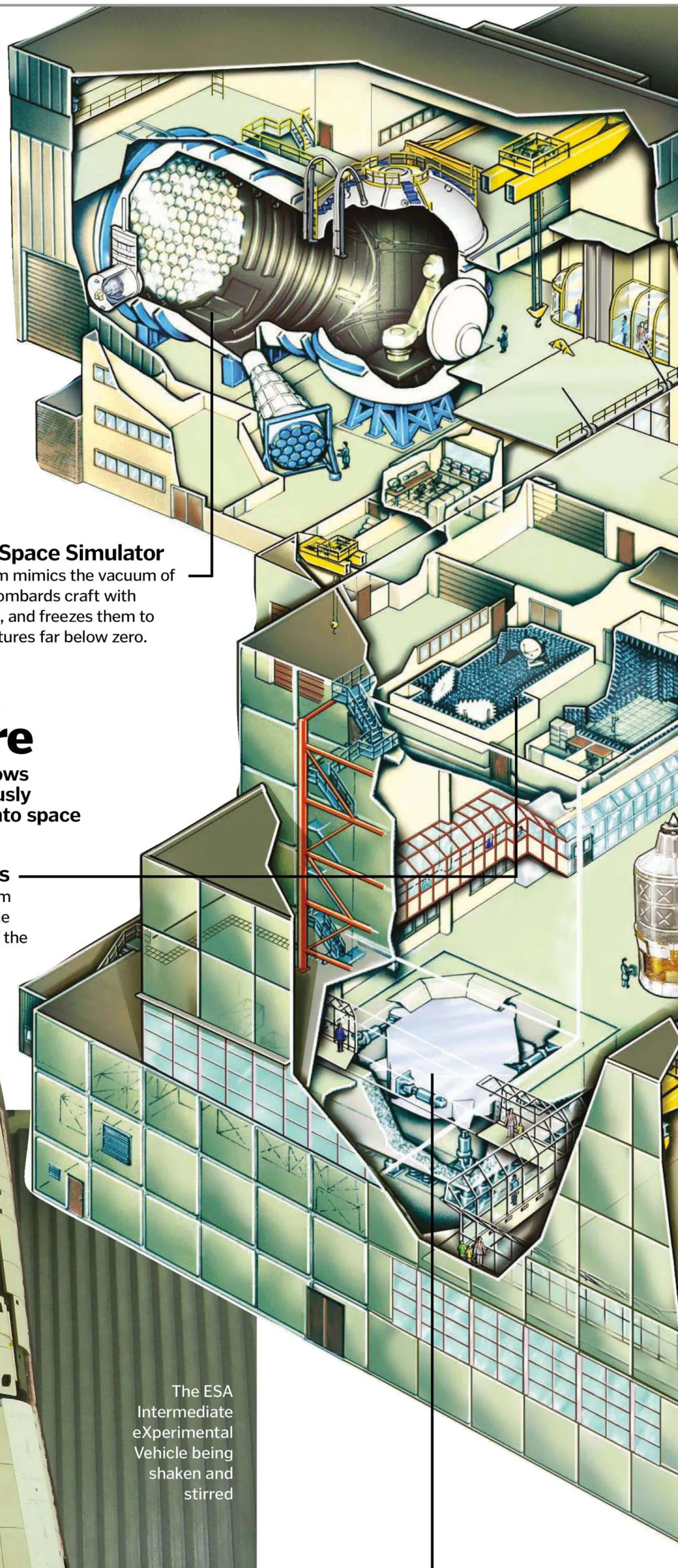
The self-contained facility was specially designed to allow spacecraft to move from one area to the next, undergoing a sequence of tests to ensure that they are ready to fly. All the rooms are kept behind airlocks, ensuring that the craft remain clean and protected throughout their stay.

Inside the centre's various rooms, the equipment is shaken, spun, blasted with sound, frozen, bombarded with radiation and exposed to a vacuum. Each room is specifically designed to test a different aspect of the launch and space-travel process. For instance, the Large European Acoustic Facility acts like a giant music speaker, blasting satellites with the kind of volumes they will need to endure at lift-off. Next, the craft may be exposed to the extreme temperatures of space for a period of several weeks.

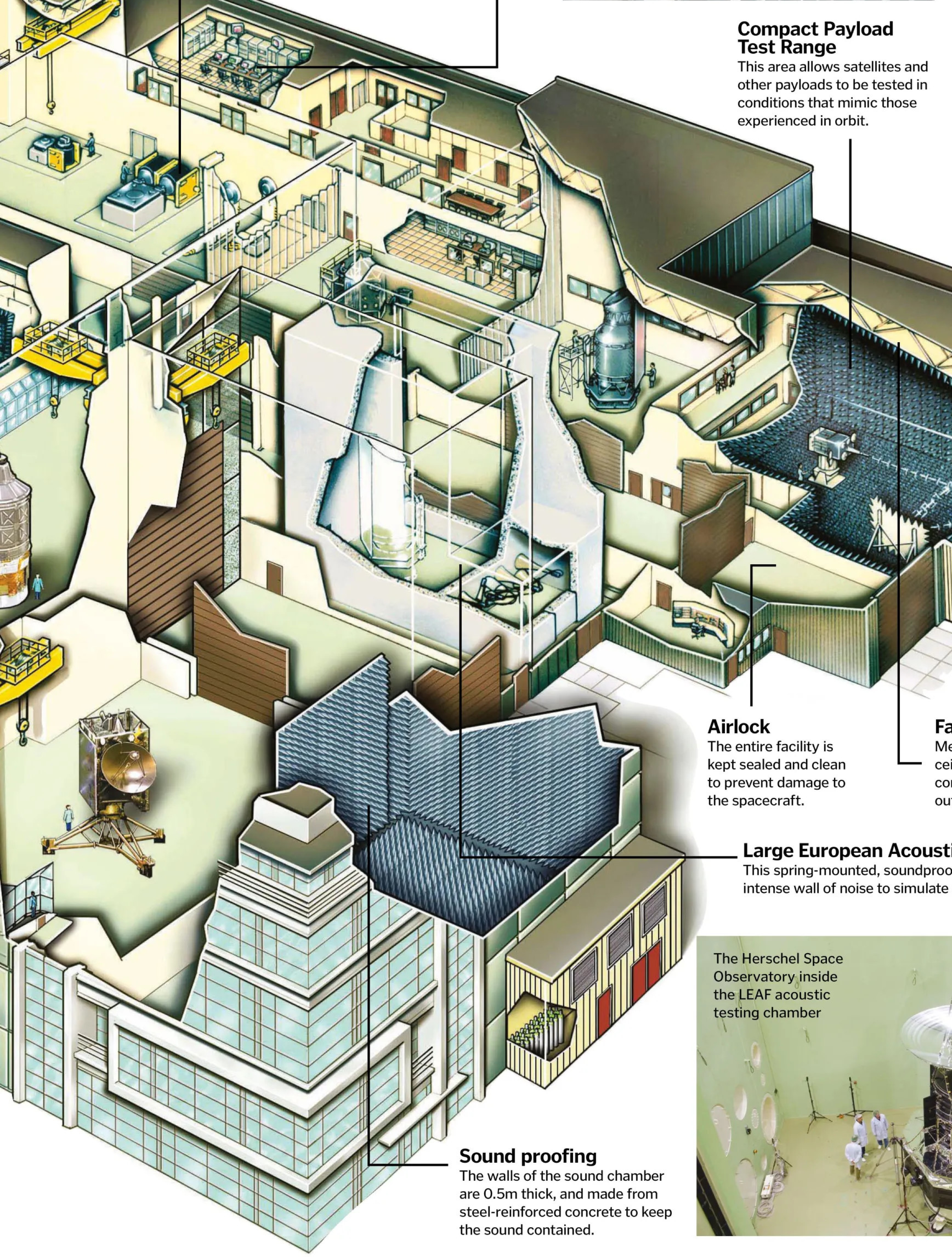
While the spacecraft and components undergo rigorous tests, the Data Handling Systems collect and analyse information from hundreds of sensors. Once they have passed every challenge that the Test Centre throws at them, the spacecraft are ready to make the dangerous trip into space.

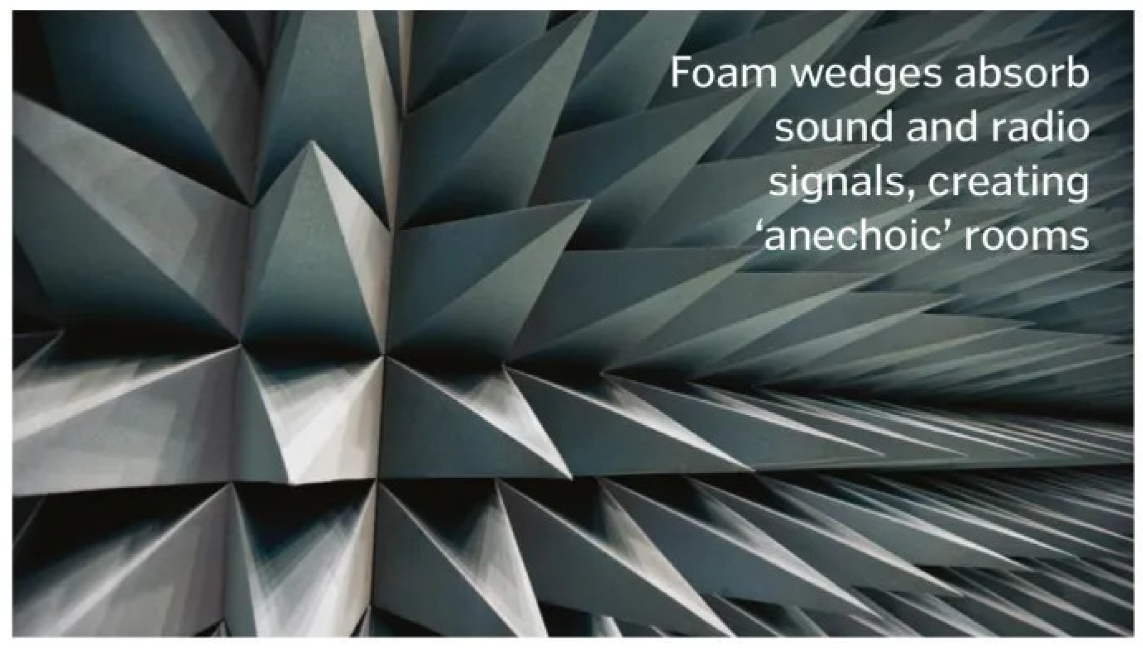
Inside the Test Centre

A network of rooms allows spacecraft to be rigorously tested before they go into space



The ESA Intermediate eXperimental Vehicle being shaken and stirred

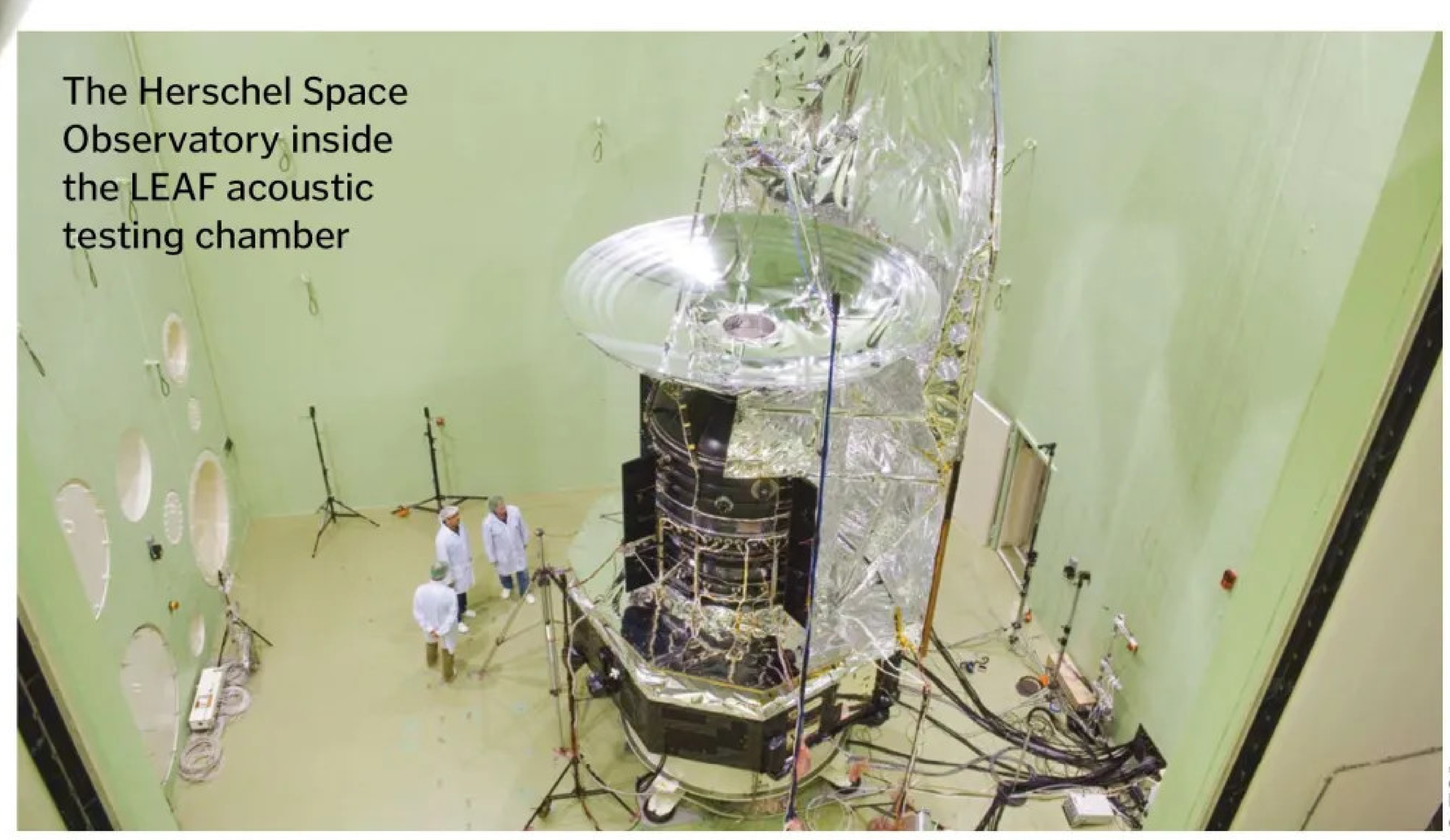



Foam wedges absorb sound and radio signals, creating 'anechoic' rooms

Pushed to the limit

The Test Centre is equipped with an impressive arsenal of kit designed to test spacecraft and their payloads to breaking point. Physical properties machines weigh and measure the equipment, determining the centre of gravity and the moment of inertia. This can help to ensure that everything is balanced if the spacecraft needs to spin in flight.

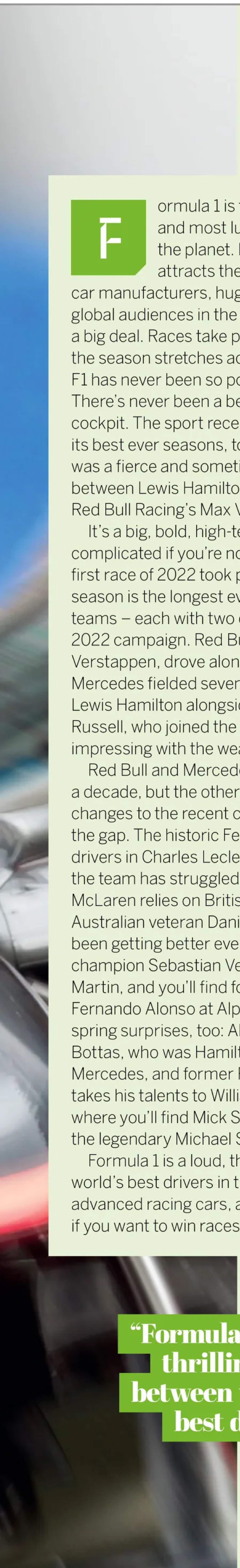
Electrically powered shakers put the equipment through the intense vibrations of launch, while a hydraulic shaker is on hand for larger, heavier equipment. The Large European Acoustic Facility (LEAF) bombards satellites with intense sound, up to 156 decibels, to ensure that they will still be able to function after launch. And the most impressive room in the facility, the Large Space Simulator, plunges test equipment into a space-quality vacuum, complete with freezing temperatures and radiation that mimics the dangerous emissions of the Sun. Throughout testing, sensitive equipment gathers data about how the spacecraft are performing, ensuring that they will be ready for the real thing.


The Herschel Space Observatory inside the LEAF acoustic testing chamber

FORMULA 1

EVERYTHING YOU NEED TO KNOW

Discover the race cars, technology, drivers and crews behind the world's biggest and most popular motorsport



Formula 1 is the fastest, most popular and most lucrative motorsport on the planet. Its status means it attracts the best drivers, the biggest car manufacturers, huge media attention and global audiences in the hundreds of millions. It's a big deal. Races take place on five continents, the season stretches across most of the year and F1 has never been so popular on social media. There's never been a better time to dive into the cockpit. The sport recently experienced one of its best ever seasons, too: the 2021 campaign was a fierce and sometimes bad-tempered battle between Lewis Hamilton's Mercedes team and Red Bull Racing's Max Verstappen.

It's a big, bold, high-tech circus, but it can be complicated if you're not sure how F1 works. The first race of 2022 took place in Bahrain, and the season is the longest ever, with 23 races. Ten teams – each with two drivers – contested in the 2022 campaign. Red Bull's world champion, Max Verstappen, drove alongside Sergio Perez. Mercedes fielded seven-time world champion Lewis Hamilton alongside young driver George Russell, who joined the big leagues after impressing with the weaker Williams team.

Red Bull and Mercedes have dominated F1 for a decade, but the other teams hope that big changes to the recent cars will help them close the gap. The historic Ferrari team has excellent drivers in Charles Leclerc and Carlos Sainz, but the team has struggled with a weaker car. McLaren relies on British driver Lando Norris and Australian veteran Daniel Ricciardo, and they've been getting better every year. Four-time world champion Sebastian Vettel drives for Aston Martin, and you'll find former world champion Fernando Alonso at Alpine. Smaller teams can spring surprises, too: Alfa Romeo will field Valtteri Bottas, who was Hamilton's teammate at Mercedes, and former Red Bull driver Alex Albon takes his talents to Williams. Then there's Haas, where you'll find Mick Schumacher – the son of the legendary Michael Schumacher.

Formula 1 is a loud, thrilling battle between the world's best drivers in the world's most advanced racing cars, and you need good drivers if you want to win races. It's not just about the driver, though. They wrangle incredible vehicles, the fastest open-wheel, single-seater racing cars around, and their aerodynamic design means they travel faster than some planes on takeoff. F1 cars produce 5G of downforce, so they can take corners at sensational speeds, and they race at more than 200 miles per hour. Teams spend millions of pounds developing their cars. And while every F1 team must adhere to strict regulations to ensure fair racing, teams with the biggest budgets and best engineers tend to develop better components and produce faster, more reliable cars.

"Formula 1 is a loud, thrilling battle between the world's best drivers"

The first corner is often the busiest in F1, with 20 cars in close proximity

Success in F1 is about strategy, too. Teams use different tyres during races: softer tyres provide more grip but deteriorate quickly, while harder tyres have less grip but last longer. No tyres last for a full race, though, so teams must decide when to pit their cars to fit a new set. A pit stop costs time, but can allow teams to gain strategic advantages. They've also got to consider the weather, because rain dramatically alters a race – it changes which tyres work well, allows some drivers to thrive and means that others will struggle.

Races take place on Sundays and usually last about two hours; here you'll get to see the world's best drivers locked in intense on-track battles. But Formula 1 is not just about those Sunday races. It's a travelling festival of motorsport, and you can watch days of on-track action in the lead-up to the main Sunday event. Qualifying, which takes place on Saturdays, determines the starting order for the Sunday race. F1 uses two different qualifying formats: most Saturdays have an hour-long session where drivers push their cars to the limit, because faster lap times mean a better starting spot on the Sunday. In 2022, six circuits hosted an alternative format called Sprint Qualifying, where a short race on the Saturday decides starting positions on Sunday. F1 weekends also featured practice sessions, with three on Friday and a final practice run on Saturday mornings. These are important: they give drivers and teams the chance to test different car set-ups, learn the circuit and devise strategies. The top-ten drivers in each F1 race get points – the winner gets 25, the second-place driver gets 18 and amounts decline further. The driver with the fastest lap during the race gets an extra point. Those points decide each year's champion.

Cars are built from deformable parts, while drivers sit in a super-strong safety cell

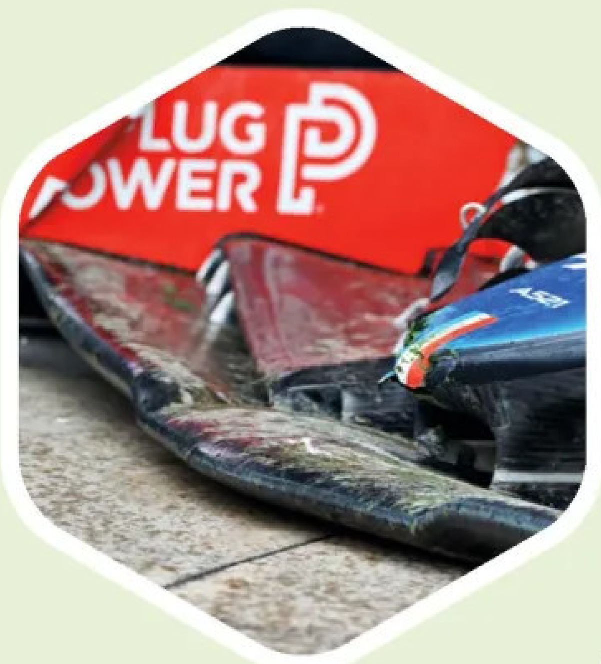
WHY IS IT CALLED FORMULA 1?

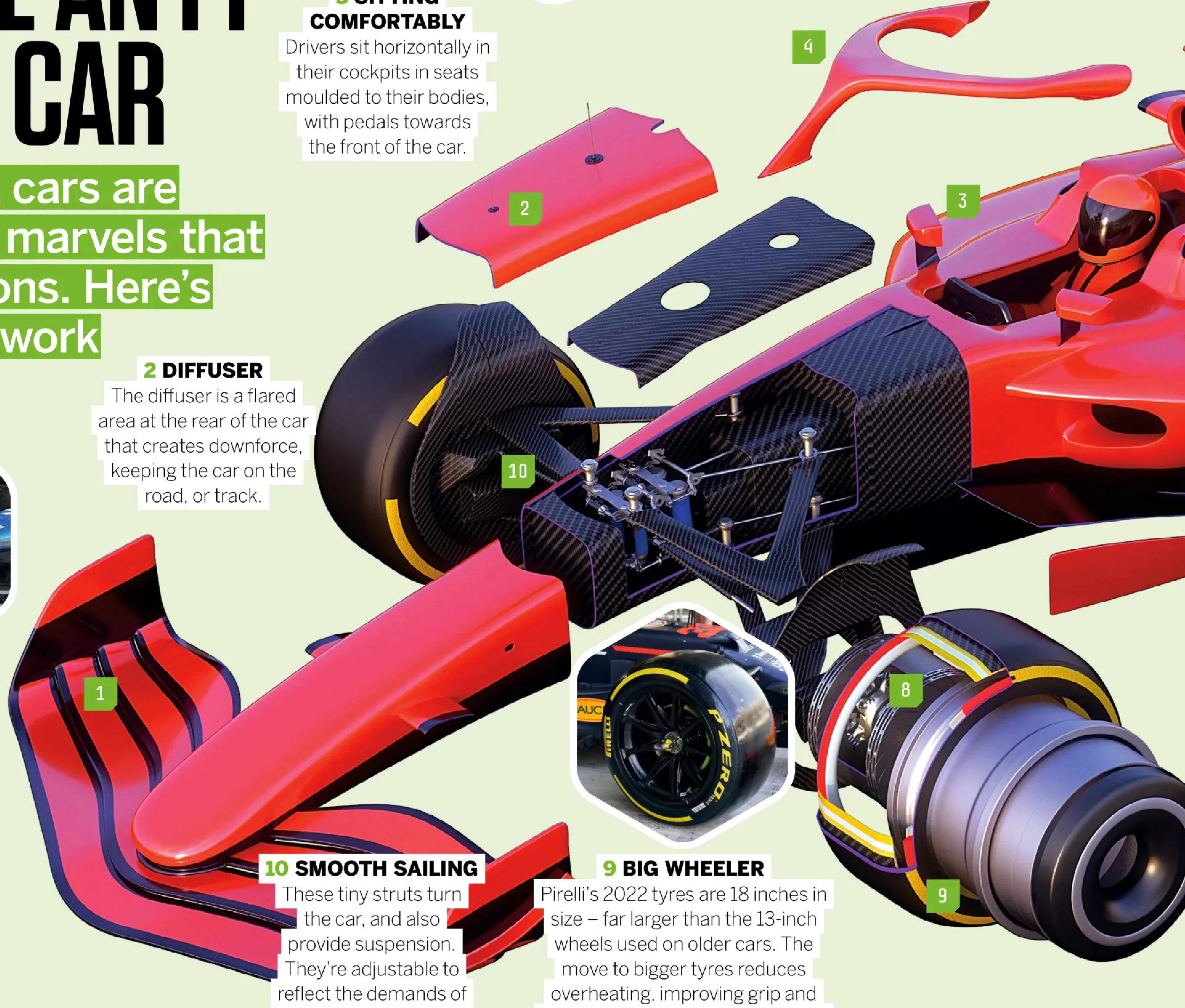
European racing used to be organised by the Association Internationale des Automobile Clubs Reconnus (AIACR). World War II stopped that, and a new organisation called the Fédération Internationale de l'Automobile (FIA) was created to rebuild racing after the hostilities. By 1946 the FIA was planning a world championship, and by 1950 Formula 1 was ready to start. The term 'Formula' represents a set of standards that every participating car must meet before it's allowed to race, and it was called Formula 1 because it's the top tier of racing. That's still in place today, where cars all adhere to the same design basics, and this naming convention is also used for other types of racing, like Formula 2, Formula 3 and Formula Renault.

The first F1 races were frantic affairs, with big crowds and little regard for safety

INSIDE AN F1 RACE CAR

Formula 1 cars are high-tech marvels that cost millions. Here's how they work





1 NOSE AHEAD
The front wing and nose sections were completely redesigned for 2022. The revised aerodynamics keep air closer to the sides of the car so other vehicles won't be disturbed by turbulence, meaning drivers can race with more confidence.

2 DIFFUSER
The diffuser is a flared area at the rear of the car that creates downforce, keeping the car on the road, or track.

3 SITTING COMFORTABLY
Drivers sit horizontally in their cockpits in seats moulded to their bodies, with pedals towards the front of the car.

4 SAFETY FIRST
Safety is crucial in F1, and a tubular titanium structure called a halo protects drivers from large objects and debris during races. The halo was introduced in 2018 and has proven a successful and life-saving addition to open-wheel racing.

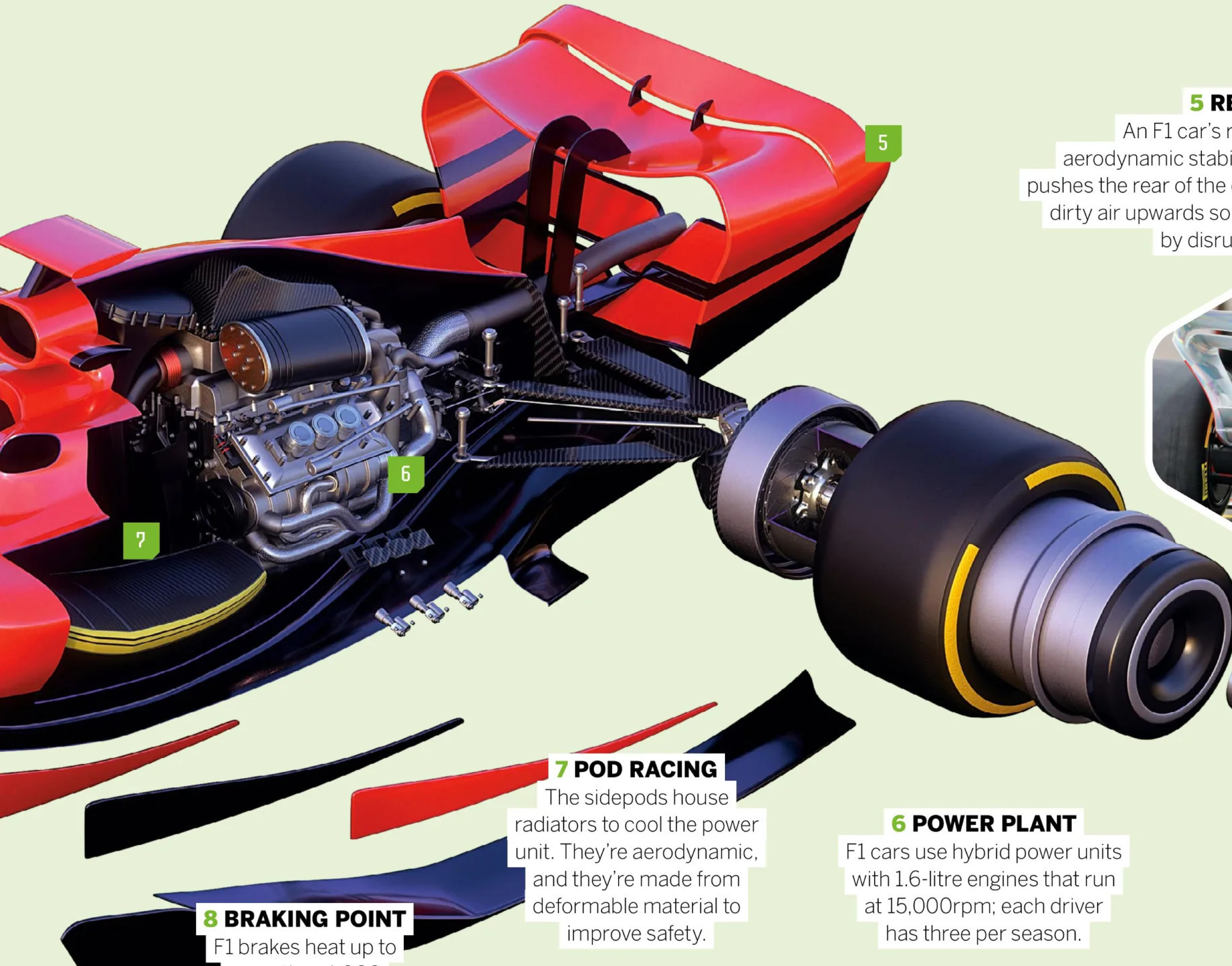
9 BIG WHEELER
Pirelli's 2022 tyres are 18 inches in size – far larger than the 13-inch wheels used on older cars. The move to bigger tyres reduces overheating, improving grip and leading to more aggressive racing.

10 SMOOTH SAILING
These tiny struts turn the car, and also provide suspension. They're adjustable to reflect the demands of different circuits.

2022'S BIGGEST CAR UPGRADES

Formula 1's 2022 cars underwent radical changes when compared to previous year's models. The big upgrades concerned aerodynamics – the way that the cars behave as they move through the air – and they should promote closer racing. The front sections of 2022's cars look very different, for starters; their curvier construction helps keep air flowing narrowly down the sides of each car so other racers aren't disturbed by unpredictable currents. The rear wing was redesigned, too. It's taller and sends air straight upwards so racers don't get jostled as they follow another driver. Newer cars also have larger tyres than before, which reduces overheating and improves grip – another move to ensure better racing. Elsewhere, the cars now use a fuel that's made from ten per cent biofuel, which reduces F1's reliance on fossil fuels. The power unit underneath all of this is unchanged, though, which means that F1 remains a hybrid motorsport.


Haas is F1's only American team.



5 REAR GUARD
An F1 car's rear wing is crucial for aerodynamic stability. This redesigned feature pushes the rear of the car onto the track while sending dirty air upwards so following cars aren't affected by disruptive turbulence.

7 POD RACING
The sidepods house radiators to cool the power unit. They're aerodynamic, and they're made from deformable material to improve safety.

6 POWER PLANT
F1 cars use hybrid power units with 1.6-litre engines that run at 15,000rpm; each driver has three per season.

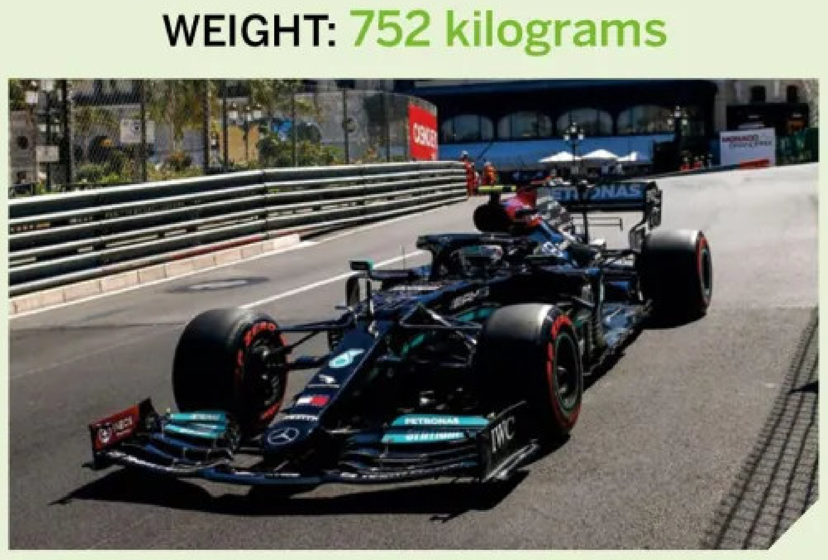
8 BRAKING POINT
F1 brakes heat up to more than 1,000 degrees Celsius, and they require huge force and finesse from drivers to work effectively.

Did you know?
7,500 simulations were used to design the 2022 car


More than 365,000 spectators attended the 2021 British Grand Prix – a record-breaking crowd


Red Bull holds the record for the fastest pit stop at just 1.82 seconds

MERCEDES W12: TITLE WINNER
F1 SEASON INTRODUCED: 2021
BRAKE HORSEPOWER: 1,050
WEIGHT: 752 kilograms



FERRARI F2002: ICONIC DESIGN
F1 SEASON INTRODUCED: 2002
BRAKE HORSEPOWER: 835
WEIGHT: 600 kilograms

WILLIAMS FW18: BRITISH BATTLER
F1 SEASON INTRODUCED: 1996
BRAKE HORSEPOWER: 700
WEIGHT: 595 kilograms

LOTUS 78: AERODYNAMIC INNOVATION
F1 SEASON INTRODUCED: 1977
BRAKE HORSEPOWER: 480
WEIGHT: 588 kilograms

The Hungaroring is one of F1's most picturesque tracks – and one of the trickiest

CIRCUIT BREAKERS

Racing circuits are loops of road that are built to challenge drivers, promote overtaking and deliver exciting racing. The best tracks allow F1 cars to reach their top speeds, and top circuits combine fast corners for brave, high-speed overtakes and slower corners for dramatic battling. Most F1 races take place at purpose-built circuits that are used for lots of different kinds of motor racing – indeed, if you attend an F1 race you'll see other cars racing during breaks between F1 sessions.

In 2022, seven races took place on street circuits – tracks built in existing cities. The most famous is the Monaco Grand Prix route, which has been used since 1929, and in 2022 a new circuit was introduced in Florida that races around the Miami Dolphins' NFL stadium.

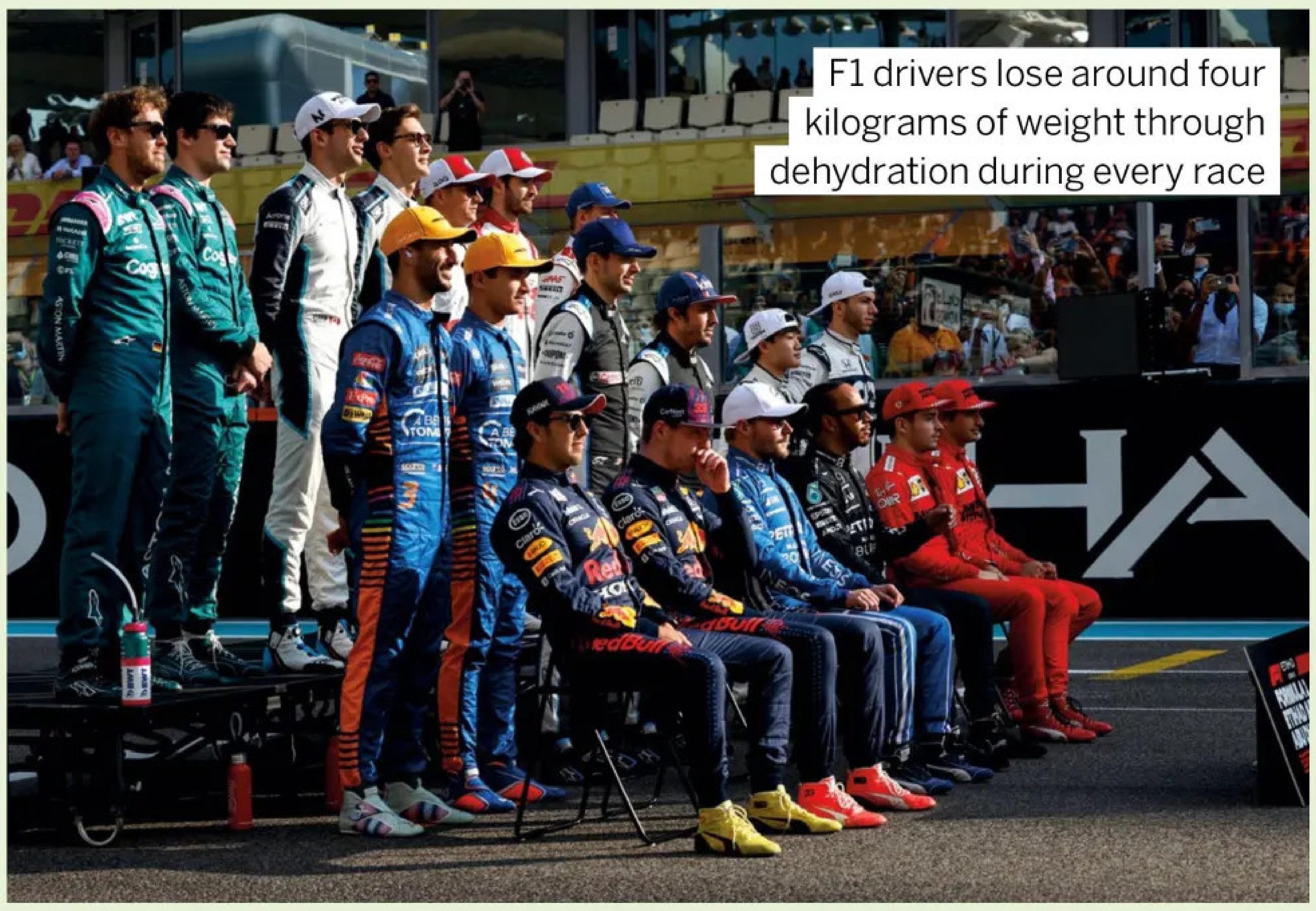
F1 circuits range from between 2.075 and 4.352 miles in length, and most F1 races need to run for at least 190 miles, so races typically last between 44 and 78 laps. Most circuits run clockwise, and they all have long start-finish straights where races begin and end. Every circuit has a pit area where cars can leave the track to get new tyres and components, and grandstands for fans surround each circuit.

Circuits have changed dramatically over the years. They're far safer now – they're surrounded by padded barriers to absorb car impacts, and corners have large gravel areas to slow cars down if they leave the track. Many circuits have undergone layout changes to alter average speeds and promote better racing, including some of F1's most famous venues.

Take Silverstone, for instance – the circuit that's hosted the British GP more than any other. It was originally an airfield, and racers used the old runways before that was deemed unsafe. Over the years it's had chicanes added and corners altered, and in 2010 new corners were added and a new start-finish straight was built. Hockenheim in Germany was famous for long straights that plunged through a forest, but in 2002 the straights were abandoned in favour of a new layout with loads of tight corners. Belgium's Spa-Francorchamps circuit was originally nine miles long, but its current design is just over four miles. For the 2022 season its most famous corners, Eau Rouge and Raidillon, were redesigned after several high-profile accidents. F1 circuits don't stay still for long – a bit like the cars that race on them.

Did you know?

Formula 1 cars contain about 80,000 components



F1 drivers lose around four kilograms of weight through dehydration during every race

5 FACTS
F1'S REAL-WORLD IMPACT

1 HARNESSING HYBRIDS
The incredible efficiency of F1's hybrid power units has made hybrid road cars more efficient, and Mercedes uses some of its hybrid tech in its road cars.

2 ENERGY-SAVING BRAKES
F1's Kinetic Energy Recovery System (KERS) charges cars' batteries by reclaiming energy during braking. It's been around since 2009, and similar systems are now found in hybrid cars and buses.

3 SUSPENSION SPREADING
Active suspension first arrived in F1 in 1992, allowing suspension height to change depending on the road conditions. Since then, it's become a standard feature on many road cars.

4 PADDLE SHIFTING
Ferrari was the first team to use paddle shifters to enable super-fast manual gear changes. Now they're standard in F1 and found on all kinds of everyday cars.

5 CARBON FOOTPRINT
Carbon fibre is sturdy and lightweight, and it was pioneered by McLaren in the 1980s. Now it's used on virtually every sports car thanks to its robust, weight-saving design.

DID YOU KNOW? *F1's tech-filled steering wheels are packed with features, screens and dials, and cost more than £50,000 ($68,000)*

STAYING ON TRACK

A spectator's guide to the technology of an F1 race track

BREAKING THE LIMITS

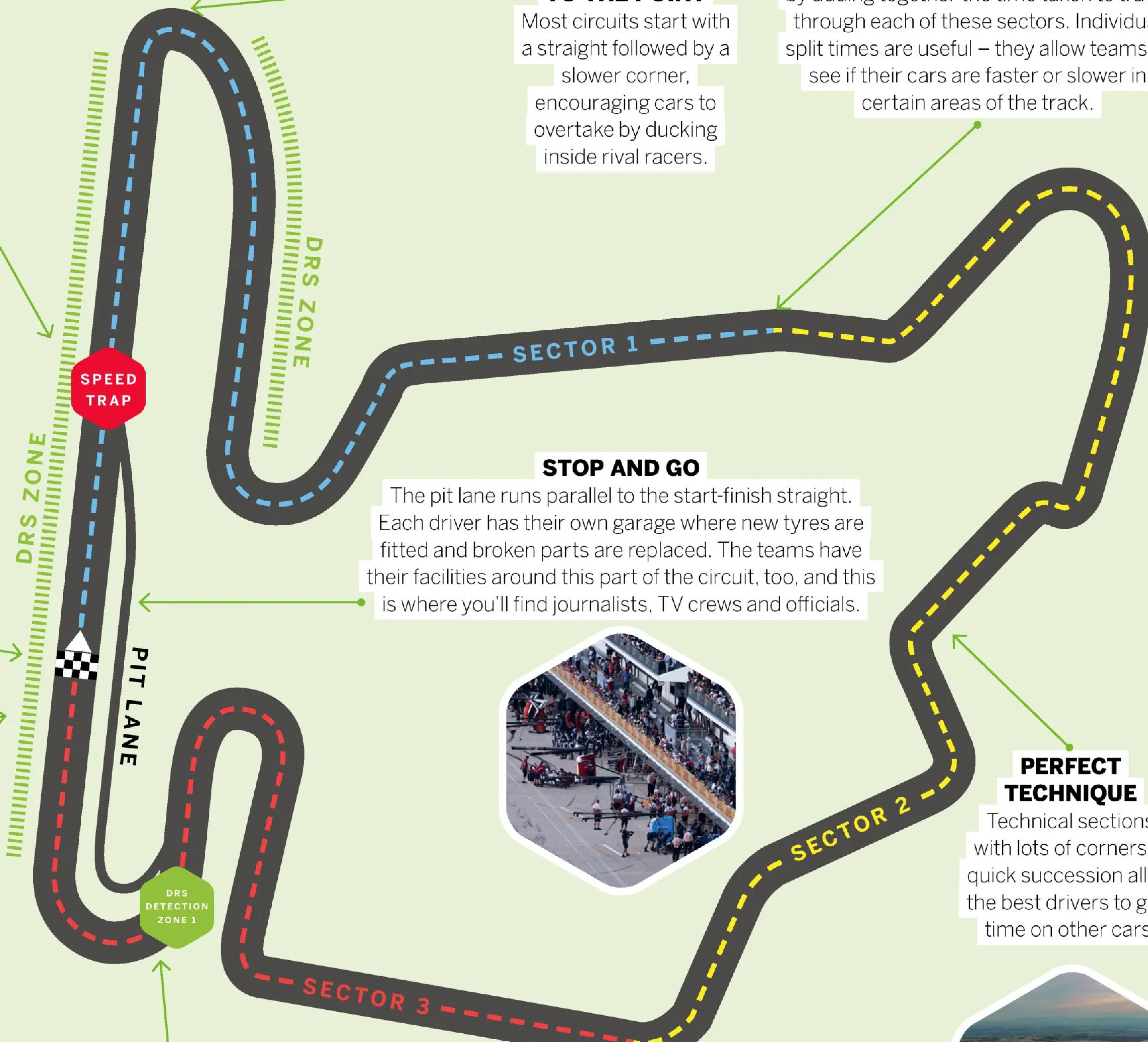
The speed trap on the circuit's longest straight highlights which cars are faster than others.

GRID GAMES

The start-finish line is where races begin and end, so this is where you'll see someone waving a chequered flag.

TAKE THE INITIATIVE

Drivers can deploy the Drag Reduction System (DRS) along the circuit's straights if they're less than one second behind the car in front. DRS activation lowers a flap on the car's rear wing, which reduces drag and increases top speeds, giving the driver behind an opportunity to overtake.



STRAIGHT TO THE POINT

Most circuits start with a straight followed by a slower corner, encouraging cars to overtake by ducking inside rival racers.

SPLIT DECISIONS

Circuits are divided into three sections, called splits, and lap times are calculated by adding together the time taken to travel through each of these sectors. Individual split times are useful – they allow teams to see if their cars are faster or slower in certain areas of the track.

STOP AND GO

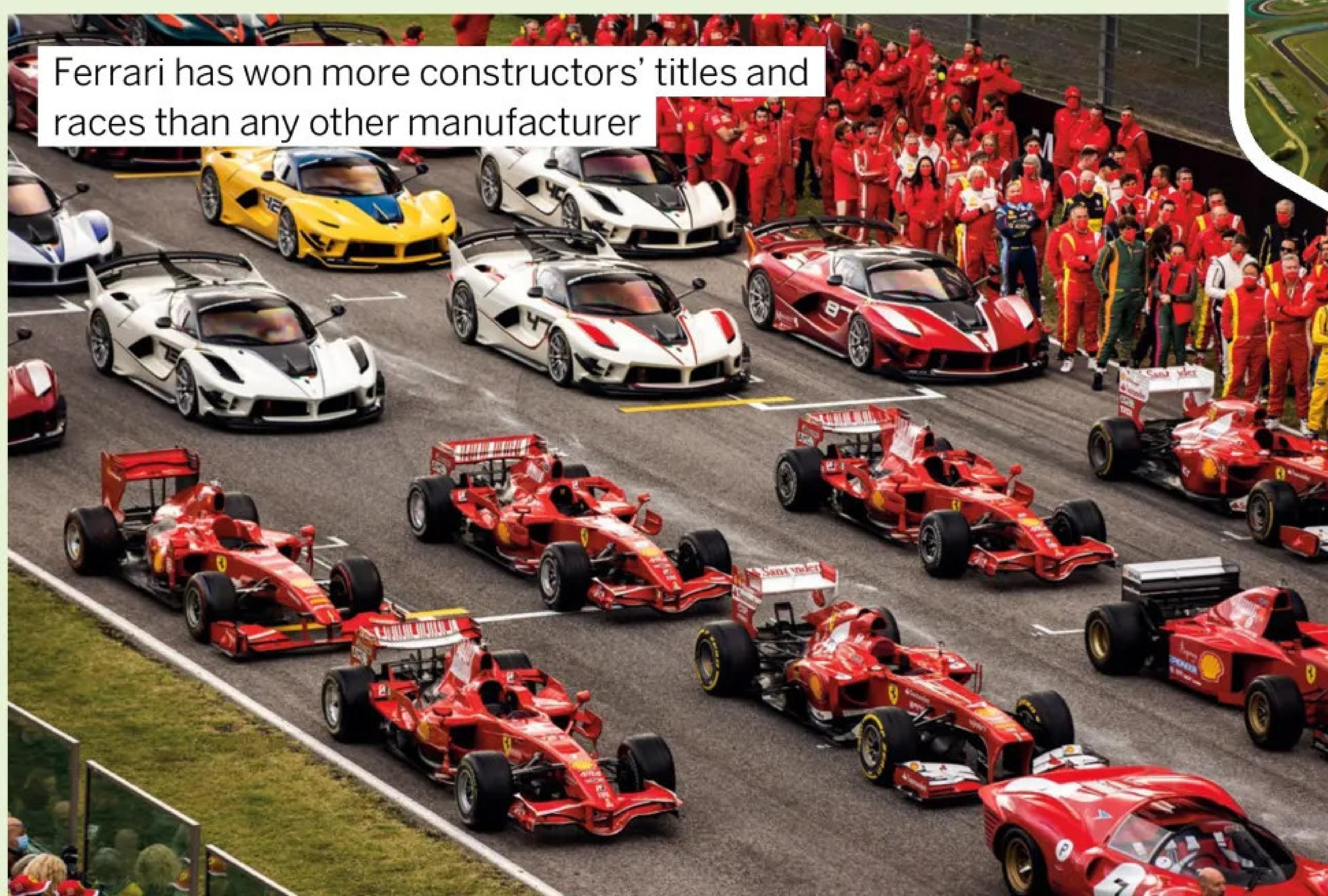
The pit lane runs parallel to the start-finish straight. Each driver has their own garage where new tyres are fitted and broken parts are replaced. The teams have their facilities around this part of the circuit, too, and this is where you'll find journalists, TV crews and officials.

PERFECT TECHNIQUE

Technical sections with lots of corners in quick succession allow the best drivers to gain time on other cars.

DRAG RACING

If a car is close behind a rival at a particular point, drivers can use the DRS.



Ferrari has won more constructors' titles and races than any other manufacturer

AUTONOMOUS FREIGHT

The world's first all-electric crewless cargo ship

In November 2021, the Yara Birkeland, the world's first autonomous electric container vessel, set off on its maiden voyage in Oslofjord, Norway. The 80-metre-long ship has been created by Yara International, a Norwegian chemical company, which will use the vessel to replace lorry haulage from its Norwegian plant in Porsgrunn to a port in Brevik, around 8.7 miles away.

The Yara Birkeland was announced in 2017 and promises to cut carbon dioxide (CO_2) emissions by 1,000 tonnes each year. This saving is equal to around 40,000 journeys made by diesel-powered lorries. Birkeland is an open-top container ship capable of transporting 120 shipping containers, also known as twenty-foot equivalent units or TEU – a total deadweight of 3,200 tonnes.

All of the cargo ship's systems, including the propellers and thrusters, are powered using electrical energy rather than burning the heavy fuel oil that's commonplace among cargo ships. The Birkeland can produce 6.8 megawatt hours of energy from its onboard batteries, equal to around 100 Tesla cars.

To handle autonomous technology, Yara teamed up with international technology group Kongsberg Gruppen. Using a range of sensors, Kongsberg has created a navigational system aboard Birkeland that allows it to not only automatically moor from port, but follow a preplanned route through the ocean and avoid obstacles or other sailing routes along the way. To ensure its safety, the vessel will be monitored by three centres of operation, all of which will be able to take control of Birkeland in case of emergency. The Yara Birkeland will begin its two-year commercial trial in 2022.

Did you know?
The vessel travels at around six knots

SAILOR-FREE FERRIES


The first automated car ferry, Falco, on its journey across part of the Archipelago Sea

Although the Yara Birkeland is the first autonomous all-electric cargo ship, it's not the first self-driving ship to set sail. In 2018, Rolls-Royce and Finferries, a Finnish state-owned ferry operator, joined forces and created the car ferry Falco, demonstrating the first successful automated ferry crossing. Using Rolls-Royce's ship-navigation technology, Falco autonomously ferried 80 people between Parainen and Nauvo in the Archipelago Sea. To avoid any obstacles or potential collisions, Falco is equipped with advanced sensors which can relay information back to Finferries' remote control centre. It also features Rolls-Royce's auto-docking system, allowing the ship to automatically alter its course and speed when preparing to dock.

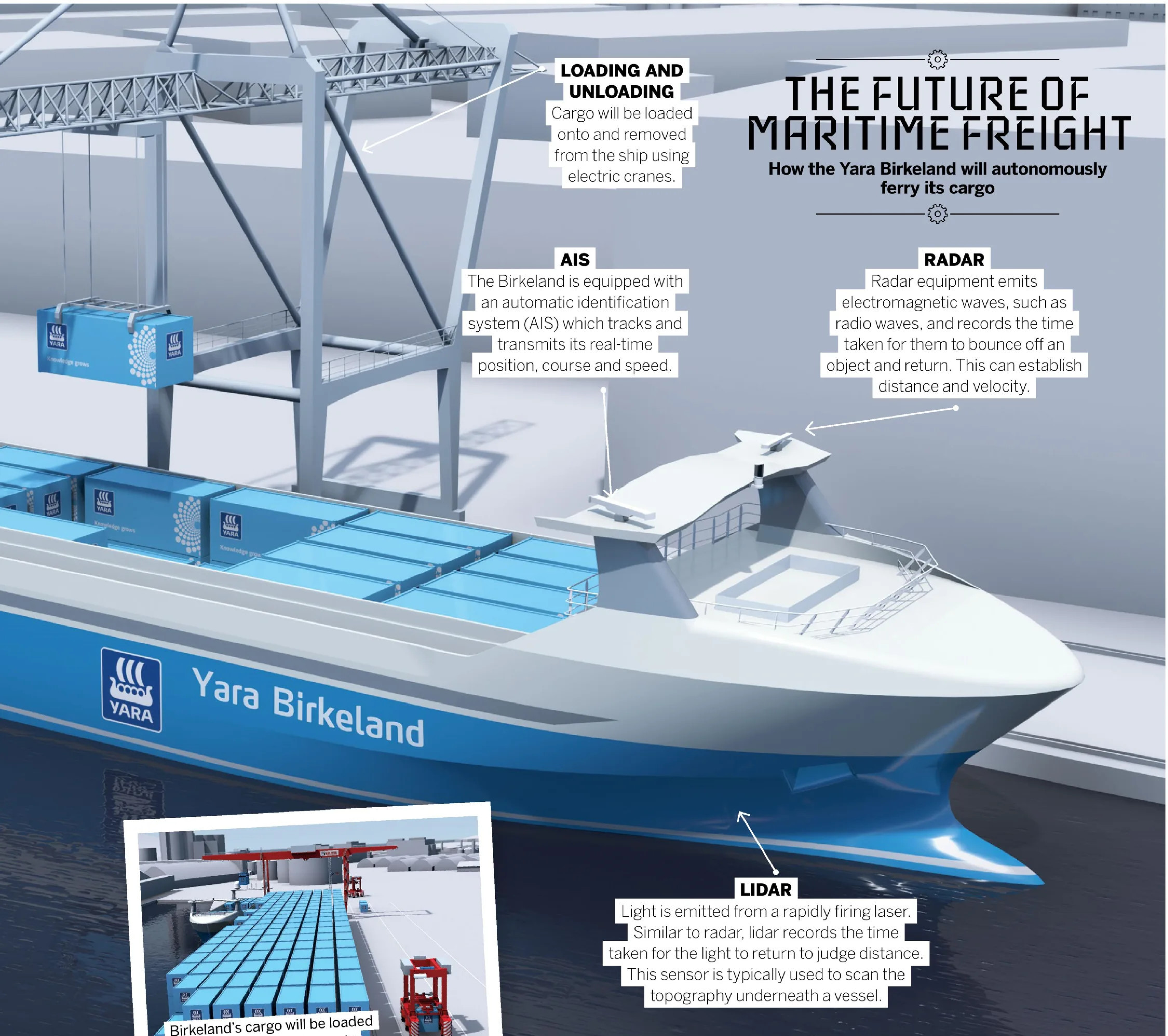
SCRAPPING BALLAST

Traditionally, large cargo ships use ballast water to remain balanced. Ballast water is extra weight that's added to the ship to prevent it from bobbing out of the water like a cork. Water is pumped into the ship's ballast tanks from the ocean at the start of its journey and then dumped upon arrival at the ship's destination. However, this can negatively affect marine ecosystems. For example, invasive species can be transported to new ecosystems and wreak havoc. To minimise the ecological damage caused by ballast water, ships like the Yara Birkeland are sailing ballast-free, using alternative weights to steady the ship. In the case of the Birkeland, the battery packs that power the ship create the same stability as ballast water, therefore removing the need for it.

A cargo ship discharging ocean water from its ballast tanks

THE FUTURE OF MARITIME FREIGHT

How the Yara Birkeland will autonomously ferry its cargo



LOADING AND UNLOADING
Cargo will be loaded onto and removed from the ship using electric cranes.

AIS
The Birkeland is equipped with an automatic identification system (AIS) which tracks and transmits its real-time position, course and speed.

RADAR
Radar equipment emits electromagnetic waves, such as radio waves, and records the time taken for them to bounce off an object and return. This can establish distance and velocity.

LIDAR
Light is emitted from a rapidly firing laser. Similar to radar, lidar records the time taken for the light to return to judge distance. This sensor is typically used to scan the topography underneath a vessel.

Birkeland's cargo will be loaded and unloaded autonomously

Space lasers

Find out why artificial stars are lighting up the Chilean sky

When we think of a collection of lasers coming together to point at a distant object, we inevitably picture the destructive force of the Death Star. But while these space lasers may look like sci-fi weapons, they are now a reality, helping us to discover more about our universe.

The 4 Laser Guide Star Facility at the Paranal Observatory in Chile fires four beams – each one about 4,000 times more powerful than a standard laser pointer – toward the sky. The light from the lasers excites sodium atoms in the atmosphere and causes them to glow, creating artificial stars that the observatory can use as a reference point.

The ability to create artificial stars is highly advantageous to an astronomer viewing the galaxy from Earth. Unlike telescopes in space, telescopes on the planet have the atmosphere to contend with, which can blur images (see 'The problem with twinkling stars'). A process called adaptive optics has been developed to correct these distortions, which involves using a relatively bright star near to the target as a reference, allowing crisp images to be obtained that nearly match those taken by space-based telescopes.

Not all targets have a suitable star nearby, but fortunately laser guide stars can be used to generate a reference point to compensate for this. With the help of this futuristic system, the telescopes at Paranal can see the universe more clearly than ever before.

The Paranal Observatory's 22W laser guide stars are the most powerful ever used in astronomy

© ESO

The problem with twinkling stars

Astronomers must be struck with a sense of irony when they look up at the glistening stars in the night sky, as the phenomena that once inspired them as children only hampers their progress as grown-up scientists.

Although stars seem to vary in brightness, their output of light is largely consistent; the twinkling we see is actually due to Earth's atmosphere. Variations in wind speed, temperature and atmospheric density affect the path of light, so it doesn't travel in a straight line. Since stars are so distant, even slight atmospheric changes can be the difference between their light hitting or missing our eyes. This is what makes stars seem to twinkle, and causes the images taken from telescopes to appear blurred.

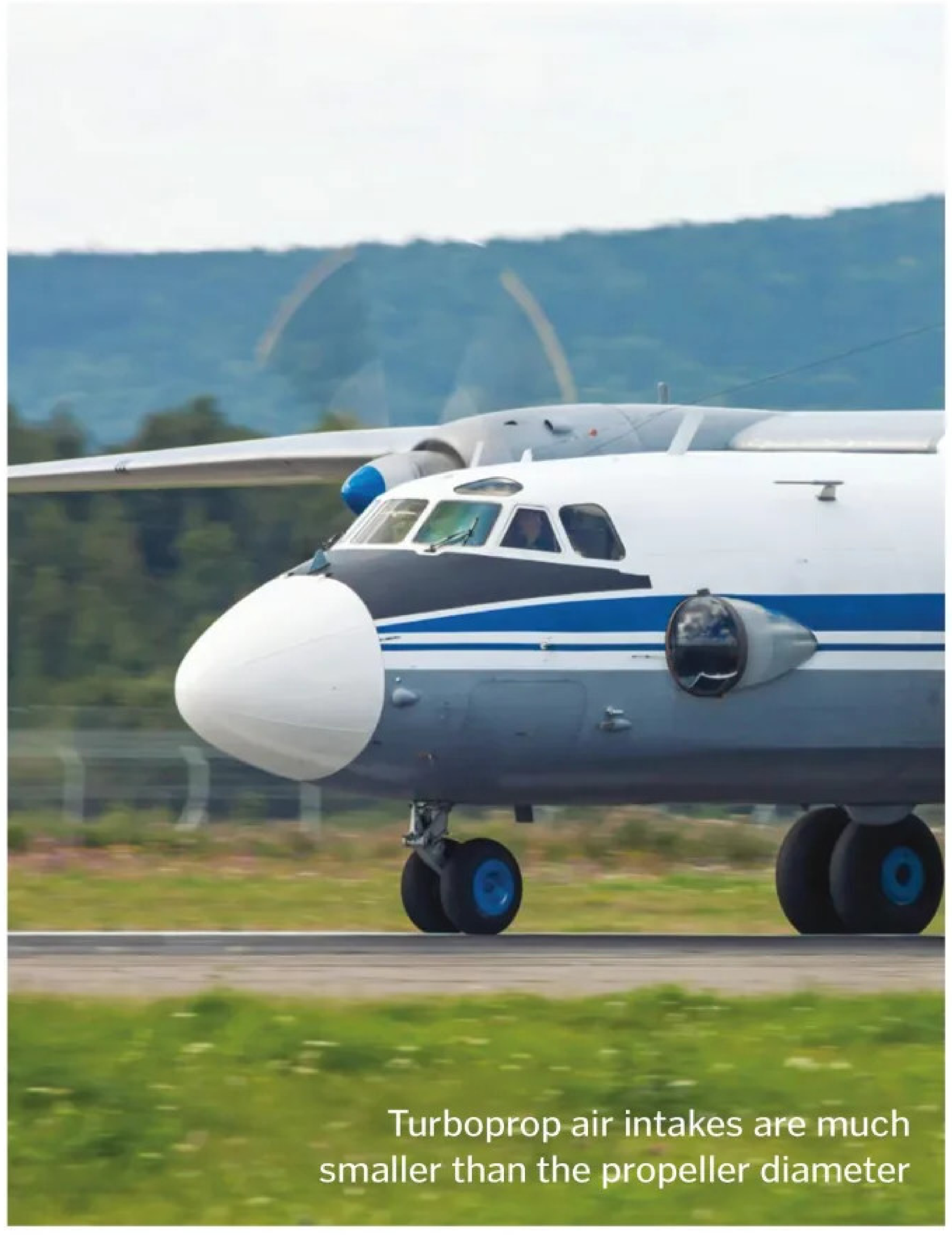
Turboprop engines

Inside the propulsion system that gets low-speed aircraft off the ground

A normal jet engine (often called a turbojet) uses fan blades in order to compress air pulled in at the front, and then adds fuel and ignites it. Some of the exhaust energy is used to keep the compressor fan turning, but most of it is expelled at the rear to produce thrust.

A turboprop engine turns this on its head; almost all of the energy is harnessed to turn the propeller shaft at the front, and only about ten per cent of the thrust comes from the exhaust gas. The propellers are much larger than the diameter of the jet engine, so most of the air they push flows past, rather than through it. This is more efficient at lower speeds, because the engine only adds fuel to the small proportion of the airflow that generates thrust. Turboprops are slower than jet engines but cheaper to run. They are mostly used in short-hop commuter planes.

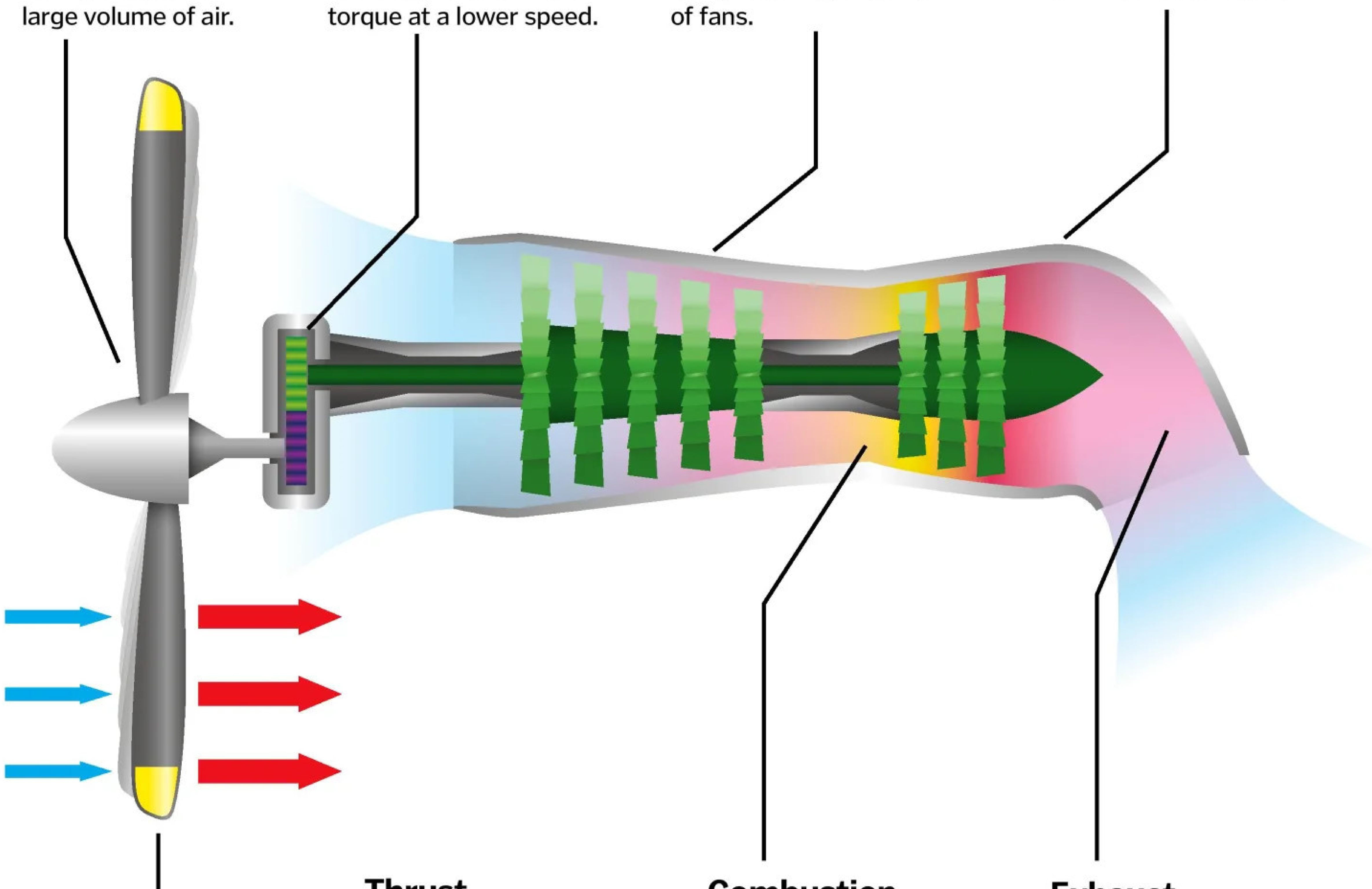
A helicopter engine is also a kind of turboprop (called a turboshaft) where the rotor blades are driven through a more complicated transmission system.



Turboprop air intakes are much smaller than the propeller diameter

Inside a turboprop

How does the jet engine turn the propeller?



Propeller
The long blades turn relatively slowly but push a large volume of air.

Gearbox
The gearbox steps down the high-speed turbine shaft to produce more torque at a lower speed.

Compressor
Air enters the front of the engine and is progressively compressed by a series of fans.

Turbine
The hot exhaust gases expand and force the turbine blades around.

Thrust
Most of the thrust comes from the propeller – which is powered by the engine – pushing air backwards.

Combustion chamber
Jet fuel is squirted into the compressed air stream and ignited.

Exhaust
A small amount of extra thrust is generated from the exhaust gases leaving the engine.

How do computers detect robots?

Bot spotting is an arms race between websites and spammers

When you register at a new website, the line of wavy or distorted text that you have to type in is called a CAPTCHA. This stands for Completely Automated Public Turing test to tell Computers and Humans Apart and it's designed to prevent automated 'bot' programs from spamming users with hundreds of fake accounts.

A CAPTCHA is supposed to be easy for a human, but difficult for computers. In 2003, when CAPTCHA was invented, reading text against a busy background was insurmountably hard for bots. But AI research has improved a lot and the best bots can now read these simple CAPTCHAs with 99.8 per cent accuracy, which is actually better than humans are capable of.

More advanced CAPTCHAs now ask you to click on all the pictures of dogs in a grid of animal snaps, or identify whether a basketball, rugby ball or ice cream should go with the picture of a basketball hoop. Google's reCAPTCHA goes one step further and watches how you interact with the website. The pattern of clicks and mouse movements can betray the difference between a human and a bot.

Inside a wind turbine

The process of generating clean electricity from the power of the wind


Wind turbines are usually found near the coast or on hilltops

Wind turbines are a familiar sight on hilltops and coastlines, their huge blades turning high above the ground. They're tall for a reason – as wind flows over the land and around buildings, it's broken into uneven packets of air that are too slow to turn a turbine's enormous blades. To capture the smoothest, fastest wind, the blades need to be far off the ground.

Each of the turbine's blades shares its shape with bird and airplane wings – they are rounded on one surface and flat on the other. This design is called an aerofoil and gives the blade lift as it turns, so it can use the energy from wind more effectively. Inside the wind turbine's cabin, the rotating blades are connected to an electric generator via a heavy-duty gearbox. Essentially, it acts like a set of bike gears; every time the blades complete one rotation, a shaft on the other side of the gearbox rotates 30 times. The generator's job then is to turn all of this kinetic – or moving – energy into electrical energy.

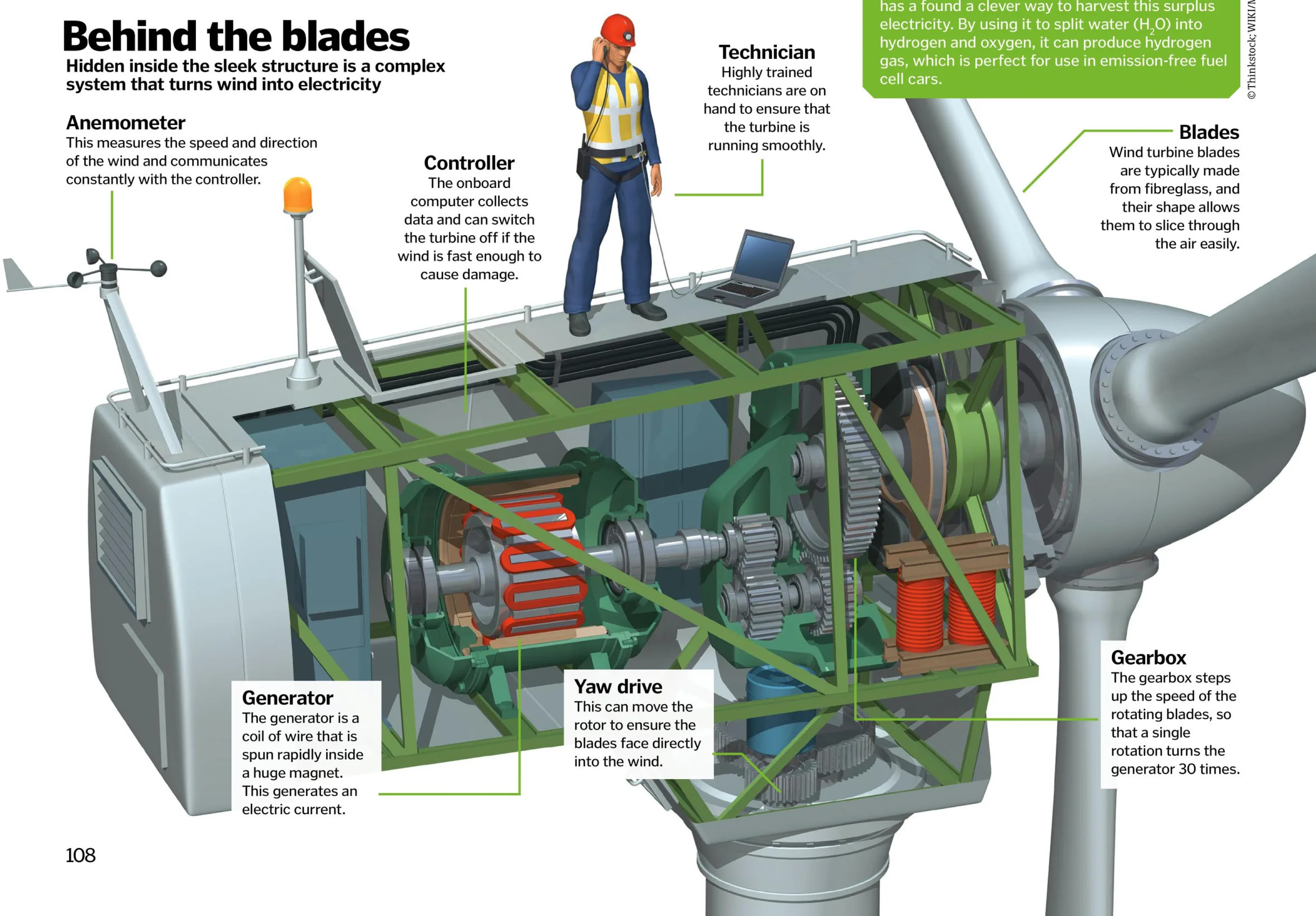
For this it uses electromagnetic induction, where a moving wire in a magnetic field produces electricity. In a wind turbine's generator, a huge magnet surrounds a loop of wire connected to the gearbox's shaft. Thanks to the wind, the blades rotate, spinning this wire up to 1,800 times every minute, and generating a stream of electricity in the process.

What can we use wind energy for?

In countries like Denmark, wind turbines produce enough electricity to power millions of homes, and it makes its way to them via the grid – a nation-wide network of cables and pylons. However, the amount of electricity they produce is tricky to manage, because wind turbines produce electricity intermittently (only when the wind blows). Often, much of the electricity they produce is wasted, but the German city of Mainz has a found a clever way to harvest this surplus electricity. By using it to split water (H_2O) into hydrogen and oxygen, it can produce hydrogen gas, which is perfect for use in emission-free fuel cell cars.

Behind the blades

Hidden inside the sleek structure is a complex system that turns wind into electricity



Haptic feedback

The touchscreens that can create virtual clicks

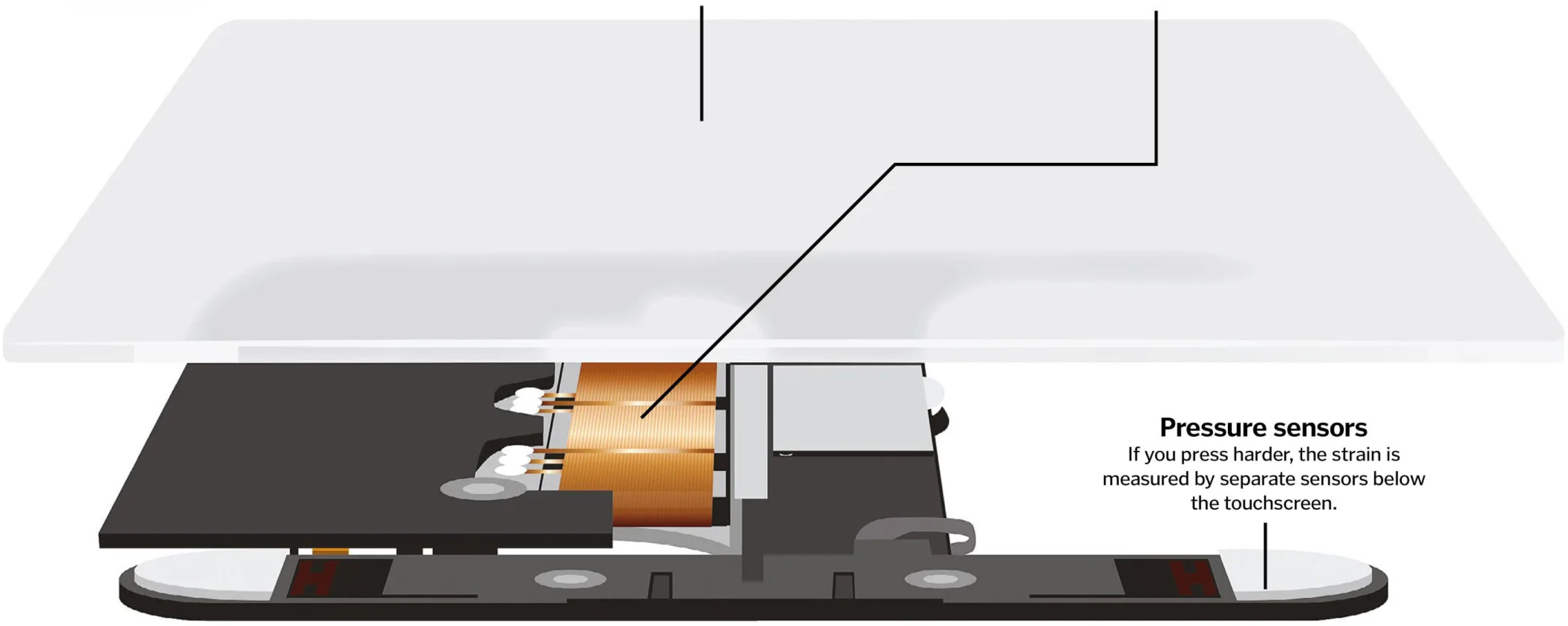
The term 'haptic' comes from the Greek word for touch, and it refers to feedback from electronic devices that use your sense of touch to alert or inform you. The rumble motors in a game console controller and the vibrate function in a phone are both simple examples of haptic feedback.

But haptic technology can be a lot more subtle too. Apple's newest touchscreens can simulate the physical sensation of clicking a button, even on a completely immobile sheet of glass. This works using a special kind of electric motor, called a linear actuator, that briefly vibrates at exactly the moment your finger presses the screen. Although there's no physical button to click downward, the jolt to your fingertip registers the same touch sensation as a button.

The trick relies on precise timing. Most phone vibration motors oscillate backwards and forwards at least ten times for a single activation, which feels more like a buzz than a click. Apple's 'Taptic Engine' can start and stop within a single cycle, and it tunes the length of the pulse to just ten milliseconds for a light touch, or 15 milliseconds for a full tap.

Faking a click

The tiny screen of the Apple Watch includes its own 'taptic feedback' engine



The ISS bathroom

A specially designed toilet is required for astronauts to boldly go

Going to the bathroom is one of many everyday activities that are much more challenging for astronauts aboard the International Space Station (ISS). Water doesn't flow in microgravity, so it's not possible to have a standard flushing toilet. Instead, the ISS's toilets use airflow to get rid of waste.

For urine, each astronaut has their own personal funnel, which attaches to a tube on the toilet. For solid waste, a collection bag is placed in the toilet bowl. In both cases, a vacuum is activated to mimic gravity, drawing waste away as the astronaut does their business.

Water is a precious resource on the ISS, so urine and other wastewater (such as sweat) is recycled. The space station's Water Recovery System collects and purifies over 90 per cent of wastewater to make it safe to drink again.

Solid waste cannot be recycled, so it is collected in a tank and ejected from the ISS to burn up in the Earth's atmosphere. However, scientists are considering potential ways that solid waste could also be made useful. For example, long-duration missions like trips to Mars could theoretically use this waste for radiation shielding within a spacecraft's walls!

Toilets on the ISS use suction to overcome the problems of going to the bathroom in microgravity

60 SECOND SCIENCE

Hydraulics

THE SCIENCE BEHIND USING LIQUID POWER TO DO HEAVY LIFTING

BACKGROUND

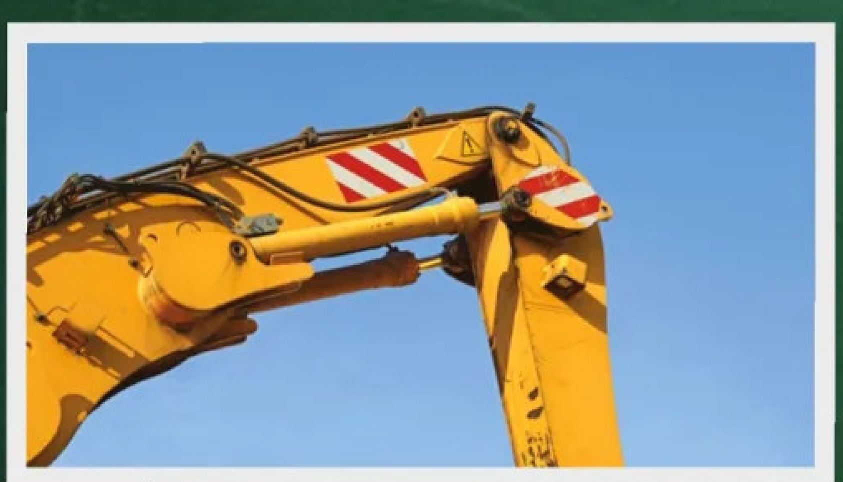
Hydraulics is the system of using liquids to produce power. Liquids can't easily be compressed, so pushing on them transmits pressure through them. The pressure is evenly transferred through the liquid, so a small push can be used to create a large force elsewhere. This can be used to move pistons, which in turn can be used to perform work, such as lifting with a crane or braking a car.

IN BRIEF

Gases can be squashed, pushing the molecules closer together to fit into a smaller space, but liquids are hard to compress, as the molecules are close already. Particles bump around as they move, generating pressure. Push on a liquid, and pressure is increased.

In a container with two cylinders and two pistons, connected by a fluid, when you push down on a piston in the first cylinder, it will push a piston up in the second. The pressure is equal to the force applied, divided by the cross-sectional area of the piston.

Put a bigger piston at the other end of the container, and the pressure can be used to generate a larger force. You can see why if you rearrange the equation – force is equal to pressure multiplied by cross-sectional area. If the area of the second piston goes up, so does the force generated.



Hydraulics are used to perform heavy industrial work

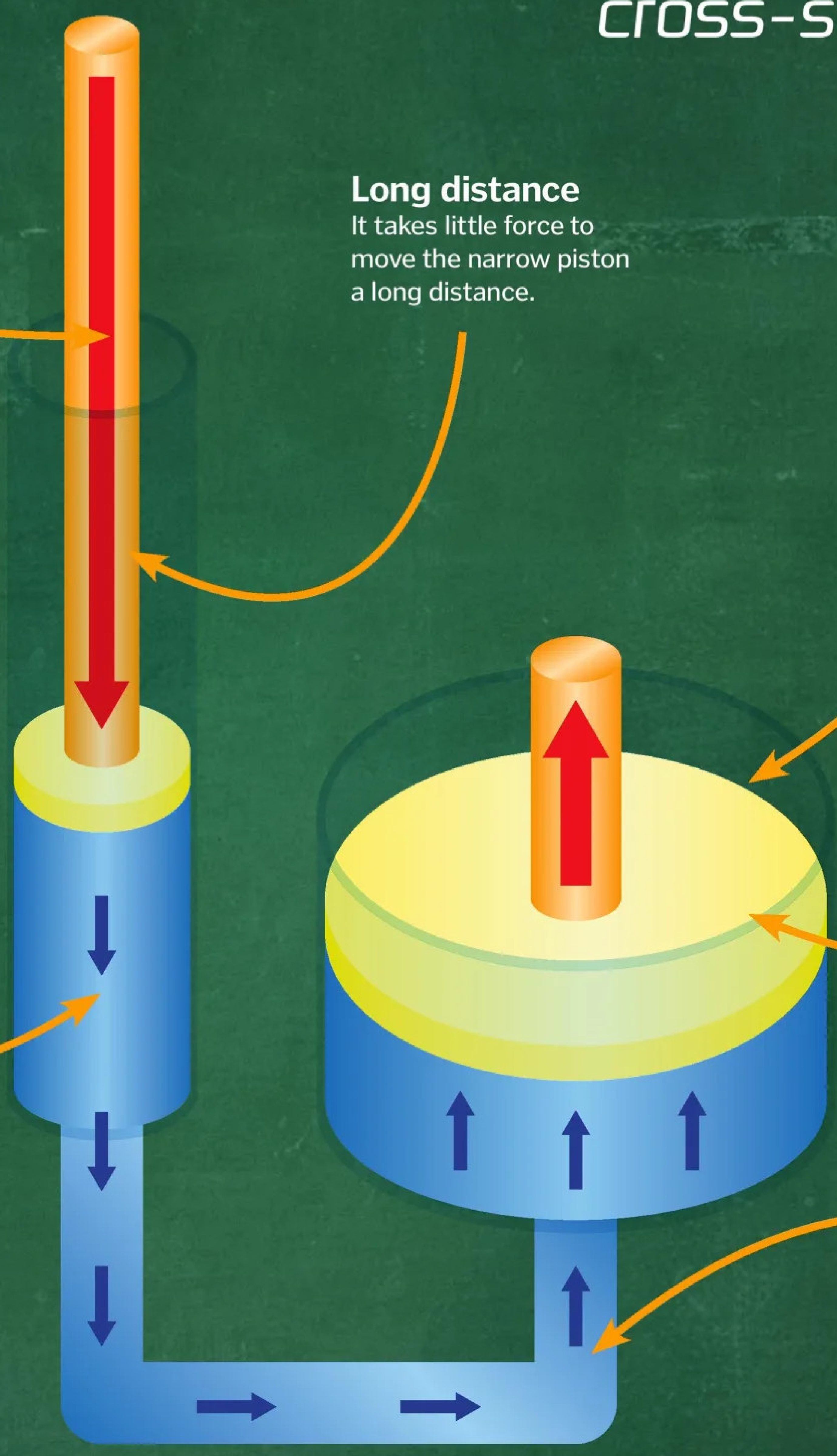
SUMMARY

Using a small piston to compress a fluid requires little force, but generates a lot of pressure. This pressure can be used to move a larger piston with greater force.

Inside hydraulics

How do hydraulic systems generate so much force?

Force = pressure x cross-sectional area

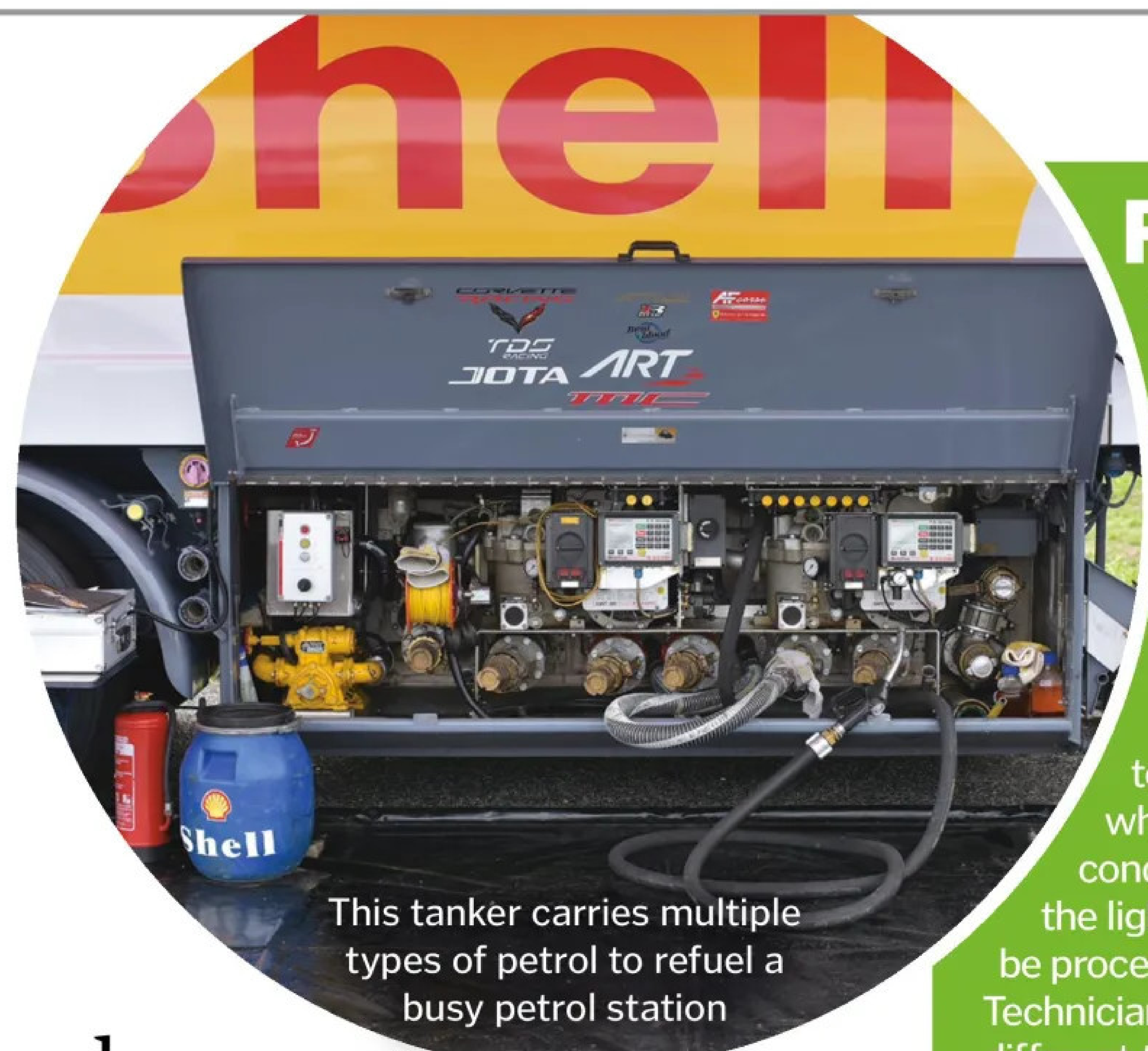


PASCAL'S PRINCIPLE

Blaise Pascal was a French mathematician in the 17th century, and responsible for our understanding of pressure and hydraulics. He explained that when you push on fluid in a closed container, the pressure is transmitted equally in all directions. A pressure change at one side of the container is transmitted to all other parts of the container, and to the walls. This is known as Pascal's principle. His work also included understanding atmospheric pressure. So important were his discoveries that the standard unit for pressure was named the pascal (Pa).

Pascal was a polymath, and also worked on the founding principles of probability with Pierre de Fermat.

Refilling service stations



This tanker carries multiple types of petrol to refuel a busy petrol station

Under the forecourt lie vast chambers filled with fuel. Here's how it gets there

When your vehicle runs out of fuel, you fill up the tank at a service station. But what do the stations do when they're running on empty? It all begins at the oil refinery, where petrol and diesel are produced. These products travel along pipes to terminals, where fuel tanker trucks load up and distribute it to service stations all over the country.

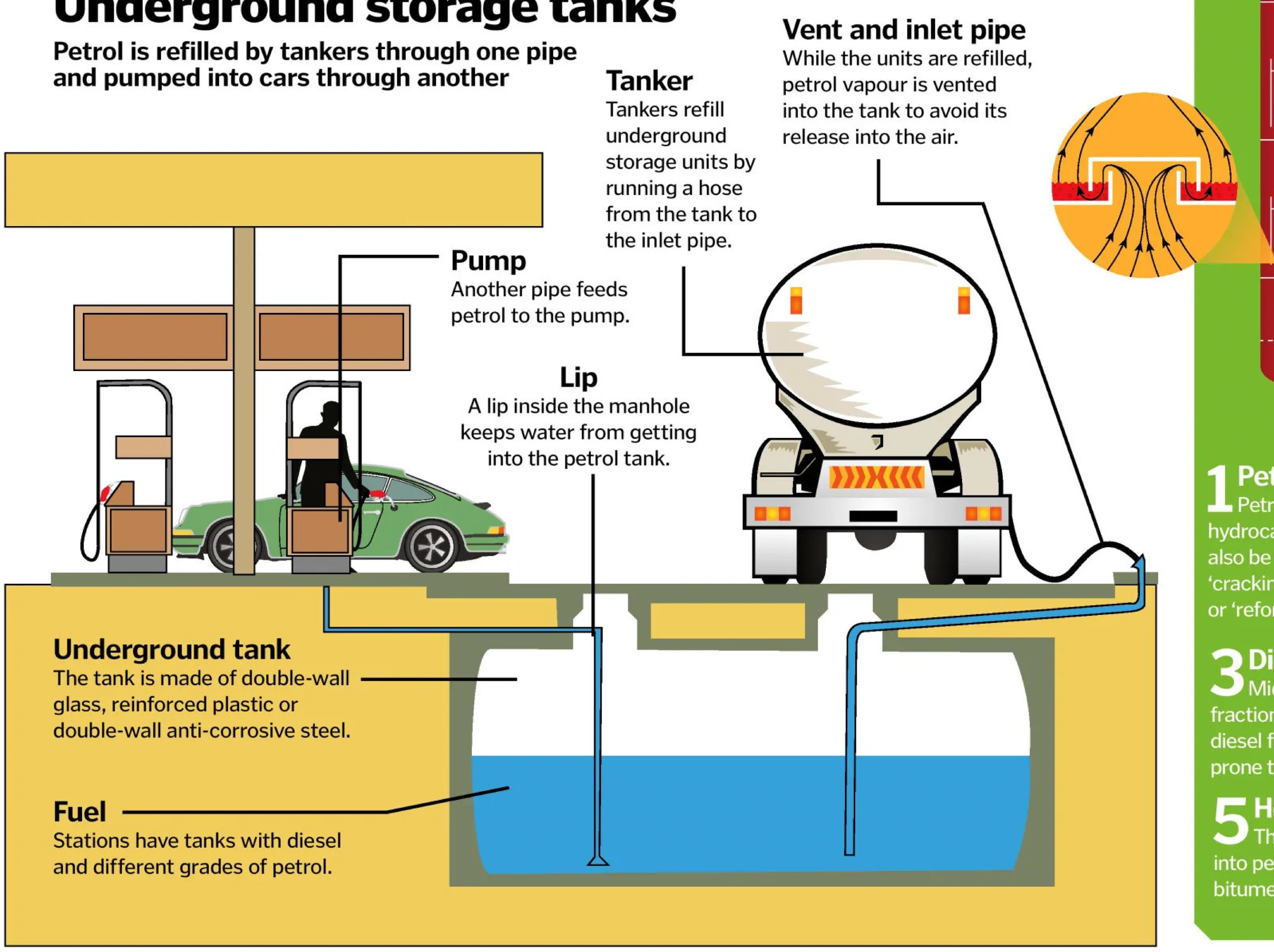
To refill a service station, the truck driver removes the manhole cover that conceals the vast underground storage units (USTs) where these flammable, dangerous liquids are kept. A station might have as many as five USTs – holding up to 75,000 litres each – and these are joined to the inlet pipe to which tankers connect.

After removing the covers, the driver uses a metal pole called a dipstick to check fuel levels in each unit. Then he attaches two hoses: one to vent fuel vapour and one to dispense fuel from the truck to the unit, and monitors the valves and gauges on the tank until the units are full. After disconnecting the hoses, he uses the dipstick again to check levels before replacing the covers.

USTs are equipped with systems that automatically monitor the volume of fuel they contain. Changes in temperature can alter the amount, and some petrol is lost through the release of vapours as we pump it into our cars. Station operators combine this data with sales projections to work out when it's time for a refill.

Underground storage tanks

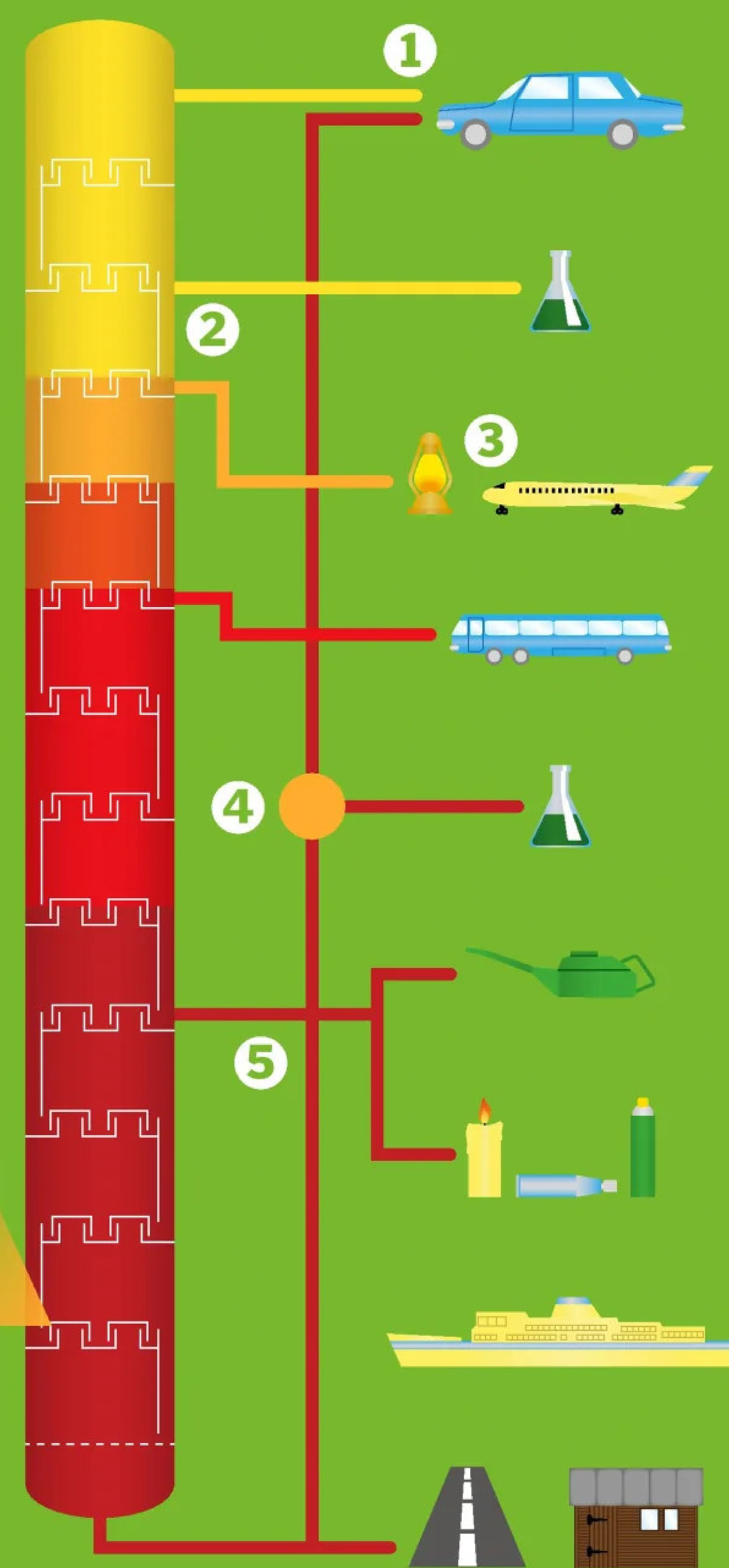
Petrol is refilled by tankers through one pipe and pumped into cars through another



From crude oil to petrol

Crude oil is changed into petrol and other products at a refinery. The oil is pumped through a distillation tower, where hot furnaces break it down into vapours and liquids. This separates components of the oil into 'fractions', according to their weights and boiling points.

Lighter fractions rise to the top of the tower before they condense into liquids, while heavier – and less profitable – fractions condense towards the bottom. Petrol is one of the lighter fractions, but heavy fractions can also be processed into petrol to increase the yield. Technicians blend various fractions to make the different types of fuels. These products are then stored in tank farms near the refinery, and carried in pipelines to additional tanks.



1 Petrol Petrol is a blend of light hydrocarbons, and can also be produced by 'cracking' heavier fractions or 'reforming' naphtha.

2 Kerosene Slightly heavier fractions are converted into kerosene and other petroleum products, such as heating oil.

3 Diesel oil Middleweight fractions are refined into diesel fuels, which are less prone to explosion.

4 Cracking Heavier fractions are converted into chemicals, lubricating oil, and petrol through cracking.

5 Heavy fractions The heaviest fractions not reformed into petrol become industrial fuel and bitumen, a material used in roofing.

Next-gen rocket engine

Meet SABRE, the revolutionary engine that could make spaceflight easier and cheaper

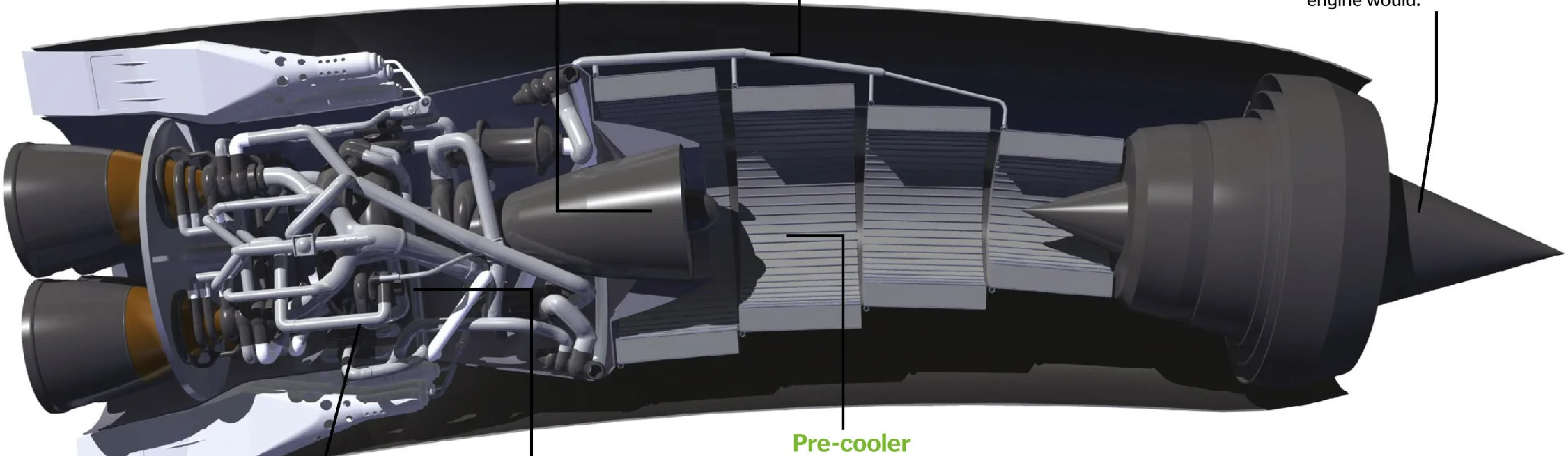
For conventional rockets to be able to launch into space, they must carry many tons of liquid oxygen in order to combust their fuel. This results in heavy, single-use rockets that must dump their empty fuel tanks to reduce weight as they ascend. In order to create reusable space planes that will be able to ferry tourists into and out of Earth's orbit, a new solution is needed, and British aerospace company Reaction Engines Ltd (REL) has an innovative answer.

The Synergetic Air-Breathing Rocket Engine (SABRE) can operate as a typical jet engine in the Earth's atmosphere, using oxygen from the air to burn with its liquid hydrogen fuel, and then becomes a rocket engine when it reaches an altitude of 25 kilometres, using the small amount of liquid oxygen fuel stored on board. Not only does this reduce the fuel payload by over 250 tons, but it also eliminates the need for empty fuel stages to be jettisoned during the launch, so the engine could be used to create reusable launch systems.

There is one major problem with creating an air-breathing rocket engine designed to travel at five times the speed of sound. The air being sucked in from the atmosphere at these speeds must be compressed before it reaches the combustion chamber, raising its temperature to 1,000 degrees Celsius, which would melt the engine's metal components. To solve this issue, REL has developed a cooling system, which cools incoming air to -150 degrees Celsius in less than one hundredth of a second. This would normally present another problem, as such low temperatures would cause moisture in the air to freeze, clogging up the engine. However, the team has also developed new technologies to stop frost from forming inside the engine.

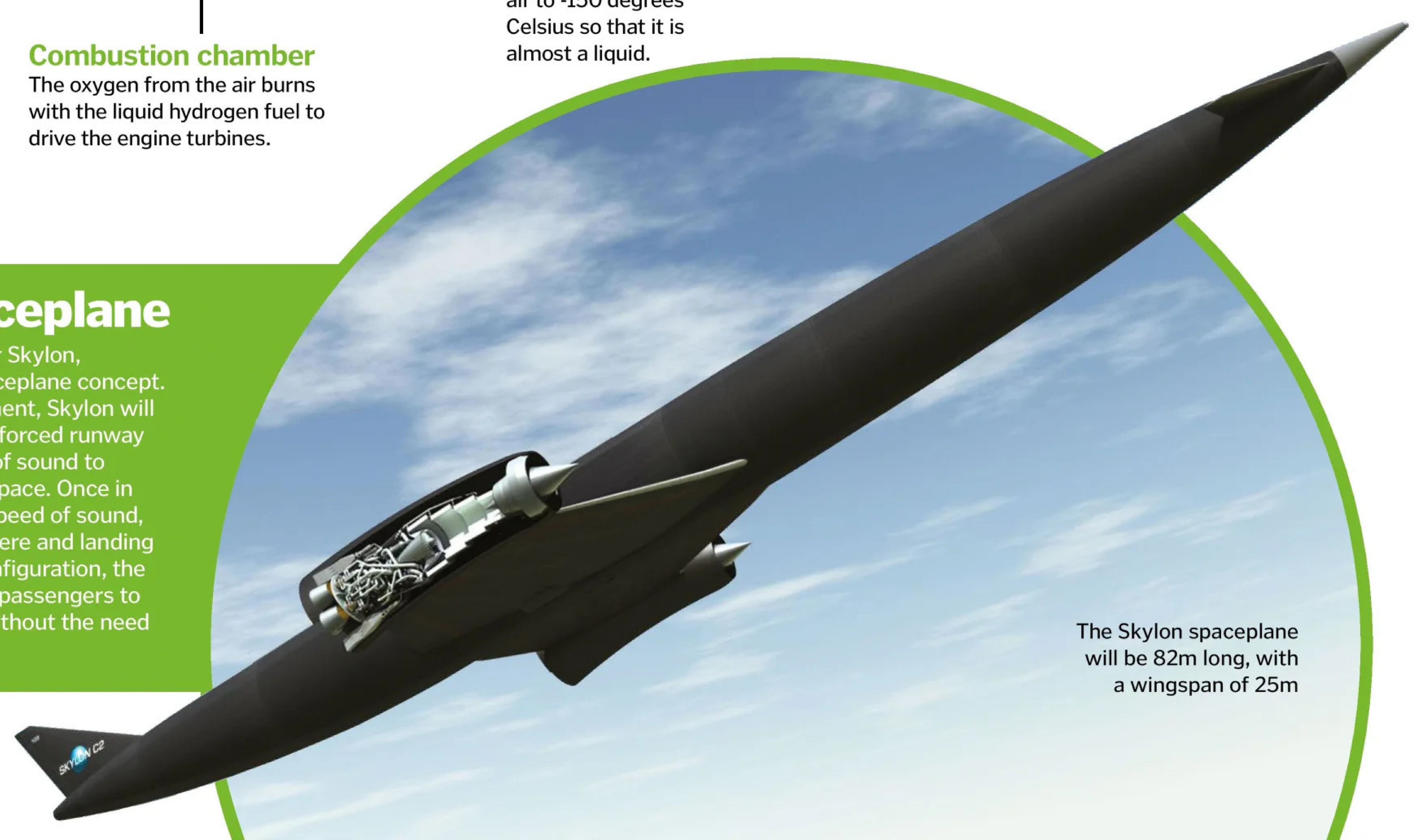
Inside SABRE

A new class of engine with both air-breathing and rocket modes



The Skylon spaceplane

SABRE has been designed to power Skylon, Reaction Engine Ltd's reusable spaceplane concept. Still in the early stages of development, Skylon will be capable of taking off from a reinforced runway and reaching five times the speed of sound to deliver up to 15 tons of cargo into space. Once in orbit, it will travel at 25 times the speed of sound, before re-entering Earth's atmosphere and landing back on a runway. In its current configuration, the plane will be able to carry up to 30 passengers to an altitude of 300 kilometres, all without the need for an onboard pilot.



The Skylon spaceplane will be 82m long, with a wingspan of 25m

Inside a loud speaker

Hear that? It's the sound of you learning about how speakers make noise

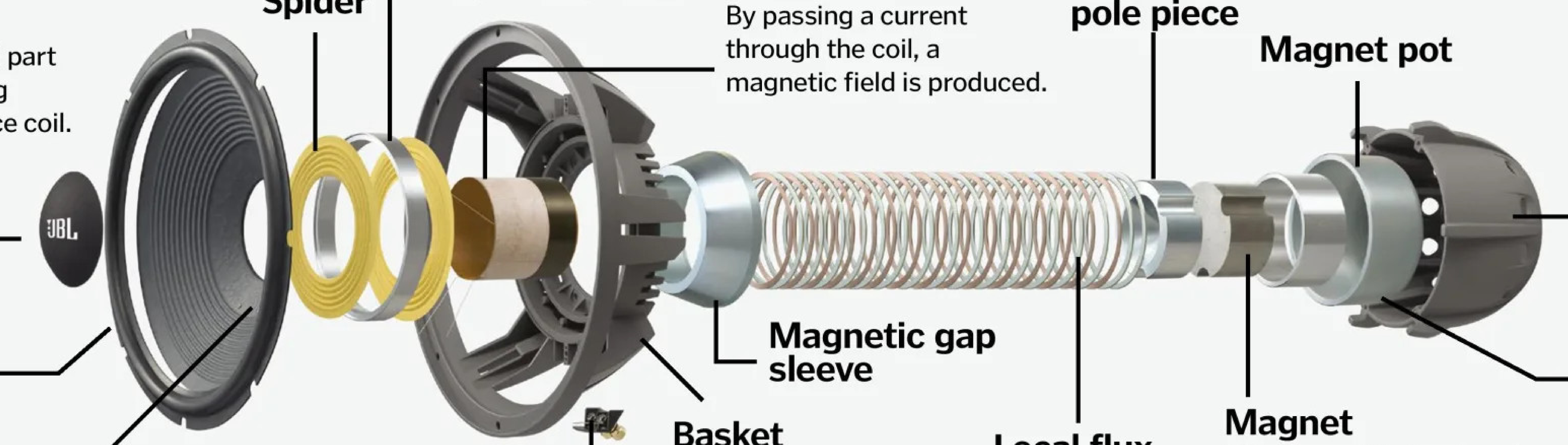
Whether you're listening to an audiobook through headphones on a train or drowning in sound in the front row at a festival, the key to how electric speakers work is magnetism.

In their simplest form, speakers use an electromagnet to move a cone-shaped membrane that vibrates to make noise. Inside the speaker, the mobile electromagnet is placed in front of a fixed, normal magnet. As electricity passes through the coil of the electromagnet, the direction of the magnetic field rapidly changes. This causes the electromagnet to continually be repelled by and attracted to the normal magnet, moving the cone-shaped membrane back and forth. The membrane pushes and pulls the surrounding air molecules, creating waves of sound that reach your ears.

The pitch of the sound is governed by the frequency of the vibrations, while the volume is controlled by the amplitude, or height, of the sound waves. Some types of speakers use multiple cones of various sizes to replicate the different frequencies in a piece of music.

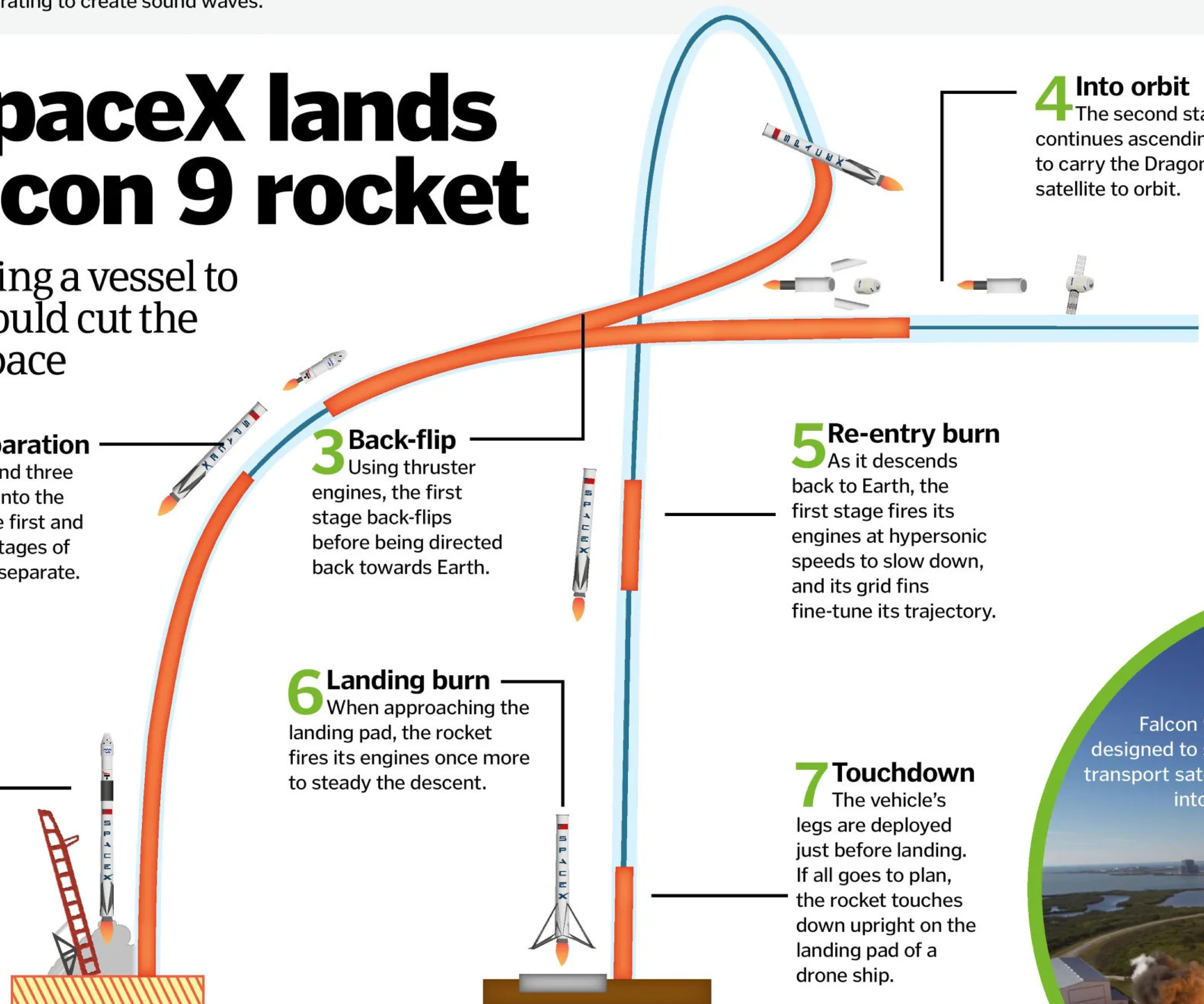
Inside a Harman speaker

The key components that allow you to listen to music loud and clear



How SpaceX lands the Falcon 9 rocket

By safely returning a vessel to Earth, SpaceX could cut the cost of trips to space



SEEK & DESTROY SUPER SUBMARINES

THE INCREDIBLE TECH POWERING THE WAR BENEATH THE WAVES

Lurking in the depths, hundreds of submarines are currently patrolling the world's oceans, performing a range of very important, and often covert, missions. These stealthy vessels were first widely used during World War I, with Germany's U-boats responsible for destroying several British supply ships during the conflict, and have since changed the face of naval warfare forever.

Always referred to as boats rather than ships, as a matter of naval tradition, submarines have come a long way since the human-powered vessels of the past. Most modern submarines use either diesel-electric propulsion or nuclear reactors to keep them running. The former are equipped with diesel engines to drive the submarine's propellers and charge its batteries while on the surface. Then, when submerged, those batteries power electric motors that spin the propellers to move it through the water.

The need to recharge the batteries and replenish fuel for the engines gives these submarines a limited range, so many navies prefer nuclear-powered vessels instead. These

The unmanned Boeing Echo Voyager

boats can stay underwater for weeks at a time, using nuclear fission to release energy in the form of heat, which in turn generates steam to drive a turbine and spin the propellers.

Now crucial tools for navies large and small, submarines transport crews all over the world; sneaking up on enemy ships, launching missiles, and gathering information while remaining hidden in dark, murky waters. They can generally be divided into two categories: attack submarines, which are designed to seek and destroy enemy ships, and ballistic missile submarines, which attack land-based targets. The US Navy currently has 72 submarines in active service, 54 of which are attack vessels.

It's not just the military that uses these clever underwater crafts, though. With scientists knowing more about outer space than they do about the world's oceans, submarines are incredibly useful for studying marine environments, at depths too great for human divers to reach alone.

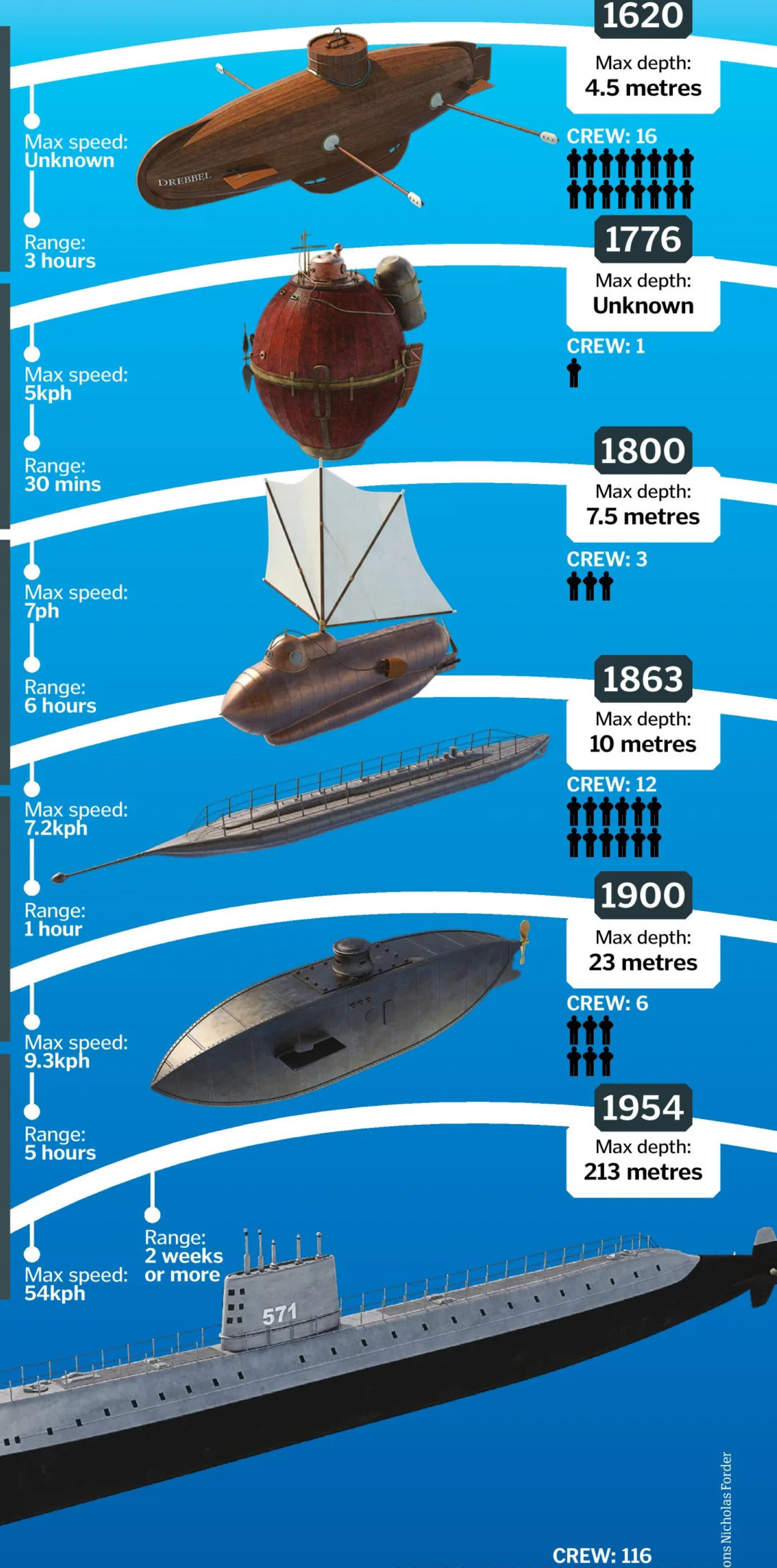
In recent years, new unmanned underwater vehicles (UUVs) have begun appearing in the water, capable of conducting dangerous missions, while human crews remain safely on the shore or a nearby ship. These vehicles are small with a limited range, but in the future they could replace the submarines we know today.

> "The US Navy currently has 72 submarines in active service"


HMS Astute firing a cruise missile

Submarines: in depth

Major milestones in the development of underwater vessels



1620

Drebbel I
The first submarine was invented by Dutch engineer Cornelius Drebbel. It was an enclosed wooden rowing boat covered with watertight greased leather, and had air tubes protruding to the surface to supply oxygen.

Max speed: Unknown
Range: 3 hours
Max depth: 4.5 metres
CREW: 16

1776

Turtle
The first recorded submarine attack was during the American War of Independence by the Turtle. It was used in an attempt to blow up the HMS Eagle, but the pilot was unable to attach the bomb to the ship's hull.

Max speed: 5kph
Range: 30 mins
Max depth: Unknown
CREW: 1

1800

Nautilus
American inventor Robert Fulton's submarine was driven by a hand-cranked propeller, but a collapsible mast and sail provided the propulsion. The sub was commissioned by Napoleon to use against the British.

Max speed: 7ph
Range: 6 hours
Max depth: 7.5 metres
CREW: 3

1863

Plongeur
Powered by engines running on compressed air, the French Navy's Plongeur was the first submarine to not rely on human propulsion. It had a ram and torpedo, but engine problems meant the boat never passed the trial stage.

Max speed: 7.2kph
Range: 1 hour
Max depth: 10 metres
CREW: 12

1900

USS Holland
Irish engineer John Philip Holland was the first to use electric motors and an internal combustion engine to power an underwater vessel. His creation was purchased by the US Navy and influenced many designs.

Max speed: 9.3kph
Range: 5 hours
Max depth: 23 metres
CREW: 6

1954

USS Nautilus
The first nuclear-powered submarine combined stealth and speed in order to revolutionise naval warfare. Constructed under the direction of US Navy Captain Hyman G Rickover, the 97-metre long USS Nautilus accomplished the first voyage under the geographic North Pole, and had a career spanning 25 years.

Max speed: 54kph
Range: 2 weeks or more
Max depth: 213 metres
CREW: 116

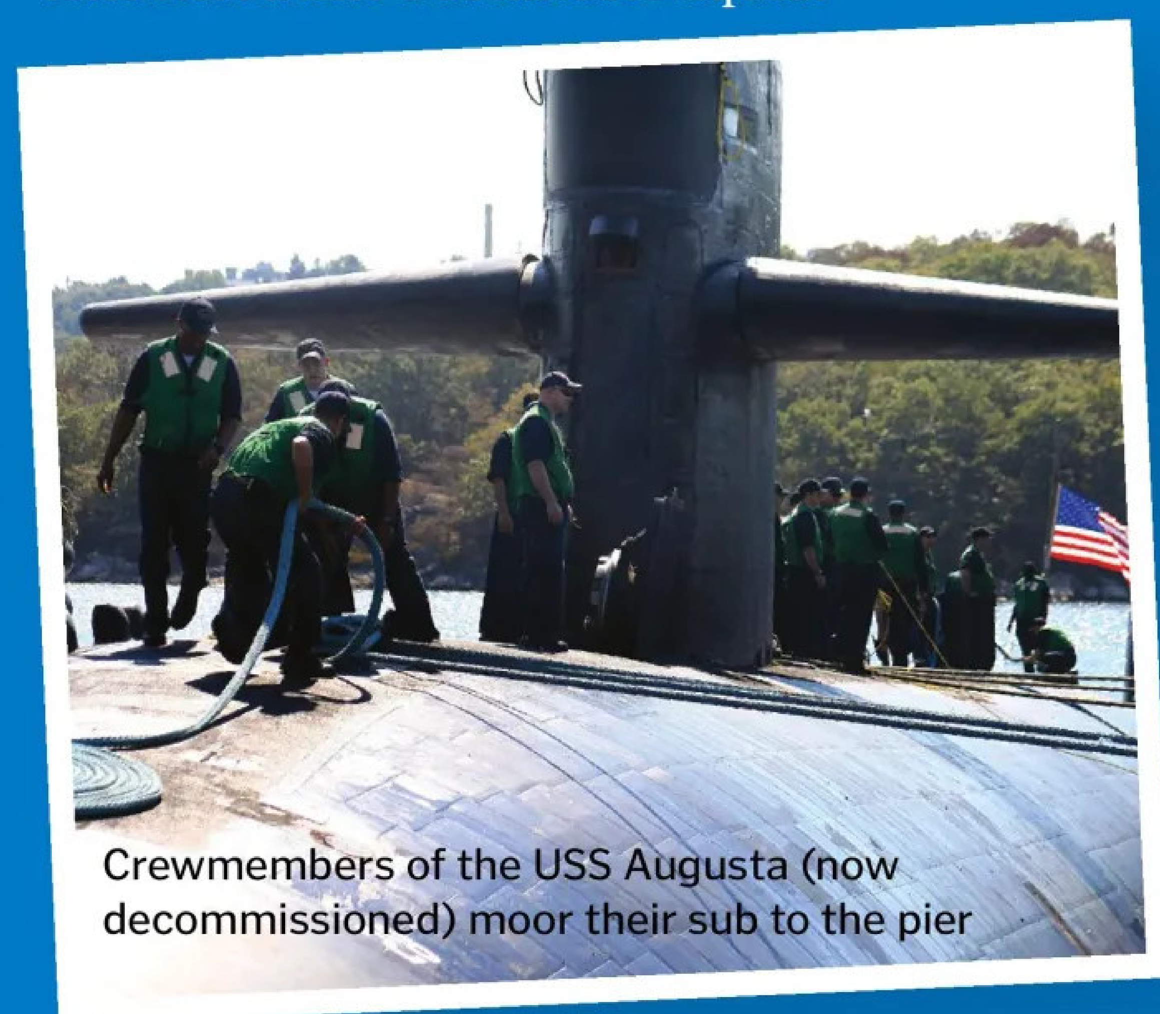
LIFE ON BOARD A SUBMARINE

How crews survive hundreds of metres beneath the sea

The job of a submariner is physically, mentally and emotionally demanding, as they can spend months at a time living in cramped conditions, with only the other members of their 100-plus crew for company. In the past, they had no means of communication with the outside world for the entire length of their mission, but today email can be used to keep in touch with loved ones at home.

Of course, the human body isn't built for life below the waves, so keeping a crew alive requires some clever technology and engineering. To protect them from the crushing water pressure, the submarine features a strong inner hull in addition to the outer hull that gives the vessel its streamlined shape.

Oxygen is supplied via pressurised tanks, or can be created on board by splitting seawater into hydrogen and oxygen using an electric current. The carbon dioxide the crew breathes out is then removed using scrubbers – devices that trap the CO_2 in soda lime using a chemical reaction. Fresh water is also created on board, as seawater can be heated to remove the salt, and then the water vapour can be cooled and condensed into a drinkable liquid.


Crewmembers of the USS Augusta (now decommissioned) moor their sub to the pier

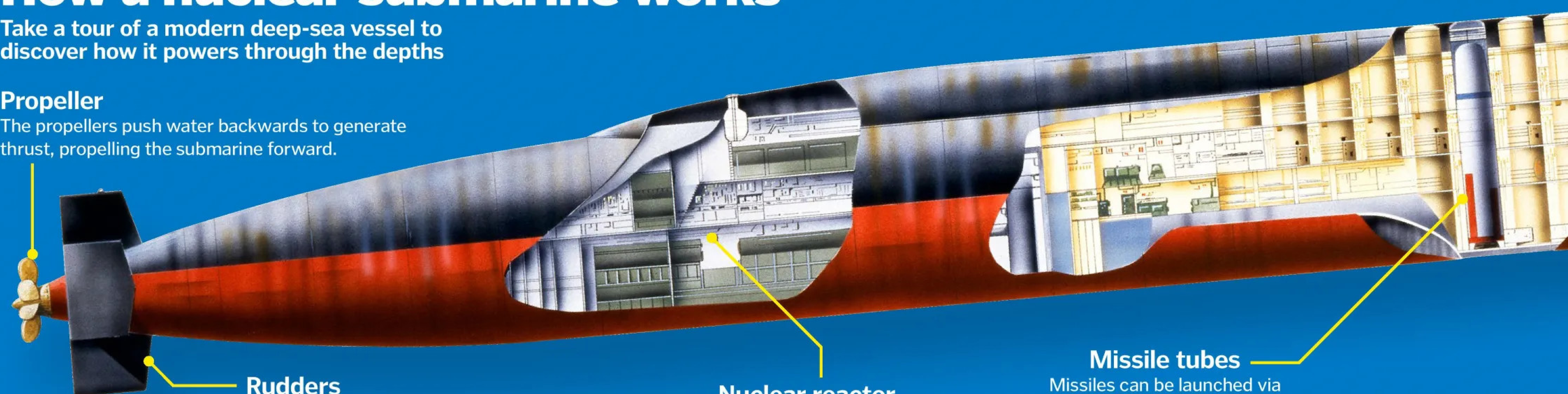
Deep-sea rescue

If a submarine is damaged, perhaps due to a collision or an onboard explosion, then the crew will radio a distress call and launch a buoy that will signal their location. Rescue will come in the form of a Deep-Submergence Rescue Vehicle (DSRV), a mini-submarine that can be transported by truck, aircraft, ship or another submarine. Once it is near to the damaged vessel, the DSRV can dive down, search for it using sonar, and then latch on to its hatch. When an airtight seal has formed, the hatch is opened and the crew can load on to the DSRV in groups of 24.

The US Navy's Deep-Submergence Rescue Vehicle, Mystic, attached to the USS La Jolla attack submarine

How a nuclear submarine works

Take a tour of a modern deep-sea vessel to discover how it powers through the depths



Propeller
The propellers push water backwards to generate thrust, propelling the submarine forward.

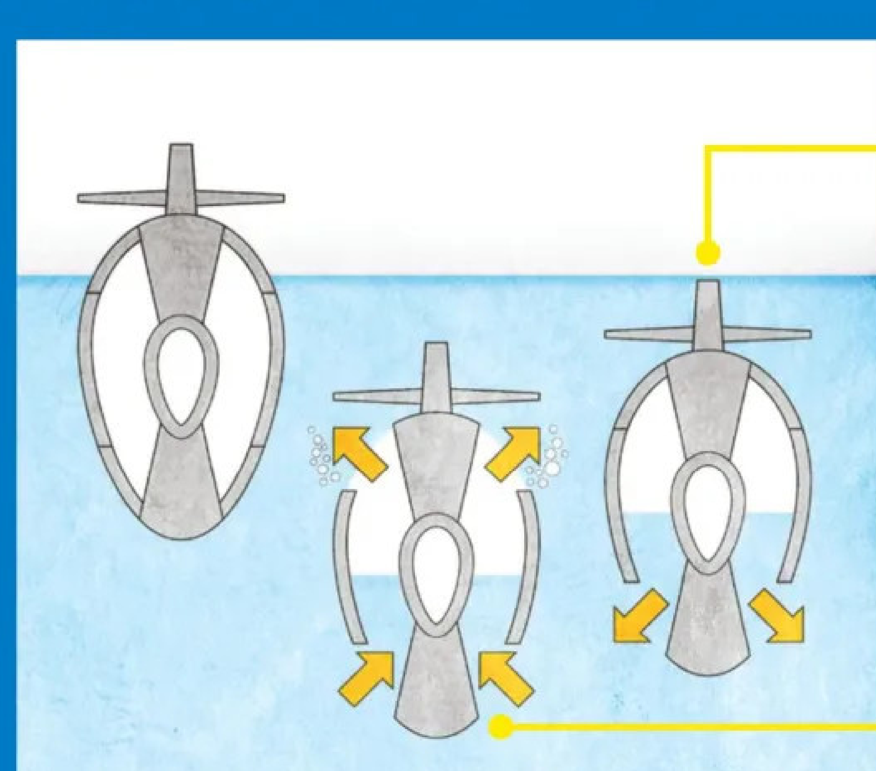
Rudders
The submarine can be steered left, right, up and down by adjusting the position of the rudders to deflect water flow.

Nuclear reactor
The reactor produces heat to generate steam, which drives a turbine that directly turns the propellers.

Missile tubes
Missiles can be launched via hatchways in the top of the submarine, sending them flying into the air and towards enemy targets.

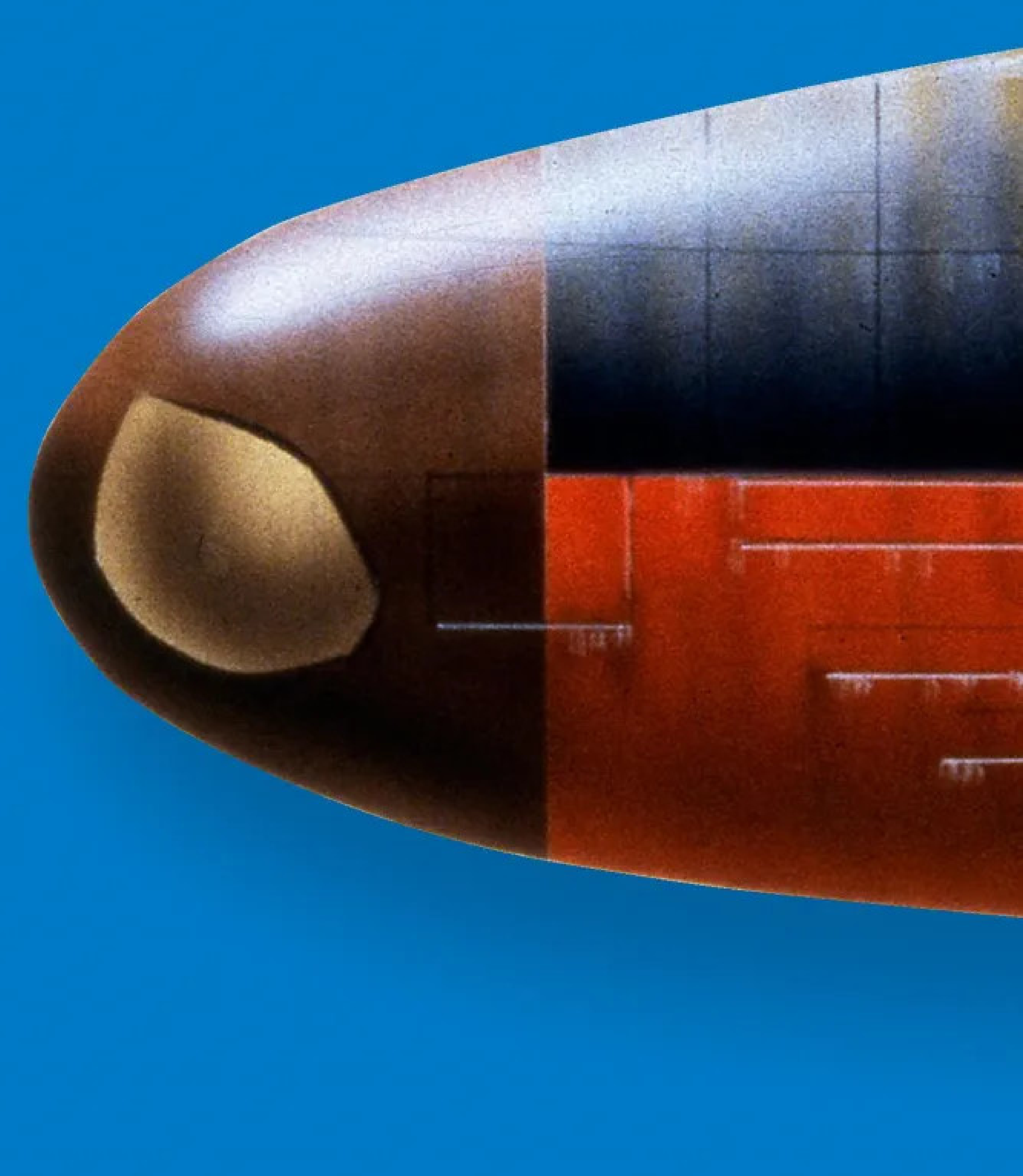
How do submarines dive?

Normally, a boat floats because the volume of water it displaces weighs the same as the boat itself. In order to sink, a submarine must weigh more than the water it displaces, creating a negative buoyancy. This is achieved by flooding ballast tanks, located between the sub's inner and outer hulls. To maintain a set depth, there needs to be a precise balance of air and water in the ballast tanks so that the sub's density is equal to that of the surrounding water.



Surfacing
The water inside the ballast tanks is pumped out and replaced with air stored in tanks, making the submarine lighter and able to surface.

Diving
Hatches are opened to fill the ballast tanks with water, making the submarine heavier than the water it has displaced, and causing it to sink.

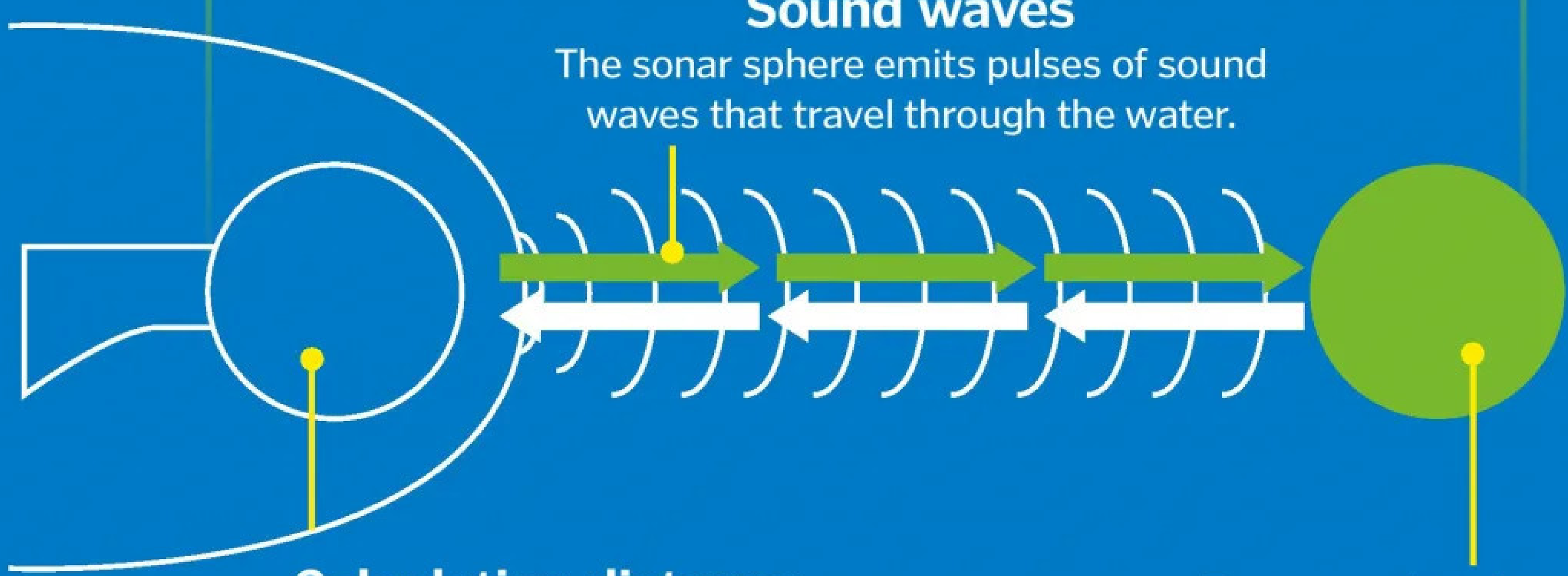


HMS Ambush returning to its home port, HMNB Clyde

"Keeping a crew alive requires some clever technology and engineering"

Underwater navigation

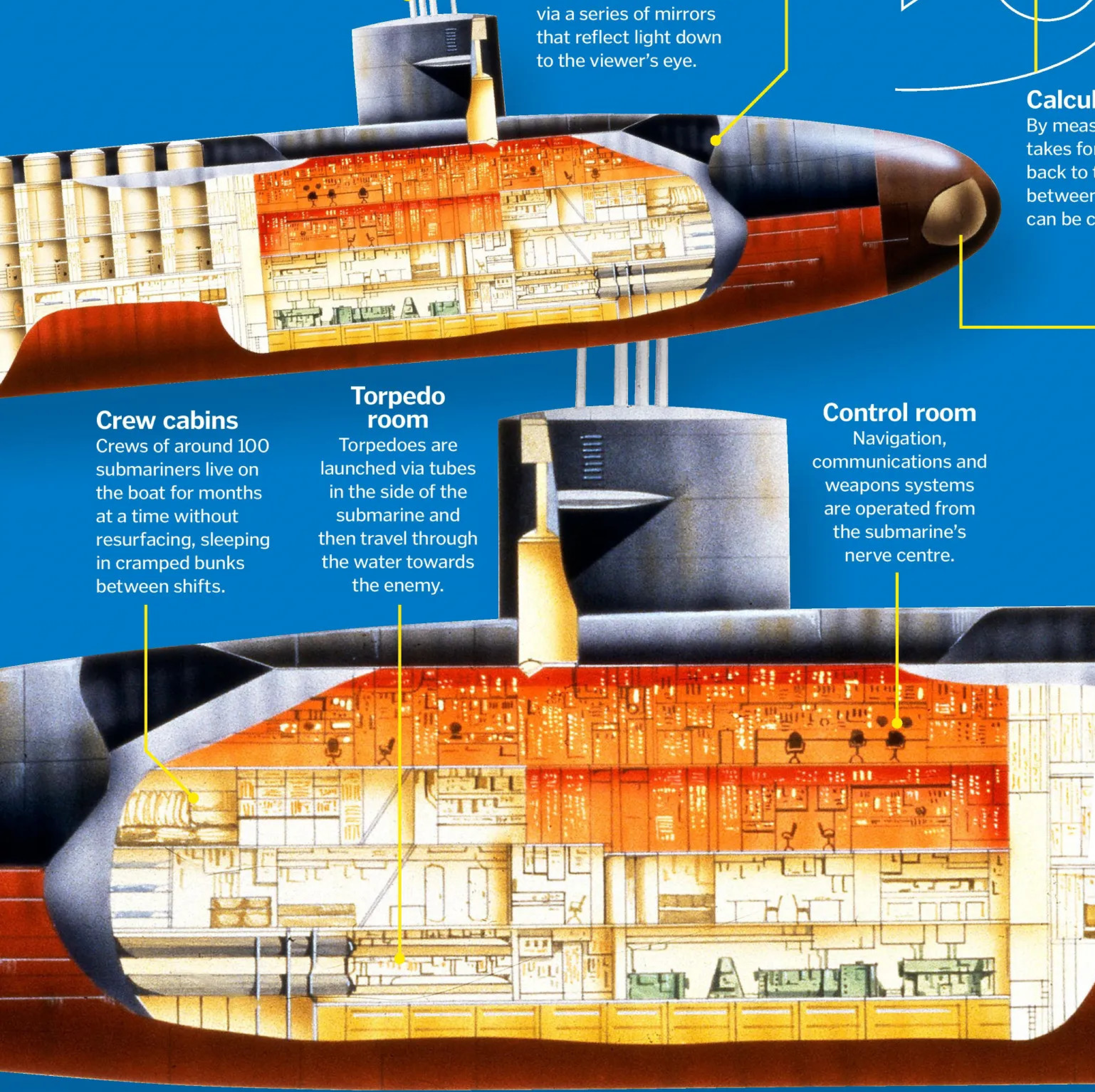
Little light is able to penetrate 200 metres below the ocean surface, so submarine crews use other methods to find their way. Inertial guidance systems can help to keep track of the sub's journey from a fixed starting point, using gyroscopes and accelerometers to measure changes in motion, but must be regularly realigned to ensure the vessel remains on course. On the surface, this can be done using GPS, radio and radar satellite navigation systems, but underwater, sound navigation and ranging (sonar) are used. This helps to identify ocean-floor features, allowing the crew to plot the sub's location.



Sound waves
The sonar sphere emits pulses of sound waves that travel through the water.

Calculating distance
By measuring the time that it takes for the sound wave to get back to the sphere, the distance between the sub and the object can be calculated.

Bounce back
When the sound waves hit an object, they reflect back towards the sonar sphere.



Snorkel
When surfaced, air enters the sub through a snorkel, but when submerged, oxygen is generated on board the boat.

Antenna
Underwater communications are carried out using low-frequency radio waves, which are able to penetrate the water.

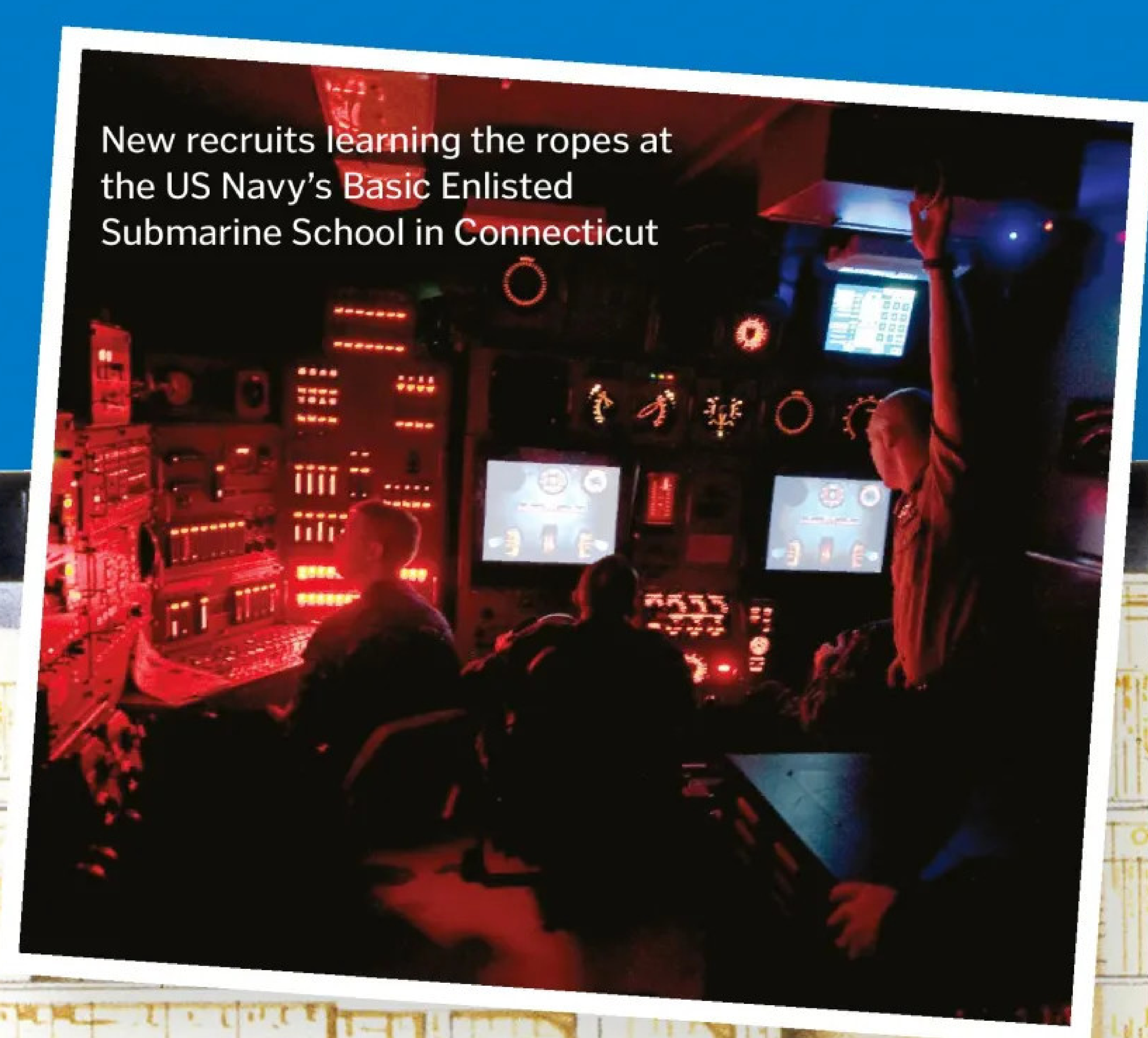
Periscope
Objects above the surface can be observed via a series of mirrors that reflect light down to the viewer's eye.

Ballast tanks
This compartment is used as a ballast to provide stability for the submarine, and works by controlling the boat's buoyancy.

Crew cabins
Crews of around 100 submariners live on the boat for months at a time without resurfacing, sleeping in cramped bunks between shifts.

Torpedo room
Torpedoes are launched via tubes in the side of the submarine and then travel through the water towards the enemy.

Control room
Navigation, communications and weapons systems are operated from the submarine's nerve centre.



New recruits learning the ropes at the US Navy's Basic Enlisted Submarine School in Connecticut

SUPERSONIC SUBS

This underwater craft could circumnavigate the globe in just half a day

Moving at speed through water is very difficult, as liquid creates more drag than air. This means that you need a lot of energy to push through water at high speeds, and most modern submarines are only powerful enough to travel at around 75 kilometres per hour. However, researchers at the Harbin Institute of Technology in China are developing technology that could allow submarines to travel at the speed of sound, so around 5,400 kilometres per hour in seawater.

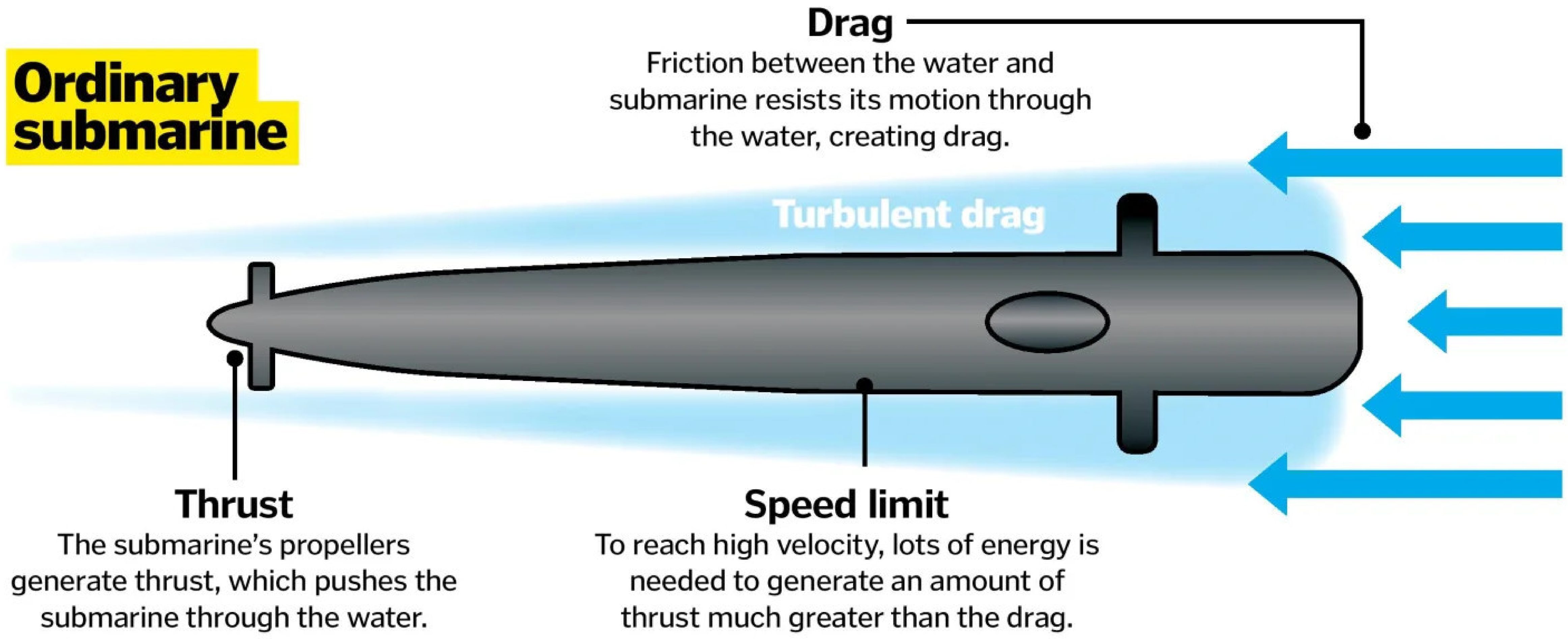
Their method is based on supercavitation, which was first developed by the Soviets in the 1960s to create high-speed torpedoes during the Cold War. It works by creating a supercavity of air around the vessel, reducing drag and allowing it to reach much faster speeds. The Soviets successfully achieved this with their Shkval torpedo, which could reach speeds up to 370 kilometres per hour, but it could only travel for a few kilometres, and couldn't be steered.

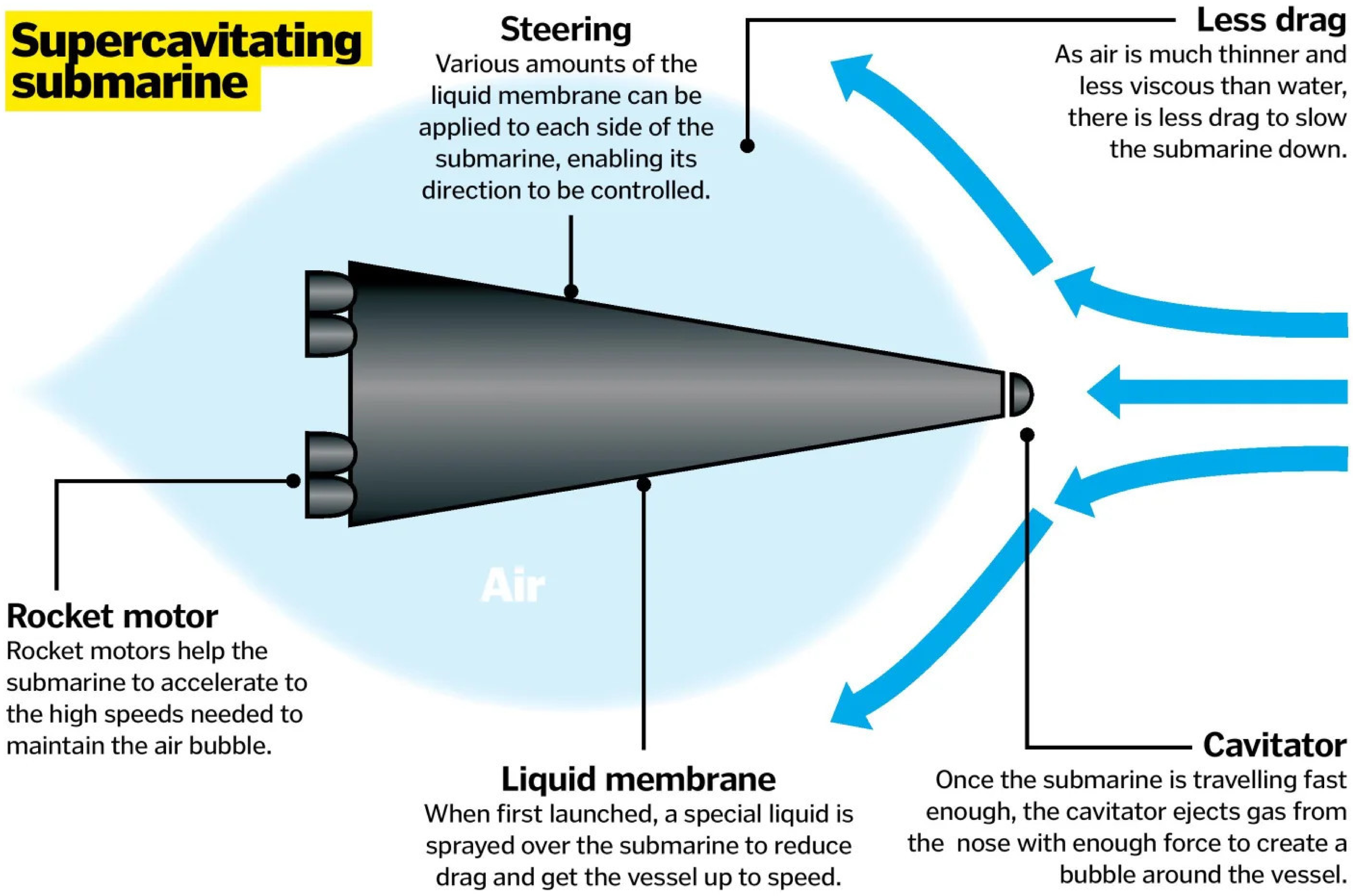
Steering is a problem because rudders, the typical method of navigation underwater, require water to create drag, and so will not work in a bubble of air. To overcome this, the Chinese scientists have created a liquid membrane that can be sprayed over the submarine, reducing drag on one side so that it can be steered in the other direction. So far, however, a method of underwater propulsion for long-range supersonic travel has yet to be developed, so their dreams of travelling from Shanghai to San Francisco in 100 minutes are still a long way off.

The cavitator of the Shkval torpedo

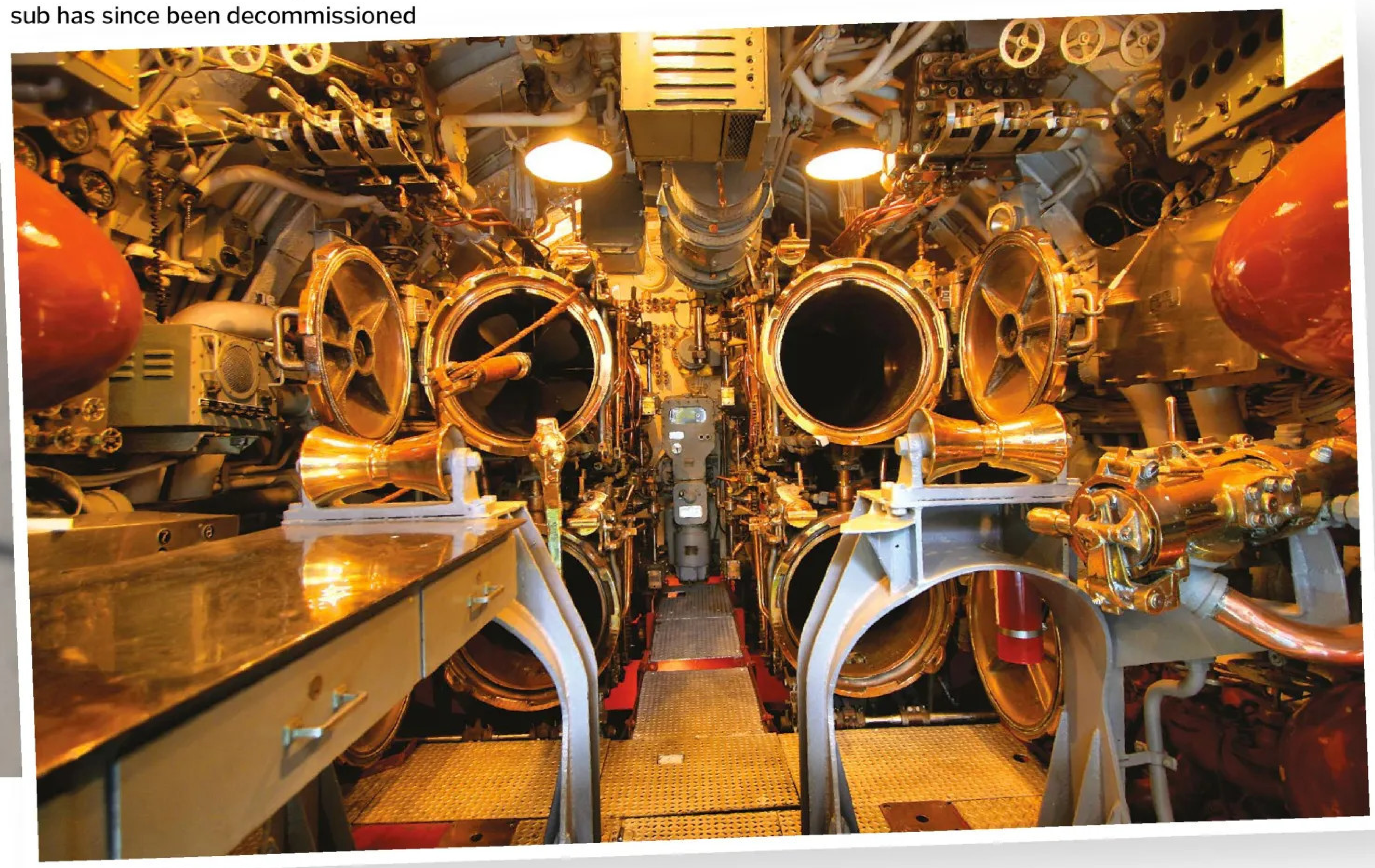
Speeding through the water

How would a supersonic submarine reach the speed of sound?





Inside the USS Bowfin torpedo room. This sub has since been decommissioned



SUBMARINE DRONES

The autonomous underwater vehicles that render crews unnecessary

Keeping crews safe and alive at sea is a risky and costly business, so it's no wonder that the world's navies are already developing unmanned underwater vehicles (UUVs) to do the dangerous work for them. One particular area where these underwater drones are useful is mine hunting, as they can search for and even destroy underwater explosives while keeping the crews of nearby ships out of harm's way. The US Navy currently uses the Woods Hole Oceanographic Institution's (WHOI) Remote Environmental Monitoring UnitS (REMUS) vehicles for this very purpose, as each one is capable of doing the work of 12 human divers.

It's not just the military that these UUVs can help, as the ability to fit them with a variety of cameras and sensors also makes them useful for conducting scientific research. Underwater drones can survey and monitor places that are incredibly difficult for humans to reach, and gather information about marine wildlife in their natural environment. For example, WHOI's SharkCam drone has enabled scientists to observe the underwater hunting behaviour of great white sharks for the first time, showing that they use the darkness at great depths to avoid detection before ambushing their prey.

Ocean robots

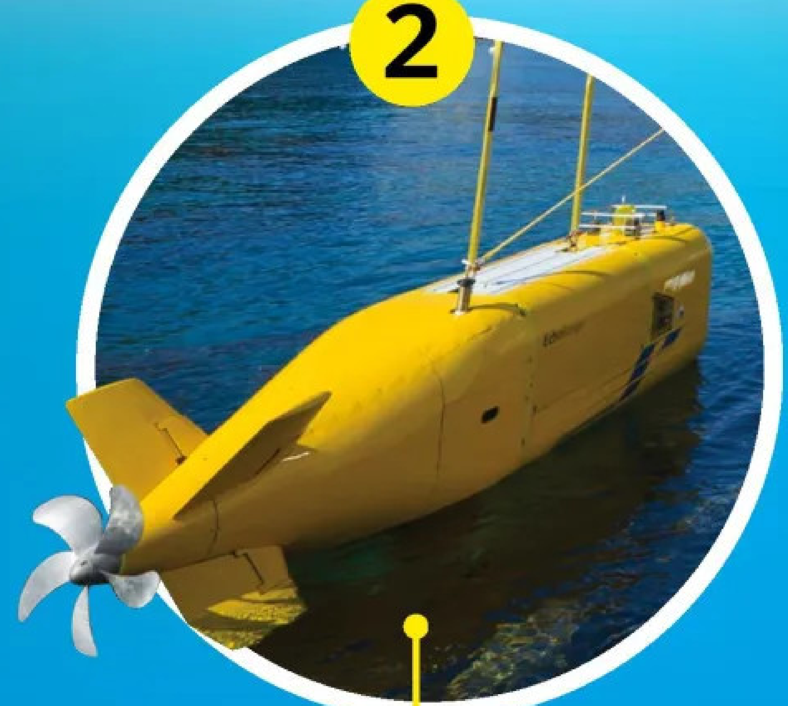
Discover the important roles of unmanned vehicles

1

Sub hunting
The US Navy's Sea Hunter is the world's largest unmanned ship. It can sail on its own for up to three months at a time, using its short-range radar to detect diesel-electric submarines.

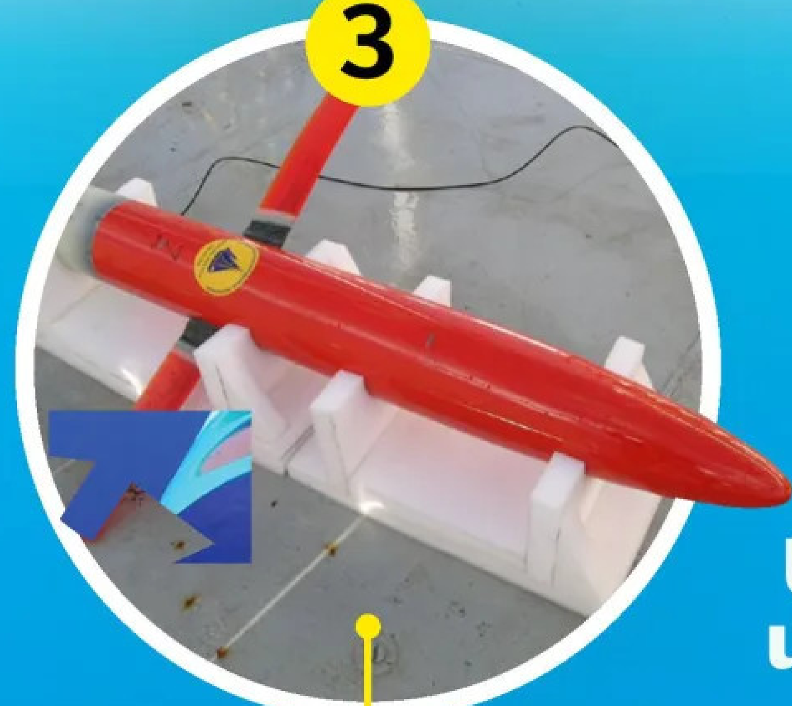
Unmanned surface vehicles

2



Deep diving
Built by Boeing, the ECHO Ranger can dive to depths of 3,000 metres, and was developed to capture high-res images of the ocean floor for the oil and gas industry. It is now also being used for underwater intelligence, surveillance and reconnaissance missions.

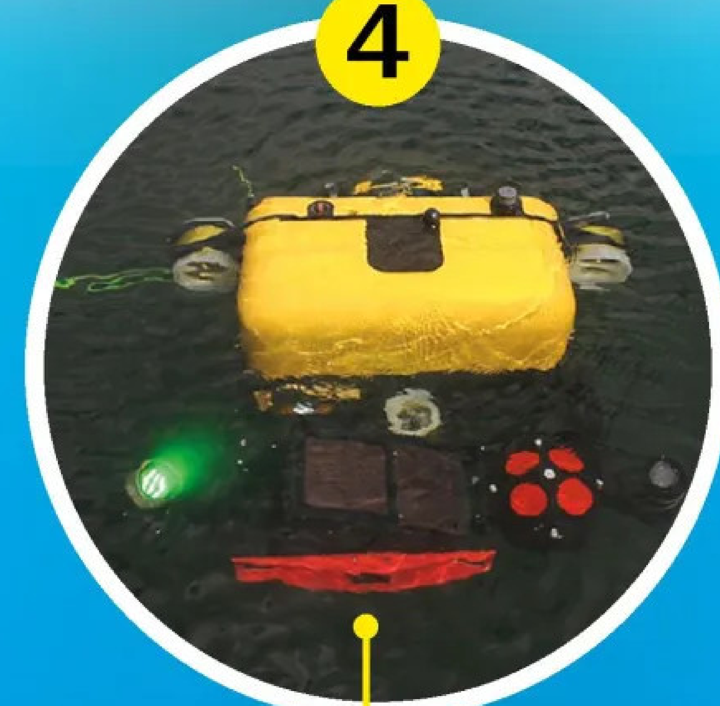
3



Long-distance gliding
WHOI's Spray Glider uses small changes in its buoyancy, combined with lift from its wings, to propel itself through the water. This means it uses little power, so can travel for 3,600 kilometres at a time, taking scientific measurements from its surroundings over long periods.

Unmanned underwater vehicles

4



Hull inspections
The US Navy's Hovering Autonomous Underwater Vehicle inspects the hulls of ships for explosive devices or damage. Data is gathered by the high-res imaging sonar, then sent to operators on board the ship in real time via a fibre-optic tether.

5

Cargo delivery
The dual-use Proteus submersible can operate autonomously or manned, as it can transport divers or deliver payloads over hundreds of kilometres without human intervention. There's space for up to six people inside, and it has a top speed of 18 kilometres per hour.

6

Harbour protection
Inspired by a tuna fish, the BIOSwimmer drone is being developed for the US Department of Homeland Security to patrol harbours and inspect ships. It has a flexible back section and fins to help it manoeuvre through the water, even in harsh environments.

7

Animal tracking
WHOI has outfitted one of its REMUS UUVs with instruments that enable it to locate, track and film marine animals. The SharkCam is pre-programmed to home in on a signal from a transponder beacon that is attached to an animal such as a great white shark.

Unmanned underwater vehicles

8

Amphibious missions
Capable of flying in the air and swimming underwater, the Naviator is the first amphibious drone. It has to stay tethered to its operator for continuous communications, but should help the military detect and map mines, and assist with search and rescue operations at sea.

9

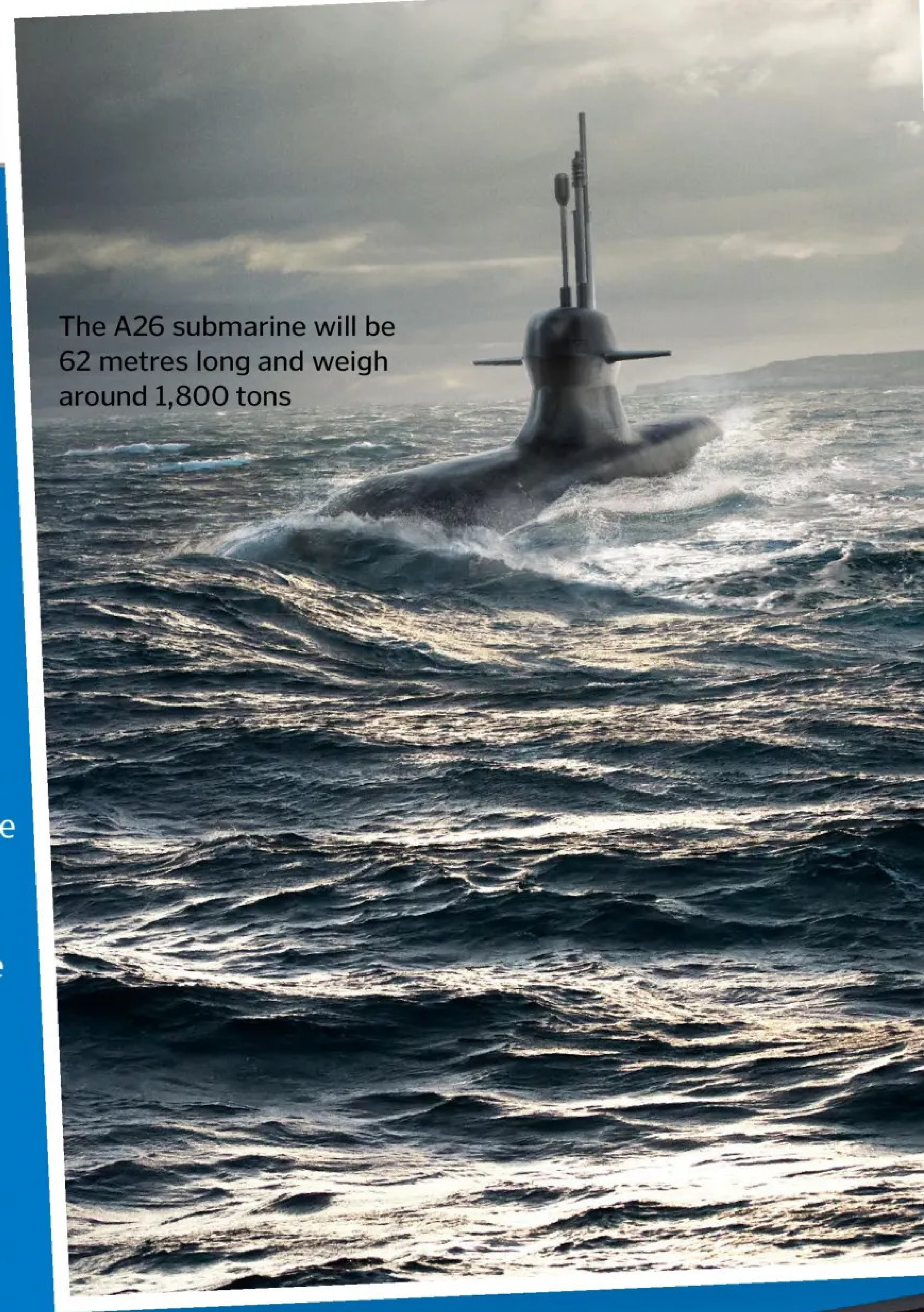
Mine hunting
Designed to swim ahead of a ship, Saab's Double Eagle SAROV can detect, classify and dispose of mines in the vicinity. It can be remotely operated or function autonomously. Once a mine has been detected, it deploys a smaller mine sniper vehicle to destroy it.

THE FUTURE OF SUBMARINES

What will underwater crafts look like in years to come?

With technology advancing at speed, it will not be long before we find out whether the future of submarines is supersonic, unmanned or something else entirely. In fact, the latter is being explored by defence and security company Saab, and it is currently constructing two new super-stealthy Type A26 submarines for the Swedish Navy. With intelligence gathering and surveillance along coastlines becoming increasingly important, these high-tech submarines will be able to operate in shallow waters, and also feature Genuine HOlistic STealth (GHOST) technology, making them virtually silent and almost impossible to detect.

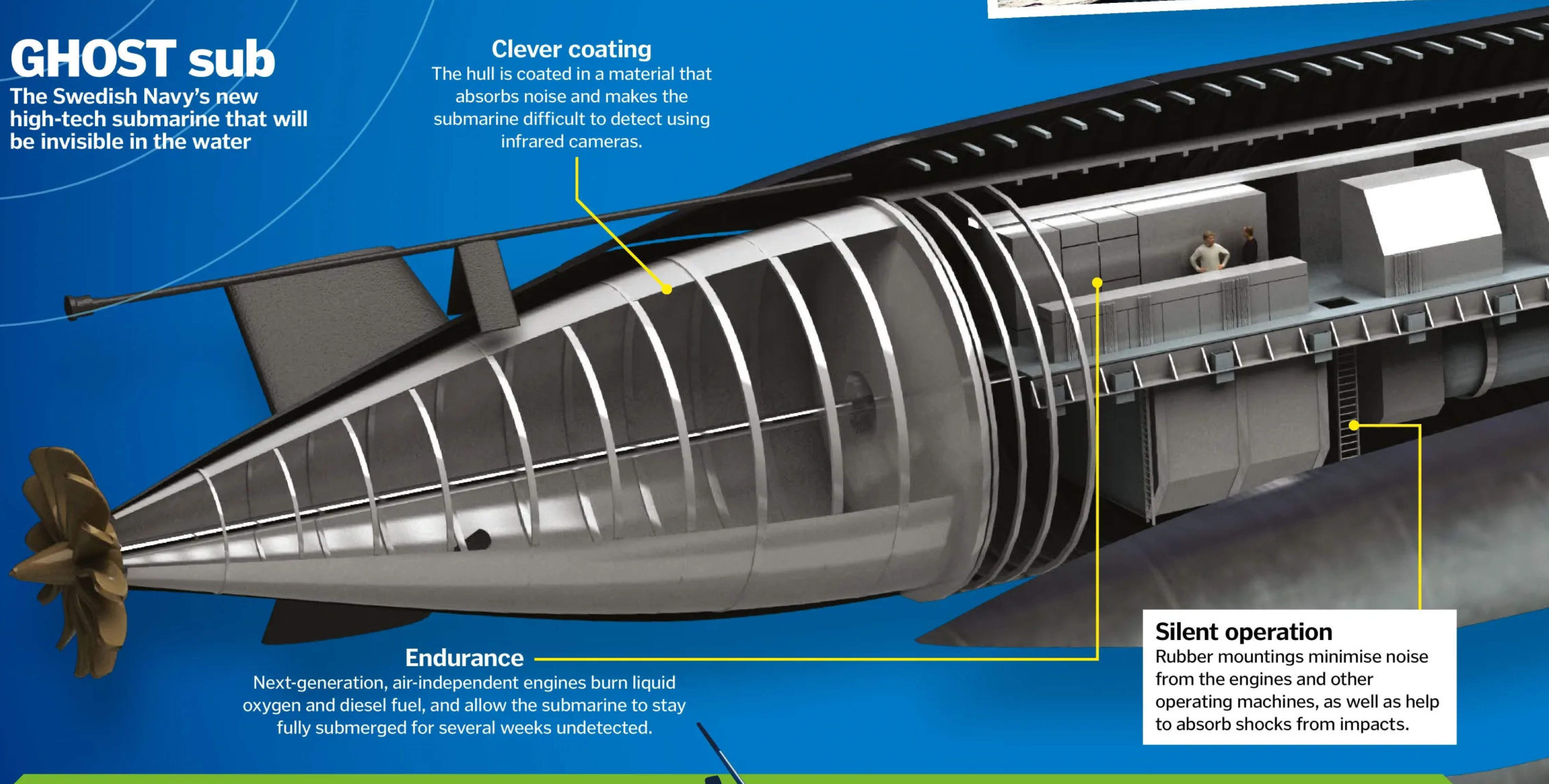
Per Neilson, program manager for the A26, says: "It will be much quieter, the sensors will be more advanced – detecting and documenting everything that goes on in the sea – and there will be a number of new capabilities such as the multi-mission portal in the bow that allows for the hosting of divers and small manned or unmanned vehicles. It will be a first-class intelligence-gathering platform." The A26 sub will dive to depths of 200 metres and carry a crew of 26. It is due to be completed by 2022.



The A26 submarine will be 62 metres long and weigh around 1,800 tons

GHOST sub

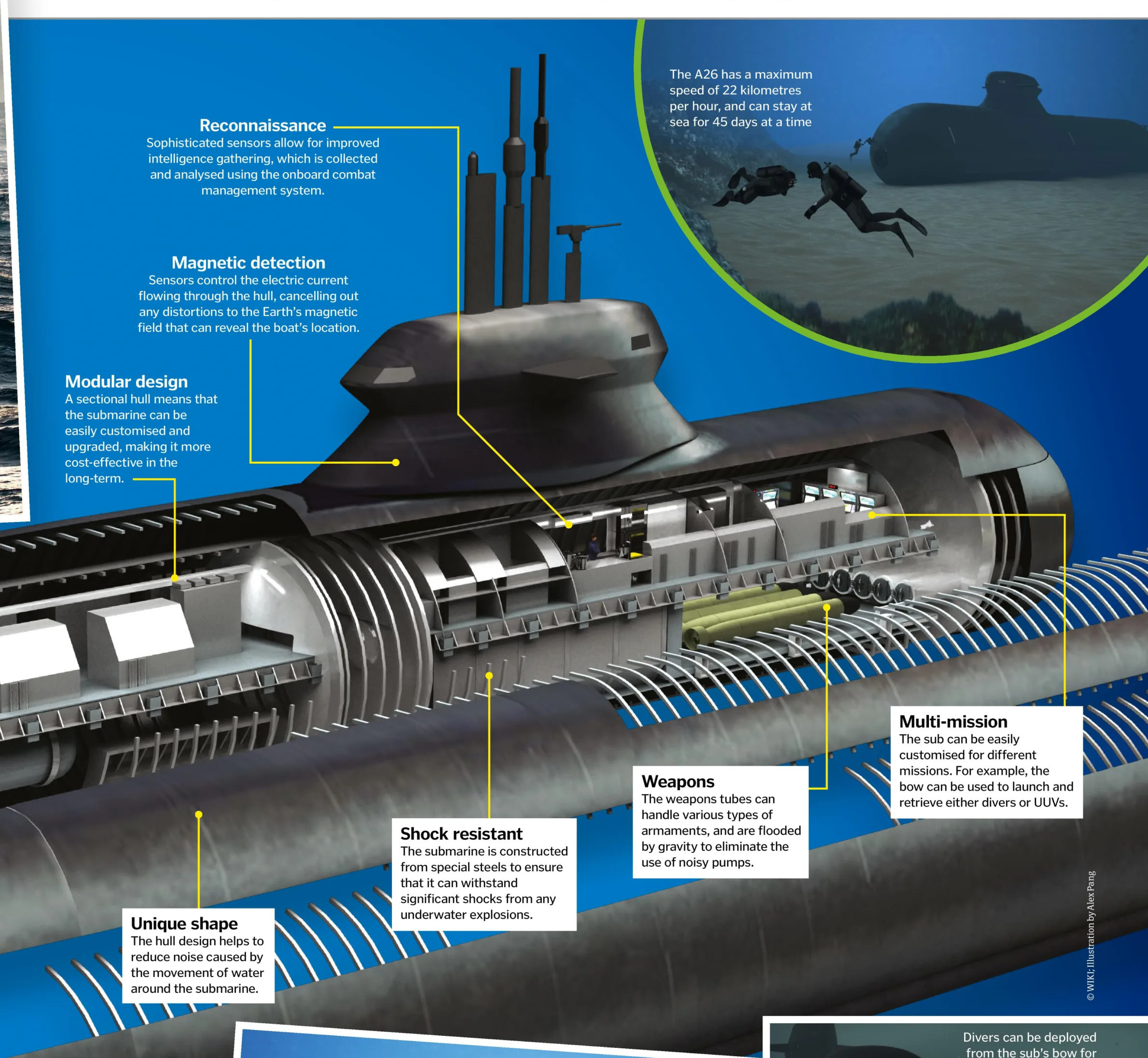
The Swedish Navy's new high-tech submarine that will be invisible in the water



How you can explore the ocean

High-tech submarines aren't just reserved for the world's navies and scientists; DeepFlight has created a personal underwater craft that just about anyone can use to explore the oceans. The Super Falcon Mark II is an electric craft that can be operated with minimal training, and dives to a maximum depth of 120 metres. It can carry two people, a pilot and a passenger, and is small enough to fit on a standard yacht, so you can take it for a dive wherever you are in the world. The submarine is safe to use around marine wildlife, and if you do encounter any trouble, whether it's shark-related or not, it will automatically return to the surface.

The Super Falcon Mark II is the underwater equivalent of an airplane, able to fly through the ocean



The A26 has a maximum speed of 22 kilometres per hour, and can stay at sea for 45 days at a time

Reconnaissance
Sophisticated sensors allow for improved intelligence gathering, which is collected and analysed using the onboard combat management system.

Magnetic detection
Sensors control the electric current flowing through the hull, cancelling out any distortions to the Earth's magnetic field that can reveal the boat's location.

Modular design
A sectional hull means that the submarine can be easily customised and upgraded, making it more cost-effective in the long-term.

Multi-mission
The sub can be easily customised for different missions. For example, the bow can be used to launch and retrieve either divers or UUVs.

Weapons
The weapons tubes can handle various types of armaments, and are flooded by gravity to eliminate the use of noisy pumps.

Shock resistant
The submarine is constructed from special steels to ensure that it can withstand significant shocks from any underwater explosions.

Unique shape
The hull design helps to reduce noise caused by the movement of water around the submarine.

Divers can be deployed from the sub's bow for stealth missions

The A26 will be able to withstand temperatures down to -2˚C


The Sun's rays are focused onto the power tower

Harnessing the Sun

How vast solar power towers generate electricity

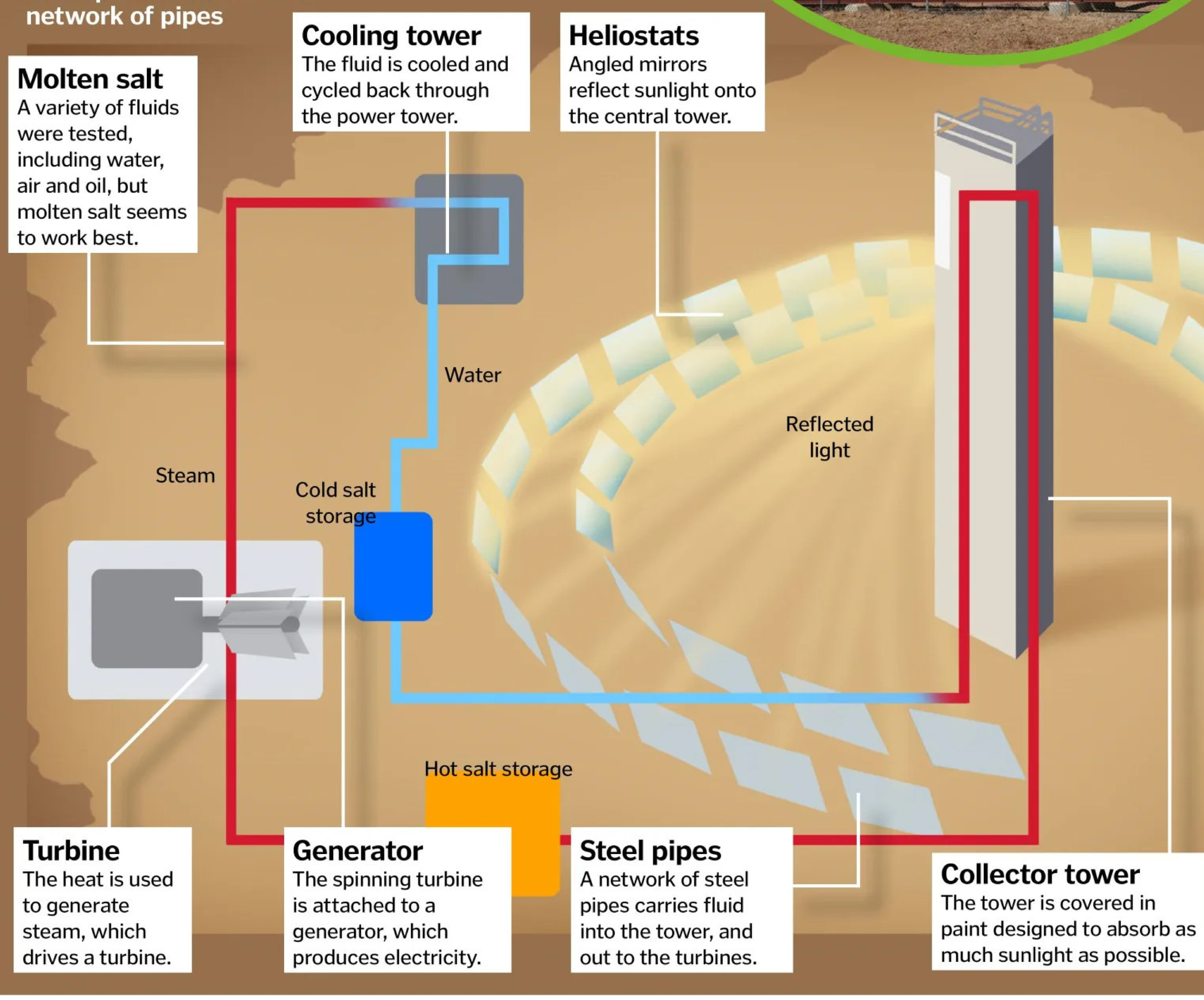
When light hits a solar panel, it generates an electrical current by nudging electrons away from their atoms, but solar power towers are different. These harness the heat of the Sun.

Power towers sit at the centre of rings of angled mirrors, or 'heliostats', which track the Sun as it passes across the sky. They reflect the light, focusing it all onto the tower. Inside, fluid (originally water, but now more often molten nitrate salt), heats up under the intense light. The heated liquid is used to generate steam, which in turn is used to drive a turbine.

This ingenious way of collecting solar energy allows heat to be stored even when the Sun goes down, providing a supply of electricity that can be used overnight and on cloudy days. Solar power towers aren't without their problems, though. The mirrors concentrate the Sun's energy to such intensities that wildlife entering the ring is in serious danger. Crescent Dunes Solar Energy Project in Nevada reportedly vaporised over 100 birds in just six hours. However, when compared to the environmental damage caused by coal-fired power plants, these towers still come out on top.

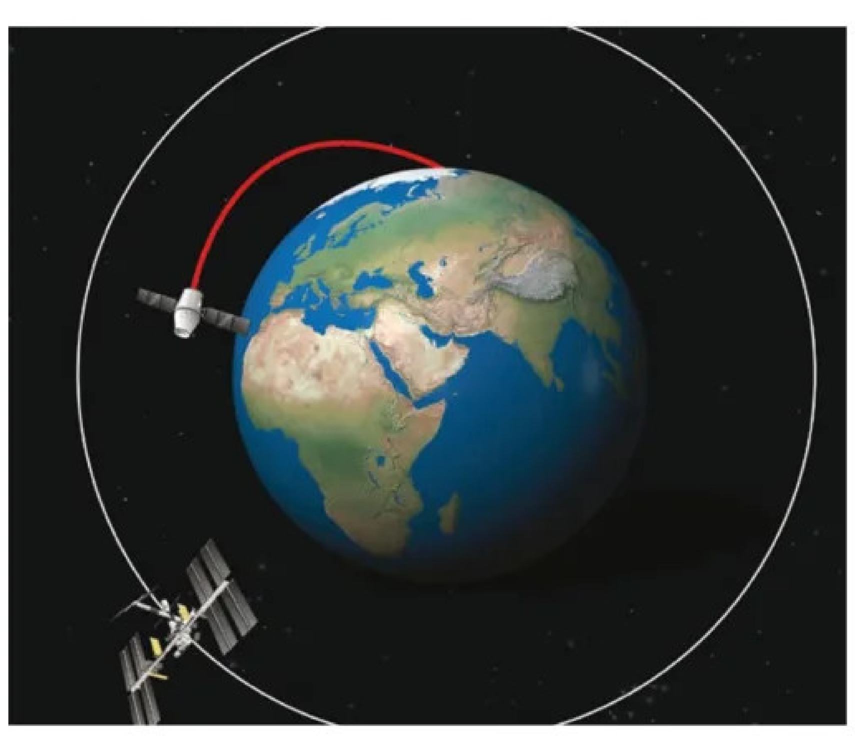
Inside a power tower

The key to harnessing the Sun's power lies inside a network of pipes

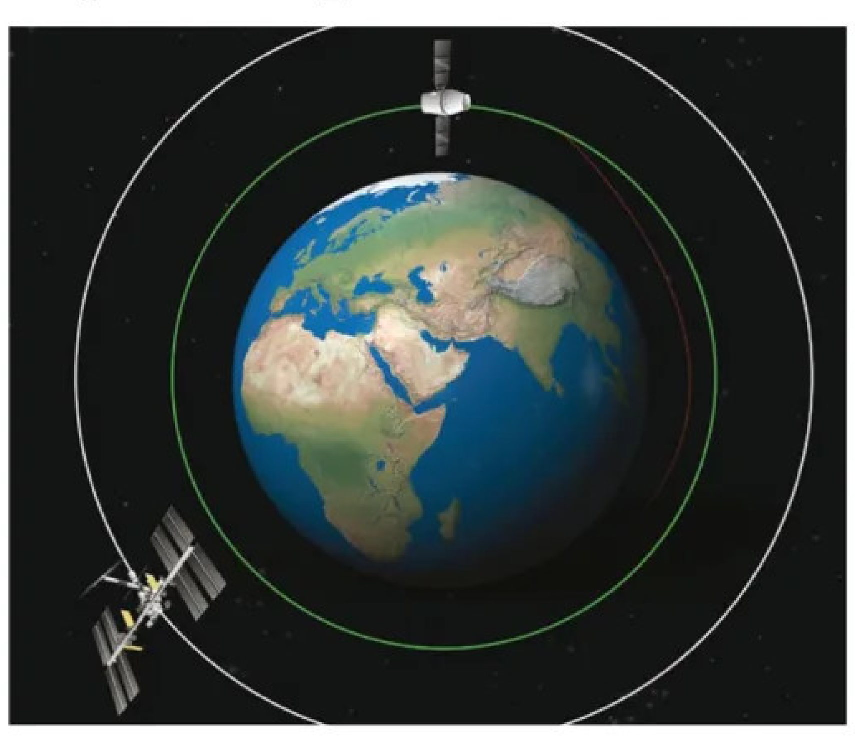


Docking a spacecraft

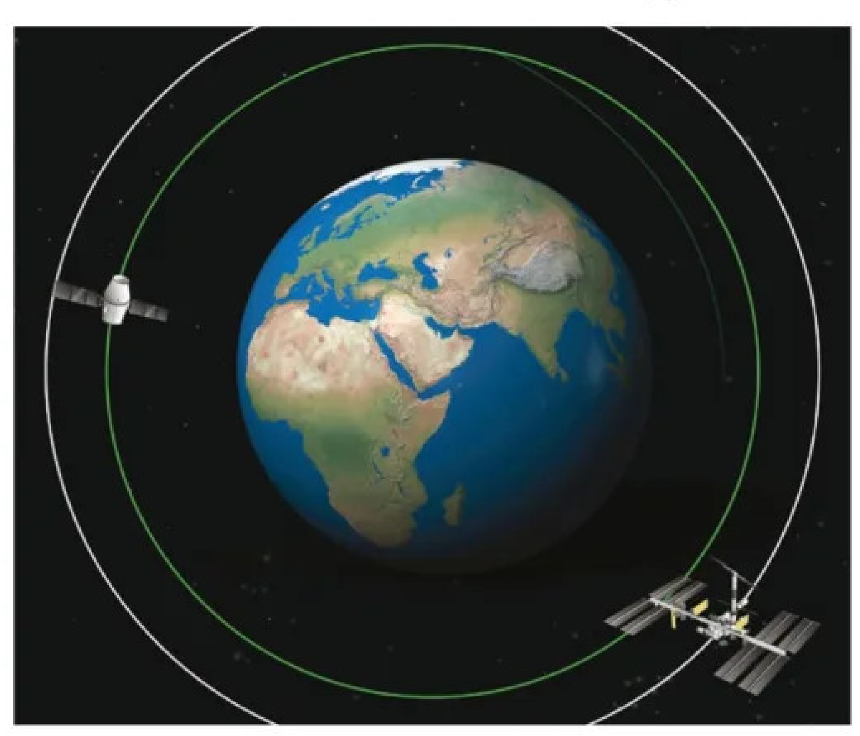
How astronauts in the Soyuz capsule board the International Space Station



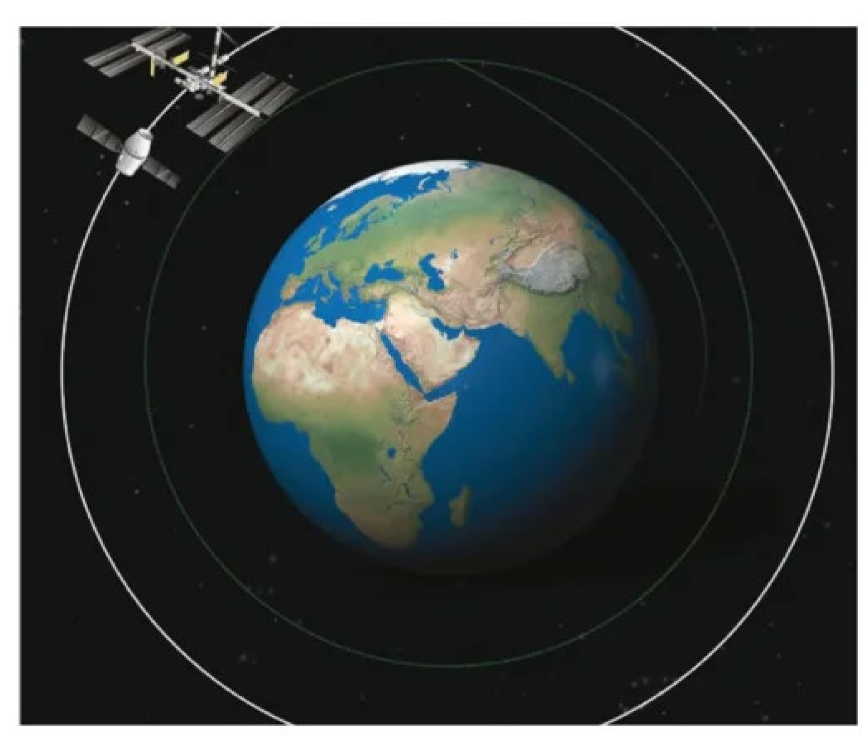
Reaching space
It only takes a matter of minutes to blast into space, but it can take hours or even days to reach the International Space Station (ISS). Following blast-off, the Soyuz capsule enters orbit by firing its rockets parallel to the spacecraft's direction of travel.



Transfer into higher orbit
The ISS orbits the Earth at a higher altitude, so the Soyuz has to reach it via an elliptical path called a Hohmann transfer orbit. This features two engine burns – one to take the Soyuz into the higher orbit and another engine burn to keep it there.



Small corrections
The Hohmann transfer orbit isn't always precise, and the Soyuz has to perform small thruster burns to manoeuvre itself into an orbit around Earth with a period of 86 minutes – four minutes faster than the slightly higher ISS, which is moving at around 28,000 kilometres per hour.



Overtaking the ISS
As the Soyuz is moving faster, it overtakes the ISS above it, then fires its engines again to enter another Hohmann transfer orbit that brings the spacecraft just in front of the ISS, 400 kilometres above Earth. Then the Soyuz turns around, fires its engines to slow down, and docks.

How the Sailrocket 2 works

Find out how this boat hits such high speeds on the high seas

The design of the Sailrocket 2 perfectly balances forces for speed

When it comes to going super fast on water, powerboats are usually the go-to craft. However, there's one sailboat out there that is capable of achieving breakneck speeds of 65 knots (120 kilometres per hour) using wind power alone. It's called Sailrocket 2, and it's the brainchild of Paul Larsen, based on designs originally by an American rocket engineer in 1917.

The Sailrocket 2 is an aerodynamic mixture of plane and boat. Its ingenious design relies on a mixture of forces to keep it stable and to transfer the energy from the wind (that would cause a normal boat to capsize) into extra speed.

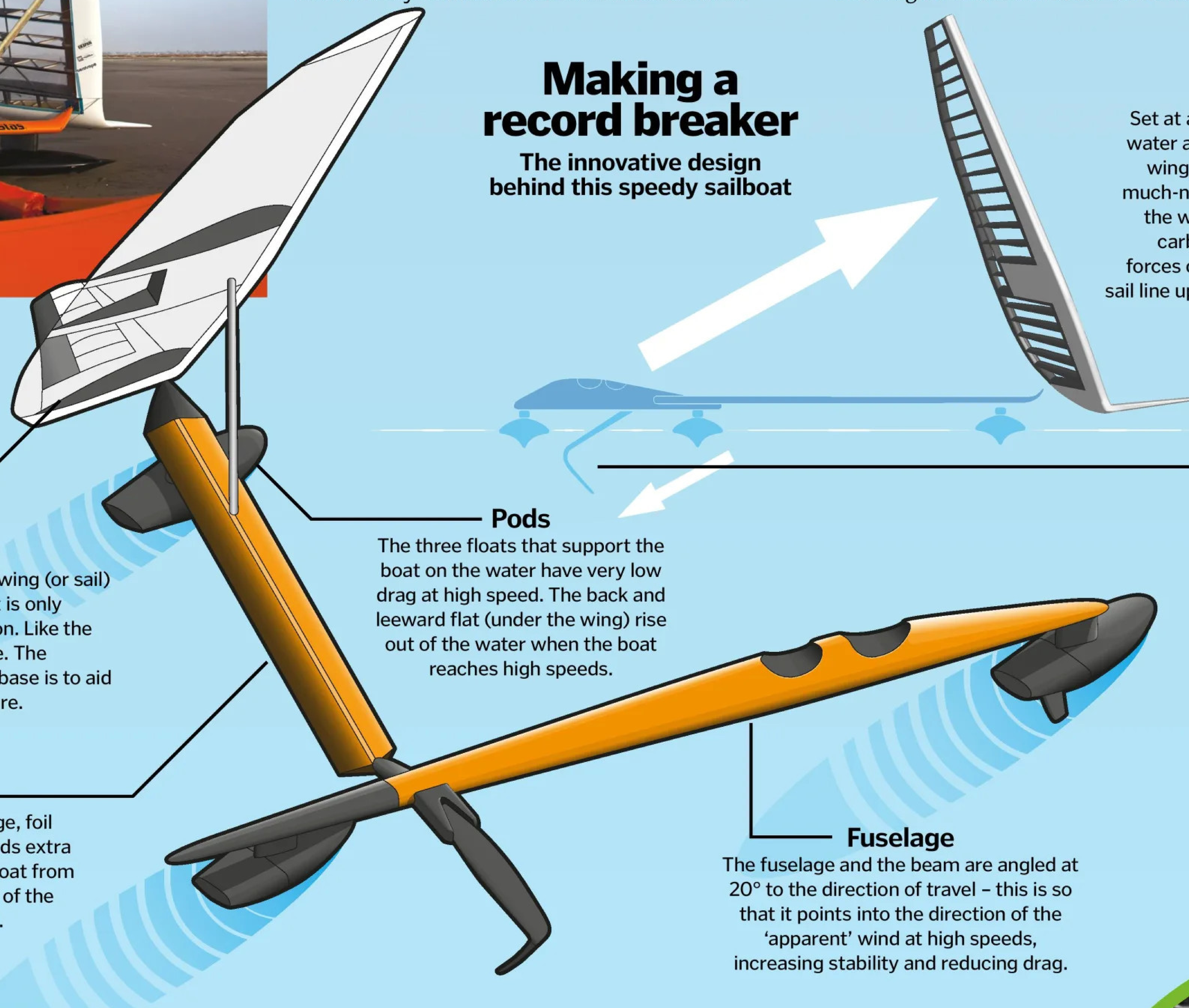
The cockpit (fuselage) sits parallel to the sail, attached by a horizontal mast. The sail is at a 30-degree angle to the water, and protruding from the cockpit is a bent carbon-fibre keel, or foil. The whole boat sits on the water atop three pods.

The foil is the real genius in this design; it's tough but thin, and helps to create minimum drag while stabilising the entire boat. It also counteracts cavitation (bubbles that cause drag) using a wedge-shape design that reduces the friction in the water caused by the phenomenon.

When the boat hits 50 knots (92 kilometres per hour), buoyancy is replaced by hydrodynamic lift. Two of the boat's pods lift out of the water, and it glides on pockets of air trapped between the pods and the water. The foil keeps it stable, allowing the Sailrocket 2 to reach record speeds, and blowing all other sailboats out of the water.

Making a record breaker

The innovative design behind this speedy sailboat



Foil
Set at a 30° angle in the water and parallel to the wing, the foil provides much-needed stability in the water. It's made of carbon fibre, and the forces of the foil and the sail line up for extra speed.

Wing
Super light and strong, the wing (or sail) is asymmetrical as the boat is only needed to go in one direction. Like the foil, it is tilted at a 30° angle. The horizontal extension at the base is to aid lifting and distribute pressure.

Pods
The three floats that support the boat on the water have very low drag at high speed. The back and leeward flat (under the wing) rise out of the water when the boat reaches high speeds.

Beam
The beam keeps the fuselage, foil and the sail apart, which adds extra stability and prevents the boat from leaning. This means that all of the energy is focused on speed.

Fuselage
The fuselage and the beam are angled at 20° to the direction of travel – this is so that it points into the direction of the 'apparent' wind at high speeds, increasing stability and reducing drag.

What is cavitation?

Cavitation is essentially the formation of bubbles (air pockets) in a liquid when it is under extremely high pressure. This happens when a foil cuts through water at speeds higher than the so-called '50-knot barrier' (the equivalent of 93 kilometres per hour). The phenomenon is not fully understood, but it causes the seawater to vaporise and form intense bubbles – a little like boiling. This causes drag and prevents the boat from accelerating.

Breaking the 50-knot barrier is difficult because the foil has to be small and light enough to enable the boat to go fast, but a smaller foil means a greater pressure change and more cavitation. To combat this, instead of a smooth, wing-like design, Sailrocket 2's foil uses a wedge-shape to cut through the water and leave a smooth pocket of air in its wake, instead of a mass of chaotic bubbles.


As a spinning propeller cuts through the water, cavitation bubbles form at the blades

Firing torpedoes

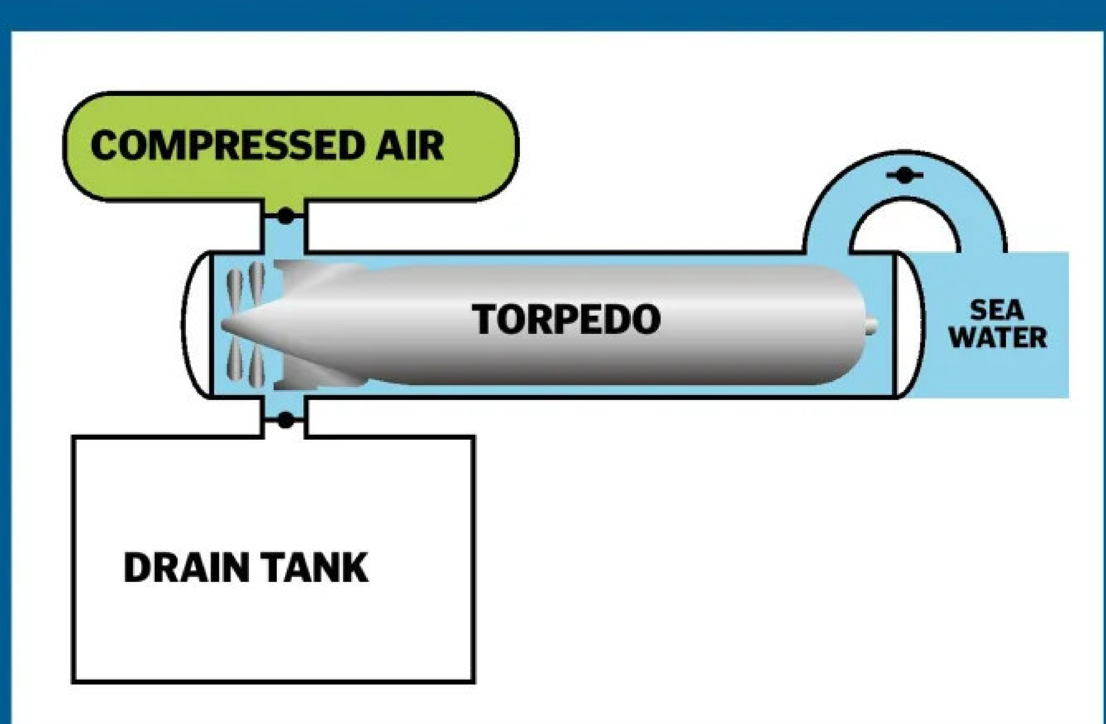
Learn how to unleash the ultimate underwater weapon

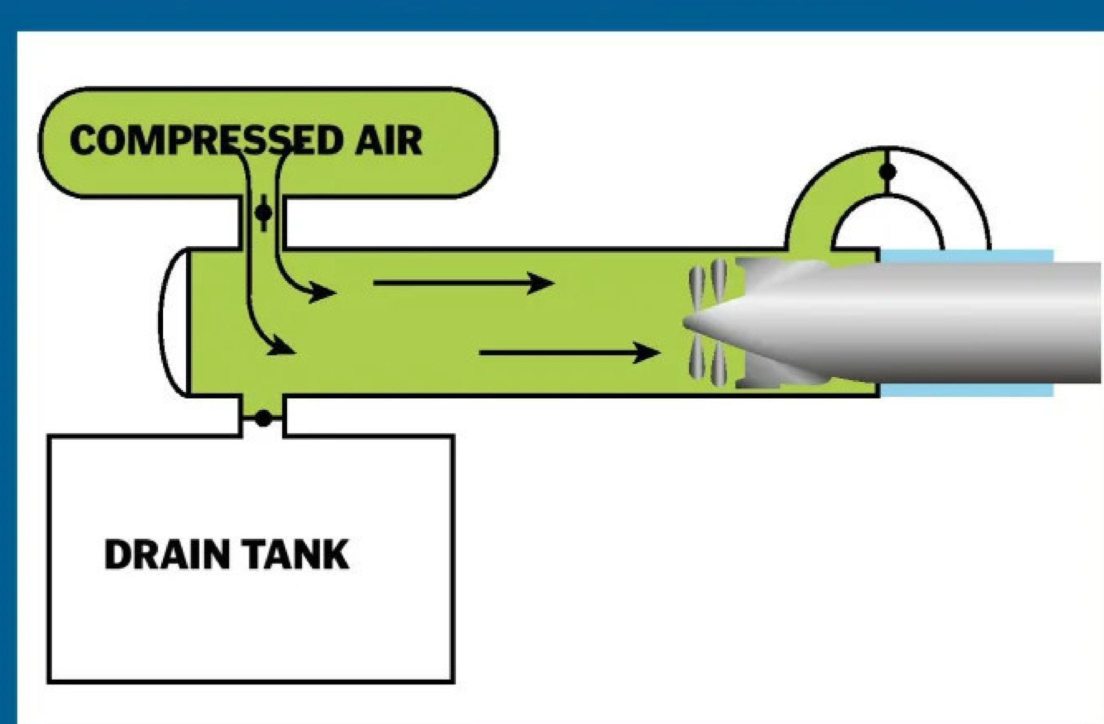
Torpedoes can be launched from both ships and submarines, using torpedo tubes lined up along the hull. World War II-era torpedoes were guided towards the target using an internal gyroscope, and their path could be fine-tuned using the rudders. A pendulum inside the torpedo kept it level. Many modern torpedoes are wire guided, so they can be controlled remotely after launch, before the wire is cut off and the internal guidance system takes over. Once the torpedo detects an enemy ship, or makes contact with it, the onboard explosive is detonated to rip a hole in its side and send it sinking without a trace.

Torpedoes are fired from ships and submarines through torpedo tubes

Load, aim and fire!

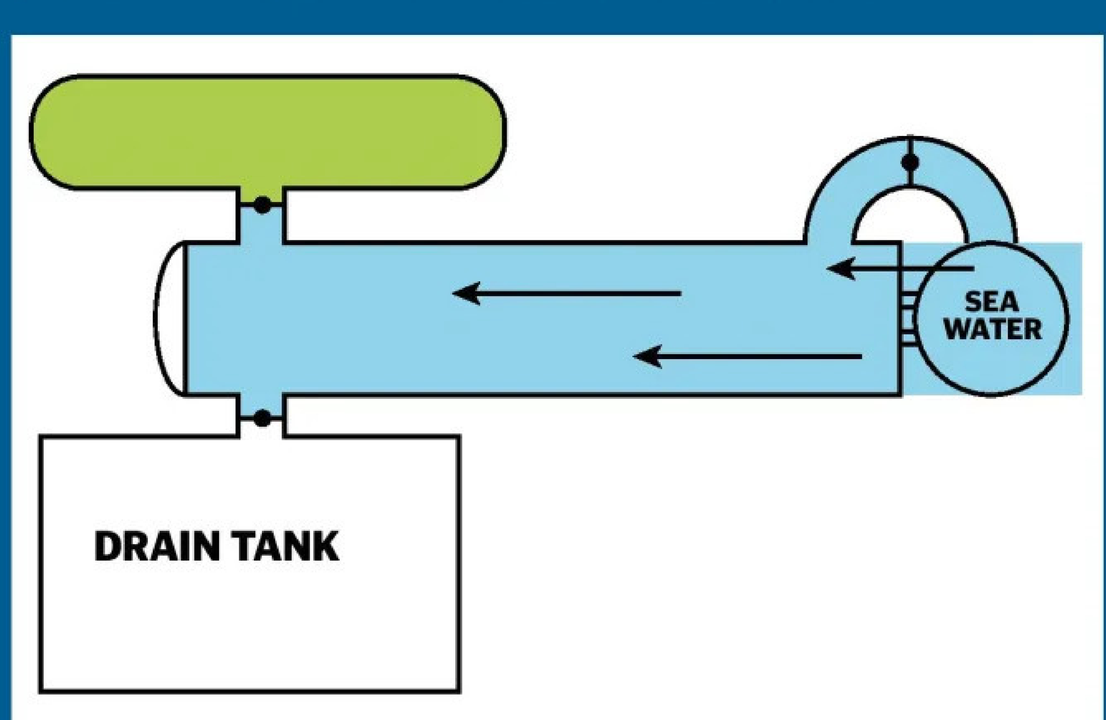
How to fire a torpedo during battle

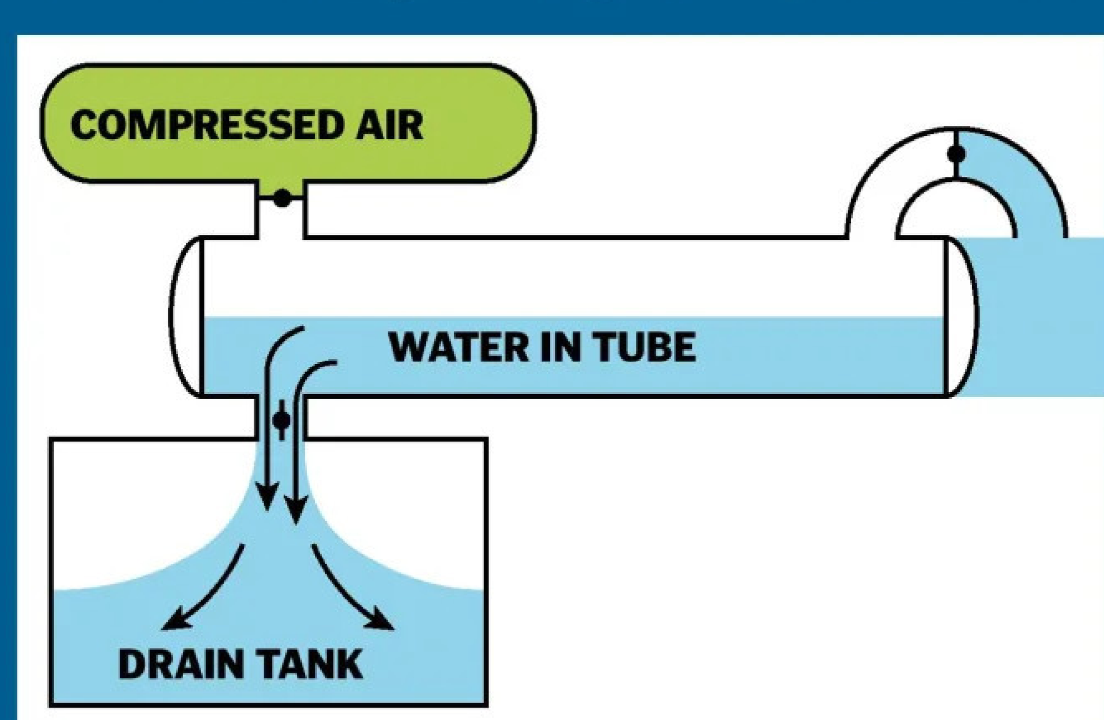




1 Load your weapon
Load the torpedo through the breech door at the back of the torpedo tube and then close it. Open the valve to flood the tube with seawater from outside the ship, equalising the pressure inside and outside the tube.

2 Fire!
Open the muzzle door at the front of the torpedo tube, then open the compressed air valve to eject the torpedo. The air is vented into the ship, so that a bubble cannot escape to the surface and give away the ship's position.





3 Maintain balance
Shut off the compressed air valve and the torpedo tube will then fill with seawater through the open muzzle door. This will help to offset the lost weight of the torpedo to keep the ship balanced.

4 Reset and repeat
Shut the muzzle door and open the valve to the drain tank to empty the water from the torpedo tube. Once it is empty, you can then open the breech door and load another torpedo to start the process again.

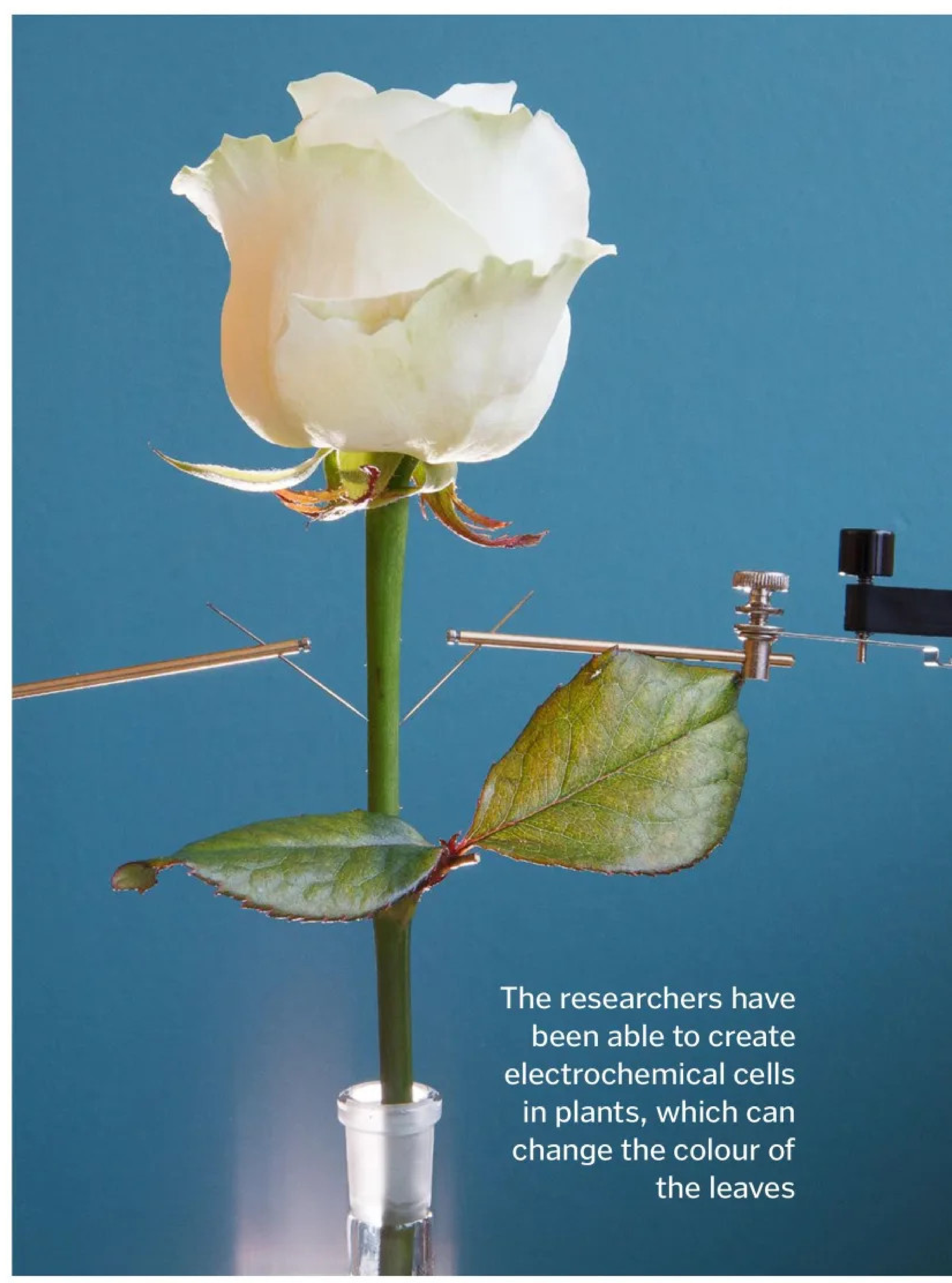
Meet the world's first cyborg plant

How to turn a living rose into an electric circuit

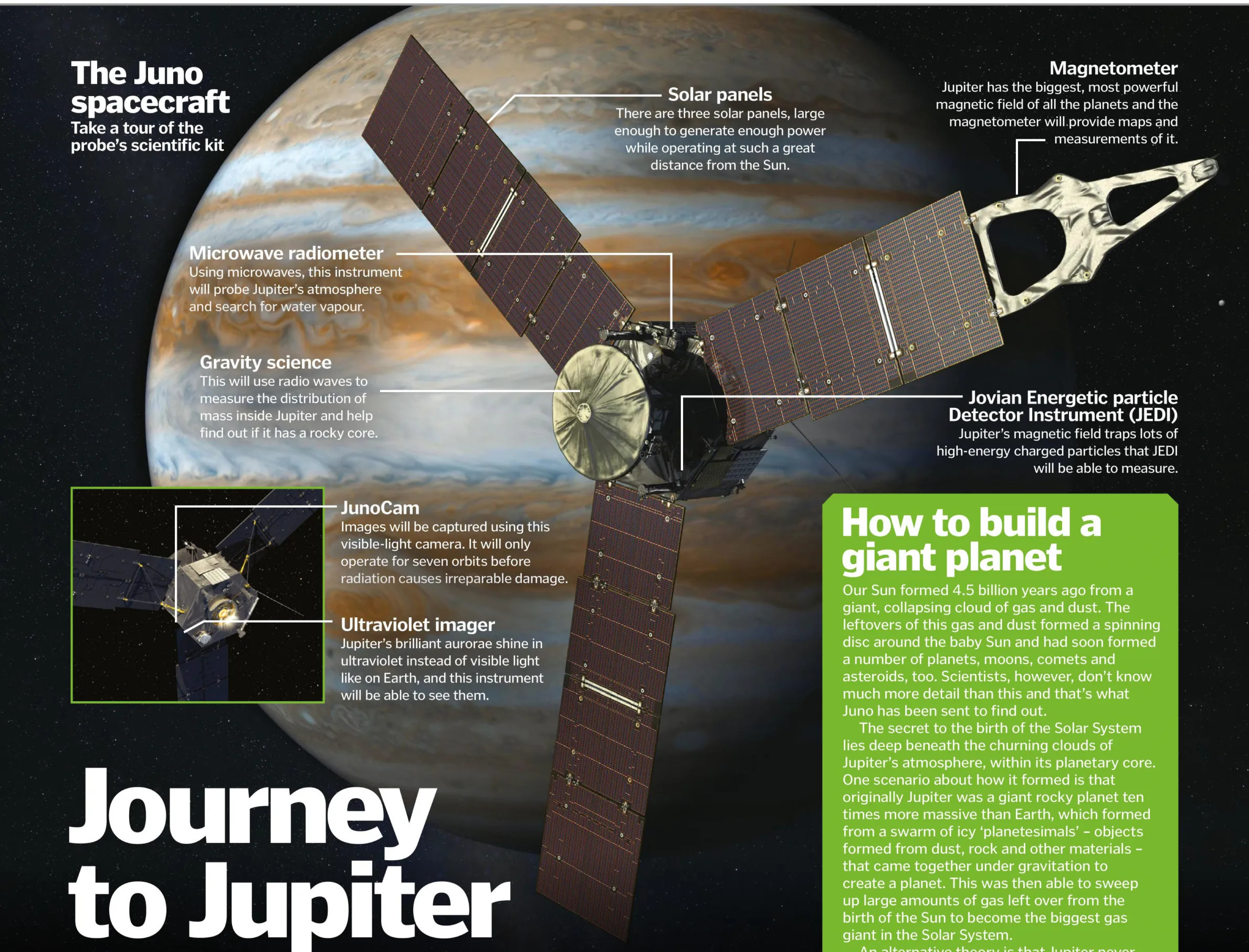
If you struggle to keep your houseplants alive, then the idea of a shrub that can alert you when it needs watering would certainly be appealing. Thanks to researchers in Sweden, that idea is much closer to becoming reality.

The team from Linköping University has created the very first electronic plant, which they say opens up the possibility of being able to read and regulate plant growth by measuring the concentration of their various molecules, as well as making use of the energy they produce through photosynthesis in a fuel cell.

To create their cyborg rose bush, the researchers used a synthetic polymer called PEDOT-S, which was drawn up through the plant's stem by capillary action – the same process plants use to absorb water. Once inside this channel, the polymer converted itself into a thin film that could conduct electrical signals, but still left enough room for water and nutrients to pass through and keep the plant alive. By placing an electrode at each end of the conductive film, the team was then able to create a transistor: an electronic switch that completed the circuit.



The researchers have been able to create electrochemical cells in plants, which can change the colour of the leaves



Journey to Jupiter

The secrets of the king of the Solar System are about to come under the scrutiny of a bold new mission

NASA's Juno spacecraft has been racing towards Jupiter at 97,000 kilometres per hour since leaving Earth in 2011. When it arrived on 4 July 2016 it had travelled 2.8 billion kilometres, setting the record for the most distance a solar-powered probe has ever flown.

Jupiter is the largest planet in the Solar System, spanning 143,000 kilometres across and weighing in at 318 times more than Earth. It's a gas giant, which means it's mostly made of hydrogen and helium gas, and its appearance is famous for the stripes of creamy white, orange and brown. The biggest cloud pattern is the Great Red Spot, a huge anticyclonic storm that's big enough to fit our entire planet inside!

What lies deep within Jupiter's core is still a mystery, however. What does its gaseous composition tell us about the materials that went into its creation? Does the atmosphere contain water, and what lurks beneath the cloud tops? Juno will attempt to unravel these mysteries, while also going where no other spacecraft has gone before by flying close over the poles of Jupiter. Here, it will be able to observe the dazzling northern and southern lights and learn how they are created by the planet's magnetic field. Incidentally, that's what inspired Juno's name: JUpiter Near-polar Orbiter.

The spacecraft will have two years to unlock secrets of the giant planet before it runs out of fuel and is sent hurtling into Jupiter itself. This is to avoid crashing into Jupiter's moon Europa, where it could contaminate any alien life that may inhabit the moon's underground ocean.

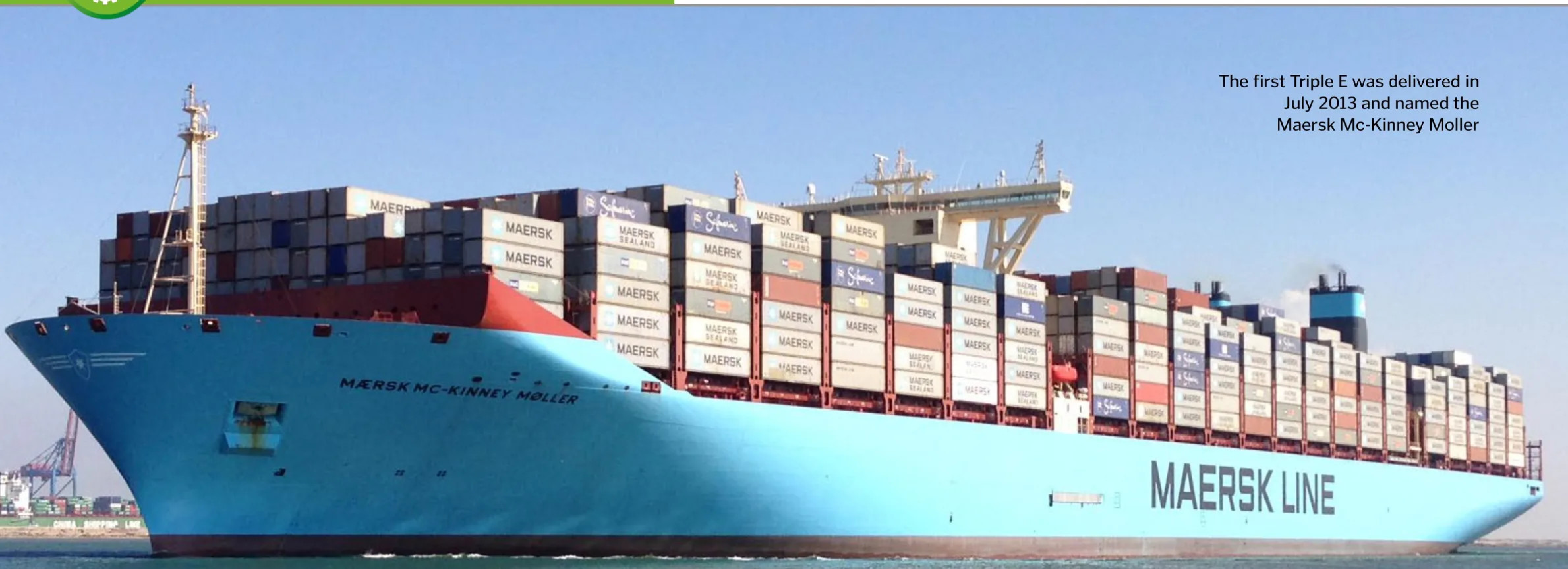
How to build a giant planet

Our Sun formed 4.5 billion years ago from a giant, collapsing cloud of gas and dust. The leftovers of this gas and dust formed a spinning disc around the baby Sun and had soon formed a number of planets, moons, comets and asteroids, too. Scientists, however, don't know much more detail than this and that's what Juno has been sent to find out.

The secret to the birth of the Solar System lies deep beneath the churning clouds of Jupiter's atmosphere, within its planetary core. One scenario about how it formed is that originally Jupiter was a giant rocky planet ten times more massive than Earth, which formed from a swarm of icy 'planetesimals' – objects formed from dust, rock and other materials – that came together under gravitation to create a planet. This was then able to sweep up large amounts of gas left over from the birth of the Sun to become the biggest gas giant in the Solar System.

An alternative theory is that Jupiter never had a rocky core and instead condensed out of gas like the Sun did. By carefully measuring Jupiter's magnetic and gravitational fields, Juno will be able to assess whether it has the remnants of a rocky core or not and determine which scenario is correct. If Jupiter does have a rocky core, then it means that the planetesimal theory is likely, and planetesimals can then be used to explain the formation of other planets, including our own.


If we could cut Jupiter in half, would we find a vaporised rocky core deep underneath the gas?



The first Triple E was delivered in July 2013 and named the Maersk Mc-Kinney Moller

The world's largest ship

How this record-breaking vessel rules the waves

The largest, most monstrous, hands-down winner in the big ships size class is Maersk's Triple E design. Only a few metres wider and longer than the previous world record holder (also made by Maersk), the Triple E offers 16 per cent more container space due to its wider, bulbous bow.

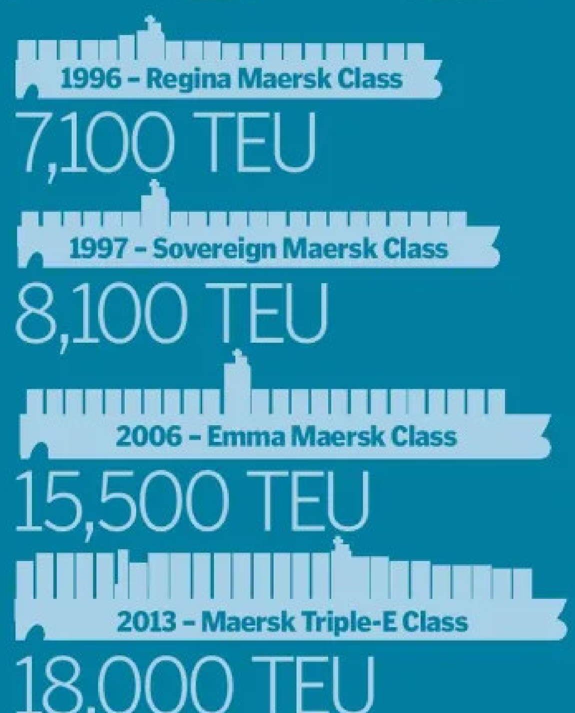
The engine is also positioned further back to aid stability and allows for yet more containers to be squeezed in above and below deck. The propellers are larger, and move slower to conserve fuel and reduce emissions, and the eco-friendly upgrades don't stop there. The hull is designed to be completely recyclable, while the ship's waste heat recovery system captures the heat and pressure from the exhaust and uses it to move turbines.

Colossal ships like this often look rather top-heavy, but they manage to stay afloat due to buoyancy. The weight of water the ship displaces is equal to the weight of the ship, so the forces balance and it floats.

The length of the vessel is so enormous that it has to be built in a way that can withstand the force of waves. To do this, cargo ships are made from flexible materials that can actually bend with the movement of the ocean. Inside the long corridors, it's possible to see the walls flexing and distorting as the craft moves in heavy swell.

18,000

The Triple E can carry 18,000 20-foot equivalent unit (TEU) containers – that's 2,500 more than Maersk's second-largest vessel, the E-Class. One TEU can carry around six thousand pairs of trainers, so the Triple E can carry 108 million pairs – almost enough to provide everyone in Mexico with a set of sneakers!



$190 million USD

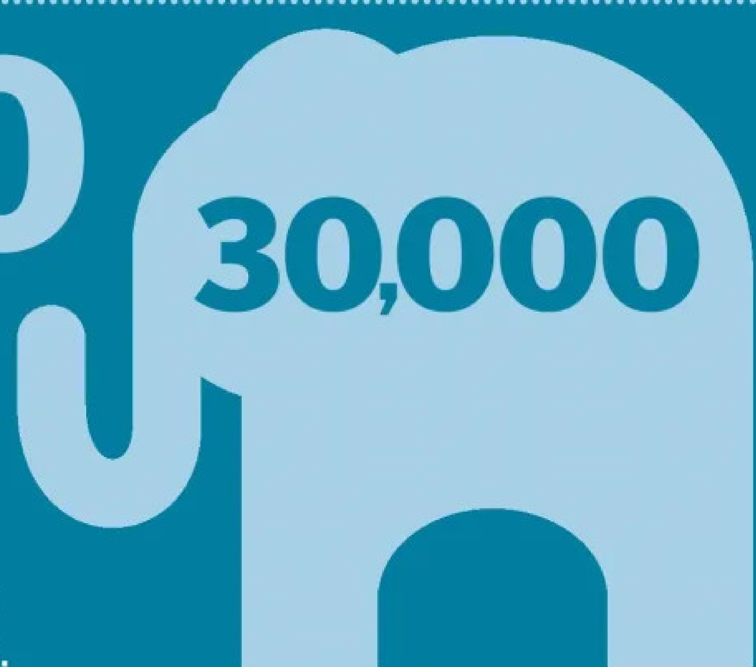
The estimated build cost of each Triple E vessel is roughly equivalent to the production cost of *Star Wars: The Force Awakens*.

2 giant propellers

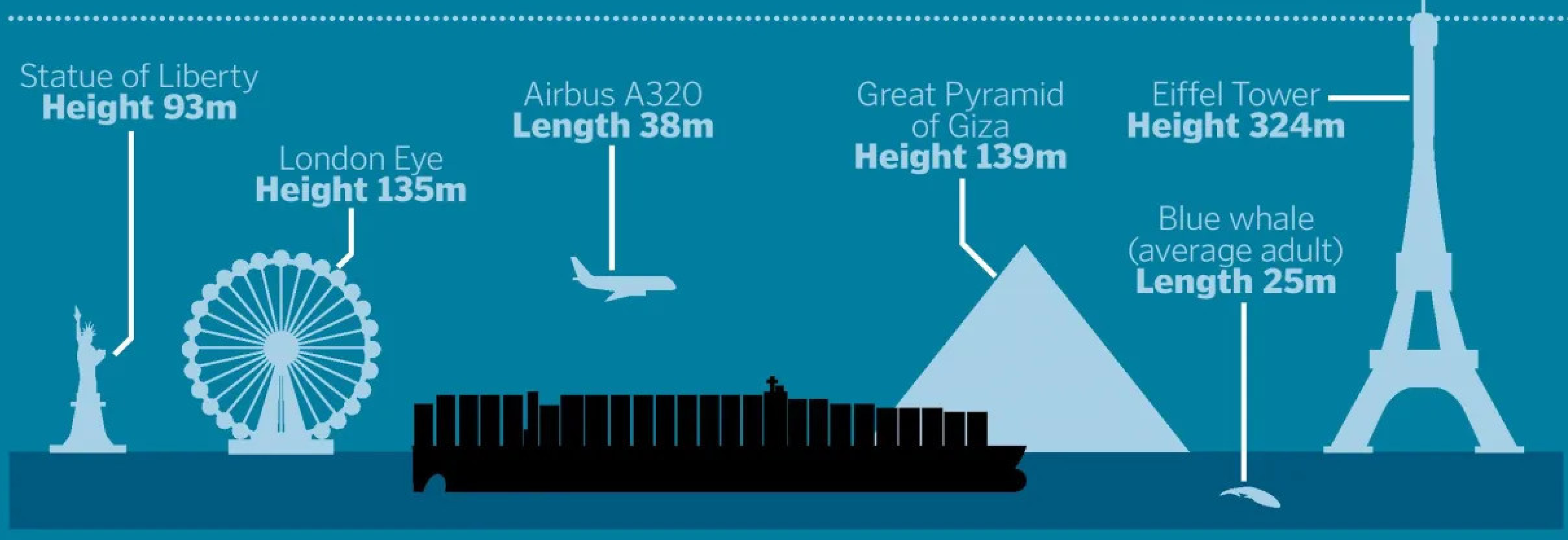
35% less CO_2

The Triple E design is more environmentally friendly.

165,000 metric tons



With a steel hull constructed from 425 individual pieces, the overall weight of the Triple E is 165 thousand metric tons – approximately the same weight as all the gold ever mined, or 30,000 African bush elephants.



400m long x 59m wide

The length of the Triple E cargo ship is slightly more than ten Airbus A320 passenger jets laid end to end.

13,500 nautical miles in 23 days

Reaching a top speed of 23 knots (43km/h), the Triple E will travel the Europe-Asia shipping route, delivering Chinese imports such as appliances, textiles and car parts.

Anatomy of a spacesuit

How this incredible device allows astronauts to survive the extremes

Spacesuits are an astronaut's life support system, providing them with oxygen, keeping them warm and protecting them from the vacuum of space. They provide communications with fellow astronauts and mission control, monitor their health and are sealed against the harsh environment outside. One of the most important parts of any space suit is the backpack: the Primary Life Support System, or PLSS. It's more than just an oxygen pack – it keeps the suit pressurised to prevent hypoxia (caused by the decrease in oxygen within the blood stream), removes harmful carbon dioxide and cools the suit by pumping water around it. It also houses medical monitors and the communication equipment.

The PLSS life support system is a closed loop, so everything is recycled. Inside the suit the astronaut wears a skin-tight Liquid Cooling and Ventilation Garment, which removes body heat through perspiration. Oxygen, carbon dioxide and water vapour are also sent back to the PLSS; the carbon dioxide is then removed by reacting with lithium hydroxide, producing lithium carbonate and water. The water vapour condenses and is also removed and stored in the pack, while oxygen is recycled back around the suit for the astronaut to breathe. Sometimes, spacesuits are referred to as an astronaut's own personal spacecraft. If an astronaut on a spacewalk (also known as extravehicular activity, or an EVA) finds themselves drifting off into space, then the modern NASA spacesuits have a device called the Simplified Aid for EVA Rescue, or SAFER for short, which is composed of little manoeuvring jets that can fly them back to the space station.

ESA astronaut Alexander Gerst tests his spacesuit at NASA's Johnson Space Center in Houston, Texas

Design details

An essential piece of clothing for space travel, each part of a spacesuit has an important job

Helmet with visor
The helmet features a visor coated with a thin layer of gold to filter out harmful solar rays.

Build a spacesuit
Spacesuits do not come in a single piece, but are built from several pieces that are fastened together: the upper torso, the arms and the lower torso assemble.

Toilet break
While in the middle of a spacewalk you can't just pop to the loo, so a spacesuit contains a 'maximum absorption garment' – a fancy name for a nappy!

Gloves
Space is so cold that the fingertips in an astronaut's gloves contain miniature heaters. The gloves are made to be dexterous while providing a strong grip.

Dexterity
Spacesuits have to provide astronauts with a range of motion for when they are working outside of the space station.

Footwear
The boots on current spacesuits are soft and not really made for walking, just floating. New boots will have to be designed for going back to the Moon or Mars.

Life support system
The life support system contains oxygen tanks as well as a battery for power, water-cooling equipment and a fan for essential air circulation.

Ventilation garment
The Liquid Cooling and Ventilation Garment is made from skin-tight Spandex and worn beneath the space suit. It contains over 90 metres' worth of tubing to remove and recycle body heat, carbon dioxide and perspiration.

SPACESUIT NUMBERS...

-160 to +120 degrees Celsius
Spacesuits protect astronauts from the extreme temperatures outside the ISS.

1961
The very first spacesuit – the SK-1 – was worn by cosmonaut and first man in space, Yuri Gagarin.

$12 million
The most recent spacesuits each cost in the region of $12 million to manufacture.

145kg
With the life support system attached, a spacesuit weighs in at around 145 kilograms. The suit alone weighs about 55 kilograms.

19,000m
Spacesuits are required beyond an altitude of around 19,000 metres to supply the oxygen needed to breathe and maintain a pressure around the body.

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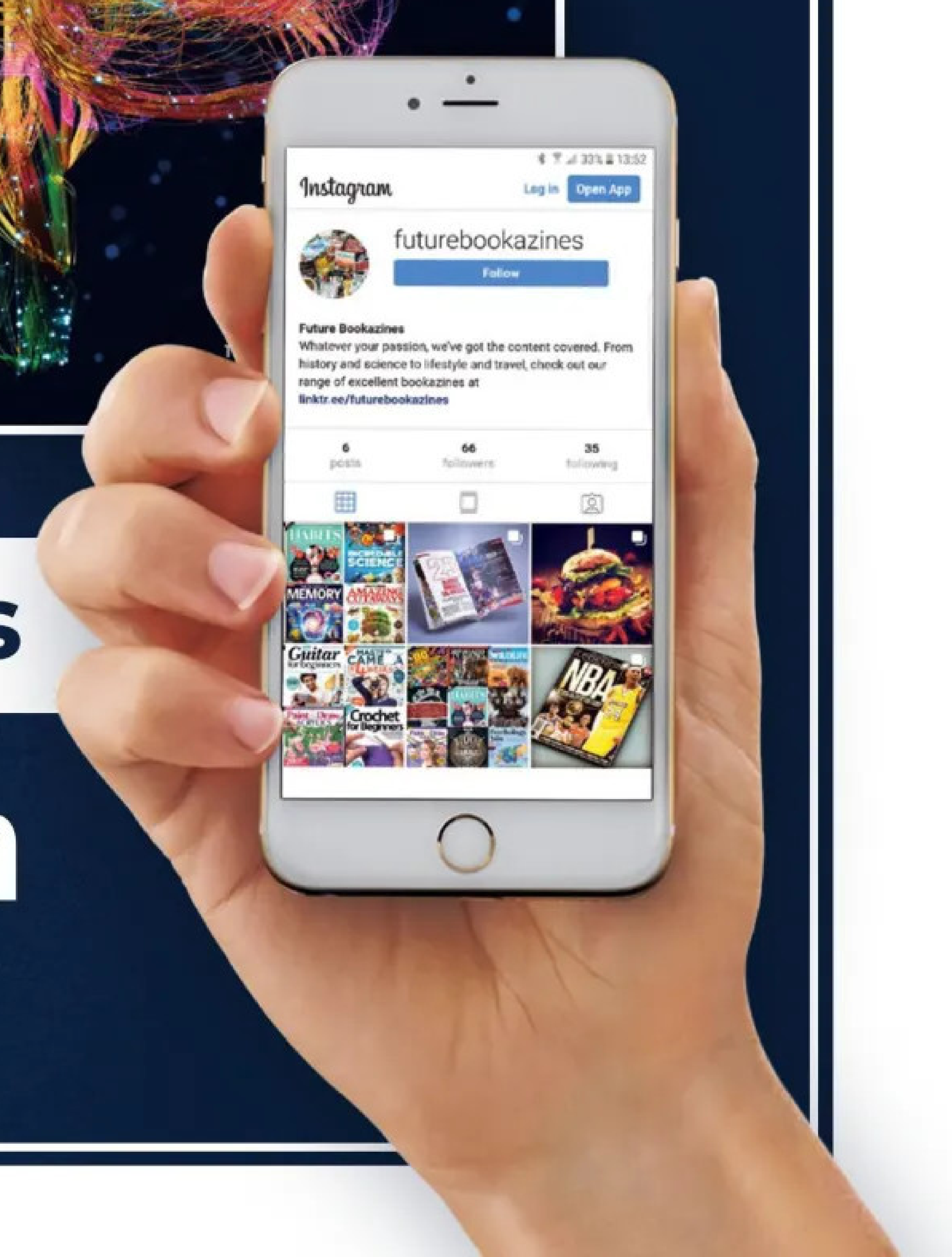

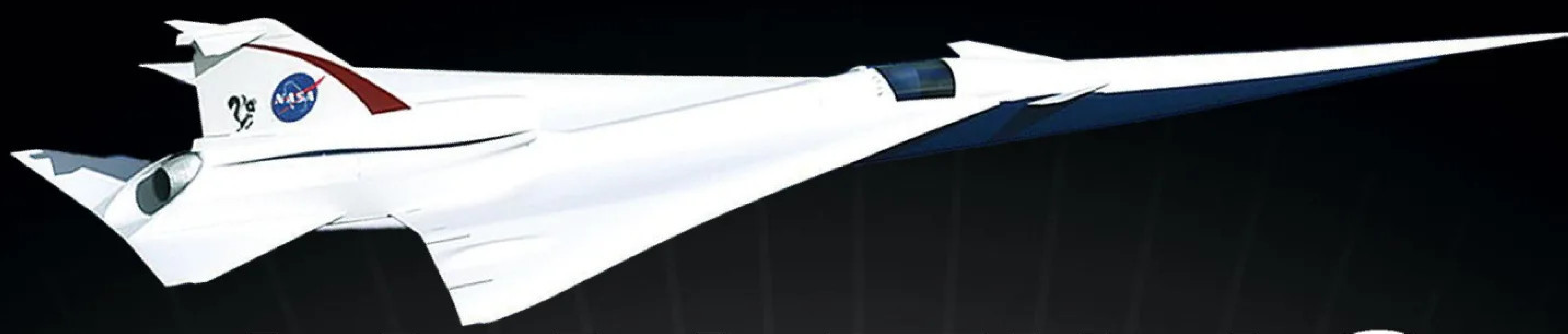

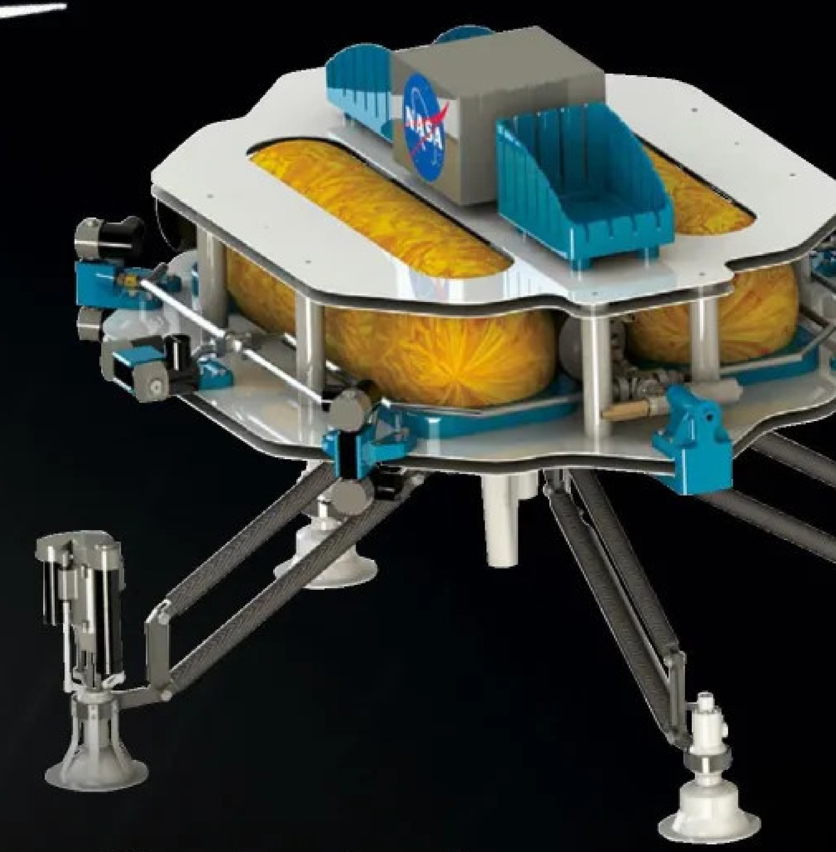

AMAZING TECHNOLOGY

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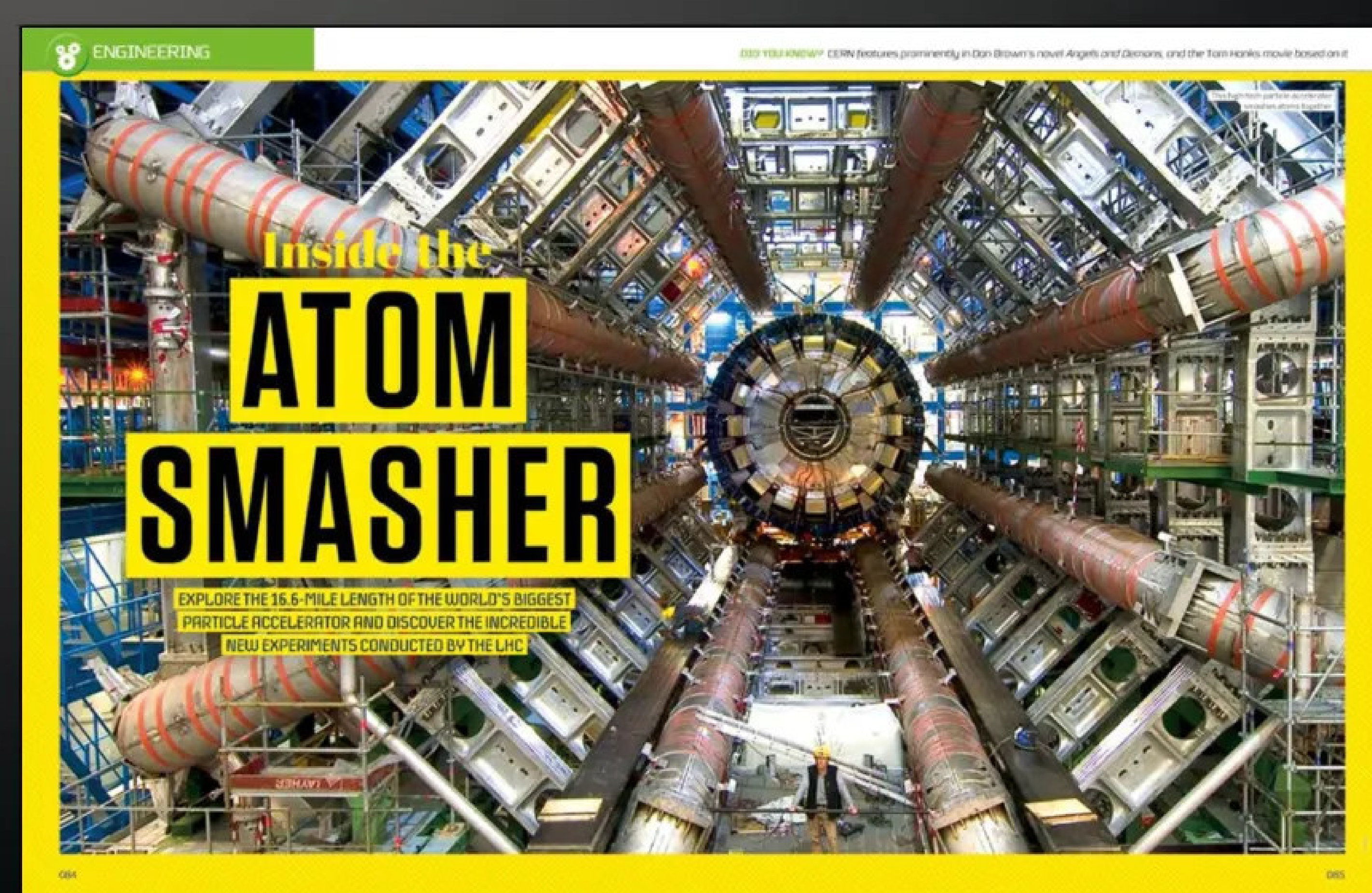
GADGETS THAT ARE SHAPING THE FUTURE

DOMESTIC TECHNOLOGY ENHANCING OUR LIVES



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