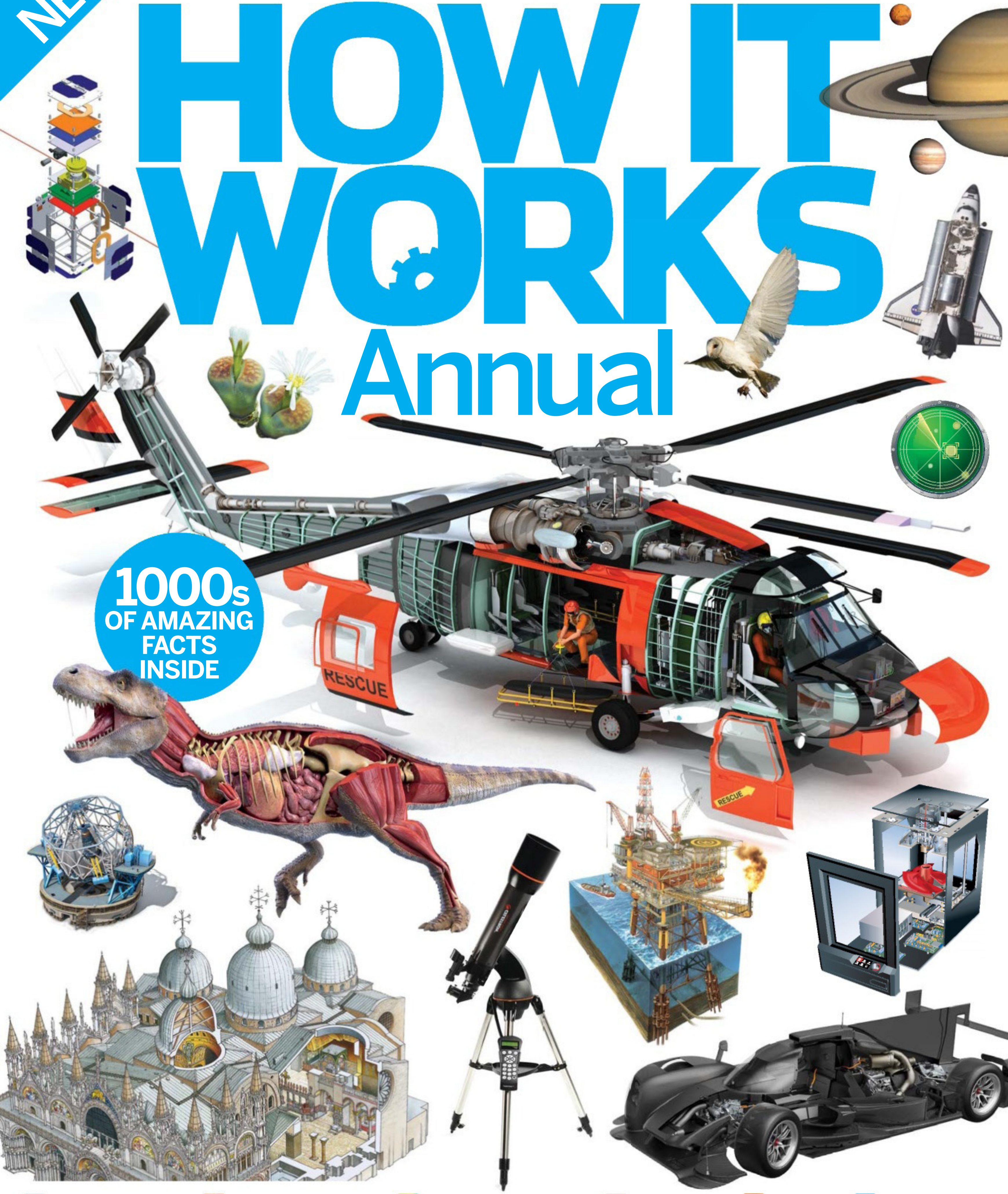
NEW

Everything you want to know about the world we live in

HOW IT WORKS Annual



1000s OF AMAZING FACTS INSIDE

TRANSPORT | TECHNOLOGY | ENVIRONMENT | SCIENCE | SPACE | HISTORY

Welcome to

HOW IT WORKS Annual

Welcome to the fifth volume of the How It Works Annual. Get ready to feed your mind with fascinating facts about the world around you. Indulge your curiosity and discover answers to questions you never even knew you had! Exciting and easy-to-understand explanations are accompanied by cutaways, illustrations and incredible images to show you exactly how things work – from the everyday to the extraordinary. The How It Works Annual explores the universe through six interesting and inspiring subjects: technology, transport, the environment, history, science and space. The articles cover a wide range of different topics, from the physics behind scoring the perfect goal to how bees can help clear old minefields. Ever wondered what causes the distinctive smell of rain? Or how fjords form? We've got the answers. Each section also contains several longer features that delve deep into interesting topics such as insects, bionics, drone aircraft and what life was like in the trenches. Get ready to fill your brain to the brim with facts, stats and wonder. Read on to uncover the world around you and find out exactly how it works!

HOW IT WORKS Annual

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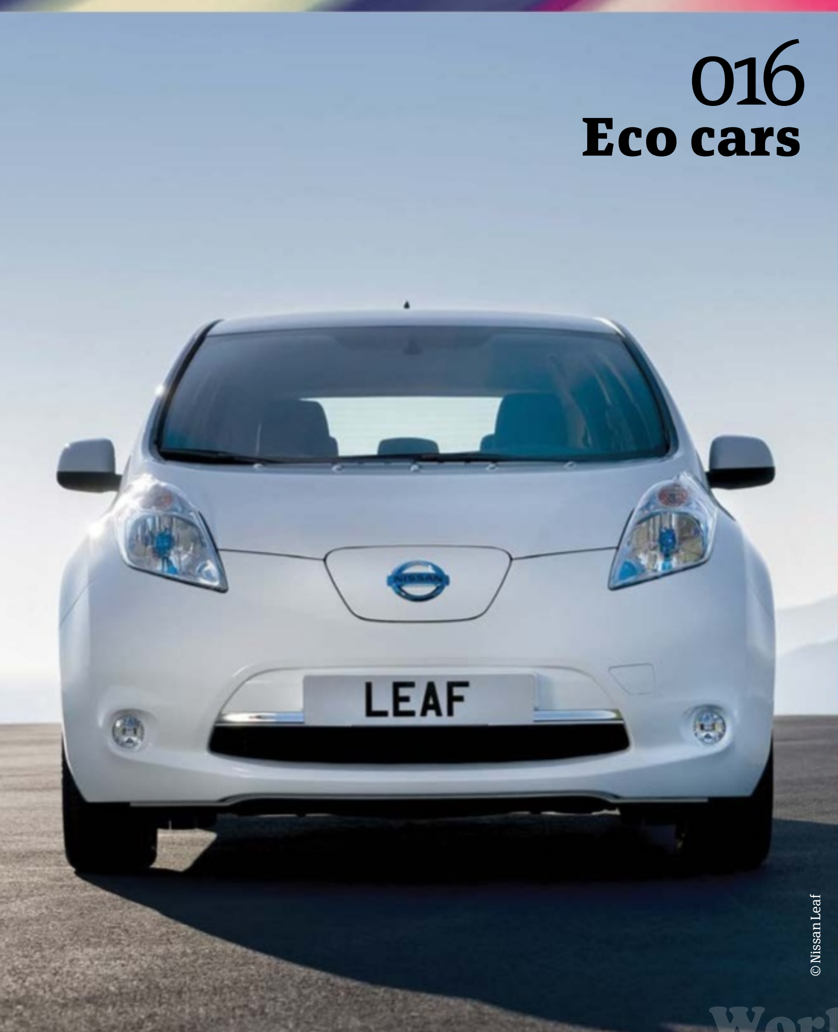

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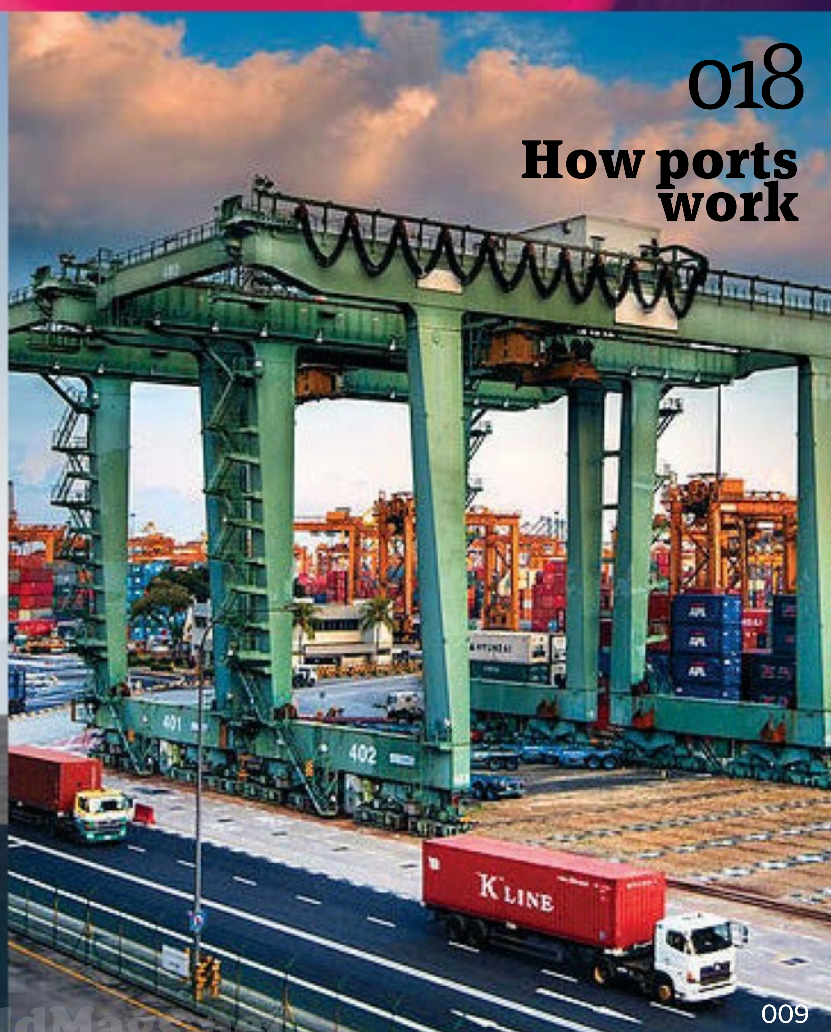


BAE's Taranis is an advanced technology demonstrator seeking to push the boundaries of unmanned military aircraft. It made its maiden flight in October 2013

High-velocity, super-efficient and – if necessary – armed to the teeth, the unmanned aerial vehicle could be the future of both military and civilian aviation

KEY DATES
UAVS IN PROGRESS

1916 English engineer Archibald Low fails to fly a powered unmanned aerial vehicle.

1951 The Ryan Firebee series becomes one of the first jet-propelled drones to be mass-produced.

1973 The Tadiran Mastiff is considered the first modern combat UAV as it features a data link.

1994 General Atomics introduces the next generation of drones with the MQ-1 Predator.

2002 UAVs go small-scale with the AeroVironment RQ-11 Raven, which is launched by hand.

DID YOU KNOW? A single MQ-9 Reaper costs £10.5mn ($16.9mn) to buy

Today one aerial vehicle reigns above all others in grabbing the news headlines on almost a weekly basis: the unmanned aerial vehicle (UAV). These pilotless planes, or drones, are being used in an ever-growing range of roles, with national militaries now fielding vast remote-controlled squadrons across all theatres of war.

You only have to look at images of the General Atomics MQ-9 Reaper, a combat-centred UAV considered one of the most advanced hunter-killer aircraft ever built, and it's not hard to see why some have claimed that drone technology is something to be feared. Indeed, as its name would suggest, the Reaper specialises in long-endurance, high-altitude strikes at enemy targets with a variety of armaments, including a combination of highly accurate AGM-114 Hellfire missiles and GBU-12 Paveway II laser-guided bombs.

However this militarisation of UAV tech and the frequent bad press it gets fails to give credit to its many other applications, and arguably shrouds its true importance in the future of aviation, which is seeing incredibly successful results across all current fields.

Just to take one example out of many, the US National Oceanic and Atmospheric Administration (NOAA) currently uses the Aerosonde UAV as a hurricane hunter and weather monitor. The reason? Because this drone is an incredibly advanced piece of kit more than capable of out-sensing and outperforming any manned aircraft in the role of collecting atmospheric data. Indeed, the Aerosonde is able to record temperature, atmospheric pressure, humidity and wind measurements over oceans and remote areas with ease, remaining airborne up to a range of 3,000 kilometres (1,864 miles), at an altitude of 4,500 metres (15,000 feet) and a speed of 148 kilometres (92 miles) per hour. This performance is delivered through the partnership of the Aerosonde's modified Enya R120 engine and sleek, aerodynamic chassis – while its endurance is guaranteed by the lack of ▶

Drone conversion

F-16 fighter jets are being retrofitted to be used as training UAVs

Currently, military contractor Boeing is retrofitting retired F-16 fighter jets with equipment that allows them to be flown remotely as a UAV. The jets, which have been obsolete for 15 years, were chosen due to their excellent handling characteristics and small radar profile. Early tests saw the first of these drone F-16s attaining speeds north of Mach 1.47 and successfully completing a series of complex manoeuvres.

The reason for the conversion of the F-16s, which from now on will be designated QF-16s, is to create a fleet of mission-capable unmanned vehicles that can be used to help train pilots and act as dummy targets for live fire tests. Currently, only six of these drone QF-16s are operational, but due to the programme's success, a production schedule is pencilled in to begin in late 2013, with the aircraft ready for deployment by 2015.

Main drone uses

COMBAT

MQ-9 Reaper; Guizhou WZ-2000

A rapidly expanding sub-section of the UAV field, combat drones specialise in delivering guided missiles and bombs to enemy targets without risking a pilot's life. Combat drones have recently seen much use in the Afghanistan and Iraq wars, patrolling battlefields for hostile infantry, vehicles and strongholds. Their high speed and small size make them excellent stealth vehicles too, capable of performing covert strikes behind enemy lines.

EMERGENCY

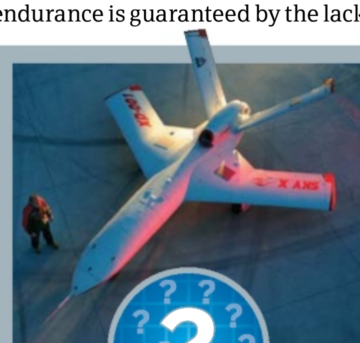
Draganflyer X6; Casper 250

From combating forest fires to exploring natural disaster zones, UAVs are increasingly seeing a large uptake across emergency services across the globe. Microdrones are often used to explore earthquake-struck buildings, thereby not risking a human life to a potential collapse. Radiation spills are also often initially explored by remote-controlled drones, with the unmanned vehicle impervious to any harmful side effects.

RECON

Elbit Hermes 450; RQ-4 Global Hawk

The bread-and-butter routine of the UAV sector, reconnaissance is being taken to new levels of omniscience with drone deployment across the world. With UAVs capable of remaining in the air for well over 24 hours without landing, thanks to the absence of pilots on board, and being fitted with next-generation sensing and recording equipment, they can deliver constant high-fidelity data streaming for far longer than any human could.



SCIENCE/RESEARCH

Sky-X; SIERRA; RQ-4 Global Hawk

Many UAV aircraft built today are done so purely for research and development, with their small size and unmanned nature making them ideal test vehicles for new aviation technologies or aircraft designs. Historically, experimental aircraft were piloted by expert pilots, with many lives lost when things went wrong. They are also perfect for conducting scientific research around the world, analysing weather and geological features – NASA uses several.

human pilot. In fact, prior to the use of drones as weather monitors and early warning systems, many lives were lost or endangered when piloted aircraft were brought down by bad weather. The arrival of drones such as the Aerosonde has removed that risk.

Indeed, what is not reported is that today, UAVs are used in many useful, non-military applications (see 'Main drone uses' on page 13), ranging from fighting forest fires to saving trapped civilians from disaster zones, and all without further endangering human life. The speed, agility and reconnaissance capabilities far outstrip those of any single human, and their deployment is seeing ever greater success across all fields.

So, why the hostility? Admittedly, the notion of a computer-controlled aircraft, which if militarised could carry high-explosive weapons, is a daunting one, but when you start to consider that these aircraft are the product of the most advanced aviation companies, with each dedicating many of their best teams to their creation – you have to question whether those concerns are justified.

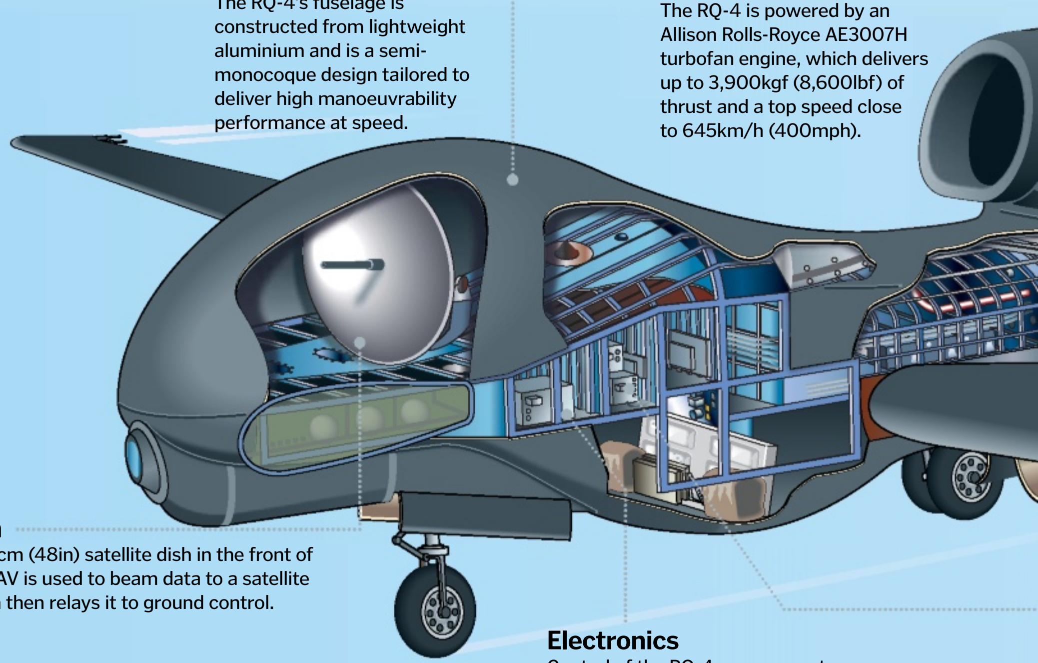
In fact, a quick browse of the world's top plane manufacturers, be it the British BAE Systems, the American General Atomics, Lockheed Martin and Northrop Grumman, or the French Dassault Aviation, shows each is pouring its most bleeding-edge technology into researching and developing UAVs.

Dassault Aviation, for example, is currently building a drone aircraft, nicknamed the 'nEUROn'. It's cloaked, has a delta wing design and is capable of hitting a top speed of 980 kilometres (608 miles) per hour. It is, in many respects, as advanced as today's most competent manned aircraft. However, the nEUROn's main purpose is not to enter production, but to trial out technology and – critically – safety features which can then be adopted into future production aircraft. This trend of stringent testing of UAVs and potential technology is at the forefront of the industry; the nEUROn did not fly when displayed at the 2013 Paris Air Show as it's not yet cleared to fly in civilian airspace – something that will likely only happen after all its flight trials in late-2015.

In fact, UAV aircraft are among the safest and most advanced on the planet, with many of their technologies pioneering and, importantly, readily transferable to other vehicles. Today, UAVs are fairly small

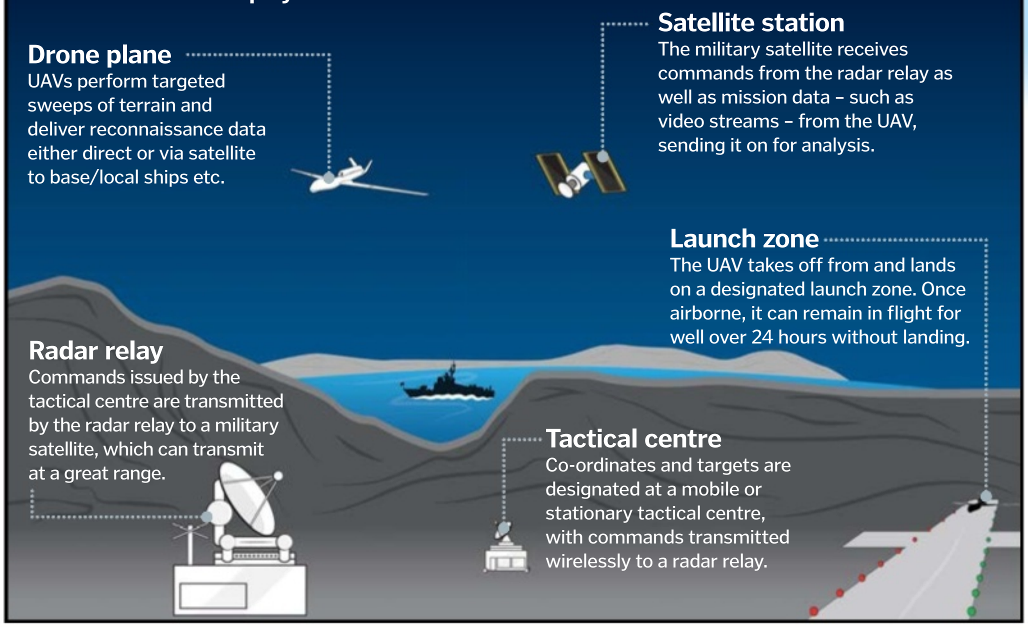
Inside the RQ-4 Global Hawk

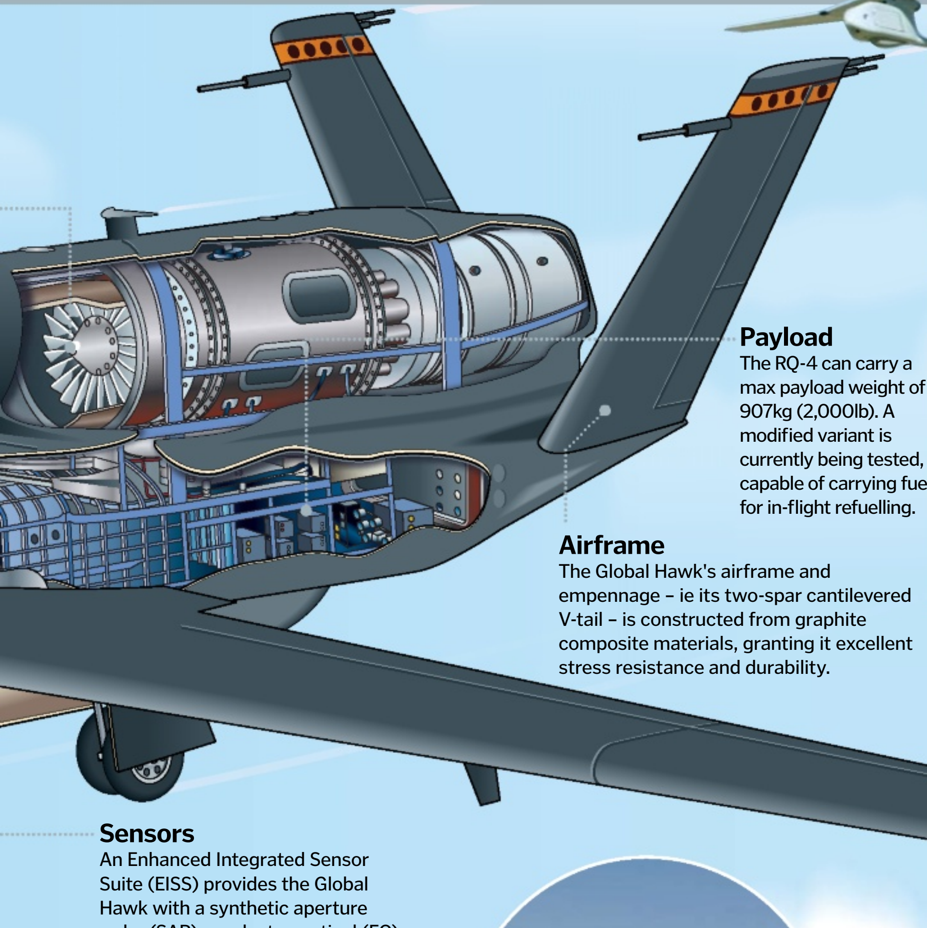
Check out the key components of this state-of-the-art surveillance UAV



Part of a network

See what role a UAV plays in a warzone





Payload
The RQ-4 can carry a max payload weight of 907kg (2,000lb). A modified variant is currently being tested, capable of carrying fuel for in-flight refuelling.

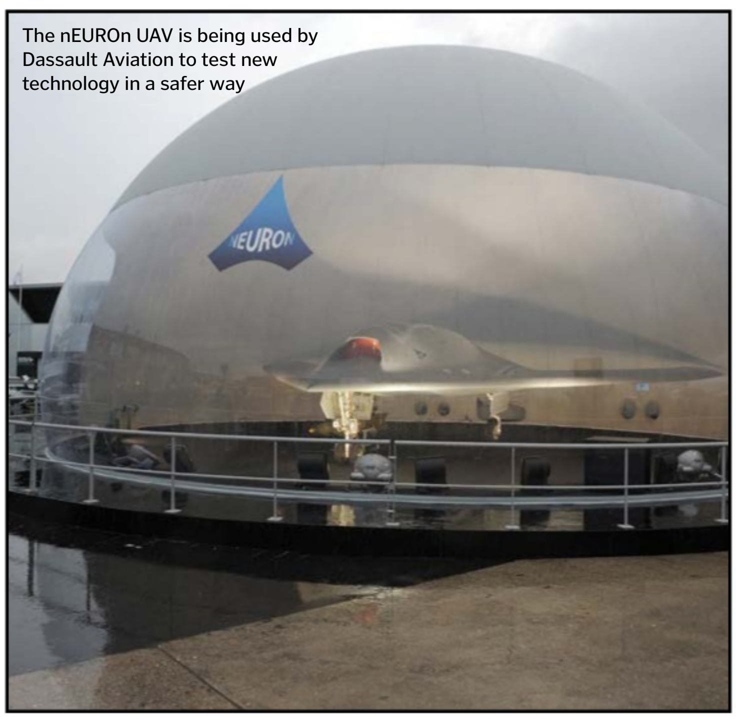
Airframe
The Global Hawk's airframe and empennage – ie its two-spar cantilevered V-tail – is constructed from graphite composite materials, granting it excellent stress resistance and durability.

Wings
The thin tapered wings of the RQ-4 are constructed from lightweight carbon fibre and help grant the drone a service ceiling of 19,812m (65,000ft).

Sensors
An Enhanced Integrated Sensor Suite (EISS) provides the Global Hawk with a synthetic aperture radar (SAR), an electro-optical (EO) sensor and infrared (IR) sensor. The EO and IR sensors can operate simultaneously with the SAR.

Depending on their size, UAVs can be launched by hand, catapult or off a runway

Ground control at NASA's Dryden Flight Research Center; inset, NASA's Global Hawk is used to perform scientific research and Earth observation



The nEUROn UAV is being used by Dassault Aviation to test new technology in a safer way

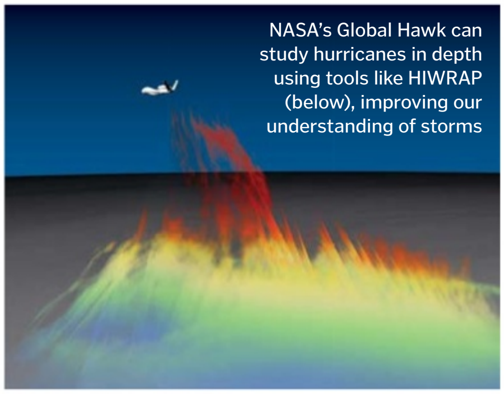
The eco-warrior drones

One of the biggest challenges environmental conservation organisations face today is monitoring large swathes of land where endangered species are at risk from a lethal combination of deforestation, poaching and illegal development. This problem is particularly acute when the protected landscape itself is largely inaccessible, with it often taking conservationists days to trek through areas to monitor a particular area or species. The rise of UAVs, however, is radically transforming the process of environmental monitoring, with small-scale, low-cost drones capable of being deployed over vast areas of rainforests and savannas and reporting back in a fraction of the time it would take a ground team to do so.

From skimming over Indonesia's jungle canopy photographing orangutans, through to deterring rhino poachers in Nepal and on to studying elephants in Malaysia, UAVs are ushering in a new era of drone ecology, where even cash-strapped charities and environmental organisations can benefit. Indeed, the current rise of UAV technology means that small operational drones can be bought and assembled for a couple of thousand of dollars, rather than the hundreds of thousands it would take to pilot, fuel and operate a manned aircraft. As a quick case study, the use of drones in South Africa, where rhino poaching has been a serious issue for decades, has seen a marked decline in the illegal activity since they were deployed.



The future for the endangered black rhino is looking brighter, thanks to economically viable drones (inset) to deter poachers


NASA's Global Hawk can study hurricanes in depth using tools like HIWRAP (below), improving our understanding of storms


It's not all about planes – the K-MAX unmanned helicopter is designed to deliver cargo behind enemy lines and can carry up to 2,720kg (6,000lb)

machines, but in the future, thanks to their autopilot systems now being more advanced than any other aircraft due to state-of-the-art R&D efforts, larger pilotless cargo or even passenger aircraft could be built, with faster, more frequent flights possible, and with far less chance of human error. What's more, it's not just future drone aircraft that will benefit from UAV development, but traditional piloted aircraft bound to see many upgrades too.

Despite increasing numbers of drones set to be used over the next 50 years, there will naturally still remain a huge demand for piloted aircraft. With the help of sensory, communication and autopilot systems delivered by drone technology, these flights will be achieved more efficiently and with greater safety than ever before.

Just because the history of unmanned aerial vehicles is largely militarised, with efforts to create a drone aircraft beginning as far back as World War I, that does not mean its future has to be. The wider air industry needs to evolve rapidly if it is to keep pace with the ever-increasing population's travel needs, and for that, drones are a key component.

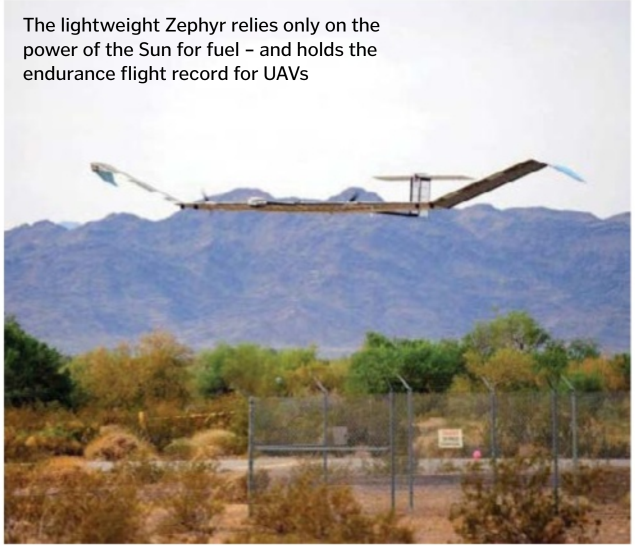
If UAVs are the future of flight, then a clear roadmap needs to be laid down for their development. Currently, UAVs are split into six functional categories including target and decoy, reconnaissance, combat, logistics, research and development, and commercial, with the latter only being granted a licence to operate in most nations' airspace on a case-by-case basis. This limited form of categorisation is fine to a point, but as the number of drone

HEIGHT 4m | WINGSPAN 9.1m | THRUST 2,939kgf
LENGTH 11.4m | WEIGHT 8,164kg | WEAPON BAYS 2


The liquid hydrogen-powered Boeing Phantom Eye taking off for a test flight

The Airspace Operations Challenge

The Airspace Operations Challenge (AOC) is a competition currently being run by NASA to help foster and develop technologies that will help advance UAV use in US airspace. The AOC's focus is very much on safety, with competitors asked to create aircraft that can demonstrate a series of controlled operations in complex air traffic environments. The AOC is currently in the registration phase for competitors, with phase 1 scheduled for April 2014. Anyone who meets the AOC's criteria can enter and there's a $500,000 prize pool for the winners!


The lightweight Zephyr relies only on the power of the Sun for fuel – and holds the endurance flight record for UAVs

aircraft and their applications increase, more refined and flexible criteria will have to be set.

For example, government use today largely revolves around emergency services, such as fire brigades using drones to detect forest fires – but as more and more services enter the private sector, then laws – like the ones slowly emerging for driverless cars – will need to be amended to account for the fact that many future vehicles will not have a pilot on board. This sort of change needs to be partnered with greater monitoring over private UAV manufacturers, as with great technology comes greater responsibility and accountability.

While certain UAVs are being scaled up, others are going the other way, with some experimental models even launchable by hand like a paper plane (like the RQ-11 Raven). If this sort of cutting-edge development continues, then soon UAVs might not just be carrying weapons, cameras and disaster relief, but performing more everyday tasks. That said, it will probably be some time yet before drones are delivering your weekly food shop!

Ones to watch...

1 Taranis
Technically referred to as a UCAV, an Unmanned Combat Air Vehicle, BAE Systems' Taranis is an experimental drone currently undergoing trials in the UK. The project is led by BAE, but also involves Rolls-Royce, GE Aviation Systems, QinetiQ and the British Ministry of Defence (MoD). The prototype cost £143 million ($230 million) to develop and is designed with fully autonomous elements in mind, though a trained operator will always be in control on the ground.

2 Phantom Eye
The Boeing-made Phantom Eye is a high-altitude, long-endurance UAV designed by the defence contractor's secretive Phantom Works. It's powered by liquid hydrogen and has been designed as a spy plane, remaining in flight at high altitude for several days without having to return to a base station. The Phantom Eye recently reached an altitude of 8,530 metres (28,000 feet) and remained there for four and a half hours while carrying a payload from the Missile Defense Agency.

3 Tempest
The Tempest is an unmanned aircraft system (UAS) designed for in-situ sensing and observation of severe storms and supercell thunderstorms. The aircraft is launched manually via radio control and is switched to autonomous mode once airborne, where it then operates via autopilot within a designated airspace region. Atmospheric data gathered by Tempest is then streamed back to a mobile base station for processing, with any early warnings instantly shared.

4 Zephyr
A lightweight solar-powered UAV that currently holds the official record for an unmanned aerial vehicle – spending 336 hours and 22 minutes airborne without landing – the QinetiQ Zephyr is an experimental drone designed to explore the possibilities of solar-powered UAVs. Made from carbon fibre, the Zephyr uses harvested sunlight to charge a lithium-sulphur battery, which in turn powers a permanent-magnet synchronous motor.

Eco cars evolved

See how modern electric cars are stepping up a gear…

Battery electric vehicles (BEVs) have been around for longer than you would expect. The first examples of cars powered by electricity were in the early-19th century, and were commonplace until the internal combustion engine took over. The first examples were very basic and couldn't be recharged. However, the modern-day BEV has evolved a lot since then and has overcome technical difficulties that made them previously unsuitable for our roads.

Charging time has always been a big issue among the motoring community where BEVs are concerned. Previous examples of BEVs have usually had charging times of around 8-12 hours from UK sockets. This time has been dramatically reduced by new technologies explored by manufacturers like Nissan with the Leaf. Indeed, the Leaf can be charged from flat to 80 per cent capacity in around 30 minutes from a special charging port.

Nissan has also applied some very creative theories to improve the overall efficiency of the Leaf. For example, the front LED lights are designed to deflect airflow away from the wing mirrors. This reduces aerodynamic drag acting on the car, so that less power is needed to propel the vehicle forwards.

Whereas existing BEVs have had issues with large battery packs taking up cabin space, the Nissan engineers have developed theirs to free up space. This is achieved by having the thin 24-kilowatt-hour battery pack underneath the floor. This also has the added benefits of improving handling and structural rigidity.

Modern BEVs are becoming increasingly technologically advanced, with the Leaf having a dedicated app for smartphones. This can be used to start a charging session, activate climate control and to check estimated driving range information without leaving your sofa.

Eco car timeline

We track the rise of electric-powered vehicles from their conception to today

1830s
First electric carriage
Scotsman Robert Anderson builds and drives a basic (non-rechargeable) electric carriage.

1897
Electric cabs
The Pope Manufacturing Company becomes the first large-scale electric car maker, filling the NYC streets with electric taxis.

1899
Speed record
The French-built 'La Jamais Contente' becomes the first electric car to reach 100km/h (62mph).

1920s
Internal combustion engine
By the end of the Twenties, the electric car is surpassed by combustion engines.

328.6

ELECTRIC CAR LAND SPEED RECORD

In June 2013, former science minister Lord Drayson set the electric land speed record for an electric car at 328.604 kilometres (204.185 miles) per hour at Elvington Airfield in Yorkshire, UK.

DID YOU KNOW? *The first US speeding ticket was given to an electric car 'hurtling' at 19km/h (12mph) in a 13km/h (8mph) zone*

Power plant
The 'engine' is a 80kW (110hp), 280Nm (210ft lb) electric motor with a top speed of 150km/h (93mph).

Charging up with Quimera RR

Quimera Responsible Racing is a company that produces spectacular all-electric race cars. Its AEGT, which stands for All Electric Gran Turismo, is considered a masterpiece of space-age technology.

It has not one but three electric motors, which propel the AEGT from 0-60mph in three seconds. The battery pack and motors produce 522 kilowatts (700 horsepower) of power, and 1,000 Newton-metres (738 foot pounds) of torque, which can be applied instantly. These battery packs are positioned as low as possible to ensure that the handling of the car is kept sharp and manoeuvring is nippy.

In many ways the AEGT is a rolling laboratory, where the innovations and developments can be tested for implementing into road-going electric cars for the future.

Advanced aerodynamics
The front LED lights are designed to deflect air away from the wing mirrors. This reduces aerodynamic drag, increasing efficiency.

Charging port
The car can be charged from 0-80 per cent capacity from the front of the vehicle in 30 minutes.

Drivetrain
Due to instant torque from the motor, there is no need for gears and clutches.

1966
GM Electrovan
This has been credited as being the first-ever hydrogen fuel cell car produced.

2004
Electric sports car
Tesla Motors begins development of the Roadster, which has been sold in over 31 countries to date.

2010
Mass production
The Mitsubishi i-MiEV becomes the first EV to sell more than 10,000 units.

2015+
The future
Eco cars are primed to compete with combustion engine cars, with extended ranges and faster charging times.

How ports work

Discover how these gateways between land and sea bring vehicles together to transport cargo around the globe

As the seas continue to play a fundamental role in globalisation, ports become an ever-more important feature in modern transport. From these trade hubs, huge cargo ships come and go bearing all manner of goods, from essentials such as food and fuel to more exclusive products like cars.

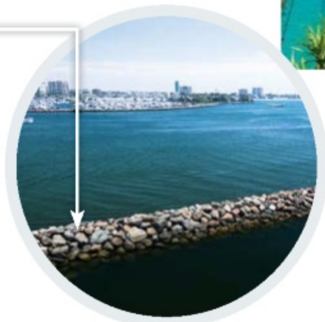
A port comprises two main sections in order to run effectively: sea-based and land-based infrastructure. The former starts with buoys positioned at sea to help direct boats via the safest route, away from shallow waters or hazardous rocks – much like the lights on a runway or cat's eyes on a road. These are followed by breakwaters at the harbour entrance. These man-made walls of concrete or natural rock help to absorb the power from the most ferocious waves, ensuring the water within is calm so vessels don't get damaged.

Further into the ports are a series of docks that allow a ship into an enclosed area where it can be moored for loading or unloading cargo or passengers. These can include dry docks, which shut gates off to drain the seawater from the enclosure, leaving the lower hull and keel accessible for restoration. The land-based infrastructure is immediately more visible when visiting a port, with huge cranes permanently fixed onto the docks to pick up heavy containers from a ship.

Ships with a drive-on capacity will be connected to a ramp mounted on the quay to enable road-going vehicles to board. Set back from the water, there will usually be easy access to railway lines and major roads so cargo can seamlessly carry on its journey inland.

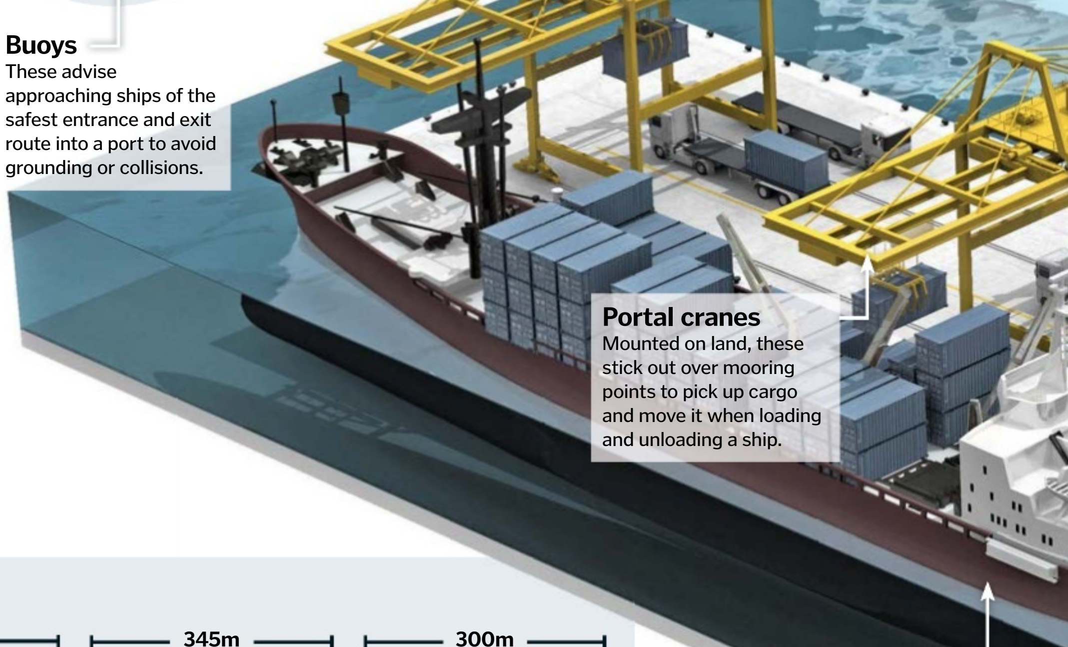
A tour of the port

From out at sea to land-based transit links, find out some of the key infrastructure every good port needs



Breakwater
These take the power out of large waves to ensure water entering the docks is calm and moored ships are safe.

Buoys
These advise approaching ships of the safest entrance and exit route into a port to avoid grounding or collisions.



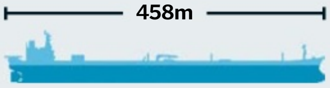
Radio tower
A harbour master communicates with captains on where to dock on arrival, or when the coast is clear to leave.

Portal cranes
Mounted on land, these stick out over mooring points to pick up cargo and move it when loading and unloading a ship.

Mooring
A dock provides an enclosed space of calm water for a ship to pull into and moor, a bit like a watery car park.

Mega vessel lineup

458m



Oil tanker
Oil tankers carry their liquid cargo in huge baffle tanks built into the ship between the hull and the deck. The baffle tanks are designed to stop the liquid from moving too much, or sloshing, which could upset the balance of the ship and capsize it.

397m

Container vessel
These are long, wide ships with a large flat deck on which to stack thousands of steel containers packed with cargo. They are stacked using heavy-duty cranes permanently mounted on the port.

345m

Cruise liner
Sometimes referred to as floating cities, these house and entertain thousands of travellers and come decked out with sleeping quarters, restaurants, casinos and even swimming pools.

300m

Bulk carrier
Transporting large quantities of loose goods such as food grains and ores, they can also be designed to hold liquids. These freighters typically use cargo holds built into the deck to carry their goods.

1. BIG

Hong Kong, China
The port of Hong Kong is responsible for shipping 23.1 million TEU (20ft equivalent units) containers every year.

2. BIGGER

Port of Singapore
Singapore oversees 31.6 million TEU per year, sending cargo on to more than 600 other ports in some 120 countries.

3. BIGGEST

Shanghai, China
Both a river and ocean port, the world's busiest container port in China ships over 32.5 million TEU every year.

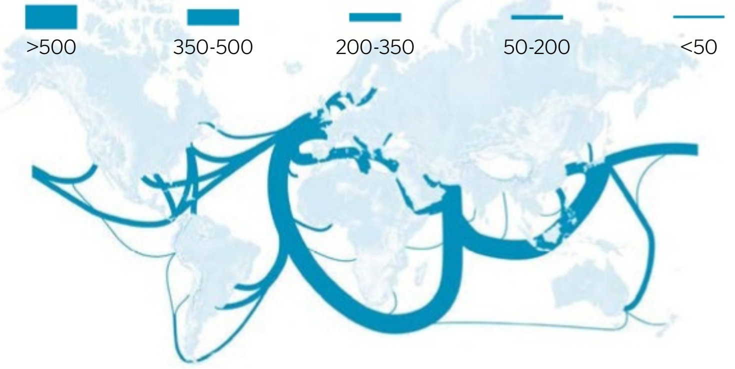
DID YOU KNOW? *In 2013, 4,500-year-old boat and rope remains were found at Wadi el Jarf, Egypt, the oldest known port to date*

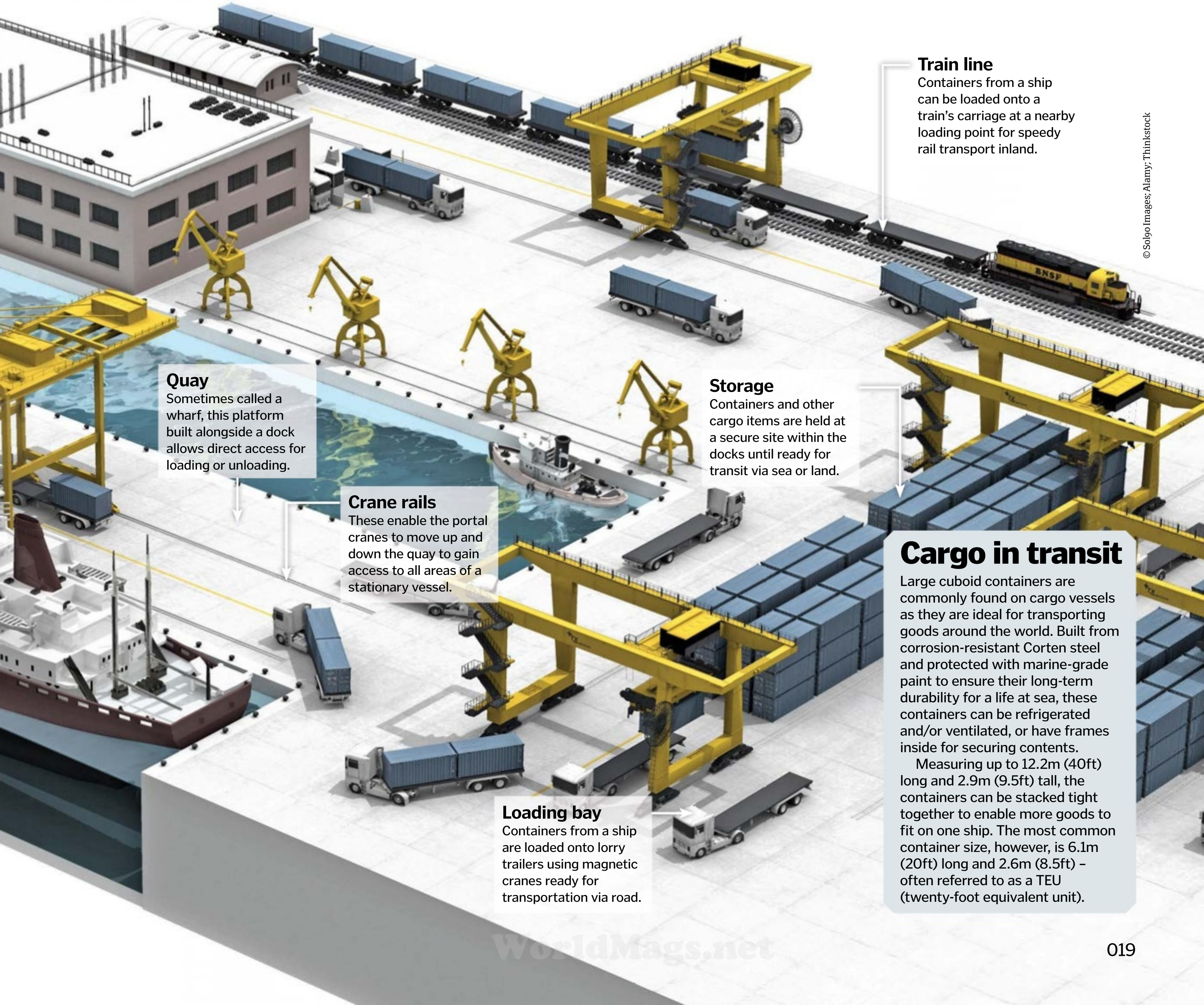
Roads of the sea

Shipping lanes refer to routes commonly used by merchant vessels, otherwise known as trade routes, in Earth's seas. These were initially selected for their favourable wind and current conditions for boats with sails, but are still used in modern times despite the rise of engine power. Boats not transporting cargo are advised to stay clear of the trade routes, as a collision with a huge cargo ship (which are incredibly difficult to turn at short notice) could prove disastrous for a smaller vessel.

The major routes are between Europe, Asia and North America, with one of the busiest routes eastbound from Asia to North America – a result of the Far East's huge export industry and its close connections with the United States.

Millions of tons transported each year





Train line
Containers from a ship can be loaded onto a train's carriage at a nearby loading point for speedy rail transport inland.

Quay
Sometimes called a wharf, this platform built alongside a dock allows direct access for loading or unloading.

Storage
Containers and other cargo items are held at a secure site within the docks until ready for transit via sea or land.

Crane rails
These enable the portal cranes to move up and down the quay to gain access to all areas of a stationary vessel.

Loading bay
Containers from a ship are loaded onto lorry trailers using magnetic cranes ready for transportation via road.

Cargo in transit

Large cuboid containers are commonly found on cargo vessels as they are ideal for transporting goods around the world. Built from corrosion-resistant Corten steel and protected with marine-grade paint to ensure their long-term durability for a life at sea, these containers can be refrigerated and/or ventilated, or have frames inside for securing contents.

Measuring up to 12.2m (40ft) long and 2.9m (9.5ft) tall, the containers can be stacked tight together to enable more goods to fit on one ship. The most common container size, however, is 6.1m (20ft) long and 2.6m (8.5ft) – often referred to as a TEU (twenty-foot equivalent unit).

Fire engines uncovered

Learn why putting out massive blazes and saving lives is all part of the day job for these superhero vehicles

Fire engines truly are incredible machines. They have evolved to tame one of nature's elemental forces – the hot, burning one – achieving this by mastering another – the cool, liquid one. Their mastery of water, along with the crew that operate them, has saved countless properties, areas of wilderness and human lives over the centuries.

These vehicles come in all shapes and sizes tailored for different kinds of emergencies, both in urban and rural environments. A typical fire engine needs to perform three primary duties: get officers to the scene as fast as possible, carry all the essential equipment and serve as a portable water pump and sometimes reservoir.

The greatest challenge to response time are its other two main roles; all that water and equipment on board are not conducive to speed. Although fire trucks can weigh 15 tons or more, they have compensated for this by installing turbocharged engines and by keeping a compact form to negotiate traffic and narrow roads.

No space is wasted, with compartments lining the walls packed with all the tools a firefighter might possibly need. One of the most important pieces of equipment, however, is too big to fit in any compartment. Telescopic ladders and hydraulic platforms sit on the roof and are vital for accessing the upper storeys of burning buildings as well as providing an elevated position to survey and extinguish fires.

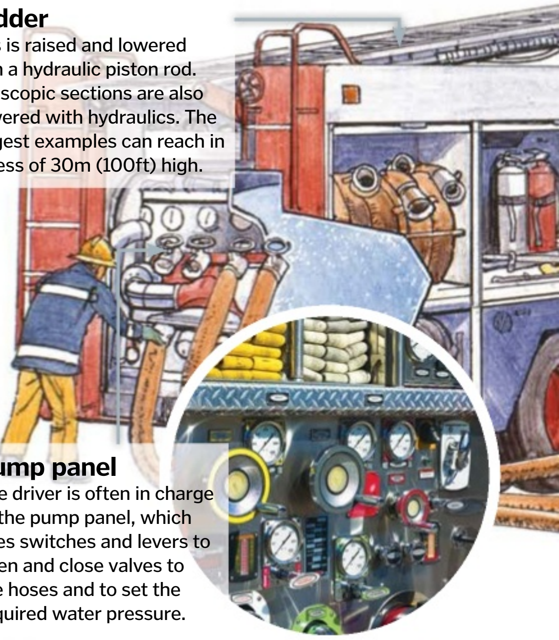
But a fire engine's most fundamental weapon is water. While some fire trucks have the capacity to hold thousands of litres in a central tank, others tap into nearby sources like a hydrant or a lake. The water is fed into a centrifugal pump at the heart of the vehicle, where a fast-spinning impeller forces it back out at great pressure.

Numerous colour-coded hoses draw from this single pump, controlled by a panel of switches and levers. Depending on the pump's size and the number of lines, a fire can be deluged with as much as 10,000 litres (2,640 gallons) per minute, though typically the flow is around half this rate.

These days special foam is often mixed with the water prior to leaving the fire engine because the way it clings to burning surfaces drastically cuts the amount of time it takes to put out a blaze.

Fire trucks on the job

A closer look at how the major technology on board these vehicles is used in an emergency



Ladder

This is raised and lowered with a hydraulic piston rod. Telescopic sections are also powered with hydraulics. The biggest examples can reach in excess of 30m (100ft) high.

Pump panel

The driver is often in charge of the pump panel, which uses switches and levers to open and close valves to the hoses and to set the required water pressure.

Fighting fire over time

Firefighting has a longer history than you might think – here are some of the biggest milestones in the war against conflagrations

100 BCE
Marcus Crassus forms the first fire brigade in Rome. Only the wealthy can afford his rates.

27 BCE
Emperor Augustus puts together the Vigiles for fighting crime and fires, but their techniques enjoy only limited success.

1500s CE
Hand pumps are used to put out small fires, but only have a short range so aren't very effective against bigger blazes.

1666
After the Great Fire of London, insurance companies begin offering personal protection schemes.

1672
Jan van der Heyden from the Netherlands invents the first fire hose made out of leather and brass.

HEAD 2 HEAD
FIRE VEHICLES

1. LAND

Airport crash tender
Designed to deal with fires at airports. They include chemicals like Purple-K that can put out jet fuel quicker than water alone.

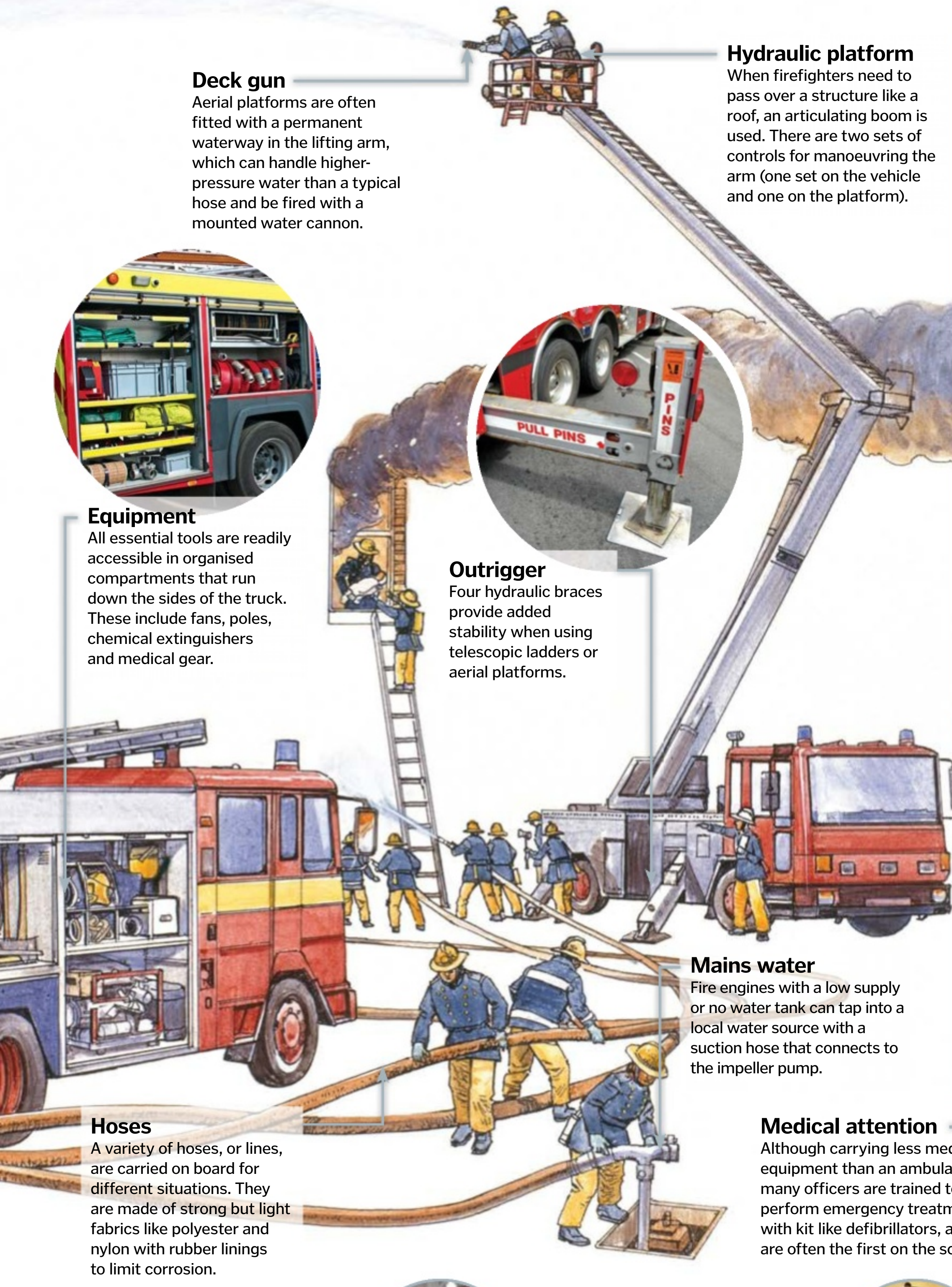
2. SEA

Fireboat
Perfect for putting out fires on vessels at sea, they're fitted with a series of pumps that supply cannons directly from the ocean so they never run out of water.

3. AIR

Helitanker
They may not have the capacity of firefighting planes, but helitankers are quicker and more manoeuvrable, making them well suited to extinguishing wildfires.

DID YOU KNOW? *William I decreed fireplaces and lamps should be put out at night, using a 'couvre feu' fire cover*



Deck gun
Aerial platforms are often fitted with a permanent waterway in the lifting arm, which can handle higher-pressure water than a typical hose and be fired with a mounted water cannon.

Hydraulic platform
When firefighters need to pass over a structure like a roof, an articulating boom is used. There are two sets of controls for manoeuvring the arm (one set on the vehicle and one on the platform).

Equipment
All essential tools are readily accessible in organised compartments that run down the sides of the truck. These include fans, poles, chemical extinguishers and medical gear.

Outrigger
Four hydraulic braces provide added stability when using telescopic ladders or aerial platforms.

Mains water
Fire engines with a low supply or no water tank can tap into a local water source with a suction hose that connects to the impeller pump.

Hoses
A variety of hoses, or lines, are carried on board for different situations. They are made of strong but light fabrics like polyester and nylon with rubber linings to limit corrosion.

Medical attention
Although carrying less medical equipment than an ambulance, many officers are trained to perform emergency treatment with kit like defibrillators, as they are often the first on the scene.

Dennis Sabre fire engine by numbers

5
Number of crew in cab

1,800l
Capacity of water the tank can hold

13 tons
Total weight of vehicle

70mm
Diameter of widest hose

2,500l/min
Flow rate delivered by pump

13.5m
Length of longest ladder

Meet the crew
A fire engine might be an impressive machine, but it would be nothing without its crew. While the number of firefighters varies between vehicles, the minimum tends to be three. Roles include the driver (who often operates the pump too), an officer-in-charge (OIC) to co-ordinate the team, an entry control officer who specialises in gaining access to blazing structures, and one or two officers to operate hoses and don breathing apparatus should there be need to enter the building. As well as learning to 'read a fire' and put out conflagrations as quickly and safely as possible, firefighters are trained in emergency medicine and hazardous materials, which can mean the difference between life and death.

1690
John Lofting patents the 'Sucking Worm Engine' to much acclaim, greatly increasing the range of water from the hose.

1720s
Taking inspiration from Lofting's design, the Little Newsham engine can pump around 605l (160ga) of water per minute up to 50m (165ft).

1733
In a groundbreaking departure from tradition, France decides a fire service should be free to all.

1824
James Braidwood establishes the world's first organised municipal fire brigade in Edinburgh, later becoming the first director of the London Fire Engine Establishment.

1853
Cincinnati in Ohio is the first city in the USA to set up its own professional fire department.

1905
The internal combustion engine is used to move the vehicle and power the water pump more efficiently than before.

A single AH-64D Apache costs over £18mn ($30mn) to build

AMAZING HELICOPTERS

Meet some of the world's most cutting-edge helicopters and find out why they are so well adapted to a range of roles

Since the first modern-era helicopters took flight a little over 100 years ago, this form of aircraft has been overshadowed by the high-speed planes of the jet age. For decades, speed and altitude ruled the roost both in the military – think of the insane Mach 3+ speeds attainable by the SR-71 Blackbird – but also in commerce, with cargo, weaponry and, most importantly, people transported by aeroplanes rather than their slower, more ungainly cousins. However, today, in 2013, things are changing…

Now, more than ever before, in specialist high-level applications, helicopters are being favoured over their faster winged counterparts. A combination of advanced technological upgrades, new base designs and a global landscape that is increasingly in a state of flux means that the versatility offered by the one-time black sheep of the family is now being warmly embraced. Helicopter manufacturers worldwide are doubling down on their existing technology and future research in a hope to win the inevitable next big contract.

Take the mainstay of the US Air Force, the intimidating AH-64 Apache, as an example. This gunship has diced with death for almost 30 years, seeing active combat service in numerous wars. However, as of October 2013, far from the Apache being steered towards retirement, the fifth iteration has just been approved, boasting a series of bleeding-edge technological systems and improvements.

Nicknamed the AH-64E Guardian, this helicopter now features improved digital connectivity, a joint tactical radio system, a

5 TOP FACTS
CHOPPER TRIVIA

Aerial screw
1 Arguably the first helicopter as we understand them today was devised by famous Italian polymath Leonardo da Vinci in the form of his 'aerial screw' sketched back in the 1480s.

Name origins
2 The word 'helicopter' was coined by French inventor Gustave de Ponton d'Amécourt in 1861. In the 20th century, this was built on with the slang 'chopper'.

First flight
3 However, the first manned flight in a helicopter didn't come until two French brothers, Jacques and Louis Breguet, flew in their Gyroplane No 1 in 1907.

Mass production
4 Mass production of helicopters began in 1942 with the introduction of Igor Sikorsky's R-4. The R-4 had a maximum speed of 121 kilometres (75 miles) per hour.

Turbine age
5 The age of the turbine-powered helicopter began in 1951 with the introduction of the Kaman K-225. A twin-turbine model followed three years later.

DID YOU KNOW? *The longest distance travelled without landing in a helicopter is 3,561km (2,213mi)*

The 8,382kW (11,240hp) delivered by the Mil Mi-26's engines makes it the most powerful helicopter ever made

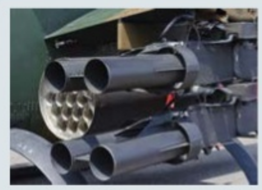
The statistics...

Eurocopter X3

Crew: 2
Length: Classified
Height: Classified
Weight: Classified
Powerplant: 2 x Rolls-Royce Turbomeca RTM 322
Rotors: 1 x 5-blade main rotor / 2 x 5-blade tractor rotors
Max speed: 472km/h (293mph)
Max range: Classified
Max altitude: 3,810m (12,500ft)
Armaments: N/A

"These upgrades vastly improve the lethality and versatility of the Apache"

The statistics...



Boeing AH-64D Apache

Crew: 2
Length: 17.7m (58.2ft)
Height: 4.05m (13.3ft)
Weight: 7,270kg (16,027lb)
Powerplant: GE T700-GE-701
Rotors: 1 x 4-blade main rotor; 1 x 4-blade tail rotor
Max speed: 276km/h (171mph)
Max range: 485km (301mi)
Max altitude: 6,400m (21,000ft)
Armaments: 1 x 30mm (1.2in) M230 Chain Gun; AIM-92 Stinger; AGM-114 Hellfire; Hydra 70mm (2.8in) rockets

brand-new set of T700-GE-701D engines, upgraded transmission system with split-torque face gears to accommodate for even more power, new composite rotor blades, updated radar system and, most impressively of all, unmanned aerial vehicle (UAV) capabilities. It's impressive stuff.

Combined, these upgrades vastly improve the lethality and versatility of the Apache, with the helicopter's cruise speed, rate of climb, payload threshold and target engagement capabilities vastly enhanced. ▶

Fastest-ever chopper

On 7 June 2013, the Eurocopter X3 hybrid set a new world record for high-speed flight in a helicopter, racking up two runs where it exceeded 472 kilometres (293 miles) per hour. By clocking in these two runs, it officially beat the previous record holder, the Sikorsky X2. The X3's record breaking run was achieved at an altitude of 3,050 metres (10,000 feet) during a 40-minute flight over the south of France. The helicopter itself was powered by a pair of RTM 322 turboshaft engines, which generated the necessary energy to rotate the five-blade main rotor and twin propellers. Speaking on the run, pilot Hervé Jammayrac stated that: "It's no exaggeration to say that the X3 is clearly in its element at high speeds."

Where the Apache is pushing the boundaries of combat capabilities in helicopters, the awesome Eurocopter X3 demonstrator is transforming people's perceptions of the speeds they can attain. Flying in June 2013, the X3 racked up 472 kilometres (293 miles) per hour and, in doing so, not only smashed the existing world record for highest speed in a helicopter, but demonstrated how compound helicopters may be the future of the field.

Indeed, the reason why the X3 can post a top speed over 160 kilometres (100 miles) per hour greater than that of the Apache is due to its addition of short-span wings with tractor propellers – two of the key features that make it what is known as a compound helicopter.

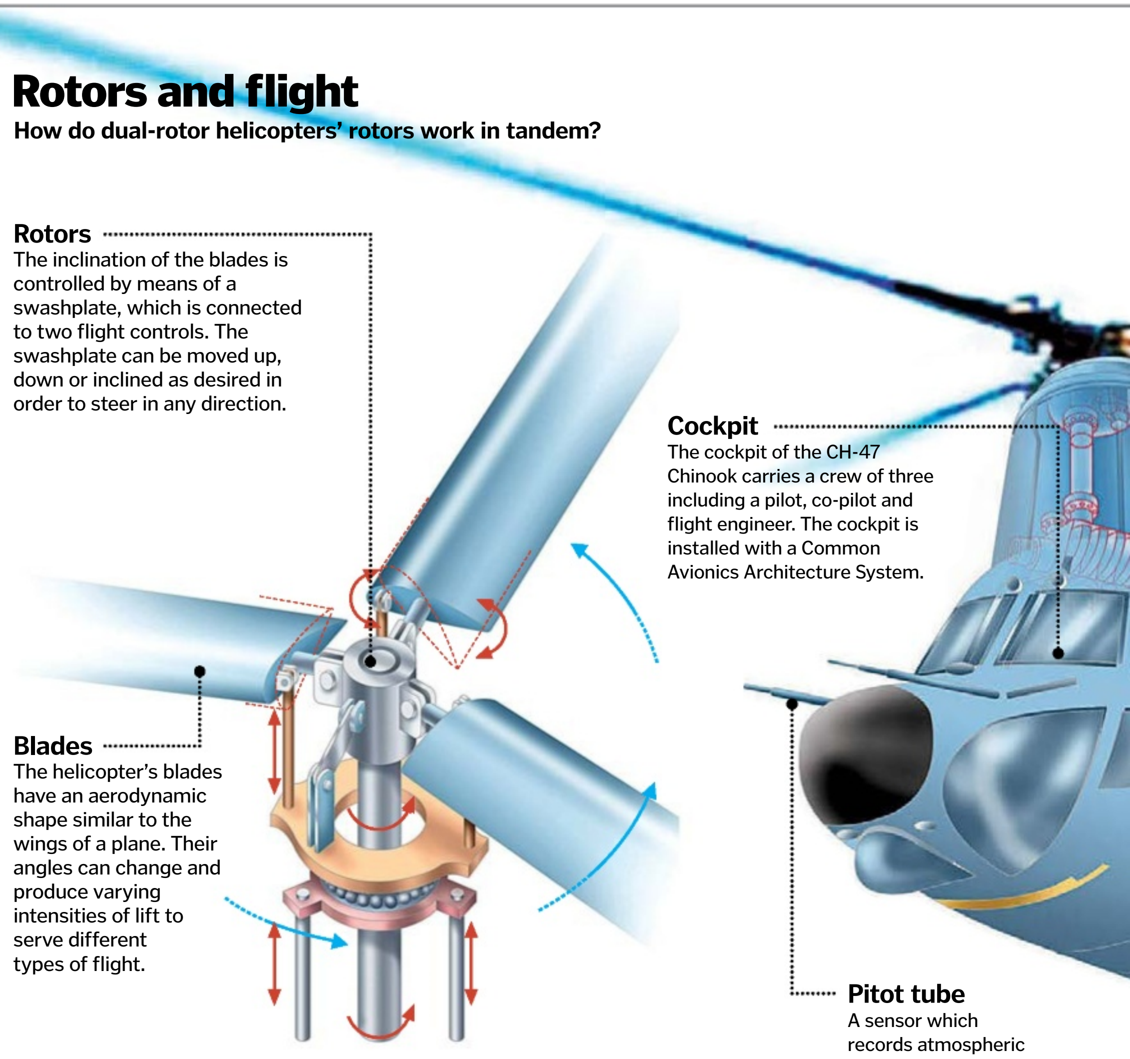
The X3 is installed with a large main rotor just like traditional helicopters, but also two forward-facing smaller propellers. Combined with the short-span wings, these three sets of rotors provide excellent levels of vertical lift as well as added quantities of forward thrust, combining the benefits of a rotorcraft with those of a propeller-driven aeroplane.

These sort of capabilities demonstrate why helicopters are currently being earmarked as the aerial vehicle of the future, with the X3 capable of landing in the tightest of spots – critical when faced with the ever-reduced space of the 21st-century urban landscape – while then also cruising internationally between countries at a pace akin to a jet airliner. As a demonstrator, the X3 is most likely not going to enter mass production itself, however the technology that it boasts is set to be incorporated into many a future helicopter.

One futuristic helicopter currently in use, where technology close to the X3's could be adopted, is the impressive Kaman K-1200 K-MAX. The K-MAX isn't slow, delivering a top speed of 185 kilometres (115 miles) per hour, but if the X3's speed could be combined with the K-1200's advanced UAV capabilities, you would have one heck of a vehicle. This is because, unlike any other helicopter listed here, the K-MAX can be operated entirely remotely and unmanned, with a secure wireless data link

Rotors and flight

How do dual-rotor helicopters' rotors work in tandem?



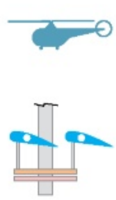
Rotors
The inclination of the blades is controlled by means of a swashplate, which is connected to two flight controls. The swashplate can be moved up, down or inclined as desired in order to steer in any direction.

Cockpit
The cockpit of the CH-47 Chinook carries a crew of three including a pilot, co-pilot and flight engineer. The cockpit is installed with a Common Avionics Architecture System.

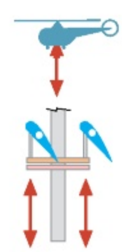
Blades
The helicopter's blades have an aerodynamic shape similar to the wings of a plane. Their angles can change and produce varying intensities of lift to serve different types of flight.

Pitot tube
A sensor which records atmospheric pressure and registers elevation and horizontal/ vertical velocities.

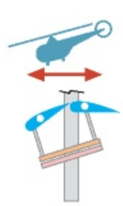
Hover
Each of the rotor blades has the same degree of inclination. This produces a lift that corresponds to the weight of the machine, which remains suspended in the air without moving backwards or forwards.



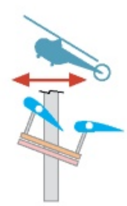
Vertical flight
As the swashplate moves upward and the angle of the blades is increased, more lift is generated, exceeding the weight of the helicopter, so it begins to climb. To descend, the swashplate moves downward and diminishes the angle, thereby reducing lift.

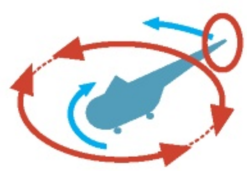


Forward flight
With the swashplate pointed forward, the inclination of the blades increases. As such, the lift is in turn increased in the tail rotor meaning the entire vehicle tilts forward and advances.



Reverse flight
With the swashplate aimed backwards, the inclination of the blades increases the lift of the front rotor. The helicopter thus moves backwards.





Tail rotor
In most helicopters this helps keep the vehicle stable and can be oriented in any direction.

Helicopter evolution

Check out some of the best, worst and just plain weird choppers ever designed

1480s
Aerial screw
Leonardo da Vinci sketches out what he refers to as an 'aerial screw' in his notebook. It is never built however.

1907
Cornu helicopter
French bicycle-maker Paul Cornu builds an experimental helicopter. It makes a number of short hops off the ground.

1924
Oehmichen No 2
Étienne Oehmichen sets the first recognised helicopter world record by flying his design 360m (1,181ft).

1942
Sikorsky R-4
Igor Sikorsky builds the first ever mass-produced helicopter, the R-4, with 131 units made over a two-year period.

97,000

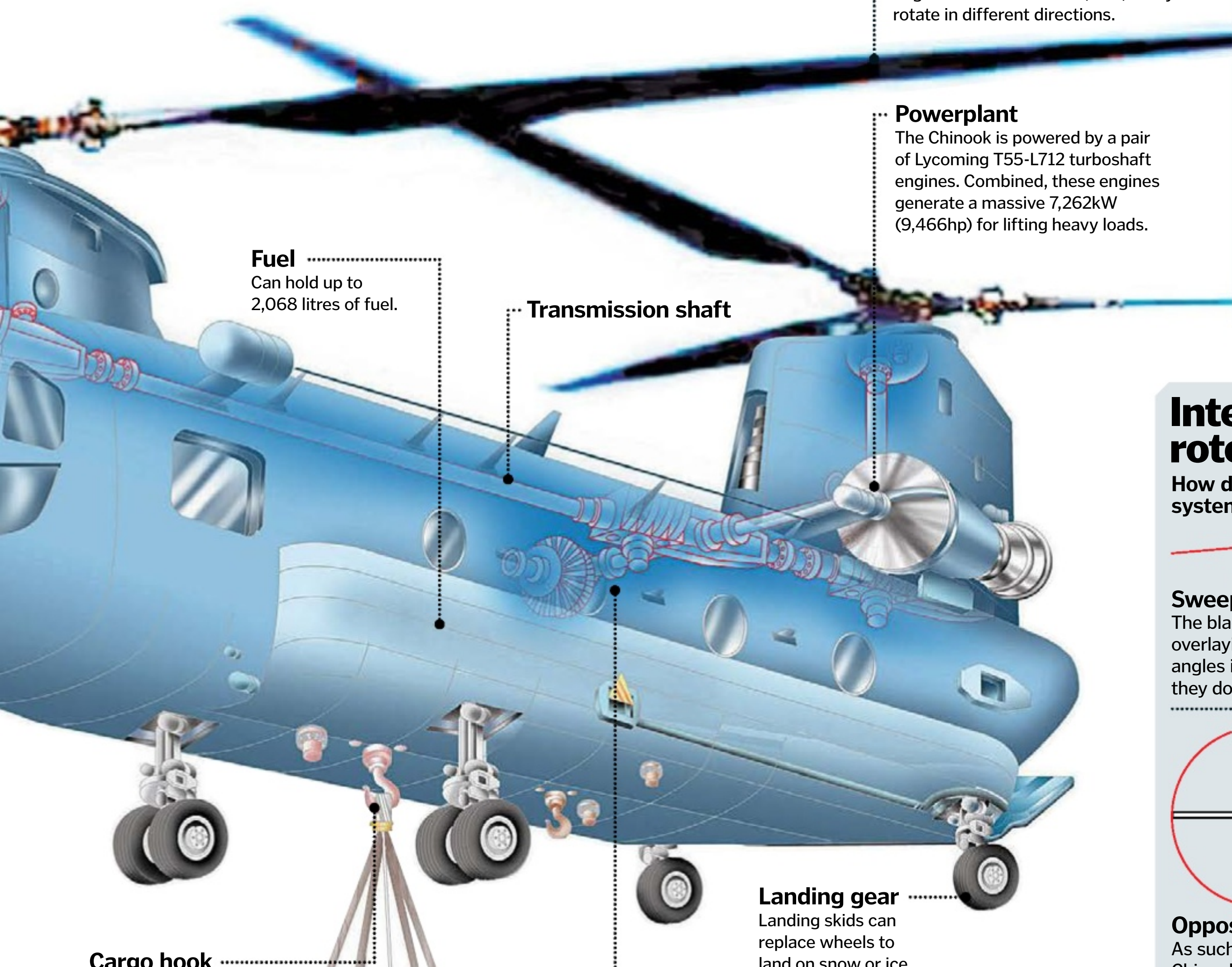
HEAVIEST HELICOPTER EVER

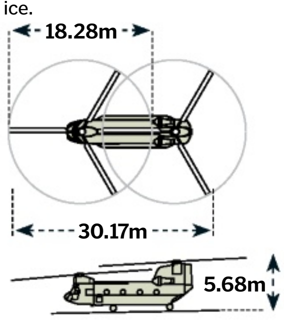
The heaviest helicopter ever built, the Russian Mil V-12, had a max weight of 97,000kg (213,850lb). The helicopter was also the second biggest ever, measuring in at a whopping 37m (121.4ft).

DID YOU KNOW? *The highest altitude a helicopter has reached is recorded at 12,442m (40,820ft)*

Chinook CH-47 engineering

Check out the key components of this heavy-duty helicopter





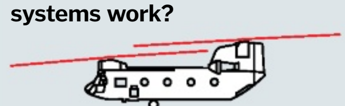
The statistics...

Boeing CH-47F Chinook

Crew: 3
Length: 30.1m (98.7ft)
Height: 5.7 m (18.7ft)
Weight: 10,185kg (23,400lb)
Powerplant: GE T700-GE-701
Rotors: 2 x Lycoming T55-L712
Max speed: 264km/h (164mph)
Max range: 741km (450mi)
Max altitude: 5,640m (18,500ft)
Armaments: 3 x M240/FN MAG machine guns

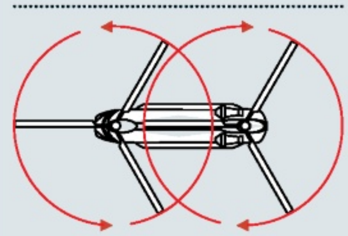
Intermeshing rotors

How do these novel rotor systems work?



Sweep

The blades sweep through overlaying areas, but at different angles in a staggered fashion, so they do not come into contact.



Opposite spin

As such, helicopters like the CH-47 Chinook do not require a tail rotor because the main rotors rotate in opposite directions. The action of one cancels out the other.

Turning

The rudder pedals alter the inclination of the plane of rotation of the rotors in such a way that the plane of rotation of one tilts to the left and the other to the right, or vice versa, to change direction.

1959
Sikorsky S-61
The S-61 betrays Sikorsky's heritage as a helicopter maker as it is marred by high mortality rate accidents.

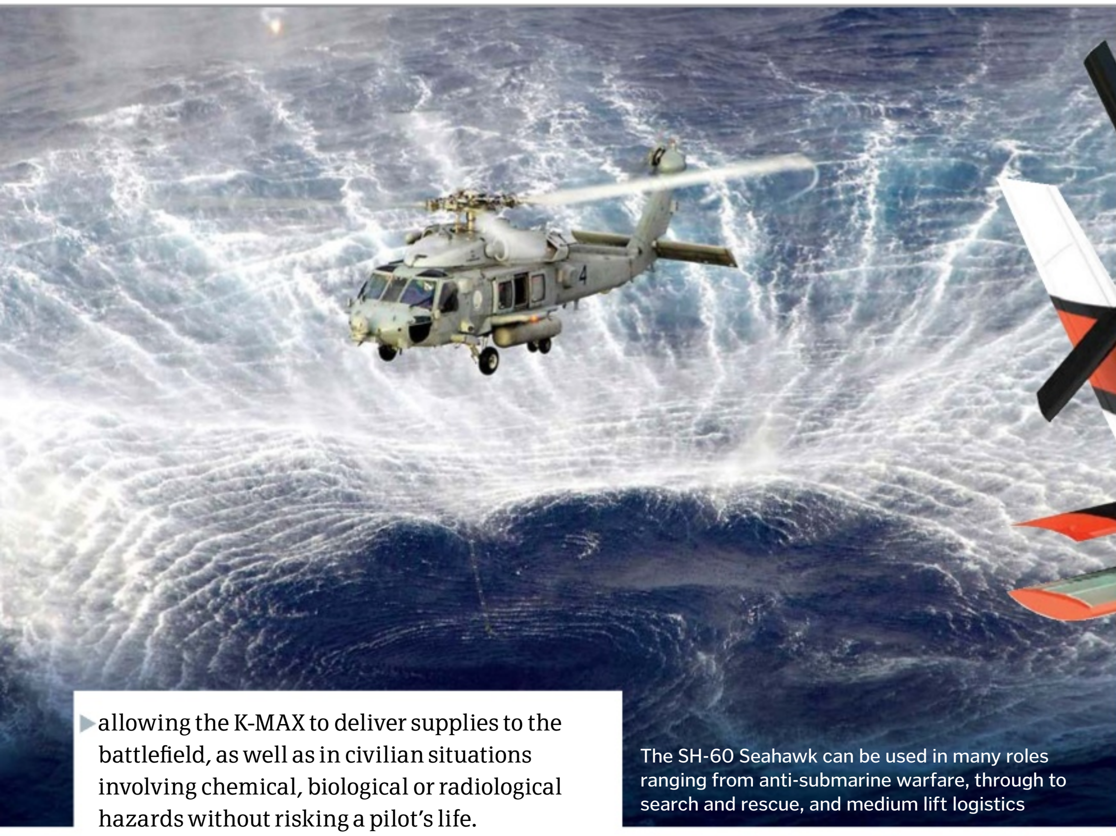
1966
Hughes YOH-6A
The YOH-6A sets a new world record for distance travelled without landing.

1972
Aerospatiale Lama
French aviator Jean Boulet pilots an Aerospatiale Lama to a height of 12,442m (40,820ft), setting a still unbroken record.

1986
Westland Lynx
English pilot John Egginton sets the first official helicopter speed record of 400km/h (249mph) in a Westland Lynx.

2003
Eurocopter Tiger
The Eurocopter Tiger becomes the first all-composite helicopter to be developed in Europe, incorporating a glass cockpit.

2011
E-copter
French-Australian inventor Pascal Chrétien builds the world's first manned, fully electric helicopter.



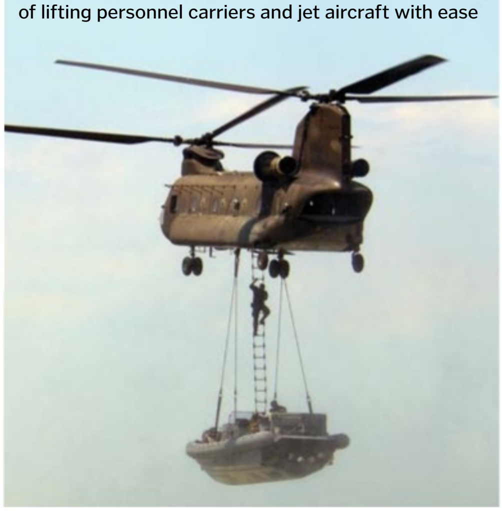
The SH-60 Seahawk can be used in many roles ranging from anti-submarine warfare, through to search and rescue, and medium lift logistics

allowing the K-MAX to deliver supplies to the battlefield, as well as in civilian situations involving chemical, biological or radiological hazards without risking a pilot's life.

The maturity of the K-MAX's UAV tech is indeed startling. As of February 2013, a pair of K-MAXes working in Afghanistan had delivered cargo over 600 unmanned missions. In total, these two helicopters have racked up over 750 unmanned flight hours and, when you consider the potential applications going forward – such as fire-fighting, civilian transportation and disaster relief – it's easy to see how the flexibility and automation it delivers is simply not deliverable by a manned aircraft or unmanned drone. For the K-MAX to live up to this multi-use ideal however, the helicopter is going to have to learn some lessons from some of the most versatile and resistant of all helicopters around, eg the Sikorsky SH-60 Seahawk and the Mil Mi-26.

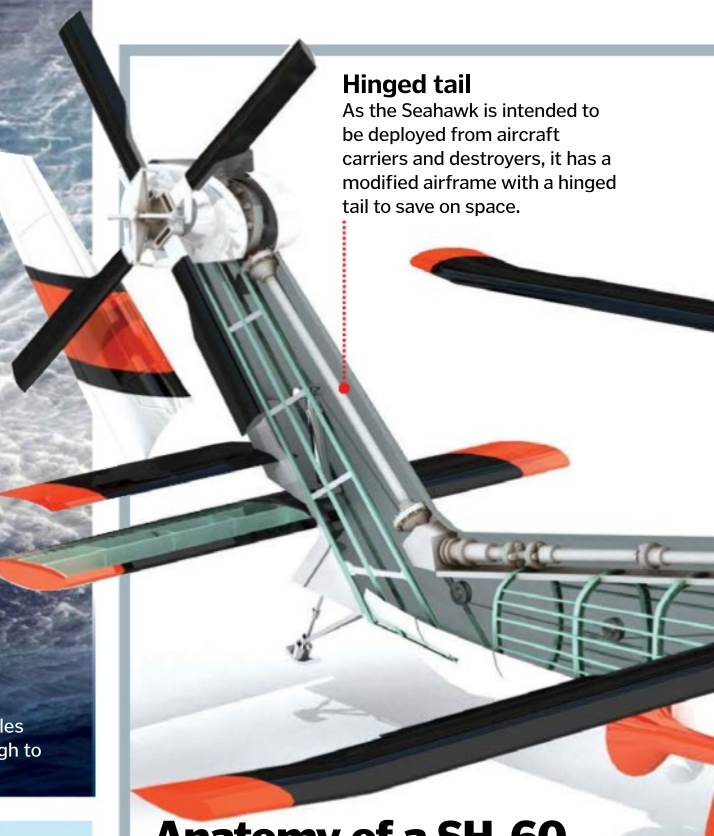
For many the Seahawk is considered the most versatile of all helicopters and for good reason. It has seen a series of upgrades over the past 20 years seeing it outfitted with the necessary tech for anti-submarine warfare, anti-surface warfare, naval special warfare insertion, civilian and combat search and rescue, vertical replenishment and medical evacuation operations. In addition, thanks to its excellent design, the Seahawk is one of the most widely deployable helicopters in the world, capable of being launched from frigates, destroyers, cruisers, fast combat support ships, amphibious assault ships and aircraft carriers when used in its native ocean habitat.

The Chinook CH-47F is a carrying colossus, capable of lifting personnel carriers and jet aircraft with ease



Where the Seahawk excels in role versatility, the Mi-26 excels in hardiness and heavy-duty lifting capabilities. The largest and most powerful helicopter ever to have gone into production, the raw power generated by this flying fortress of a chopper is epic, with its twin Lotarev D-136 turboshaft engines pushing out a colossal 8,382 kilowatts (11,240 horsepower) each, and allowing the Mi-26 a maximum takeoff weight of 56,000 kilograms (123,459 pounds); that's nearly six times that of the SH-60 Seahawk and almost 20 times that of the K-MAX. This amazing lifting ability – which can also extend to transporting 90 troops at a time – has seen the helicopter's manufacturer Rostvertol recently be commissioned to produce another 22 top-spec Mi-26Ts for the Russian Air Force, while also winning a contract to upgrade the existing fleet.

However, of all the helicopters currently being granted a new lease of life in this re-birth of the field, it is the king of logistical operations – the Boeing CH-47 Chinook – which is arguably seeing most success. Despite being intended to



Anatomy of a SH-60 Seahawk helicopter

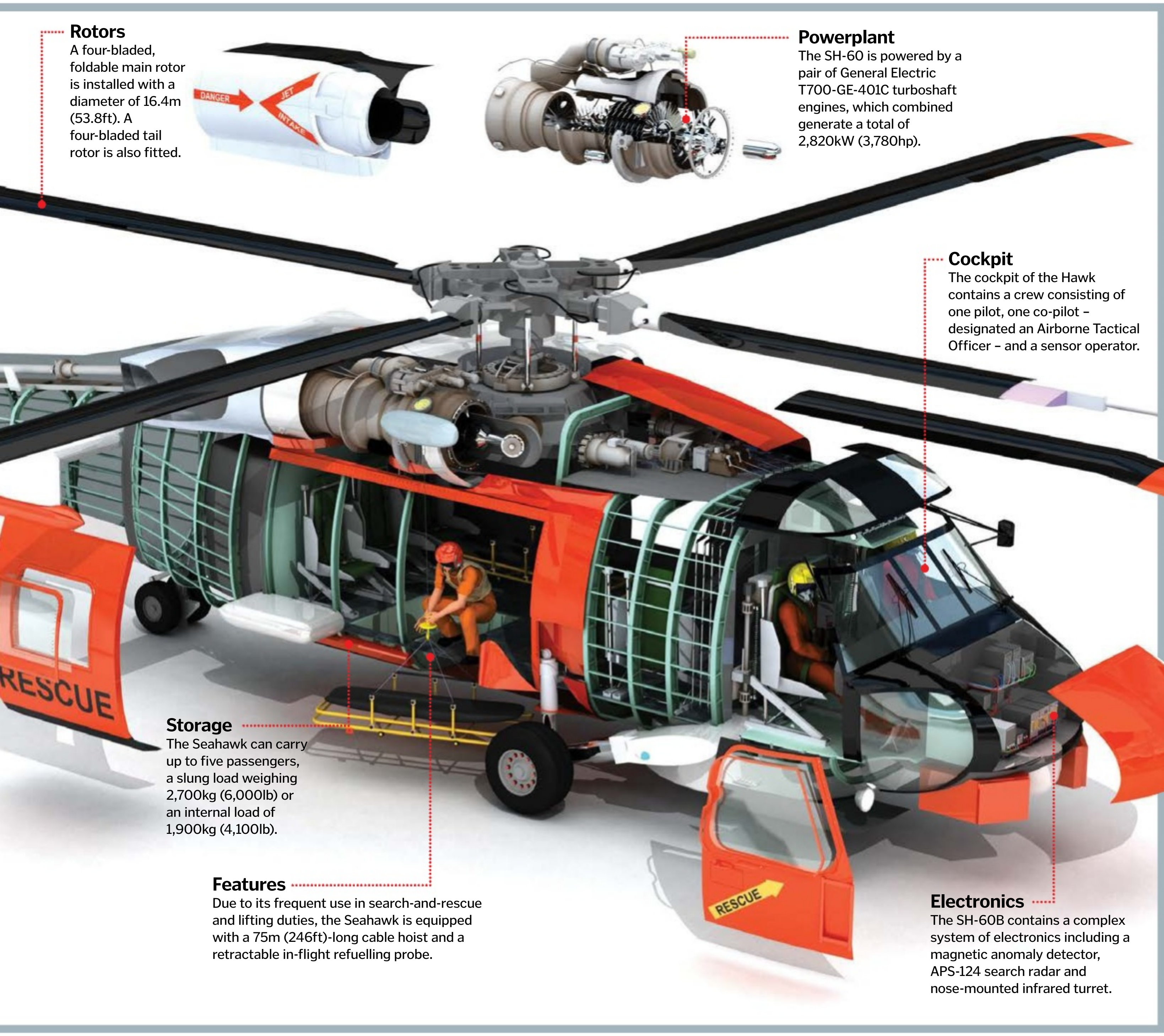
A look at the core features of this versatile chopper built for a life at sea

The statistics...

Sikorsky SH-60 Seahawk

Crew: 3-4
Length: 19.8m (64.9ft)
Height: 3.8m (12.3ft)
Weight: 9,450kg (21,000lb)
Powerplant: 2 x General Electric T700-GE-401C
Rotors: 1 x 4-blade main rotor; 1 x 4-blade tail rotor
Max speed: 270km/h (168mph)
Max range: 600km (373mi)
Max altitude: 3,580m (12,000ft)
Armaments: N/A

DID YOU KNOW? *The world's first manned electric-powered helicopter was flown in 2011*



be replaced by the advanced tilt-rotor V-22 Osprey, so far over 1,179 Chinooks have been built. Thanks to a series of technological improvements such as the integration of a Common Avionics Architecture System (CAAS), a next-generation global positioning system (GPS) and terrain following and avoidance radars, as of 2013, Chinooks worldwide – there are 20 nations that operate them – are thriving. They combine modest military capabilities with ruggedness, heavy-duty lifting capabilities, role versatility, high-speed travel (read: 264 kilometres/164 miles per hour), stability thanks to its tandem rotors (see the boxout on page 65 for more information) and solid fuel economy.

Indeed, in many ways, the CH-47 Chinook is the best all-round helicopter on the planet, combining almost every quality aeronautical engineers look for when designing an aircraft. It also demonstrates that, while speed will always remain important in all forms of airborne vehicle, it will probably not be the most critical quality for future aircraft, with lifting power, efficiency, adaptability all more crucial to 21st-century travel. It also shows that despite being overshadowed by fixed-wing aircraft for decades, helicopters are continuing to up their game, bringing innovation and hi-tech engineering to the aviation world.

High-flying paramotors

The secret to soaring on an engine-powered glider

The latest craze that's literally taking off is paramotoring. These powered paragliders are the cheapest and most compact form of flying, offering mere mortals the chance to explore the heavens where the sky is literally the limit!

It's remarkably simple: combining a backpack engine attached to a ram-air parafoil wing so you wear the engine itself. Variations include a tandem flown by two people and a trike, which has wheels attached to increase the device's ground adaptability. It is usually foot launched so there is no need for a long airfield or runway to ascend and with the powerful two or four-stroke propelled engine in tow, there is no reliance on wind assistance.

The engine can be stopped and restarted mid-air to easily change direction and altitude. The steering controls work via brake lines that increase or decrease the drag on each side of the wing. But perhaps its most appealing feature is the low carbon footprint, with minimal emissions coming from a paramotor. Costing between £3,500 and £12,000 ($5,900 and $20,200) each when brought from a constructor, many people also make their own and combine it with a second-hand paraglider wing. The pilots must also wear the appropriate safety gear including a flying suit, boots and a helmet.

In many countries paramotoring does not require a special licence, but pilots must learn and obey airspace regulations in order to avoid commercial airline flight paths.

Paramotors give the pilot an almost-unique sensation of free flight

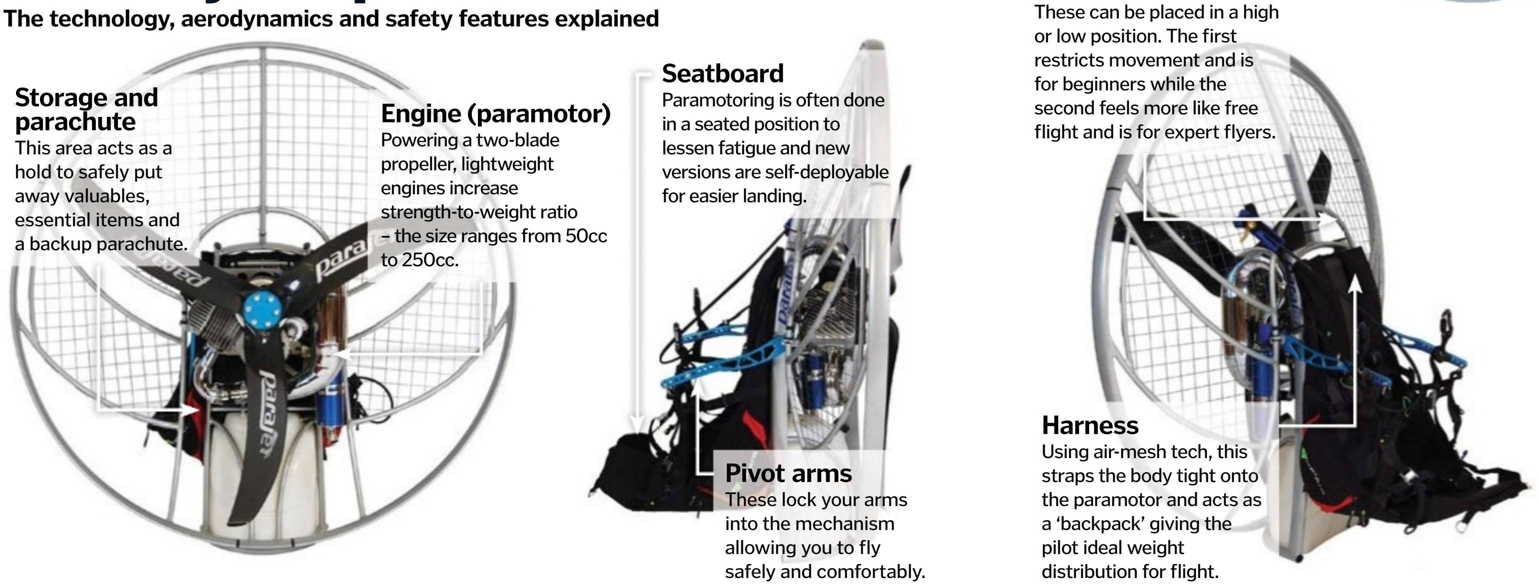
The SkyRunner

UK-based Parajet International is designing a paramotor-vehicle hybrid known as the SkyRunner. Designed to be all-terrain, it has been described as the 'ultimate recreational sports vehicle.' The first prototype emerged in 2009 when a design of attaching a paraglider to a buggy appeared. Through continual modifications it has morphed into its current incarnation.

The SkyRunner is a lightweight, high-strength construction intended to tackle demanding landscapes and be road legal. As well as its impressive specs, the vehicle takes the pilot's comfort seriously with new paraglider wing technology, which absorbs turbulence, and a flywheel design that counters uncomfortable engine vibration without affecting performance.

Anatomy of a paramotor

The technology, aerodynamics and safety features explained



1. SMOKIEST

Cigarette
Smoke leaving a cigarette begins with a smooth laminar flow, but as both its velocity and length increase, it becomes more and more turbulent.

2. SPORTIEST

Golf ball
Golf balls are dimpled to *create* turbulence. This is because smooth surfaces lead to a region of low pressure forming behind which results in high drag.

3. WINDIEST

Aeroplane
Clear-air turbulence (CAT) occurs when atmospheric warm and cold air are mixed by wind. This is the type of turbulence we experience when flying.

DID YOU KNOW? *Mountain waves are a form of turbulence produced when strong winds hit a peak and break over the summit*

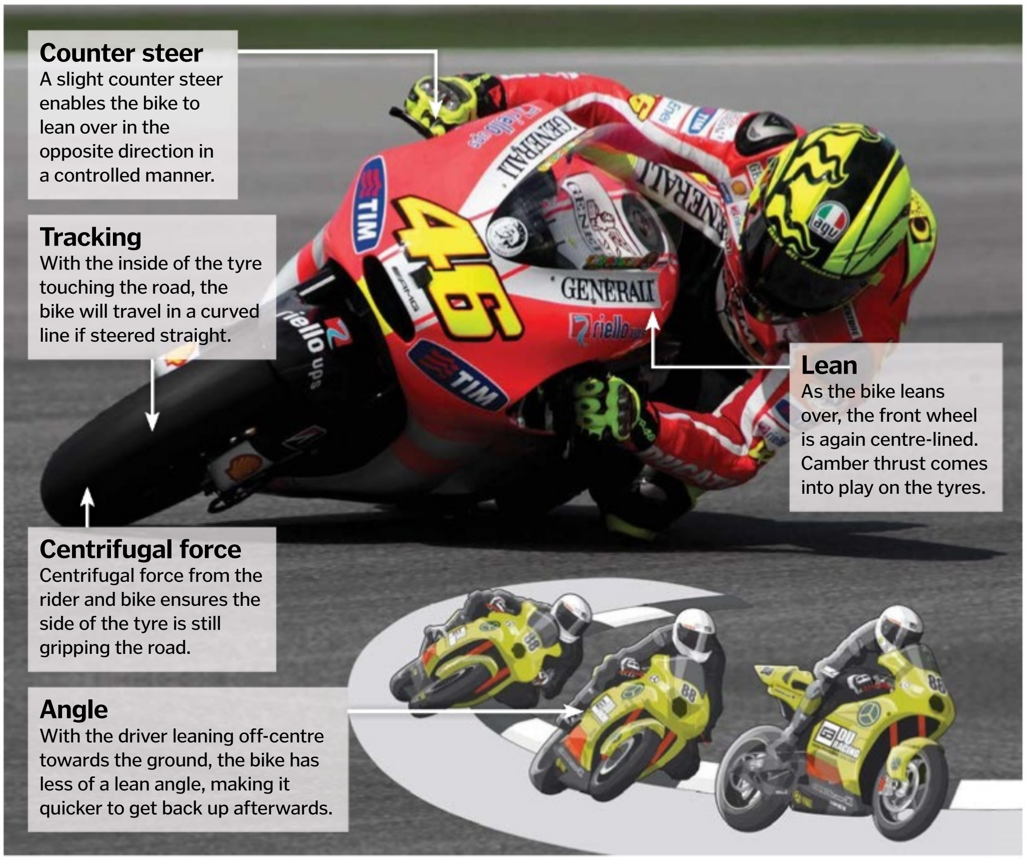
The physics of cornering

It may look precarious, but leaning into a corner on a motorbike actually offers more grip

As bikes only have two wheels, they don't simply turn through corners in the way a four-wheeled vehicle does. Instead, they effectively carve through the turns, leaning from side to side and using the full outer radius of their tyres to maintain contact with the road.

When a biker leans into a corner at pace, a number of extra forces come into play to help the bike maintain grip. Firstly, camber thrust is created, which means a point on the outer surface of a leaned, rotating tyre that would normally follow an elliptical path when in contact with the ground is forced to follow a straighter path. Meanwhile, as the bike tracks round a bend, the cornering causes a centrifugal force to press the tyres into the road, ensuring grip is maintained.

The harder a tyre is pressed into the ground, the more grip the tyre enjoys, and thanks to centrifugal force and camber thrust acting against the tyres here, more weight is essentially put on the vehicle when leaning over. A bike therefore technically has more grip through a corner than it does when vertical in a straight line, despite the same amount of tyre surface area being in contact with the road.



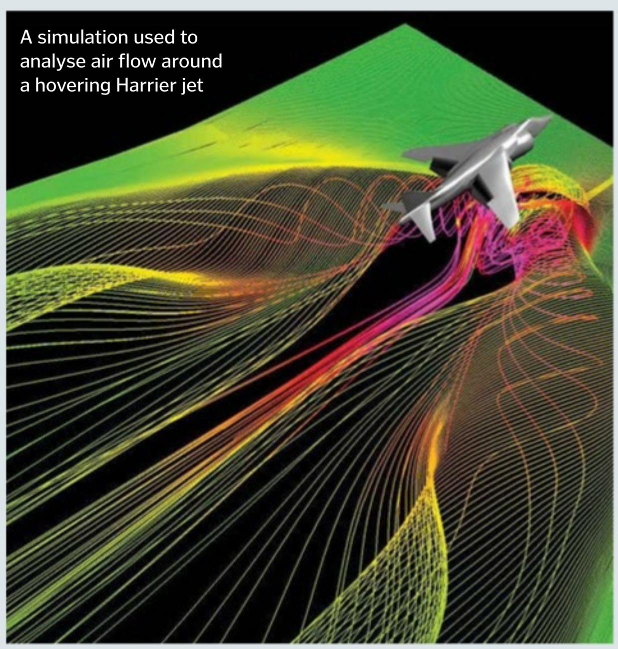
What is turbulence?

Strap in to discover what causes bumpy flights

Turbulence is a flow condition within a medium – such as air or water – in which local speed and pressure changes unpredictably within an overall stable flow direction. As such, turbulence is characterised by rapid changes of momentum diffusion and convection, as well as velocity. It is the result of a medium like air having unseen, intermingling layers moving at varying speeds and in many directions.

In general we are most familiar with turbulence while travelling on aeroplanes, when the cabin experiences a period of buffeting. This in-air bumpiness is referred to as clear-air turbulence (CAT) and is caused when atmospheric warm and cold air are mixed by high winds. Often occurring near jet streams, the segments of air have varying pressures due to their heat differential. CAT is invisible and so can occur suddenly without warning.

The severity of turbulence is measured in fluid mechanics by its Reynolds number. For example, if the medium's Reynolds number is less than 2,000, the medium's flow is laminar (ie steady, parallel layers), while if the number exceeds 2,000, then its flow is generally described as turbulent (ie disruptive, intermixing layers).


A simulation used to analyse air flow around a hovering Harrier jet

Aerial transfer bridges

Learn how transporter bridges carry cargo and passengers across water

One of the biggest challenges in bridge building across busy rivers is allowing boats to navigate them freely. Solutions have been invented in the form of a variety of movable bridges, with sections that retract, lift up or even sink to make room.

A rare example is the transporter bridge, or aerial transfer bridge, which uses a movable platform, or gondola, to carry loads from one bank to the other. There are very few examples worldwide – indeed, less than 25 of these bridges have ever been constructed – and only a few remain in use today.

The construction of transporter bridges varies. The Vizcaya Bridge in Spain has two pillars connected by a crossbeam and supported suspension cables, while the Tees Transporter Bridge (pictured) in the UK is a cantilevered design with two halves, each supported entirely by two towers at either end.

Despite the differences in their overall structure, transporter bridges all work using the same fundamental mechanics. The gondola is suspended below the bridge by a series of steel cables, which attach to an overhead trolley. The trolley sits on a track, which runs the length of the bridge, and a winch system is used to draw the platform and its cargo back and forth across the waterway.

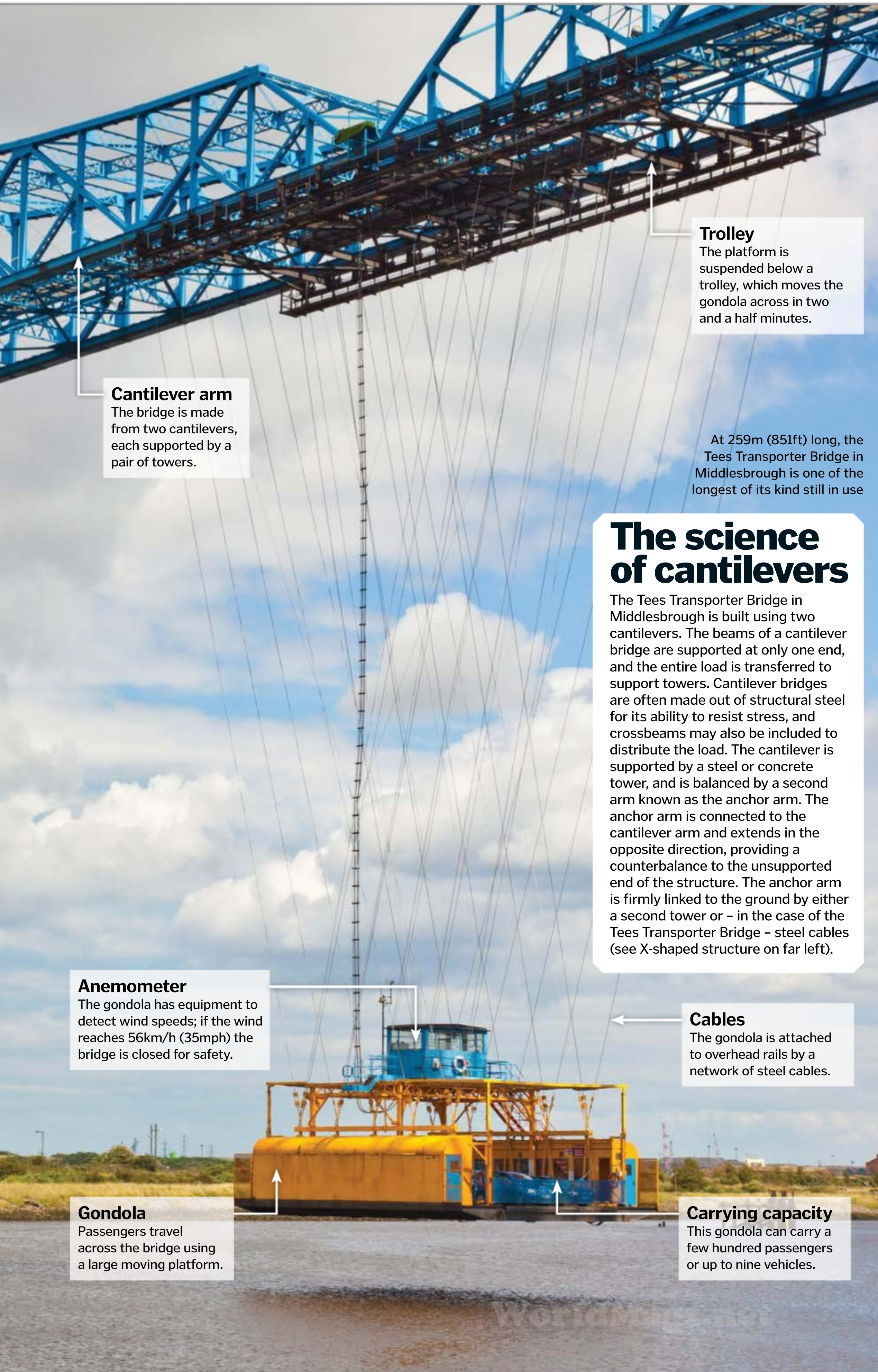
The gondolas have a large carrying capacity and can often transport several hundred people or several vehicles at once. They also provide an advantage over traditional bridges in that they can take passengers directly from ground level. If the riverbanks are very low, a long approach road is required to get vehicles to the correct altitude to cross a normal bridge.

300m

BIGGEST TRANSPORTER BRIDGE

The Widnes-Runcorn Transporter Bridge over the River Mersey, UK, was the largest ever built. It had a main span of 300 metres (984 feet) and two towers each 58 metres (190 feet) high. However it was demolished in 1961.

DID YOU KNOW? *Only six transporter bridges remain in operation around the world, most of which are in Europe*



Trolley
The platform is suspended below a trolley, which moves the gondola across in two and a half minutes.

Cantilever arm
The bridge is made from two cantilevers, each supported by a pair of towers.

At 259m (851ft) long, the Tees Transporter Bridge in Middlesbrough is one of the longest of its kind still in use

Anemometer
The gondola has equipment to detect wind speeds; if the wind reaches 56km/h (35mph) the bridge is closed for safety.

Cables
The gondola is attached to overhead rails by a network of steel cables.

Gondola
Passengers travel across the bridge using a large moving platform.

Carrying capacity
This gondola can carry a few hundred passengers or up to nine vehicles.

The science of cantilevers

The Tees Transporter Bridge in Middlesbrough is built using two cantilevers. The beams of a cantilever bridge are supported at only one end, and the entire load is transferred to support towers. Cantilever bridges are often made out of structural steel for its ability to resist stress, and crossbeams may also be included to distribute the load. The cantilever is supported by a steel or concrete tower, and is balanced by a second arm known as the anchor arm. The anchor arm is connected to the cantilever arm and extends in the opposite direction, providing a counterbalance to the unsupported end of the structure. The anchor arm is firmly linked to the ground by either a second tower or – in the case of the Tees Transporter Bridge – steel cables (see X-shaped structure on far left).

Five bridges that move

1 Drawbridge

Drawbridges were one of the first types of movable bridge. Attached to rope or chain and a counterweight, they are raised and lowered by turning a crank, and function not just as a bridge over a moat or ditch but also as a door.

2 Folding bridge

Folding bridges are made from several segments. As the bridge opens, the segments are pulled into a concertina by counterweights, forming a folded 'N' shape and allowing boats to pass underneath.

3 Bascule bridge

The arms of a bascule bridge like London's Tower Bridge swing up, so boats pass through the centre. They work in a similar manner to a seesaw, using a counterweight to move the arms upwards.

4 Tilt bridge

A tilt bridge has a curved deck, which rotates around its central axis. When a boat needs to pass, the bridge spins upwards, transforming the walkway into an arch for the vessel to travel beneath.

5 Submersible bridge

Instead of rising up, a submersible bridge, like that in the Corinth Canal in Greece, has a section that sinks below the water to allow boats to pass. This means no height restriction is imposed on the river traffic.

Next-gen lifeboats

What makes the Shannon one of the most cutting-edge rescue boats in the world?

The latest vessel made by the Royal National Lifeboat Institution (RNLI) to enter service is the Shannon class – an innovative design incorporating a host of cutting-edge technology. Luke Blissett from the RNLI reveals: "The Shannon is the first RNLI lifeboat to be powered by water jets, making it the most agile lifeboat in the fleet." The Shannon is self-righting so even if it were to capsize in extreme conditions it could get itself out of trouble. This ability is achieved by having a watertight superstructure that makes the boat unstable when it is upside down.

"The Shannon's hull has been designed to minimise slamming of the boat in heavy seas," Blissett continues: "The crew sit in shock-absorbing seats making it safer and more comfortable for our volunteer crews." The hull is made from composites – a combination of glass and carbon fibres and epoxy resins for maximum strength while remaining lightweight. Once the moulding is completed with all the internal strengthening structures attached, the engines and equipment are installed. The deck and superstructure moulding are the last features to be fitted.

The water jet propulsion replaces the conventional propeller with a high-capacity pump that expels water from the rear for propulsion thrust and more manoeuvrability than previous lifeboats. "This increased manoeuvrability helps when precision matters, such as when operating alongside a stricken vessel," Blissett explains. The jets are less prone to damage and allow the lifeboat to operate in shallower waters. Capable of speeds of 25 knots (46 kilometres/29 miles per hour), the Shannon is 50 per cent faster than the models it replaces.

Beyond the boat's advanced structure, the RNLI has also made a full commitment to electronics on its next-gen lifeboats. The conventional steering wheel has disappeared, replaced by an electronic tiller arm placed in the armrest of the coxswain's seat. Facing them are displays that show all the required navigation, collision avoidance and monitoring information, and the remaining crew of five have similar displays.

"We will build at least 50 Shannon-class lifeboats over the next ten years," Blissett concludes. "Once the rollout is complete the RNLI will have achieved its aim of operating a lifeboat fleet around the coasts of the United Kingdom and Ireland consisting entirely of lifeboats capable of 25 knots and able to reach out to 100 miles [160 kilometres] offshore in all weathers."

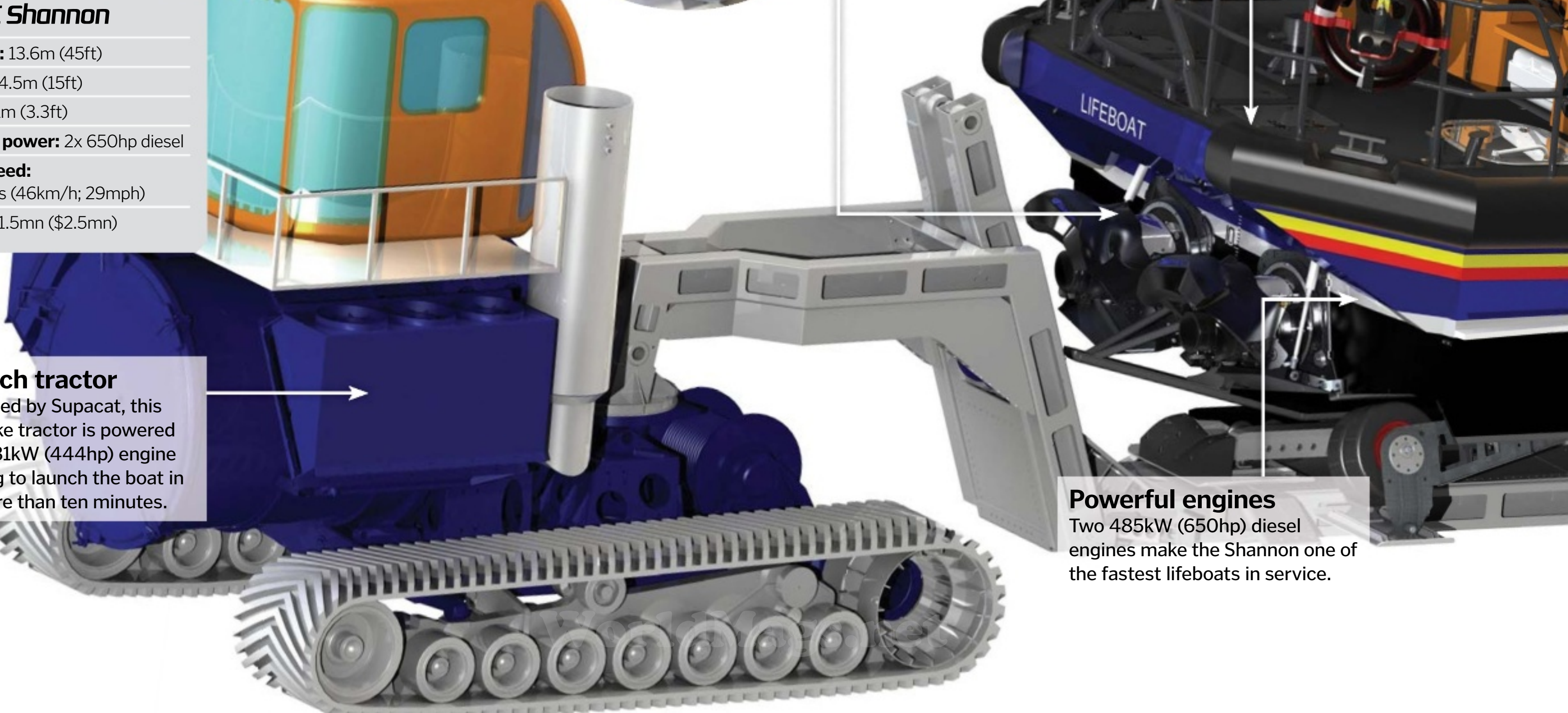
On board the Shannon

Discover what features make the latest RNLI vessel one of the most advanced to ever patrol the seas

The statistics...

RNLI Shannon

Length: 13.6m (45ft)
Beam: 4.5m (15ft)
Draft: 1m (3.3ft)
Engine power: 2x 650hp diesel
Top speed: 25 knots (46km/h; 29mph)
Cost: £1.5mn ($2.5mn)



Water jets
The Shannon is the first RNLI lifeboat with water jet propulsion to give excellent manoeuvrability combined with shallow draft.

Deck line
The deck is lowered in this area so the crew can quickly aid survivors in the water.

Launch tractor
Designed by Supacat, this bespoke tractor is powered by a 331kW (444hp) engine helping to launch the boat in no more than ten minutes.

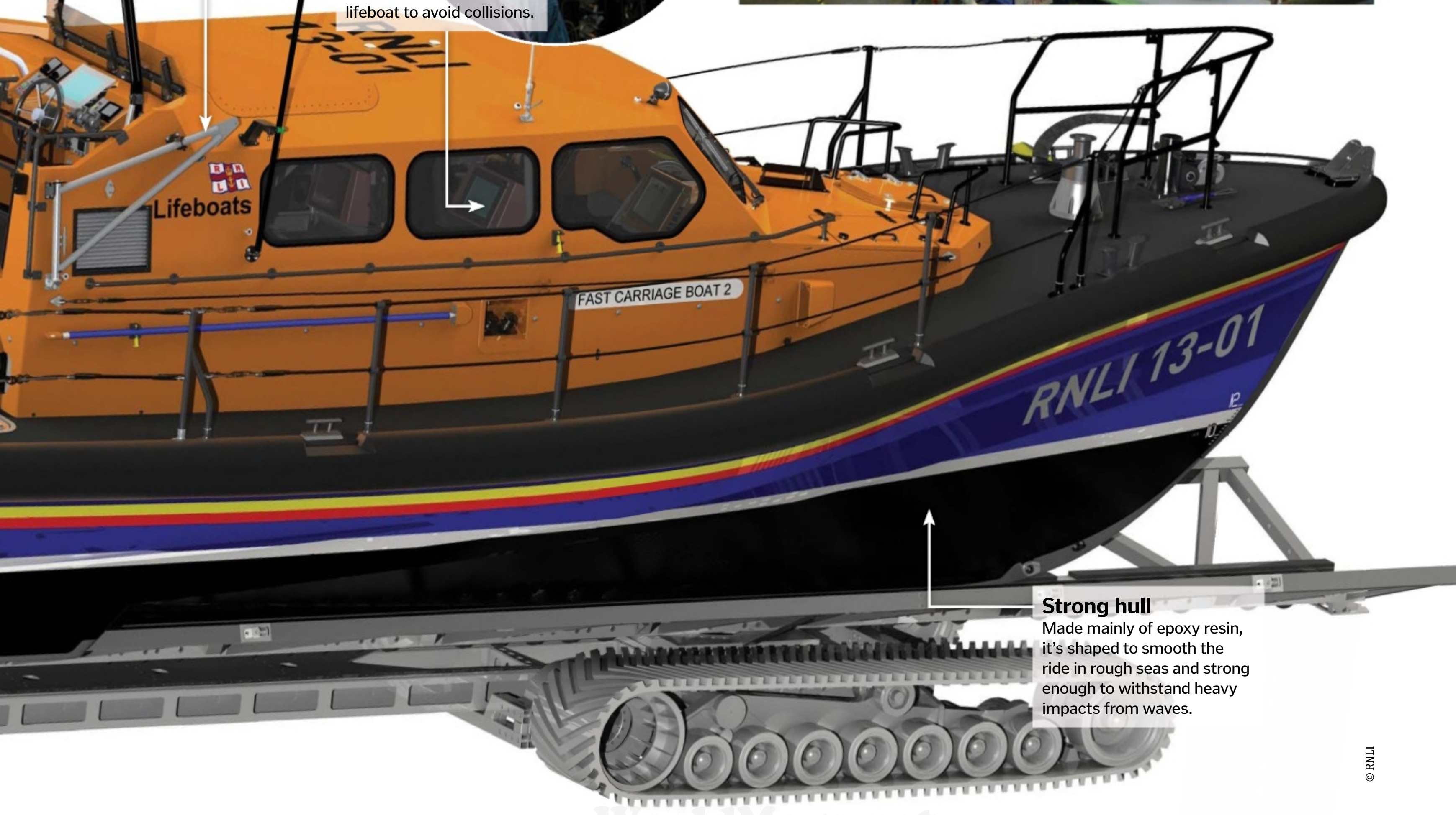
Powerful engines
Two 485kW (650hp) diesel engines make the Shannon one of the fastest lifeboats in service.

DID YOU KNOW? *The Shannon can be launched from an open beach by a tractor and carriage that can negotiate steep gradients*

History of the RNLI

Since it was established in 1824 the lifeboats of the Royal National Lifeboat Institution have saved over 140,000 people from the sea. The aim was to give local seamen a safe boat to go to the rescue of those in peril. First they were rowing and sailing lifeboats that demanded supreme seamanship, before power lifeboats came. The constant evolution of lifeboat design has led to faster and more advanced vessels designed to tackle even the roughest waters in order to bring the crew and survivors safely back to shore.

These images show the process of building a Shannon lifeboat, from setting the hull to adding the cabin



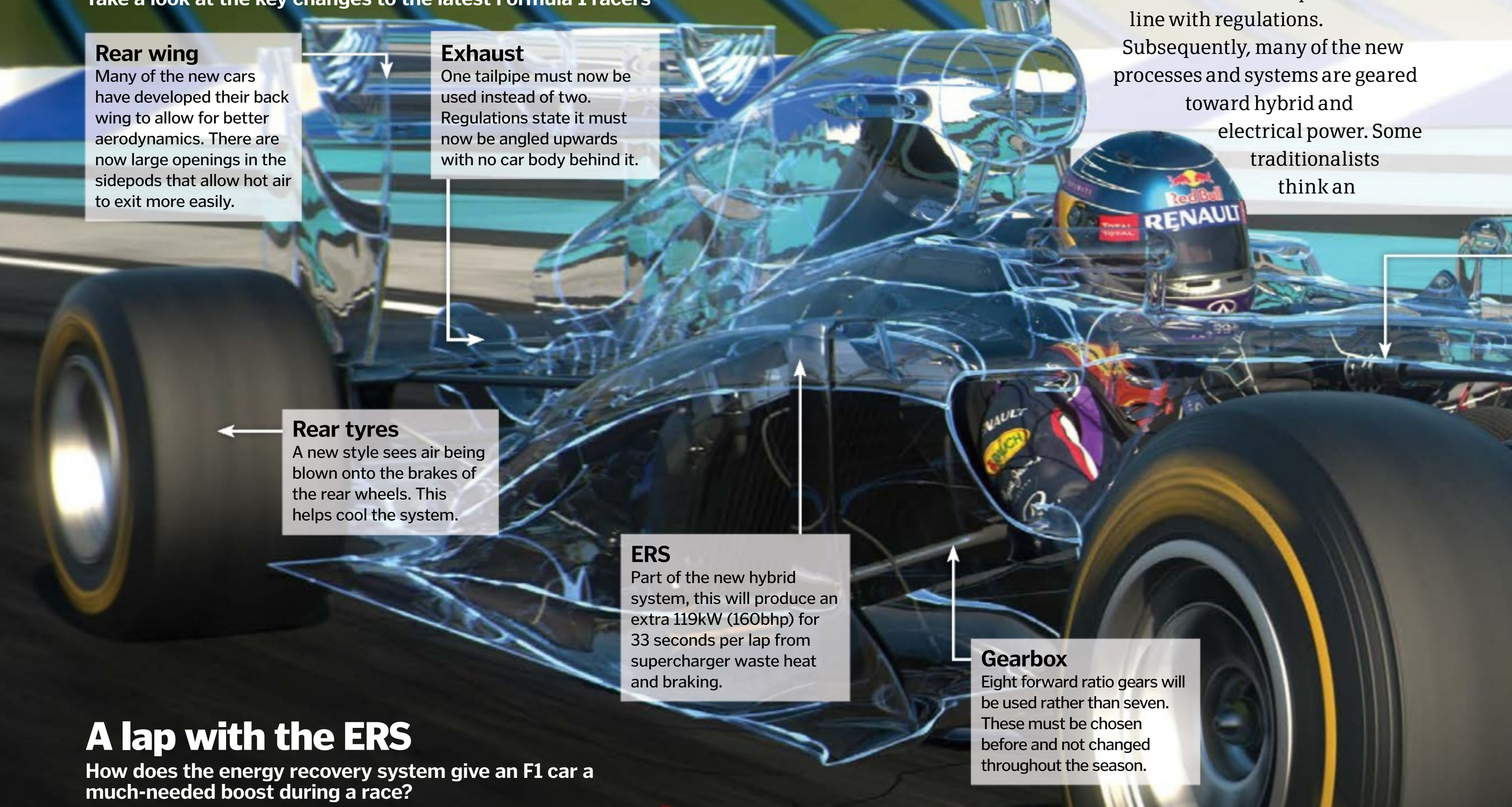
Racing cars

From hybrid engines to new designs, today's racing engineering is stepping up a gear…

All through the racing spectrum, vehicles are being constantly developed and improved to reach new levels of excellence. Whether it's top speed, aerodynamics, fuel consumption or safety, every area is constantly being upgraded. If there is one prominent theme throughout, it is the environment. All new cars that roll off the production line today are carefully monitored to ensure their greenhouse gas emissions and environmental impact are in line with regulations. Subsequently, many of the new processes and systems are geared toward hybrid and electrical power. Some traditionalists think an

On board a 2014 F1 car

Take a look at the key changes to the latest Formula 1 racers



Rear wing
Many of the new cars have developed their back wing to allow for better aerodynamics. There are now large openings in the sidepods that allow hot air to exit more easily.

Exhaust
One tailpipe must now be used instead of two. Regulations state it must now be angled upwards with no car body behind it.

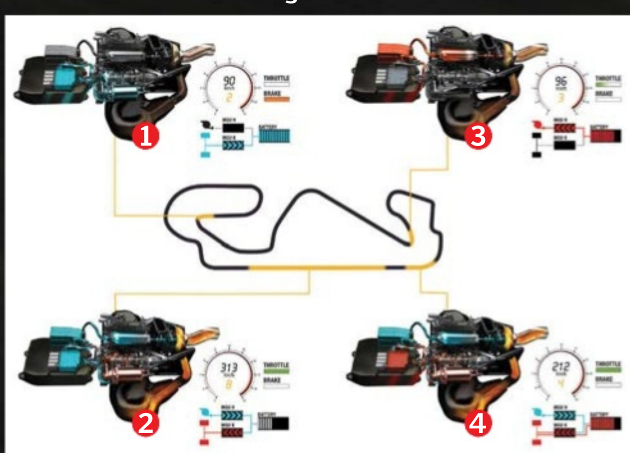
Rear tyres
A new style sees air being blown onto the brakes of the rear wheels. This helps cool the system.

ERS
Part of the new hybrid system, this will produce an extra 119kW (160bhp) for 33 seconds per lap from supercharger waste heat and braking.

Gearbox
Eight forward ratio gears will be used rather than seven. These must be chosen before and not changed throughout the season.

A lap with the ERS

How does the energy recovery system give an F1 car a much-needed boost during a race?



1 Braking
When the car enters a corner, the kinetic energy from the driver braking is converted and stored in the battery.

2 Acceleration
As the car hurtles down the straight, the MGU-H takes heat energy from the exhaust and passes it to the MGU-K or battery.

3 Exiting a corner
When the driver accelerates again, 'turbo lag' occurs due to a lack of energy after braking. The stored electrical energy gives the turbo a boost until it can recover.

4 Overtaking
Driver intervention is not needed. However, the driver can override the system to get a boost for overtaking.

KEY DATES
RACING TECH

1955
Disc brakes are first used. This drastically increases braking power, as a result reducing stopping distance.

1960
The first significant safety measures are introduced. Cars now have a fire extinguisher and a circuit breaker on board.

1987
Computer-controlled active suspension is soon followed by anti-lock brakes and semi-automatic gearboxes.

2008
To add excitement for fans, traction control is banned to ensure more dramatic starts and more overtaking.

2009
KERS (Kinetic Energy Recovery System) kicks off the idea of storing power for a boost later in the race.

DID YOU KNOW? *The first hybrid system was made by German inventor Henri Pieper in 1909*

increased emphasis on eco tech will prevent existing records from being broken, but read on and you will see that while the racing cars of the future may be greener, they haven't compromised on their fundamental purpose: to be the first across the finish line.

Formula 1

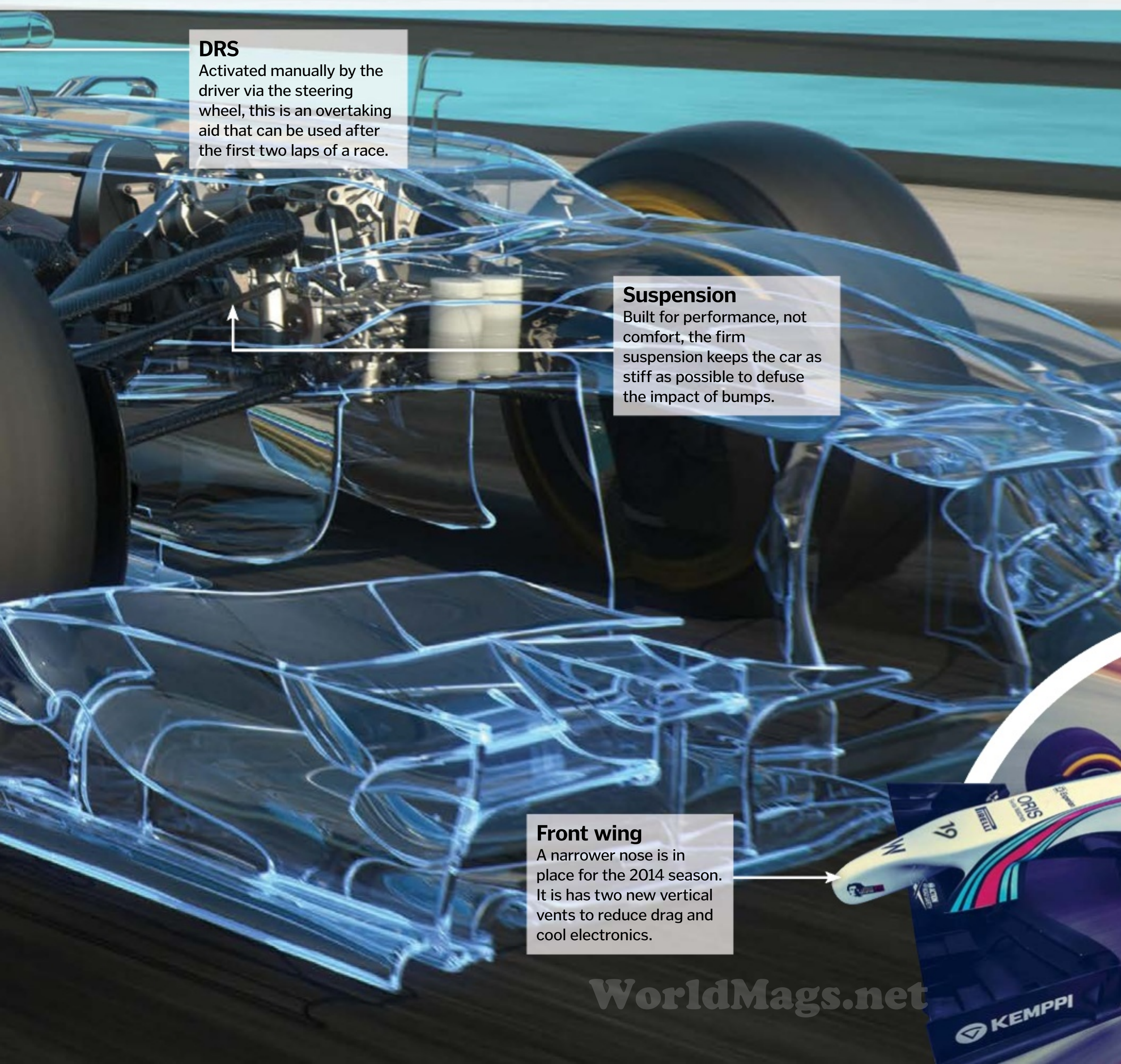
The Australian Grand Prix kicked off in Melbourne on 14 March 2014 and new technology has taken centre stage in what is being hailed by some as the biggest shakeup of regulations in the history of F1. Every car now has on-board chargeable batteries, which will recycle energy that's normally wasted.

The new Energy Recovery System (ERS), taking over from the older Kinetic Energy Recovery System (KERS), is designed to capture waste energy during braking and turn it into electric power for the car. The ERS will provide drivers with an added 119 kilowatts (160 horsepower) per lap and will be delivered automatically rather than manually. Moreover, a heat motor generator unit (MGU-H) will also transfer exhaust heat into energy. These new systems will be essential, as engines have been reduced to one exhaust tailpipe and from 2.4-litre V8s to 1.6-litre V6s. The rev limit will also now be at a maximum of 15,000rpm. Gearboxes in 2014 cars will have eight forward ratios rather than seven.

All these measures will look to decrease emissions and fuel use while still maintaining high-octane racing performance; indeed, 35 per cent less fuel will be burned with a new limit of 100 kilograms (220 pounds) per race rather than the previous 160 kilograms (353 pounds). The ERS and MGU-H will almost completely subsidise the reduction in power, highlighting the power of hybrid engines.

As well as these general modifications, each of the constructors is incorporating their own changes to their cars. For instance, Toro Rosso is introducing two oil radiators to help with cooling and a new nose to improve airflow. Mercedes has a new aerodynamic package, Williams is experimenting with a simpler cooling system and Ferrari is trialling a different location for the battery pack as well as an upgraded front wing.

Pierre-Jean Tardy, director of testing and development at Renault F1, claims the new regulations have been, "a complete revolution for Renault", and that the new rules formed, "a blank sheet and no single piece is the same between the old and new power units. It's been a big expenditure and investment." ▶



DRS
Activated manually by the driver via the steering wheel, this is an overtaking aid that can be used after the first two laps of a race.

Suspension
Built for performance, not comfort, the firm suspension keeps the car as stiff as possible to defuse the impact of bumps.

Front wing
A narrower nose is in place for the 2014 season. It is has two new vertical vents to reduce drag and cool electronics.

The statistics...

Formula 1 car

Power: 1.6l V6 turbocharged engine with ERS
Transmission: Semi-automatic eight gears
Length: 463cm (182in)
Width: 180cm (71in)
Weight: 691kg (1,523lb)
Fuel: 100kg (220lb) per race

▸ Racing beyond F1

Following F1's lead, all of the major global car companies are fully embracing new state-of-the-art technology in their motorsport divisions. Porsche is just one of them. The 919 is a hybrid and has two electric motors that supplement the 353-kilowatt (480-horsepower) engine. The electric energy is stored in a lithium-ion battery pack and applied to the petrol engine when required. The model has been raced extensively around the Nürburgring and has entered the 2014 Le Mans endurance race. It uses the new F1 ERS system and is concentrating on turbocharging to utilise the best use of engine power. It will also include regenerative braking strategies and an improved fuel economy.

In February, Toyota revealed that it is racing its new TS040 in the 2014 FIA World Endurance Championship. A progression from the previous 2012 model, it will be four-wheel drive and have an electric power boost in a similar vein to the ERS. This boost will allow the V8 engine to be as efficient as possible while still having the extra electric grunt behind it. Toyota is even talking of a decrease of five to ten seconds in its lap times with the new system. Therefore, with the new regulations, the car with the most powerful engine won't necessarily make the fastest car anymore. The fact that existing models are being given the hybrid treatment (as opposed to creating a whole new car from scratch) demonstrates the rising popularity of hybrids in the motoring world.

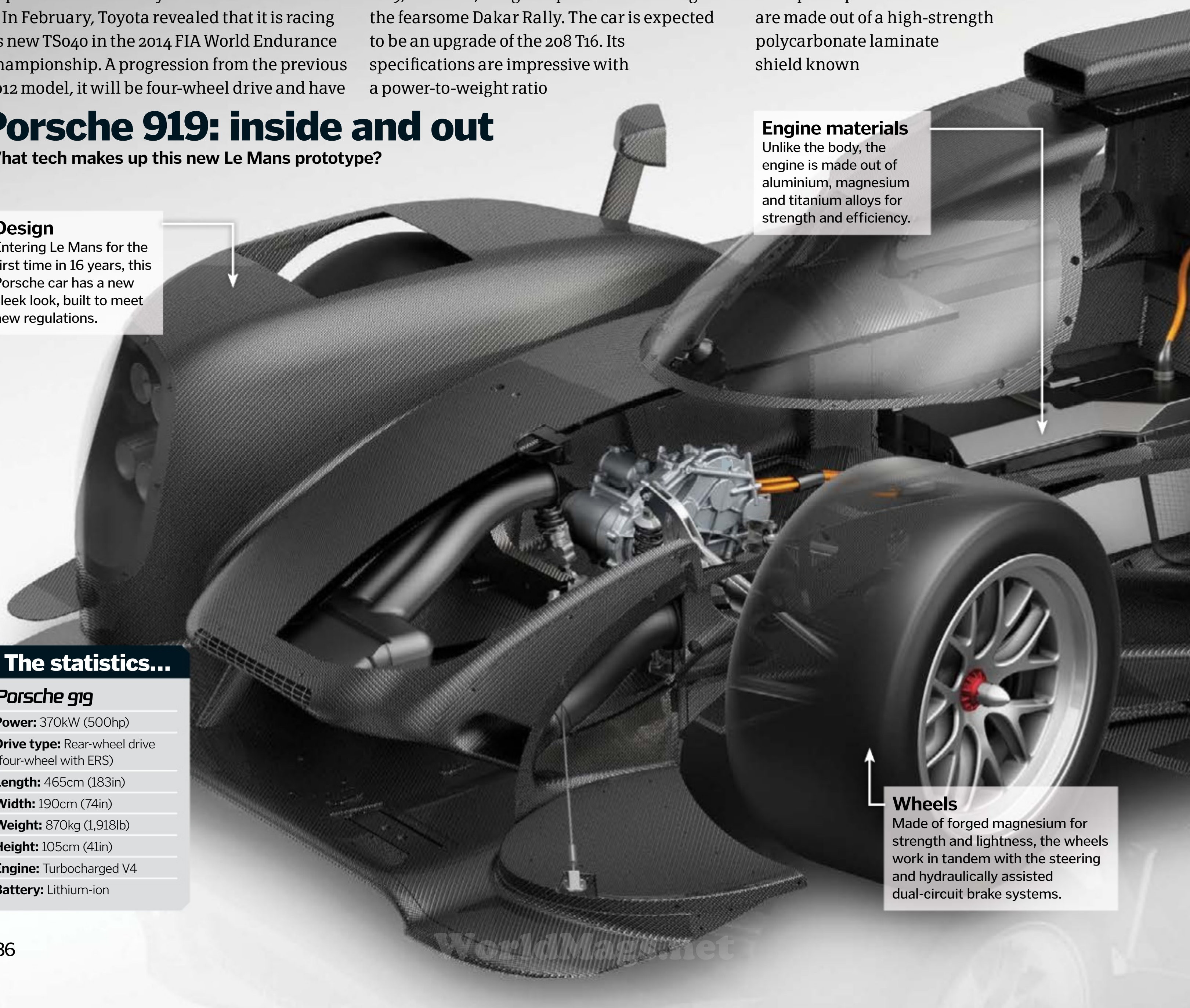
Peugeot is a company that isn't always mentioned in the upper echelons of racing. In 2015, however, Peugeot Sport will be taking on the fearsome Dakar Rally. The car is expected to be an upgrade of the 208 T16. Its specifications are impressive with a power-to-weight ratio of 756 kilowatts (1,000 horsepower) per ton, which is more than an F1 car and nearly twice as much as a Bugatti Veyron! To keep all this power on the road, the downforce will be supplied by a two-metre (6.6-foot) spoiler alongside an aerodynamic underbody tray.

Other than Le Mans, the 24 Hours of Daytona, has the MazdaSKYActiv car, which uses turbodiesel fuel. The Ford Daytona EcoBoost is also attempting to be different by incorporating a V6 rather than a V8.

Also stateside NASCAR is another motorsport implementing big changes. As well as having the largest environmental sustainability programme in US sports, new strategies have been put in place. New windshields are made out of a high-strength polycarbonate laminate shield known

Porsche 919: inside and out

What tech makes up this new Le Mans prototype?



Design
Entering Le Mans for the first time in 16 years, this Porsche car has a new sleek look, built to meet new regulations.

Engine materials
Unlike the body, the engine is made out of aluminium, magnesium and titanium alloys for strength and efficiency.

Wheels
Made of forged magnesium for strength and lightness, the wheels work in tandem with the steering and hydraulically assisted dual-circuit brake systems.

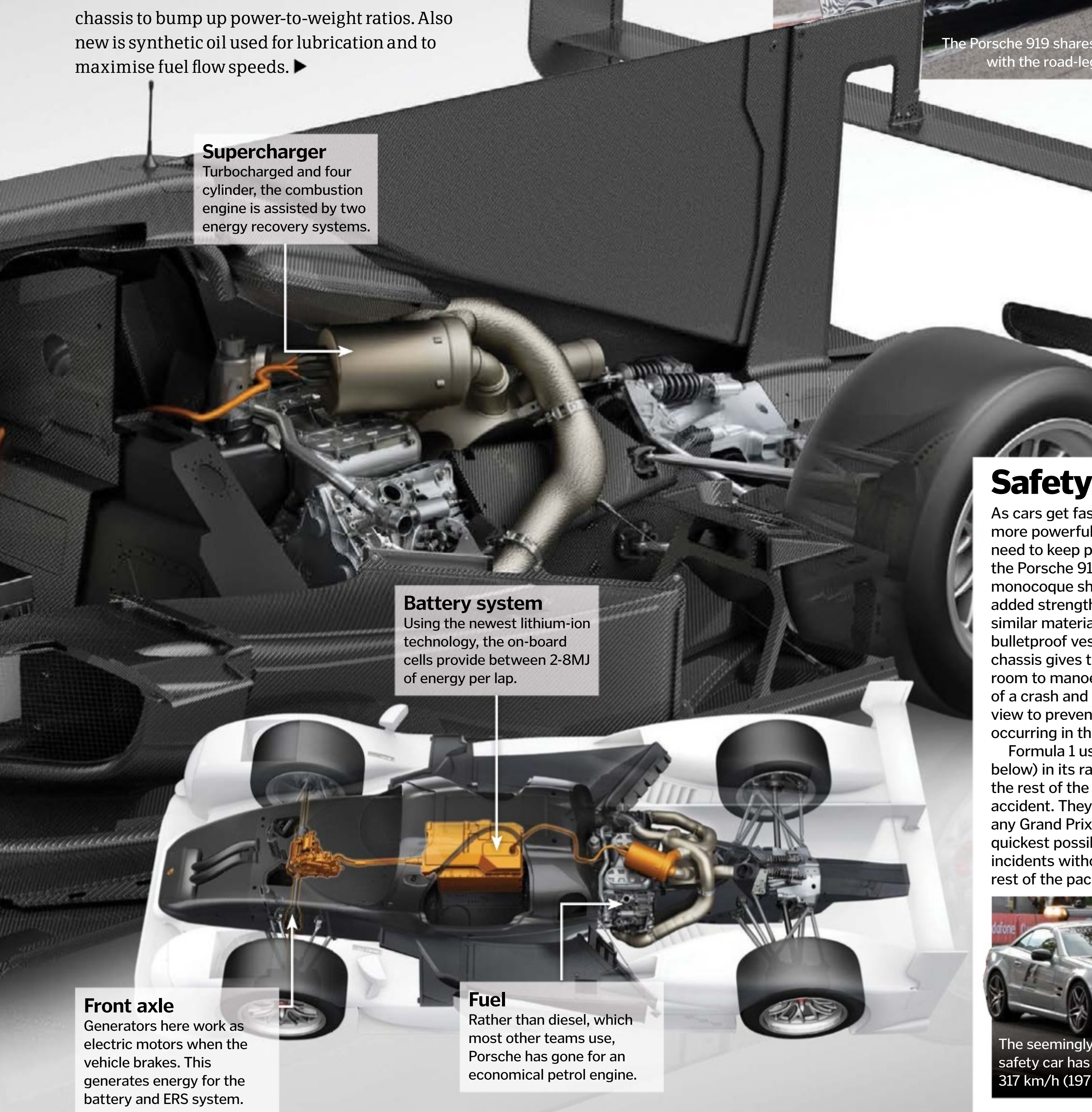
The statistics...

Porsche 919

Power: 370kW (500hp)
Drive type: Rear-wheel drive (four-wheel with ERS)
Length: 465cm (183in)
Width: 190cm (74in)
Weight: 870kg (1,918lb)
Height: 105cm (41in)
Engine: Turbocharged V4
Battery: Lithium-ion

as Lexan. Much like in Formula 1, NASCAR is also witnessing a raft of new regulations. From now on, there will be no ride height rules, which will allow the teams to incorporate as much downforce as they like to their cars. This will result in more grip, allowing faster and more side-by-side racing that will wow crowds. The new cars are part of NASCAR's 'Generation 6' that will see the wide use of carbon fibre and Kevlar chassis to bump up power-to-weight ratios. Also new is synthetic oil used for lubrication and to maximise fuel flow speeds. ▶


The Porsche 919 shares a lot of its hybrid tech with the road-legal Porsche 918 Spyder



Safety matters

As cars get faster, lighter and more powerful, safety procedures need to keep pace. For instance, the Porsche 919 has a closed monocoque shell, which has added strength granted by a similar material to that used in bulletproof vests. The enlarged chassis gives the driver more room to manoeuvre in the event of a crash and a better field of view to prevent an incident occurring in the first place.

Formula 1 uses a safety car (see below) in its races to help divert the rest of the racers if there is an accident. They are now integral to any Grand Prix as they allow the quickest possible response to incidents without disrupting the rest of the pack.


The seemingly dead-slow F1 safety car has a top speed of 317 km/h (197 mph)

▶ The rise of electric cars

Perhaps the most radical addition to the racecar roster this season is Formula E. Devised by the FIA (Fédération Internationale de l'Automobile), it began its inaugural season in September 2014. It is the world's first fully electric racing series and it includes ten teams racing through ten cities including London and Los Angeles.

The new competition is showing its potential by attracting big names like Sir Richard Branson who have entered a Virgin racing team. Famous drivers like ex-Formula One drivers Jarno Trulli, Bruno Senna and Jérôme d'Ambrosio also lent their support and test-drove the cars.

The cars themselves are pushing the boundaries of electric motorsport. They use a power-saving mode during the race to lengthen race times and a 'push-to-pass' system that gives a temporary max power boost to help overtaking. The batteries, as on hybrids, are rechargeable 800-volt lithium-ion cells. All the cars have identical specifications in the first season, but if a second is commissioned, constructors will be allowed the chance to modify the vehicles. Formula E's ultimate goal is to make electric vehicles (EVs) the norm, not just in racing, but in everyday driving too. Its official target is to put 52-77 million extra EVs on the road over the next 25 years. According to Formula E and FIA calculations, this will reduce annual CO_2 emissions by 900 million tons, save 4 billion oil barrels and save £20.7 billion ($34.4 billion) on healthcare costs due to the expected reduction in pollution levels. ▶

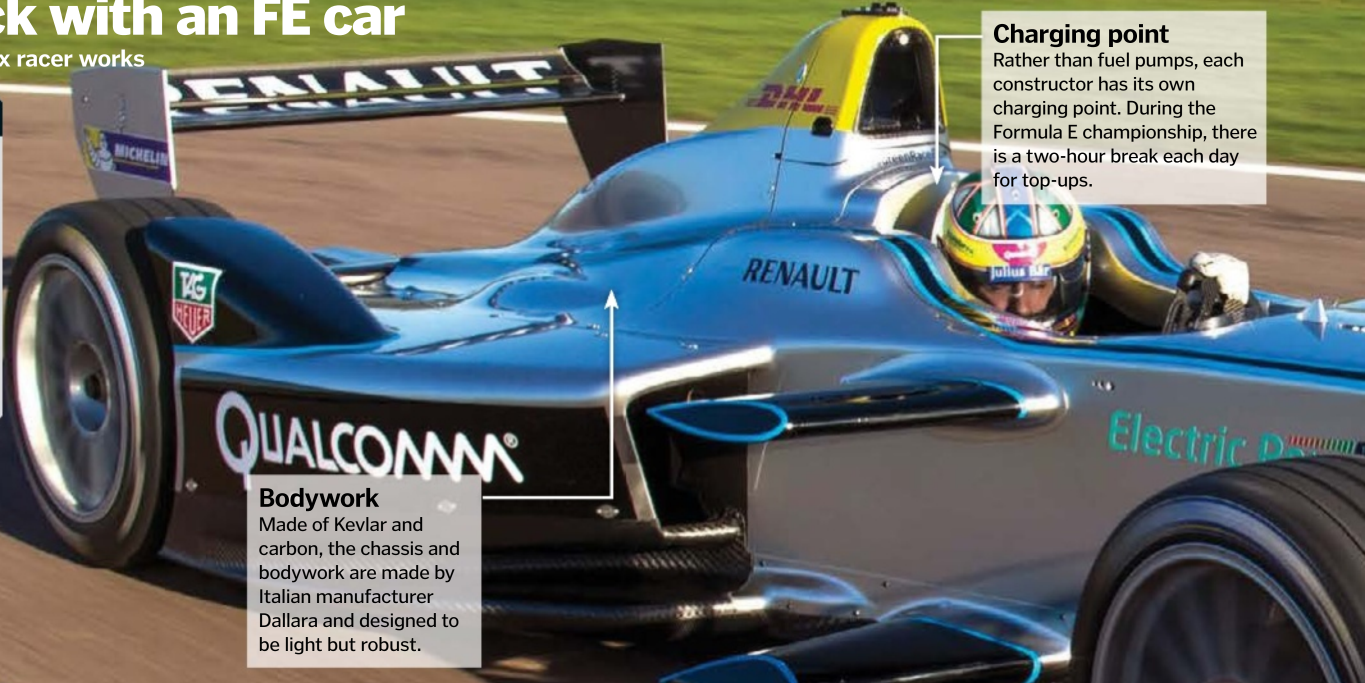
Game-changing electric car

Tesla sprang to attention in 2008 when it released the impressive Roadster, which effectively showed the world that electric cars could be workable, reliable and, above all, cool.

Now the new Model S and Model X are stepping things up a gear. The S looks like a saloon car but can still hit speeds of 209km/h (130mph) and has a range of around 483km (300mi). Meanwhile, the X is an SUV and will boast a battery of up to 85kW (114bhp).

On the track with an FE car

How an electric Grand Prix racer works



The statistics...

Formula E car

Max power: 200kW (270bhp)
Top speed: 225km/h (140mph)
Length: 500cm (197in)
Weight: 800kg (1,764lb)

Charging point
Rather than fuel pumps, each constructor has its own charging point. During the Formula E championship, there is a two-hour break each day for top-ups.

Bodywork
Made of Kevlar and carbon, the chassis and bodywork are made by Italian manufacturer Dallara and designed to be light but robust.

ON THE MAP

Formula E teams
1 Drayson Racing (UK)
2 China Racing (China)
3 Andretti Autosport (USA)
4 Dragon Racing (USA)
5 E.Dams (France)
6 Super Aguri Formula E (Japan)
7 Audi Sport ABT (Germany)
8 Mahindra Racing (India)
9 Virgin Racing (UK)
10 Venturi Grand Prix (Monaco)

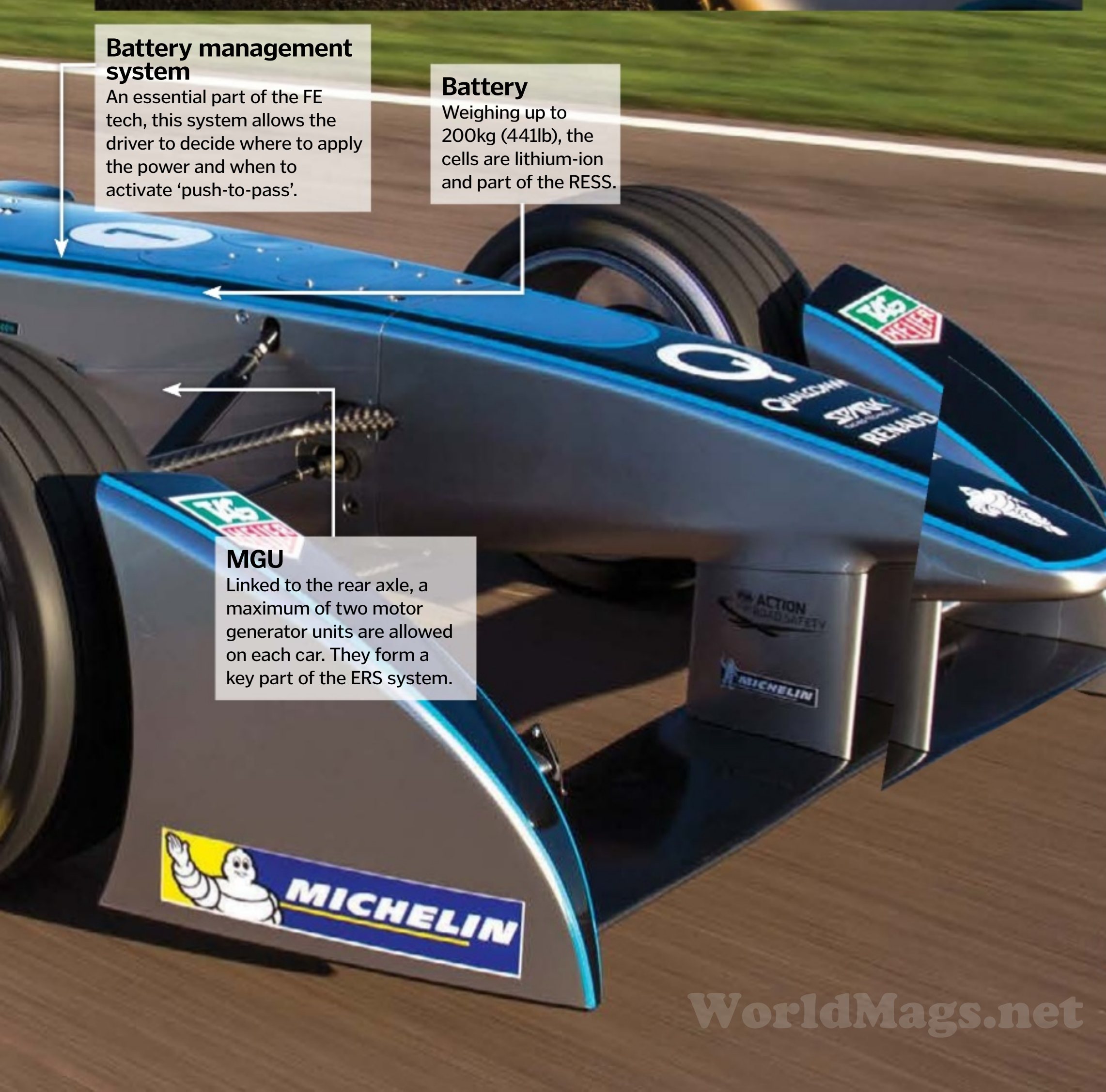
46YRS

OLDEST-EVER WORLD CHAMPION

Argentinian racing legend Juan Manuel Fangio became the oldest-ever Formula 1 champion after winning the 1957 German Grand Prix, when he was aged 46 years old.

DID YOU KNOW? *Hollywood actor Leonardo DiCaprio is a cofounder of Formula E team Venturi Grand Prix*

Formula E involves many companies working in Formula 1 and the electric cars' design is an obvious testament to the traditional racers



Battery management system
An essential part of the FE tech, this system allows the driver to decide where to apply the power and when to activate 'push-to-pass'.

Battery
Weighing up to 200kg (441lb), the cells are lithium-ion and part of the RESS.

MGU
Linked to the rear axle, a maximum of two motor generator units are allowed on each car. They form a key part of the ERS system.

The electric revolution

A revealing interview with Formula E CEO Alejandro Agag on the future of motorsport

Tell us what Formula E is all about.
Formula E is the world's first fully-electric racing series [and began] in Beijing in September 2014. For the first season, there are ten races all taking place on street circuits in the heart of cities around the globe. We have ten teams – backed by top names including Michael Andretti, Alain Prost, Sir Richard Branson and Leonardo DiCaprio – each with two drivers. We want to create a new and exciting racing series that will appeal to a new generation of motorsport fans.

Where did the idea for FE come from?
The idea for Formula E came from the FIA. In essence, the concept behind Formula E is to promote the electric-car industry and to act as a framework for research and development around EV technology. One of the biggest barriers preventing the uptake of electric cars are the stigmas attached to them. People don't see them as 'cool' or 'exciting' and they are worried about battery life and, of course, cost. Formula E hopes to [rectify] this and act as a catalyst for change.

How are FE cars made?
The Spark-Renault SRT_01E is a very sophisticated fully electric open-wheel racing car. It has been built and designed by French-based Spark Racing Technology together with a consortium of the leading names in motorsport including McLaren (powertrain & electronics), Dallara (chassis), Williams (battery design), Renault (system integration) and Michelin (tyres). For the first season, all the cars are identical but from season two teams will be able to build their own cars. It is this new technology that we eventually want to filter down into everyday electric road cars.

What does the future hold for FE?
We hope the future of Formula E is the future of motorsport. We also want the series to act as a catalyst to promote sustainability and make people think about the environment they live in – particularly in cities. Our aim is to appeal to the next generation of motorsport fans but also car buyers so that their first car is an electric one.

Despite being fully electric, a Formula E car can still generate about 80db

Coming to a car near you…

Taking a leaf out of motorsport's book, modern production cars are incorporating new technology with a racing pedigree. Two standout examples are the McLaren P1 and Ferrari LaFerrari. They use a similar version of the new ERS to enhance acceleration and both have had extensive modifications to their aerodynamics and materials.

Carbon fibre has been a mainstay in racing ever since it was attributed with saving F1 driver John Watson's life in 1981. The McLaren driver lost control and crashed into a barrier but the material's tough properties allowed him to escape unharmed. Since then, production cars have been hesitant to embrace the material due to its high cost and lack of continuous supply but it is starting to replace aluminium and other metals as the boundaries between racing and everyday cars increasingly blur.

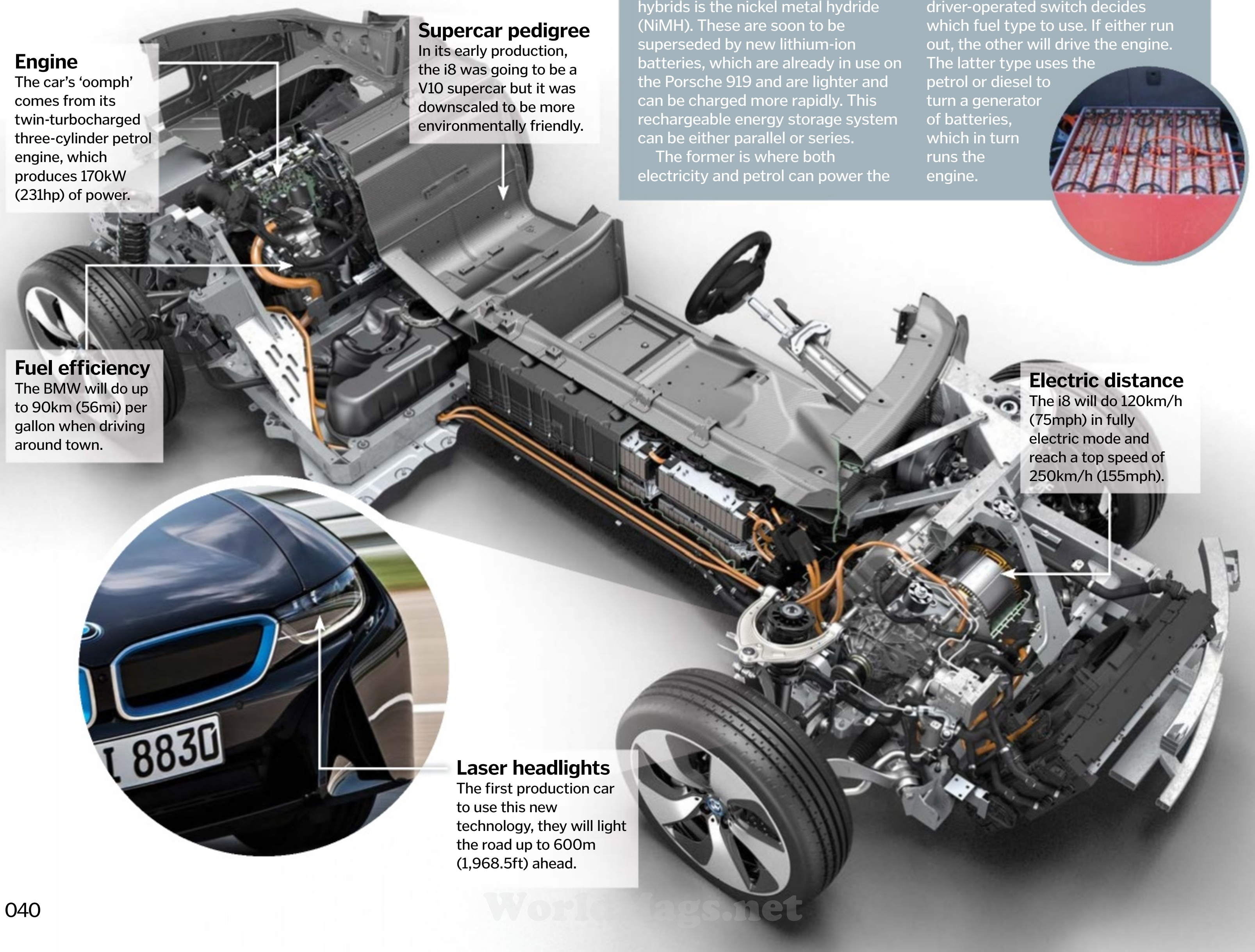
It might come as a surprise to many, but the Nissan DeltaWing – which competes in Le Mans and the United SportsCar Championship – shares its engine with the Nissan Juke. The Juke is an SUV and its engine was the blueprint for the racing DeltaWing. As both are turbocharged, this is a clear demonstration that today racecars and mass-produced cars can learn from each other. Tech that was once solely used for racing and out of reach for the public is now becoming much more familiar.

Many of the modern and upcoming releases were shown at the 2014 Consumer Electronics Show (CES) in January. For instance, the dashboard and panel display are also getting big upgrades. Google is looking to utilise its Android technology as a 'virtual cockpit' in new cars. Usually reserved for smartphones and tablets, the operating system will integrate your favourite apps into your car's system. It will include 4G, LCD panels and twin quad-core CPUs. The new Audi TT is pioneering the new systems and Honda and Hyundai have also registered an interest. A rival system known as UConnect is being used on the Dodge Viper.

Moreover, the age of CD players could be nearing an end. Known as 'Signal Doctor', the future system aims to have 'studio quality' songs for digital music players in cars.

Racing tech in road cars

We go under the hood of the new BMW i8



Next-gen batteries

The most common battery used in hybrids is the nickel metal hydride (NiMH). These are soon to be superseded by new lithium-ion batteries, which are already in use on the Porsche 919 and are lighter and can be charged more rapidly. This rechargeable energy storage system can be either parallel or series.

The former is where both electricity and petrol can power the engine separately. Usually, a driver-operated switch decides which fuel type to use. If either run out, the other will drive the engine. The latter type uses the petrol or diesel to turn a generator of batteries, which in turn runs the engine.

5 TOP FACTS
MAKING AN F1 CAR

Conceptual stage
1 An F1 car takes over five months and 300 designers to develop. Supercomputers are used to envision the finished vehicle and create a template for construction.

Tunnel run
2 Aerodynamics is tested on a 60 per cent scale version of the car. Racing situations are simulated to see how the racer will hold up in future competitions and events.

Materials
3 Lightweight but ten times stronger than steel, carbon fibre is an ideal composite material for F1 cars. First used in 1981, it is sterilised and pressurised in an autoclave.

Manufacture
4 As well as automatic machinery, the majority of an F1 car is handmade. The paint used has to fit weight and smoothness regulations as well as looking good.

Assembly
5 In the end, five copies of the finished chassis are created: one for each driver, two for the race-weekend backup cars and lastly a spare one for emergencies.

DID YOU KNOW? *In the UK, car tax is much lower on hybrid cars due to their lower CO2 emissions*

Perhaps the biggest state-of-the-art change, though, is the possibility of self-driving cars. At CES, BMW demonstrated a 2-Series and a 6-Series completing laps without any human intervention. The cars used ultrasonic 360-degree sensors to understand their surroundings and even drifted and powerslided on their run. This new equipment will aim to aid safety by helping the driver make key decisions on the road, such as lane discipline and parking.

There have also been further advances in hybrid cars, as well as alternatives to hybrids. French firm Renault, for example, has found a way to reduce CO_2 levels without using hybrid tech. Vice president of Renault's powertrain strategy, Marc Bodin, told us: "Hybrid, for us, is not at the right level of balance between cost and customer value at the moment." Renault, which has the lowest CO_2 emissions of Europe's car companies, is exploring alternative internal combustion engine (ICE) improvement and EV (electric vehicle) development. Both the Clio and Mégane models are at the same CO_2 level as a standard hybrid but less expensive for the customer. Bodin did concede, however, that the new emission targets in 2020 would require some sort of hybrid mechanism.

The BMW i8 (pictured below) looks to be a revolution in combining racing tech with low emissions. It has a CO_2 efficiency of A+, which is the highest band available in production cars, but can still reach speeds of 250 kilometres (155 miles) per hour and get from 0-100 kilometres (0-60 miles) per hour in 4.4 seconds!

New types of fuel are being developed too, such as compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), solar power and hydrogen. LNG has a higher storage density than fuels and is cleaner and cheaper than petrol while hydrogen can increase mileage by up to 25 per cent.

For example, the Honda Civic GX is the first production car to run on CNG, the Ford C-Max Solar Energi Concept utilises sunlight to get around and the Toyota FCV has a hydrogen fuel cell. The rise of these alternative fuels looks set to make future motoring greener than ever.

The statistics...
BMW i8

Max speed: 250km/h (155mph)
CO_2 emissions: 59g/km
Length: 469cm (185in)
Width: 194cm (76in)
Unladen weight: 1,490kg (3,285lb)
Height: 130cm (51in)
Electric range: 35km (22mi)

The BMW i8 has been in constant development since 2009's Vision EfficientDynamics concept car was presented

GPS to control your gears

First we had little more than local knowledge, then we had maps and then GPS systems came along. Now we have satellite-aided transmission, or SAT.

This new technology, pioneered by Rolls-Royce on its latest Wraith cars (below), calculates what is beyond the driver's line of sight. Whether it's around a corner or for the next motorway junction, SAT anticipates what's ahead and chooses the best gear for you. The system can be used in both production and racing cars and could increase lap times and fuel efficiency by preparing the car for what's around the next bend, though many would argue this should be down to the driver's skill rather than a computer.

Hybrid types

Mild hybrids
These permit the energy generated while braking to be recovered and temporarily stored. This provides the vehicle with additional power the next time it accelerates, which in turn leads to a significant fuel-consumption saving.

Micro hybrids
Cars that are powered by an internal combustion engine but are equipped with certain functions that use a battery for energy.

Full hybrids
Vehicles that are equipped with both an internal combustion engine and an electric motor, which allows them to run on electricity alone at low speeds, or to combine both sources to provide a power boost when accelerating.

Plug-in full hybrids
These are equipped with a battery that allows electricity drawn from the grid to be stored and then used to run for a short distance on electricity alone.

TECHNOLOGY

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Intelligent fingerprinting

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Lifesaving straws

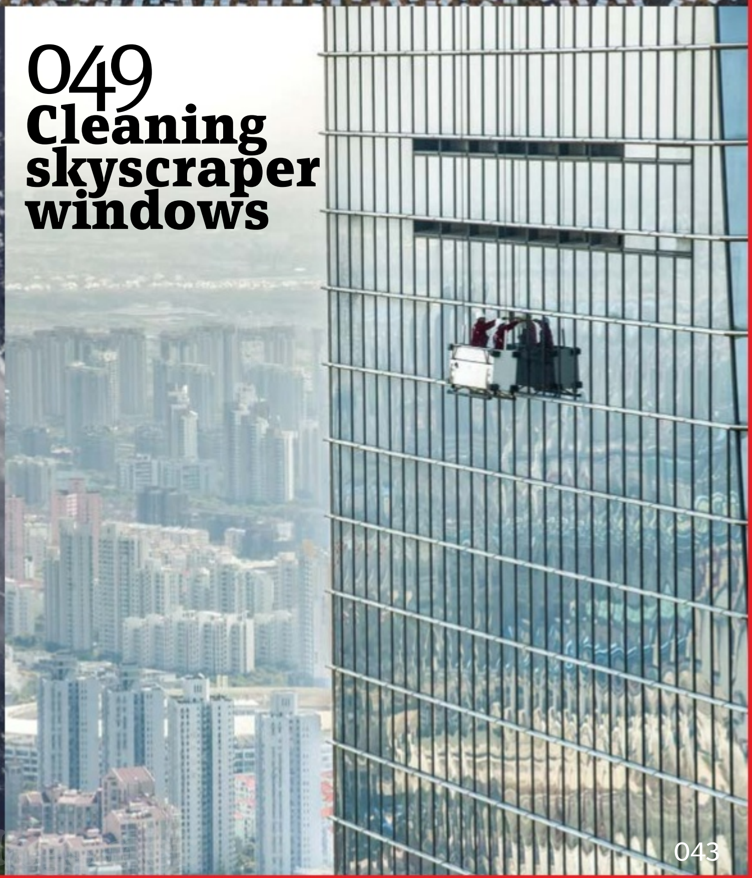
Bionic humans
044

063
Waterproof smarphones

060
Ivanpah Solar Power Facility

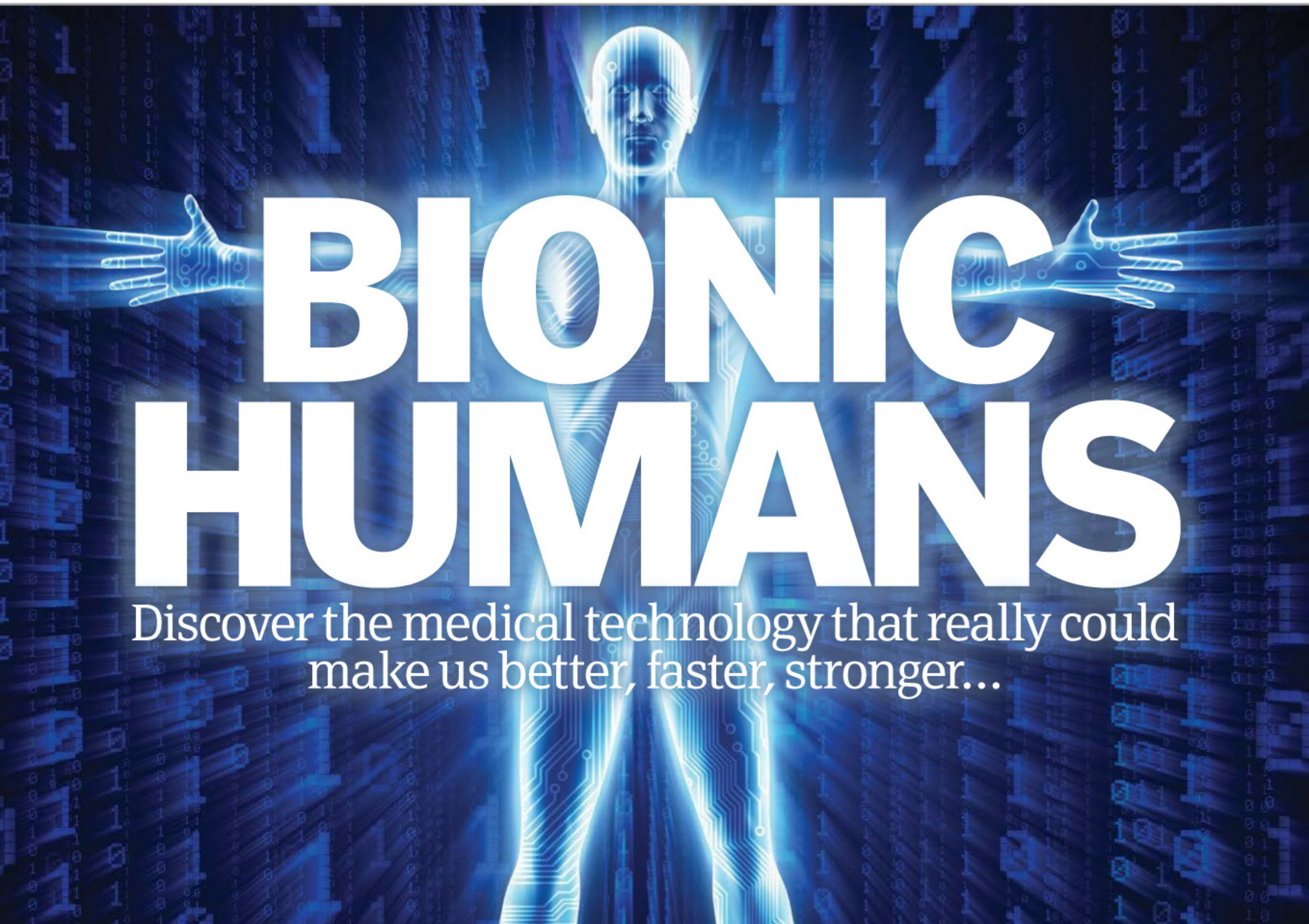
© Ivanpah Solar

050
Controlling the weather



049
Cleaning skyscraper windows

© Dreamstime



BIONIC HUMANS

Discover the medical technology that really could make us better, faster, stronger…

Bionics experts attempt to build mechanical and electronic devices to mimic biological functions. With the exception of the brain, the human body can essentially be broken down and rebuilt using a combination of mechanical, electronic and biological technologies.

A bionic limb strips human biology back to its constituent parts. Tough materials like aluminium and carbon fibre replace the skeleton, motors and hydraulics move the limb, while springs replace the tendons that store and release elastic energy. A computer controls motion and wires relay electrical signals, as nerves would have done in a real limb. Users are now even able to control these limbs with their minds (see 'The power of thought').

Technology is also in development to replace individual muscles and tendons following injury. The synthetic muscles are made from a polymer gel, which expands and contracts in response to electrical currents, much like human muscle. The tendons are made from fine synthetic fibres designed to imitate the behaviour of connective tissue.

The mechanical nature of limbs makes them excellent candidates for building robotic counterparts, and the same applies to the human heart. The two ventricles, which supply blood to the body and lungs, are replaced with hydraulically powered chambers. However, it's not just the mechanical components of the human body that can be replaced; as time goes on, even parts of the complex sensory system can be re-created with technology.

Cochlear implants, for example, use a microphone to replace the ear, while retinal implants use a video camera to stand in for the human eye. The data that they capture is then processed and transformed into electrical impulses, which are delivered to the auditory or optic nerve, respectively, and then on to the brain. Bionic touch sensors are also in development. For example, the University of California, Berkeley, is developing 'eSkin' – a network of pressure sensors in a plastic web. This could even allow people to sense touch through their bionic limbs.

Replacing entire organs is one of the ongoing goals of bionic research. However, breaking each organ down and re-creating all of its specialised biological functions is challenging.

If only part of an organ is damaged, it's simpler to replace the loss of function using bionics. In type 1 diabetes, the insulin-producing beta cells of the pancreas are destroyed by the immune system. Some

STRANGE BUT TRUE

LIMB LOSS CULPRIT

What is the number one cause of limb amputation?

A Car accident **B** Diabetes **C** Lightning

Answer:
Diabetes is the leading cause of lower limb amputation. High blood sugar damages the nerves and blood vessels in the feet, which can lead to ulcers and eventually gangrene.

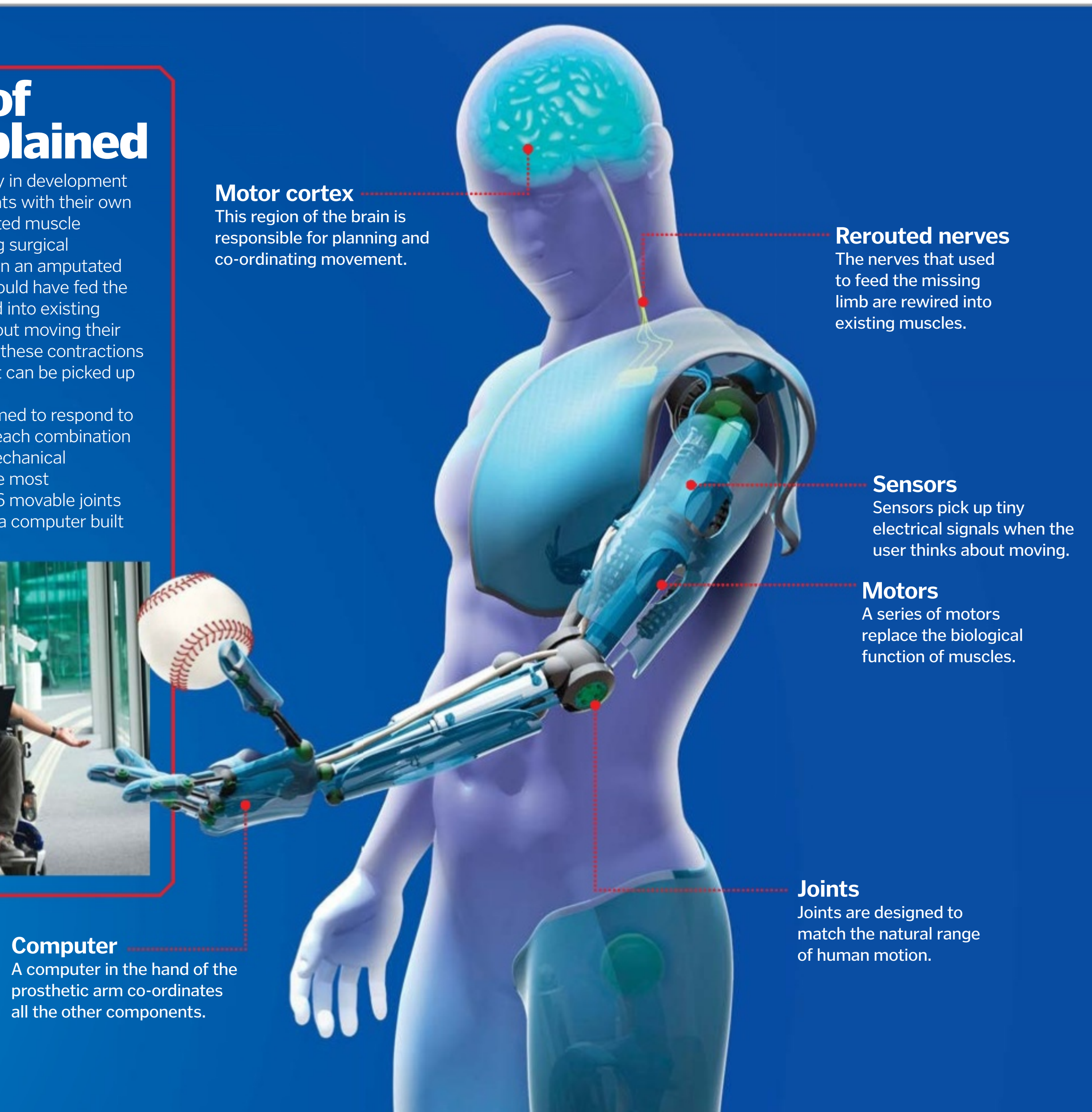
DID YOU KNOW? An artificial heart implant operation costs about £80,000 ($125,000) and £11,500 ($18,000) a year to maintain

The power of thought explained

Cutting-edge bionic limbs currently in development allow the user to control movements with their own thoughts. Technically called 'targeted muscle reinnervation' it's a groundbreaking surgical technique that rewires the nerves in an amputated limb. The remaining nerves that would have fed the missing arm and hand are rerouted into existing muscles. When the user thinks about moving their fingers, the muscles contract, and these contractions generate tiny electrical signals that can be picked up by the prosthetic.

The prosthetic is then programmed to respond to these muscle movements, taking each combination of signals and translating it into mechanical movement of the arm. Some of the most sophisticated have 100 sensors, 26 movable joints and 17 motors, all co-ordinated by a computer built into the prosthetic hand.

A scientist controls a wheelchair using a brain-machine interface



patients are now fitted with an artificial pancreas: a computer worn externally, which monitors blood sugar and administers the correct dose of insulin as required.

Entire organ replacements are much more complicated, and scientists are turning back to biology to manufacture artificial organs. By combining 3D printing with stem cell research, we are now able to print cells layer by layer and build up tissues. In the future, this could lead to customised organ transplants made from the recipient's very own cells.

Advances in bionics mean that already limbs are emerging that exceed human capabilities for weight bearing and speed. That said, the sheer complexity of our internal organs and how they interact means that it is not yet possible to fully replace man with machine. But maybe it's just a matter of time…

The right materials

One of the most important factors in biomedical engineering is biocompatibility – the interaction of different materials with biological tissues.

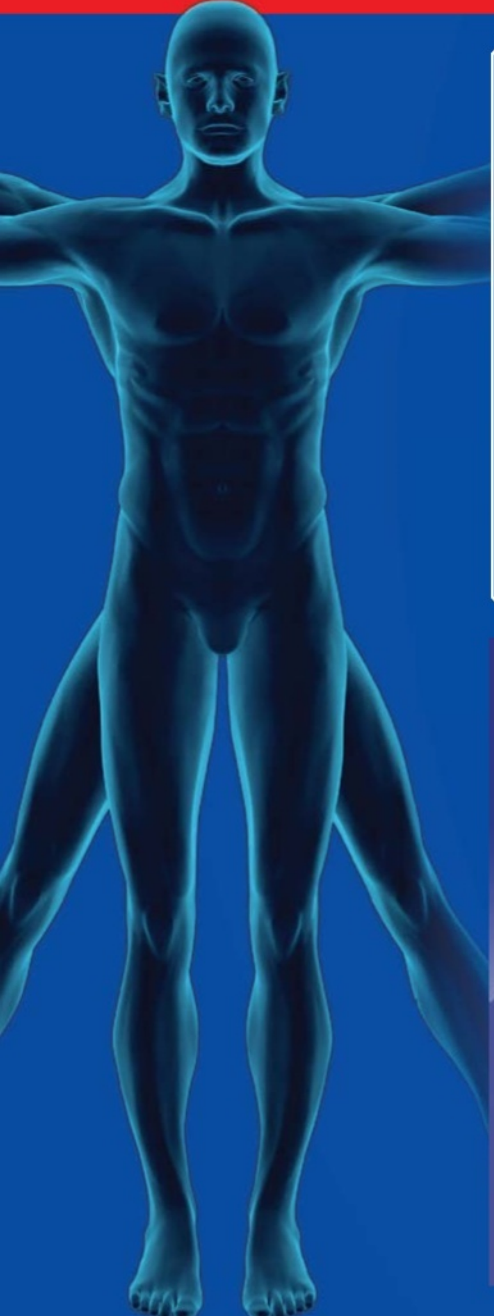
Implanted materials are often chosen because they are 'biologically inert' and as a result they don't provoke an immune response. These can include titanium, silicone and plastics like PTFE. Artificial heart valves are often coated in a layer of mesh-like fabric made from the same plastic used for soft drink bottles – Dacron. In a biological context, the plastic mesh serves as an inert scaffold, allowing the tissue to grow over the valve, securing it in place. Some scaffolds used in implants are even biodegradable, providing temporary support to the growing tissue, before harmlessly dissolving into the body.

Bionic limbs are worn externally, so their materials are chosen for strength and flexibility as opposed to biocompatibility. Aluminium, carbon fibre and titanium are all used as structural components, providing huge mechanical strength.

Artificial heart valves are often made from metal, such as titanium or stainless steel

Building a bionic human

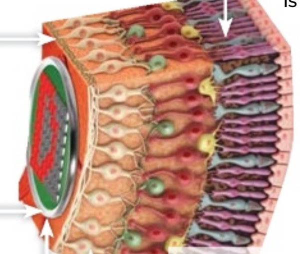
Advances in technology make it possible to build limbs with components that mimic the function of the skeleton, musculature, tendons and nerves of the human body. Meanwhile, the sensory system can be replicated with microphones, cameras, pressure sensors and electrodes. Even that most vital organ, the heart, can be replaced with a hydraulic pump. Some of the newest technologies are so advanced that the components actually outperform their biological counterparts.



Retinal implant

Argus II, Second Sight

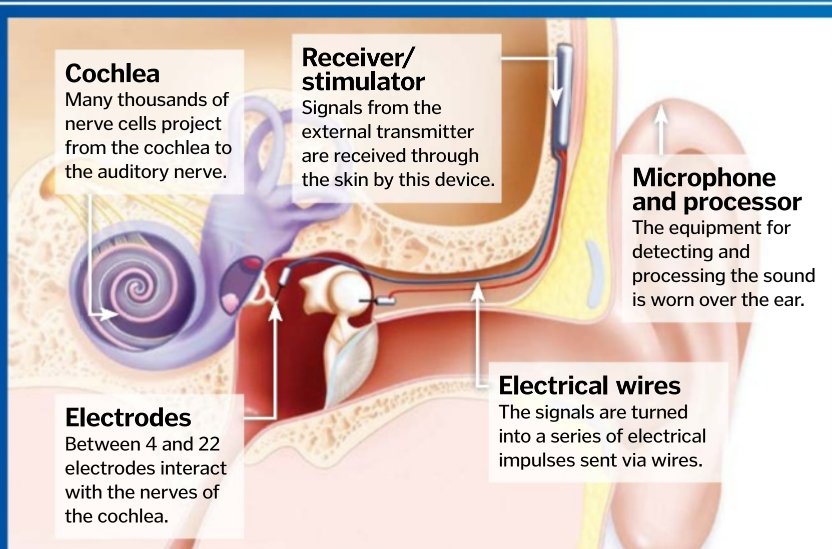
A camera mounted on a pair of glasses captures real-time images and transmits them wirelessly to an implant on the retina. The implant contains 60 electrodes and, depending on the image, will generate different patterns of electrical signals, which are then sent to the remaining healthy retinal cells. These cells are activated by the signals, and carry the visual information to the brain for processing.

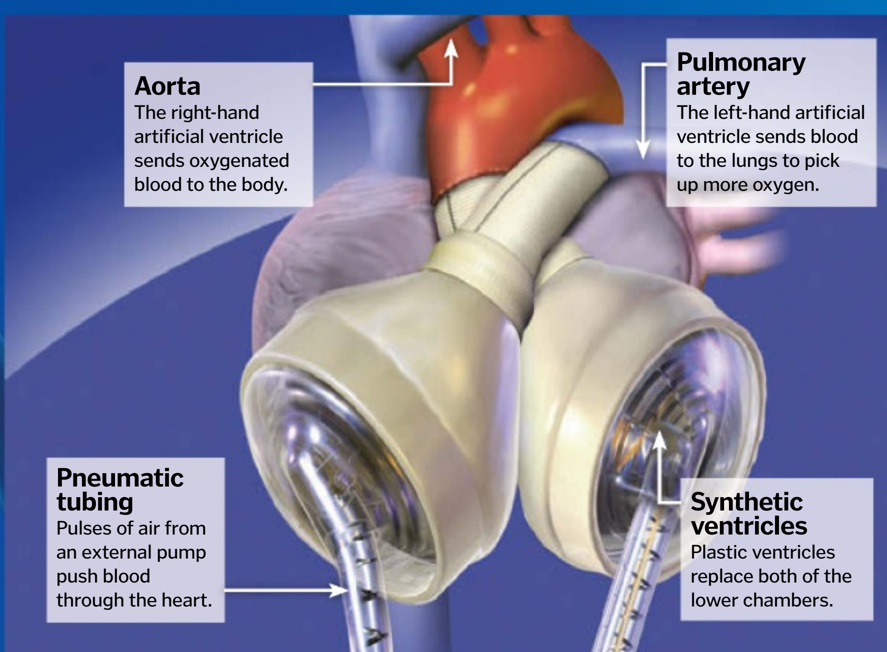


Cochlear implant

Nucleus 6, Cochlear

A cochlear implant has four main components. A microphone, worn near the ear, detects audio and transmits a signal to a sound processor. The processor then arranges the signal and sends it to a built-in transmitter. The transmitter passes the signal to an implanted receiver/stimulator, which transforms it into electrical stimuli for the electrodes. Finally these signals are relayed to the auditory nerve.





Artificial heart

Total Artificial Heart, SynCardia Systems

Plastic hearts can be implanted to replace the two ventricles of the heart. Plastic tubing is inserted to replace the valves, and two artificial chambers are also attached. The heart is then connected to a pneumatic pump worn in a backpack, which sends bursts of air to the chambers, generating the pressure that's required to pump blood around the body. Unlike donor organs, artificial hearts are available for implantation immediately so patients don't face long waits.

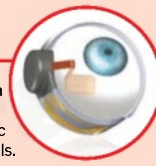
KEY DATES
BIONICS FIRSTS

500 BCE The first known mention of a wooden prosthetic limb, worn by a prisoner after his foot was amputated.

1957 The first cochlear implant is created. Sounds are unprocessed, but it does help with lip reading.

1982 The first successful artificial heart implant operation is performed at the University of Utah.

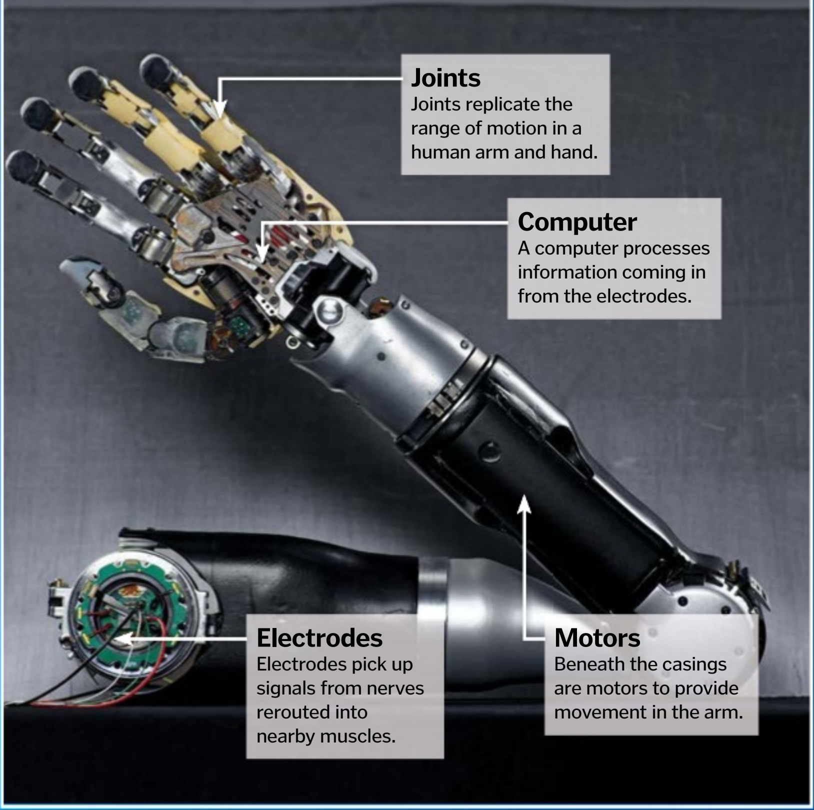
2011 The first artificial trachea transplant takes place in Sweden, using a synthetic scaffold coated in stem cells.



2013 The Argus II retinal implant is licensed, enabling patients with retinitis pigmentosa to see again.

DID YOU KNOW? *In 1812 a prosthetic arm was invented that could be moved using cables attached to the opposite shoulder*

Bionic arm



Bionic limbs

Prosthetic limbs have come on leaps and bounds in the past couple of decades. They still retain characteristic features, such as an internal skeleton for structural support and a socket to attach to the amputation site, however the most innovative models are now able to reproduce, or even exceed, biological movements. Motors are used in place of muscles, springs instead of tendons and wires instead of nerves.

The movement of many prosthetics is controlled externally, using cables attached to other parts of the body, or using a series of buttons and switches. New technology is emerging to allow the user to move the limb using their mind (see 'The power of thought'). The next logical step in this process is developing technology that enables the prosthetic limb to sense touch, and relay the information back to the user. DARPA-funded researchers have developed FINE, a flat interface nerve electrode (see below left) which brings nerves into close contact with electrodes, allowing sensory data to pass to the brain.

The future of bionics

1 3D-printed organs
3D printing is the future of manufacturing and biologists are adapting the technology in order to print using living human cells. The cells are laid down in alternating layers alongside a transparent gel-like scaffold material. As the cells fuse, the scaffold disappears.

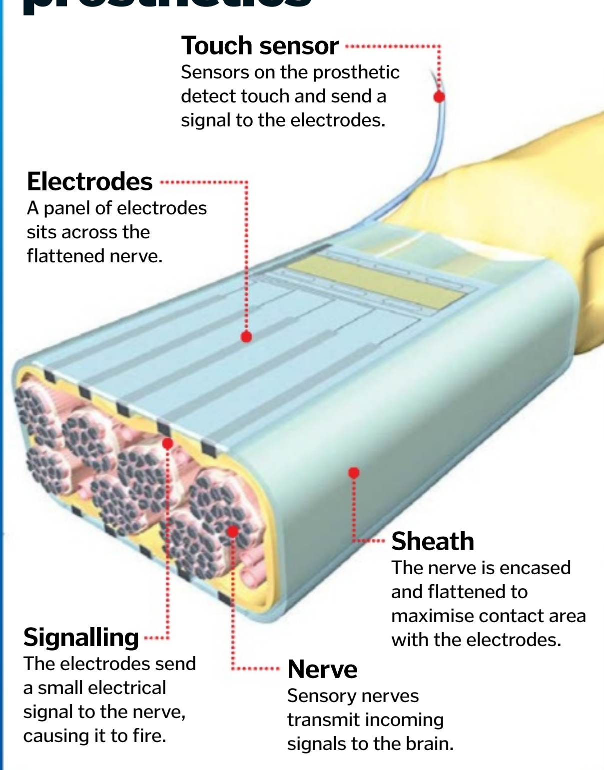
2 Ekso skeleton
Ekso Bionics has made bionic exoskeletons to allow people with lower limb paralysis to walk. Ekso supports their body and uses motion sensors to monitor gestures and then translate them into movement.

3 Artificial kidney
The University of California, San Francisco, is developing a bionic kidney. At about the size of a baseball, it contains silicone screens with nano-drilled holes to filter blood as it passes. It will also contain a population of engineered kidney cells.

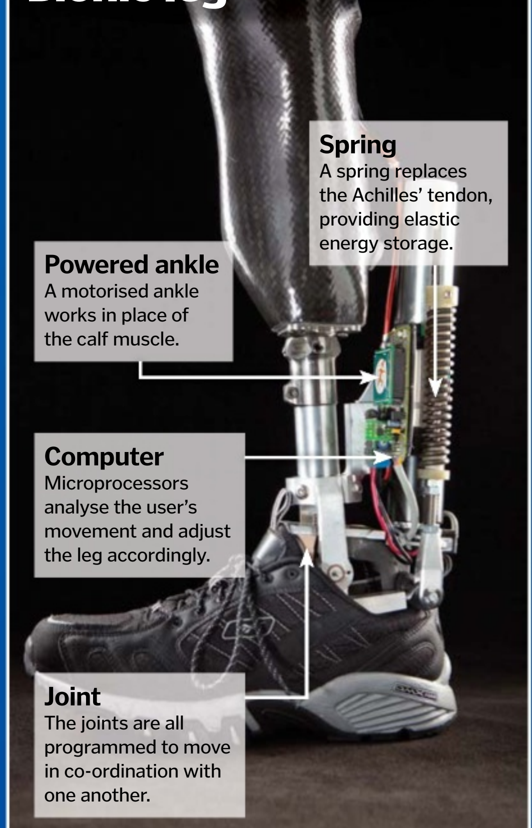
4 Man-made immunity
Leuko-polymersomes are plastic 'smart particles' that mimic cells of the immune system. They are being designed to stick to inflammatory markers in the body and could be used to target drug delivery to infections and cancer.

5 Robotic blood cells
The Institute for Molecular Manufacturing is developing nanotechnology that could increase the oxygen-carrying capacity of blood. Known as respirocytes, the cells are made atom by atom – mostly from carbon.

Touch-sensitive prosthetics



Bionic leg

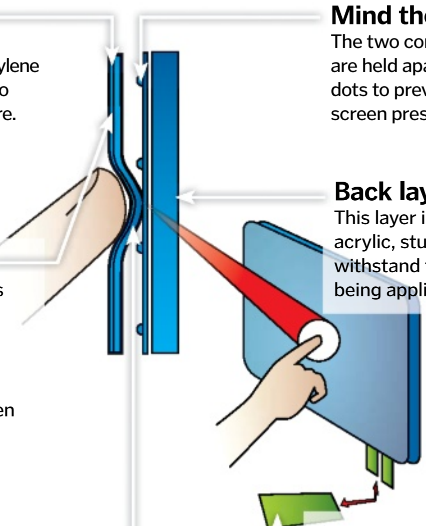


Touchscreen interaction

This tactile technology comes in two main flavours – resistive and capacitive – but what are the key differences between them?

Resistive screen

Tougher, cheaper and simpler, resistive touchscreens are widely used in our everyday devices



Top layer
This is typically made of scratch-resistant polyethylene (PET) which is designed to flex slightly under pressure.

Mind the gap
The two conductive layers are held apart by spacer dots to prevent accidental screen presses.

Back layer
This layer is glass or acrylic, sturdy enough to withstand the pressure being applied at the front.

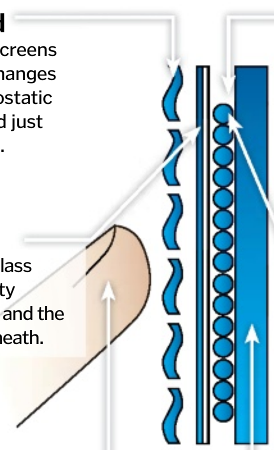
Resistance
Resistive touchscreens are made of several layers, each with a conductive indium tin oxide (ITO) coating. A current passed between these layers creates electrical resistance.

Push technology
When pressed with a finger or stylus, the two ITO coatings below meet, completing a circuit.

Controller
An image-processing controller recognises changes in the electrical field and translates these into instructions.

Capacitive screen

More accurate and much more versatile, capacitive has to be today's touchscreen of choice



Invisible field
Capacitive touchscreens monitor minute changes in the local electrostatic field being created just above the surface.

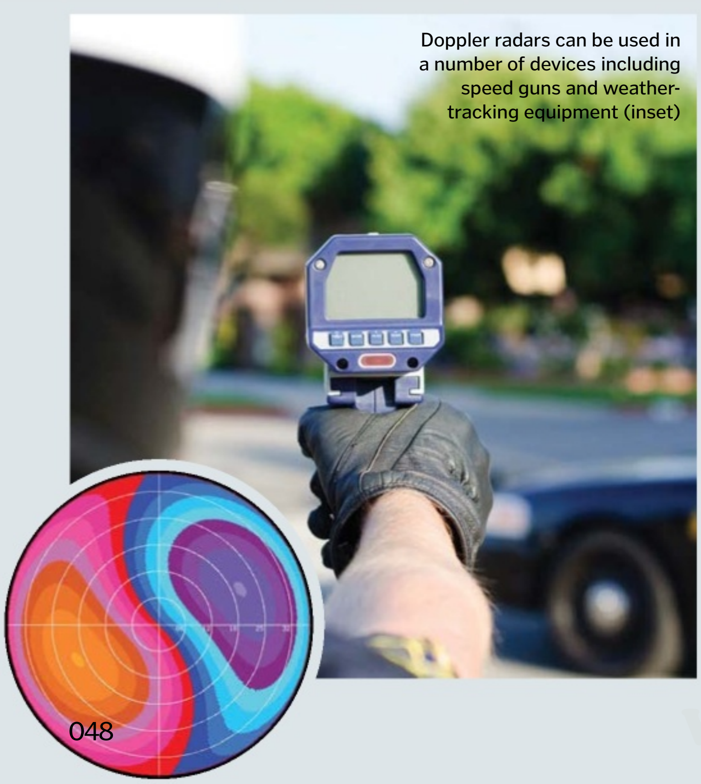
Charged space
The screens are made up of spaced layers of glass coated with a fine film of indium tin oxide (ITO). A minute charge is applied to this space.

Glass layer
Touching the top glass creates conductivity between your skin and the charged space beneath.

On the grid
Some touchscreens use technology where one layer is etched with a grid pattern of electrodes for even greater precision.

Human touch
Capacitive touchscreens respond to the unique conductive qualities of the skin. They rarely work with gloves (except special capacitive ones).

Behind the screens
Behind every electrode lies an embedded microcontroller. Nanosecond response times enable today's smartphones and tablets to interact almost instantly to our touch.



Doppler radars can be used in a number of devices including speed guns and weather-tracking equipment (inset)

Doppler radars

Learn about the technology that tracks the motion of objects using echoes and the Doppler effect

Radar equipment produces electromagnetic waves, such as microwaves or radio waves. The waves hit the target and are reflected back towards the detector. In a similar way to echolocation in bats, the time it takes for the wave to reflect back can be used to determine the distance.

By sending out waves of a known frequency, the radar can also be used to determine the velocity of the target. When a police car drives past, the siren sounds high-pitched as it heads towards you, and rapidly changes to a lower pitch once it has zoomed past – this is known as the Doppler effect. If the radar target is moving towards the detector the frequency of the waves arriving at the detector is increased, and if the target is moving away, the frequency is decreased, allowing its velocity to be calculated.

Doppler radar has a variety of applications. The police use handheld radar guns to determine the speed of passing vehicles, while military planes contain pulse radars for targeting. Large-scale Doppler radar is also used to scan the atmosphere to follow aircraft, or to track and predict the weather.

How are skyscraper windows cleaned?

Discover how the tallest buildings on the planet keep up appearances

There are three main factors involved when it comes to cleaning skyscraper windows: cleaning equipment, cleaning mechanism technology and environmental considerations.

Due to the epic heights and natural factors like wind involved in the operation, every cleaner is equipped with a harness, descent and safety rope, rope protector, rope-grabbing tool, descent mechanism, lanyard and suction cups. Together these tools enable the worker to negotiate a building's vertical façade at speed, while attached to a roof-mounted anchor. This anchor allows cleaners to descend in 'drops' – the measurement of one vertical cleaning operation from roof to the below floor or platform – without fear of falling.

When group work is necessary, a cleaning mechanism will be employed (see boxout on the right for more information). These mechanical gantries enable teams of cleaners to work in unison and are powered by roof-mounted hydraulic and pneumatic support systems. The ascending and descending of the gantries is dictated by a control panel, but as a backup additional control systems are typically placed on the roof of the building.

Lastly, when cleaning skyscraper windows, workers must constantly be vigilant of potentially deadly environmental factors – the chief one being wind. At the high altitude of skyscrapers, wind flow is not just fierce but highly turbulent, with the building acting as a disrupter to the general environmental flow. These gusts can blow cleaners off course, cause tools to be dropped (a risk to anyone passing below) and render gantries unusable. Luckily, many modern skyscrapers – such as the world's tallest, the Burj Khalifa in Dubai – are now being designed to smoothly redirect winds around their structures and prevent the buildup of vortices and turbulence.

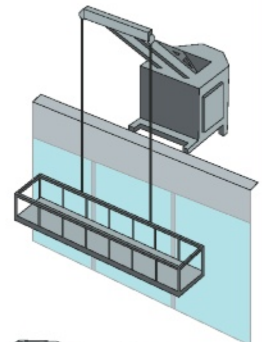
A head for heights is a must for any skyscraper window cleaner!

High-altitude window cleaning

Here are four of the most common skyscraper cleaning mechanisms

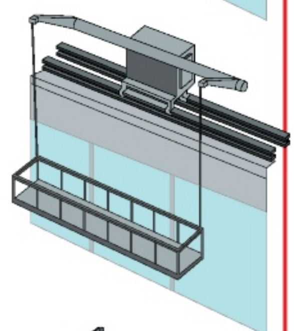
Boom

One of the most popular cleaning systems historically, the boom lets a building's façade be accessed easily by a large team. The boom system is permanent and can be operated on-gantry or off.



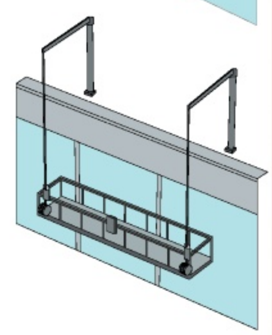
Carriage

These rail-mounted carriages enable gantries to cover larger areas of a building's façade due to their ability to move left and right. As with booms, they are permanent structures and cannot be moved around the building.



Portable davit

The cheapest and simplest solution for cleaning skyscraper windows, portable davits move between fixed bases on a roof, enabling access to different sides of the edifice with just one davit-based system.



Bosun's chair

A more modern development in skyscraper window cleaning technology, the bosun's chair gives a single cleaner access to a tall building's windows from a safe seated position. They are ideal for tight areas and use over long periods.

CONTROLLING THE WEATHER

DISCOVER HOW WE MAKE RAIN AND THE AMBITIOUS PLANS BEING HATCHED TO TACKLE CLIMATE CHANGE

Superhero Storm in the *X-Men* comics can conjure rain, end droughts and create hurricanes with the power of her mind. Now, scientists and meteorological technology are opening more and more opportunities for us mere mortals to manipulate weather and Earth's climate.

In 2009, Chinese meteorologists from the Beijing Weather Modification Office claimed to be responsible for the city's earliest snowfall since 1987. Around 16 million tons of snow reportedly fell over drought-afflicted northern China after workers fired rockets carrying pellets of silver iodide into heavy clouds.

The rockets were cloud seeding, a process invented in the late-Forties. Supporters claim it can reduce hail damage, increase rainfall and disperse fog among other things. There are cloud-seeding projects in at least 20 countries worldwide, from Israel to Australia; in 2003, in the US alone, ten states were conducting at least 66 cloud-seeding programmes. In China, around 32,000-35,000 people are employed in the weather modification industry.

The big question in cloud seeding is: how effective is it? A 2003 US National Academies report concluded there was no concrete scientific proof it worked. According to Professor Michael Garstang from the University of Virginia, who chaired the report, the situation hasn't changed much since; there remains "a lack of definitive evidence," he says.

Even cloud-seeding supporters admit it doesn't currently lead to a huge rise in rain and snowfall. "It doesn't increase precipitation by 50 per cent in most cases," says Bruce Boe from Weather Modification Inc, a private weather control company based in North Dakota, USA.

US enthusiasm for weather modification research waned in the late-20th century, with funding falling to less than five per cent of its Seventies peak. But there are signs of fresh interest in the field. The US National Science Foundation (NSF) is funding a cloud-seeding project in the Wyoming mountains, operated by Weather Modification Inc. New technology, such as advanced computer models and radar instruments that can see inside clouds is driving the resurgence of interest, says Boe: "We're bringing a lot of new tools to bear on the question. These tools weren't available before and they're starting to bear fruit."

The Wyoming project, launched in 2005, uses aircraft-mounted radar and ground-based

5 TOP FACTS MYTHS BUSTED

Geoengineering is ready
1 Today's geoengineering ideas are untested or small-scale experiments. Cooling Earth by 1°C (1.8°F) would require a minimum five years of military-scale effort.

One tech is enough
2 No single 'magic technology' can cool the Earth. Future geoengineers might use many fixes, like reflective buildings, a space-based deflector and encouraging reforestation.

It solves climate change
3 Geoengineering doesn't stop greenhouse gas emissions – the root cause of man-made climate change. It's a 'plaster', pausing harmful warming to give us time to cut emissions.

We can't create rain
4 There's emerging evidence that cloud seeding *can* make rain. An Australian project in 2005-2009 found that rainfall increased in suitable clouds by an average 14 per cent.

It's all a conspiracy
5 There's no scientific evidence behind claims that HAARP, a US facility studying Earth's ionosphere, is a secret conspiracy for creating hurricanes as weapons.

DID YOU KNOW? *A global survey in 2010 found 72 per cent of us supported research into reflecting sunlight to cool the planet*

instruments. It tests the effectiveness of seeding winter orographic clouds – which are cold clouds formed when air rises over mountains – with silver iodide.

"In the mountains of the American West, these types of storms are the main target for cloud seeding. Often the clouds are not efficient at generating snow, so cloud seeding is used to enhance snow production," says Dan Breed from the US National Center for Atmospheric Research (NCAR), who is evaluating the project.

Another aim of the experiment is to increase snowfall by perhaps ten per cent a year, building up the winter snowpack so it's available for use. The extra water running off the mountains each spring would be worth an estimated £1.5-3 million ($2.4-$4.9 million).

Cloud seeding affects the weather in a local region, but there are other technologies being devised to alter climate on a much bigger scale. Space mirrors and giant floating hosepipes might sound far-fetched, but they're two proposals for geoengineering. Geoengineering is deliberate global modification of Earth's climate to counter man-made climate change.

Geoengineering may sound impossible, but serious scientists are investigating how it might cool down the planet. In the last few years, billionaire Bill Gates reportedly donated £2.8 million ($4.5 million) to geoengineering research, and the UN IPCC report, a summary of what most scientists agree we know about climate change, mentioned geoengineering for the first time this year.

Geoengineering is essentially 'Plan B' in case we reduce greenhouse gas emissions 'too little, too late' to avoid dangerous climate change, argues a 2009 report by the UK's Royal Society. A temperature rise of just two degrees Celsius (3.6 degrees Fahrenheit) could melt the Greenland ice sheet and cause a long-term sea level rise of seven metres (23 feet). That's enough water to submerge both London and Los Angeles.

To avoid this wide-scale warming, we'd need to cut global carbon dioxide emissions by 50 per cent of 1990 levels by 2050, according to the Royal Society. Yet emissions are still rising – by 1.4 per cent during 2012. Even if we cut carbon emissions today, temperatures will continue rising for decades. The climate system is like an oil tanker – ie slow to turn around.

Dr Hugh Hunt is an engineer from Cambridge University working on SPICE (Stratospheric Particle Injection for Climate Engineering) – a UK government-funded geoengineering research project: "We don't know what the scale of unabated climate change will be," he says. "You've got to think in advance what emergency measures you might need, and then hope you won't need them."

There are two types of geoengineering. Solar radiation management (SRM) cools the Earth by reflecting the Sun's heat back into space, while carbon dioxide removal (CDR) scrubs CO_2 – the primary greenhouse gas causing man-made climate change – from the atmosphere.

Examples of SRM include space mirrors, injecting sulphate aerosols into the atmosphere through giant hosepipes and painting urban roofs white. One idea uses cloud seeding to make clouds more reflective. Fleets of unmanned barges could sail the oceans, spraying clouds with saltwater. Salt particles should create more water droplets in the clouds, whitening them. Proposals for CDR include fertilising tiny marine plants with iron, growing new forests or fast-growing crops and burying charcoal, all of which lock up CO_2 and remove it from the air. Most geoengineering proposals remain concepts at this stage. "We can do very little right now because the ▶

Geoengineering plans include ideas for orbiting sunlight reflectors in space

Special barges could send up sea salt to whiten clouds and help reflect sunlight

Cloud-whitening barge © John MacNeill Illustration

New technology has led to a resurgence in cloud-seeding projects

Weather-changing tech in action

Discover the machines and techniques capable of adapting Earth's climate

Space mirrors

A giant sunshade made of tiny mirrors could be put into orbit to cool the Earth. Taking decades and trillions of dollars to deploy, its effect on our weather is unknown and it would not stop the oceans acidifying.

Reflective buildings

Painting roofs white and brightening roads/pavements should help bounce the Sun's heat back into space and cool the Earth, but some scientists believe white roofs could reduce cloud formation and increase warming.

Enhanced weathering

This would involve spreading crushed olivine – a silicate mineral – over agricultural land, which chemically reacts with CO_2 to produce alkaline limestone; this could then be used in the ocean to reduce acidity. A simple idea, but would require huge mining and chemical plants.

Artificial trees

These towering machines would scrub carbon dioxide from the air, turning it into liquid that can be stored in porous rocks beneath the oceans. Millions of artificial trees would be needed and the CO_2 needs storing for millions of years.

Reflective crops

Certain crops, shrubs and grass reflect more sunlight back into space than others. This would be cheap to implement, but needs a huge land area and has unknown effects on food prices, plant growth, disease and drought resistance.

Biochar

Biochar is charcoal produced by 'cooking' plants or manure with little or no oxygen. It is decay-resistant and can store carbon in soil for thousands of years. Useful on a small scale, but growing biochar crops conflicts with the demand for food and biofuel production.

Volcano balloons

Hosepipes attached to giant helium balloons would spray particles high into Earth's atmosphere to mimic the cooling effect of volcanic eruptions. For example, aerosols released by the 1991 Mount Pinatubo eruption cooled global temperatures by an average 0.5°C (0.9°F). The proposed balloons would be the largest and tallest man-made structures in history.

1 Helium balloon

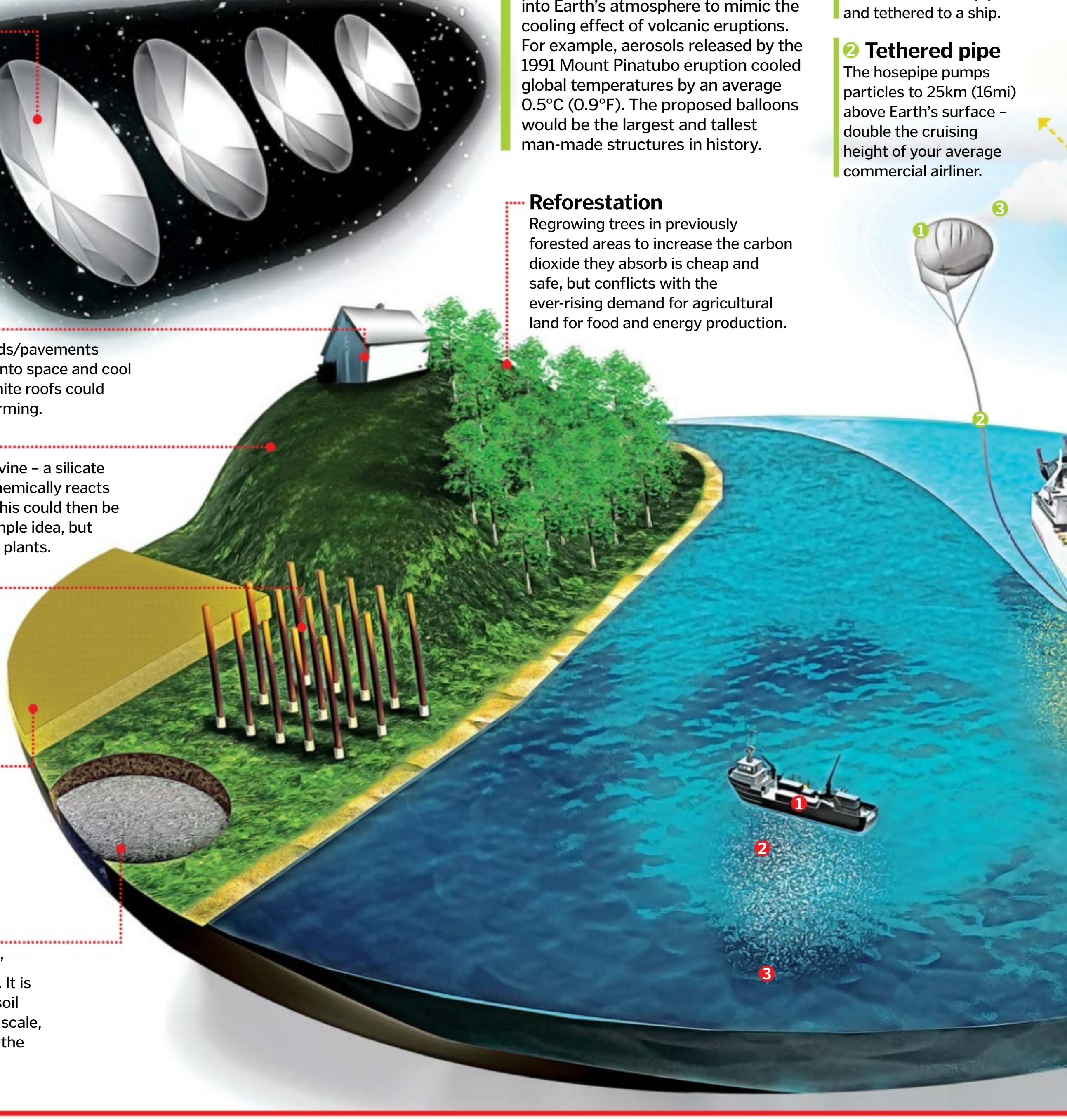
A helium balloon the size of a football stadium is attached to a hosepipe and tethered to a ship.

2 Tethered pipe

The hosepipe pumps particles to 25km (16mi) above Earth's surface – double the cruising height of your average commercial airliner.

Reforestation

Regrowing trees in previously forested areas to increase the carbon dioxide they absorb is cheap and safe, but conflicts with the ever-rising demand for agricultural land for food and energy production.



technology hasn't been developed to intervene on a planetary scale," notes Dr Andy Parker, a researcher into solar geoengineering from Harvard University.

Still, there are a few examples of outdoor field tests. The SPICE project included a plan, later abandoned, to pump water one kilometre (0.6 miles) vertically through a pipe attached to a helium balloon. Its aim was to test the feasibility of squirting sulphate aerosols into the sky through a giant hosepipe. "We don't know if it's technically possible," continues Dr Hunt. "No one has built a 20-kilometre (12-mile) pipe that goes vertically upwards." The questions are: can we build and launch a balloon big enough, and secondly, can we build a pipe strong enough?

Other geoengineering proposals rely on pre-existing technology. Fertilising oceans with iron, for example, has already happened on a small scale although not necessarily legally. It needs lots of tanker ships, chemical plants and iron. "There's nothing technically difficult about that," says Professor Andy Ridgwell from Bristol University.

It would take hundreds of years to see results from iron fertilisation and other CDR technologies though. They rely on slow natural processes, such as fertilising tiny marine plants that transport carbon into the deep ocean when

KEY DATES
MAN-MADE WEATHER

1891 Rainmaker Robert Dyrenforth tries proving noise causes downpours by exploding dynamite kites over Texas.

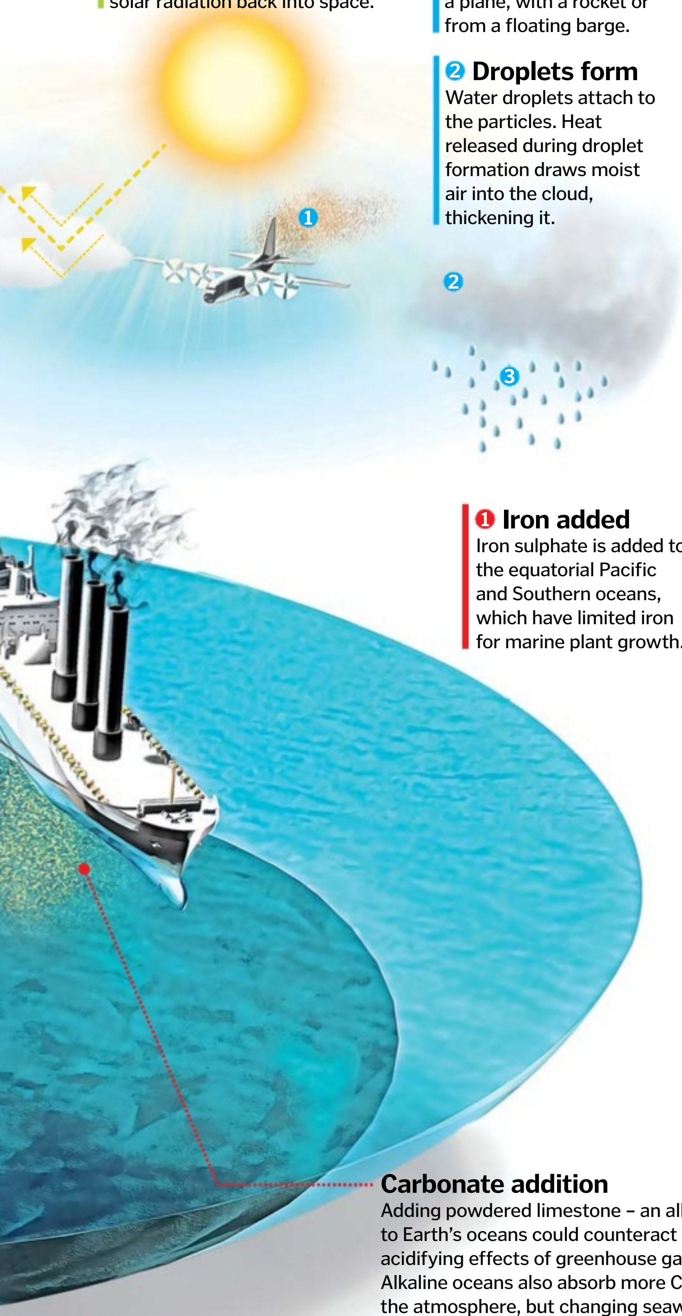
1946 Vincent Schaefer performs the first cloud-seeding experiments, dropping dry ice pellets into clouds.

1952 34 die in a flood in Lynmouth, England. The UK cloud-seeding Operation Cumulus is blamed.

1967 Operation Popeye, a secret US cloud-seeding project, seeks to deluge enemy troops in Vietnam.

2008 The Chinese government tries to prevent rain at the 2008 Beijing Olympics by launching 1,104 rockets.

DID YOU KNOW? *Global temperatures could rise by over 1°C [1.8°F] by the year 2100, even if we reduce carbon emissions*



3 Spray of particles
The hosepipe squirts the particles into the stratosphere, scattering solar radiation back into space.

1 Clouds seeded
Silver iodide or salt is sprayed into clouds from a plane, with a rocket or from a floating barge.

2 Droplets form
Water droplets attach to the particles. Heat released during droplet formation draws moist air into the cloud, thickening it.

Cloud seeding

Cloud seeding is a technique for man-made rainmaking already used around the world to varying degrees of success. Rainfall naturally occurs when water droplets attach to sand, dust or salt particles. Cloud seeding squirts extra particles into clouds to spawn new raindrops. Salt is used in warm tropical clouds, while silver iodide is added to cold clouds to create extra ice crystals.

Some scientists believe cloud seeding can brighten clouds to counteract climate warming too. The extra particles make the clouds denser, whiter and more reflective, deflecting more sunlight back into space.

3 Rain falls
The droplets or ice crystals collide, growing bigger and heavier until eventually they fall as precipitation.

1 Iron added
Iron sulphate is added to the equatorial Pacific and Southern oceans, which have limited iron for marine plant growth.

Ocean fertilisation

Marine plant life is at the core of the ocean food chain. The plants are a source of food for other marine life, and happen to take up and bind carbon dioxide as well. They rely on the availability of nutrients to grow – most commonly nitrogen or iron. Fertilising the oceans with iron sulphate is believed to increase their growth and reproduction, which would in turn increase the amount of carbon dioxide they take up, reducing the effect of carbon emissions. Some scientists also believe that the increased marine plant life may increase the number of fish in the sea, in turn improving our food supply.

2 Microalgae bloom
The rich iron supply creates vast blooms of tiny marine plants, which take up CO_2 as they grow.

3 Carbon locked away
As the plants die, some fall to the ocean floor, taking locked-up carbon dioxide with them which becomes buried as sedimentary rock.

Carbonate addition
Adding powdered limestone – an alkali – to Earth's oceans could counteract the acidifying effects of greenhouse gases. Alkaline oceans also absorb more CO_2 from the atmosphere, but changing seawater alkalinity might harm certain marine life.

Can we stop a hurricane?

Hurricane Katrina in 2005 was arguably the worst natural disaster in American history, and many scientists believe hurricanes will only worsen with climate change.

So there's no shortage of ideas for stopping these devastating storms. In 2009, Bill Gates backed a proposal to halt hurricanes by towing tub-like barges into their path. These would cool the warm ocean waters fuelling the storm.

Most plans underestimate a hurricane's power though; according to the NOAA Hurricane Research Division, one storm can release the energy of 10,000 nuclear bombs. For example, to fight a hurricane with water-absorbent powder you'd need hundreds of planes to make sorties every one and a half hours.

Some therefore argue that it's cheaper and more practical to adapt to hurricanes by, for instance, building stronger houses.

The risks of geoengineering

Geoengineering is controversial because it involves large-scale changes to Earth's climate. Critics discuss possible negative side effects, like that ocean fertilisation might cause toxic algal blooms, or that geoengineering gives industry and government excuses not to cut carbon emissions.

Geoengineering also raises issues of ethics. Cooling the climate with sulphate aerosols "is potentially cheap enough for single countries to do", says Professor Andy Ridgwell, Bristol University, but could impact other countries' climates as well.

Others fear 'rogue' geoengineers. For example, an American businessman dumped 100 tons of iron sulphate into the Pacific in July 2012 in an unauthorised ocean fertilisation scheme.

they die. "You can't suddenly pull loads of CO_2 out of the atmosphere with any of them," explains Professor Ridgwell. "They lend themselves to gradual mitigation."

Growing vast new forests or fast-growing crops competes with existing land uses, explains Dr Tim Lenton from Exeter University. The idea is to repeatedly harvest fast-growing crops like eucalyptus, which capture the CO_2 they use to grow. But we want to use the best soils to grow food. "The plausibility problem is that you're in potential competition with other land uses in a world where dietary demands are rocketing."

Reflecting sunlight back into space with aerosols is the fastest geoengineering method. It mimics the rapid cooling effect of a large volcanic eruption. "Once you start blocking out some sunlight, temperatures drop quite quickly," explains Andy Parker. For example, in the two years after the eruption of Mount Pinatubo in the Philippines in 1991, global temperatures cooled by about 0.5 degrees Celsius (0.9 degrees Fahrenheit) on average.

So realistically how fast could we cool the planet? Dr Hunt concludes: "Let's suppose the Greenland ice sheet completely melts and we get a one-metre [3.2-foot] sea-level rise. It could be done in five years – if we've got time to think about it, 20-30 years from now."

Camera capsules

How do we capture images from inside the human digestive system?

An endoscopy is a medical procedure to examine the inside of the body via a natural opening or a small incision. Traditionally, an instrument called an endoscope is used, but more recently tiny cameras inside capsules we can swallow have been taking their place. Specialising in the inspection of the intestines, oesophagus and stomach, it can examine places the endoscope could never reach. In particular, it is used to study the three major sections of the small intestine: the duodenum, jejunum and ileum.

About the size of a pound coin, the capsule transmits images to outside data recorders. It moves naturally through the digestive tract and is designed to help diagnose the causes of chronic diarrhoea, inflammatory bowel disease, abdominal pain and malabsorption.

To capture images, the mechanism shines a light from its LED source onto the wall of any part of the gastrointestinal tract. These images are then transported by radio waves to a nearby receiver or monitor for analysis.

If there's a downside, it is that currently the camera can't be stopped to take a closer look at anything, as it's moved by natural peristalsis.

To date, over 400,000 procedures have been performed worldwide and retention has occurred in only 0.75 per cent of cases, so the chances of it not passing through safely are very slim. In around eight hours the capsule can capture an incredible 50,000 or so images.

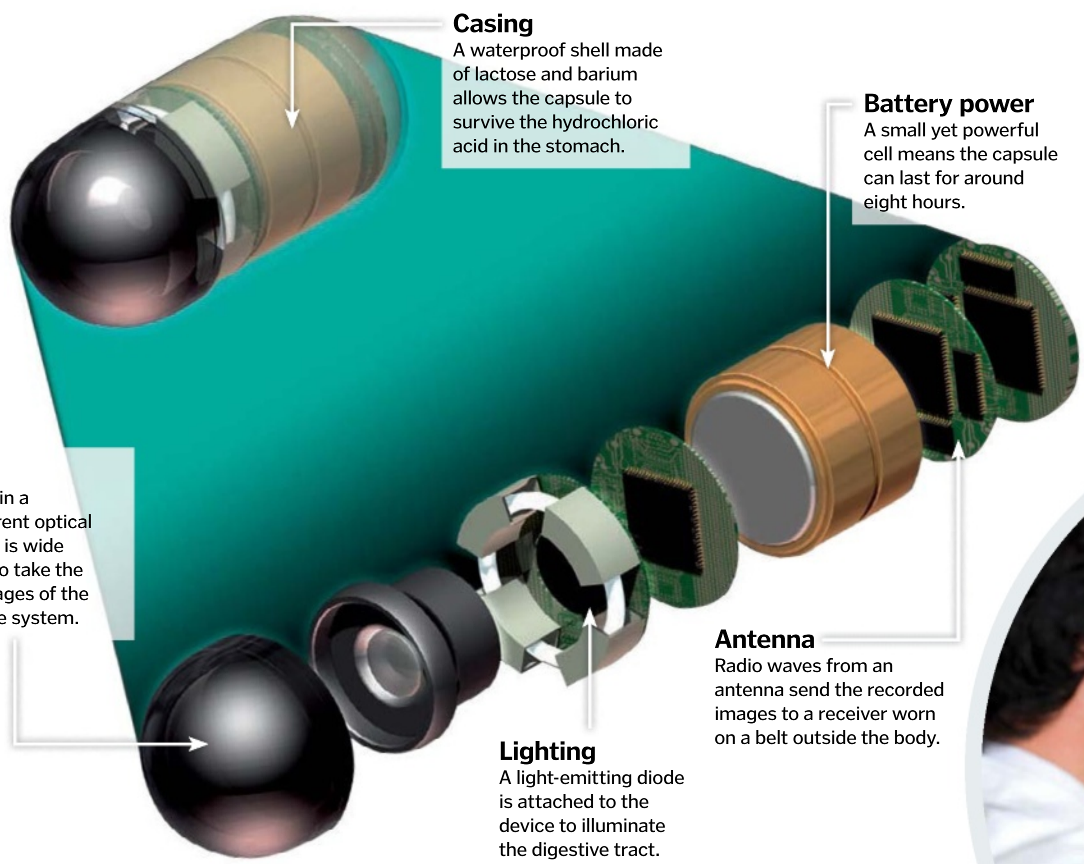
It costs about £600 ($1,000) to administer but its ability to explore parts of the digestive system in unprecedented detail – outside invasive surgery – is invaluable.

Nil by mouth

Camera capsule endoscopy is a painless and relatively fast process. To allow the procedure to work effectively, the patient must observe a few important measures. Prior to examination, the patient must not eat or drink anything for 12 hours. In some cases, patients may also need to cleanse their bowel before the procedure takes place. After taking the capsule, you can move around as long as you don't make any sudden movements. The vast majority who have used the capsule said they felt no pain or discomfort. You can drink clear liquids two hours after ingestion and eat food after four hours.

The camera in a pill

What technology makes up this inner-body explorer?



Images can be instantly transmitted to a computer for closer analysis

DID YOU KNOW? *Each day the UK produces enough rubbish to fill the whole of Trafalgar Square and bury Nelson's Column!*

Intelligent fingerprinting

The tech that enables illegal substances to be detected with just a fingerprint

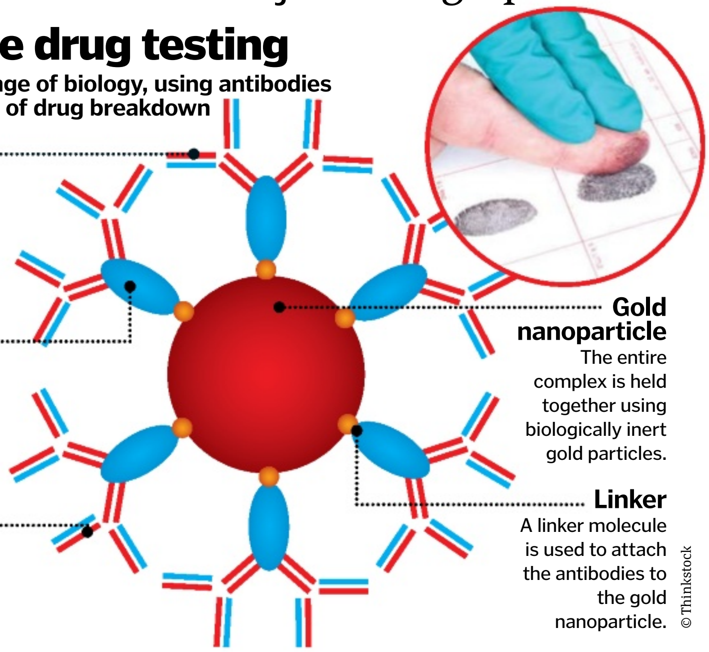
The University of East Anglia in the UK has developed a handheld device that detects the breakdown products of commonly abused drugs in sweat released from pores in the fingertips.

First, an image of the fingerprint is taken to create a reference point and treated with a solution containing gold nanoparticles, which stick to the breakdown products of illicit substances. The particles are then stained with a fluorescent dye and a second image of the print is taken.

This innovative test is much quicker than alternative methods and provides proof that the results belong to the person in question and are not down to sample contamination. Sweat released from pores in the fingertips tracks along the fingerprint ridges, carrying with it traces of drug metabolites. If the staining of the print is greatest at the pores, it provides solid evidence that the metabolites are being released from the sweat glands of the person being tested.

Nanoparticle drug testing

The test takes advantage of biology, using antibodies to detect the products of drug breakdown



Antibody
Antibodies are generated by the immune system and can be manufactured in the laboratory to stick to almost any target.

Protein
In combination with the linker molecule, proteins are used to bind the antibodies to the gold nanoparticle.

Detection
Antibodies stick specifically to the metabolites of commonly abused substances.

Gold nanoparticle
The entire complex is held together using biologically inert gold particles.

Linker
A linker molecule is used to attach the antibodies to the gold nanoparticle.

© Thinkstock

Solar-powered rubbish bins

They crush our litter, send an email when they are nearly full and are powered entirely by the Sun – but what tech makes these trash cans so sophisticated?

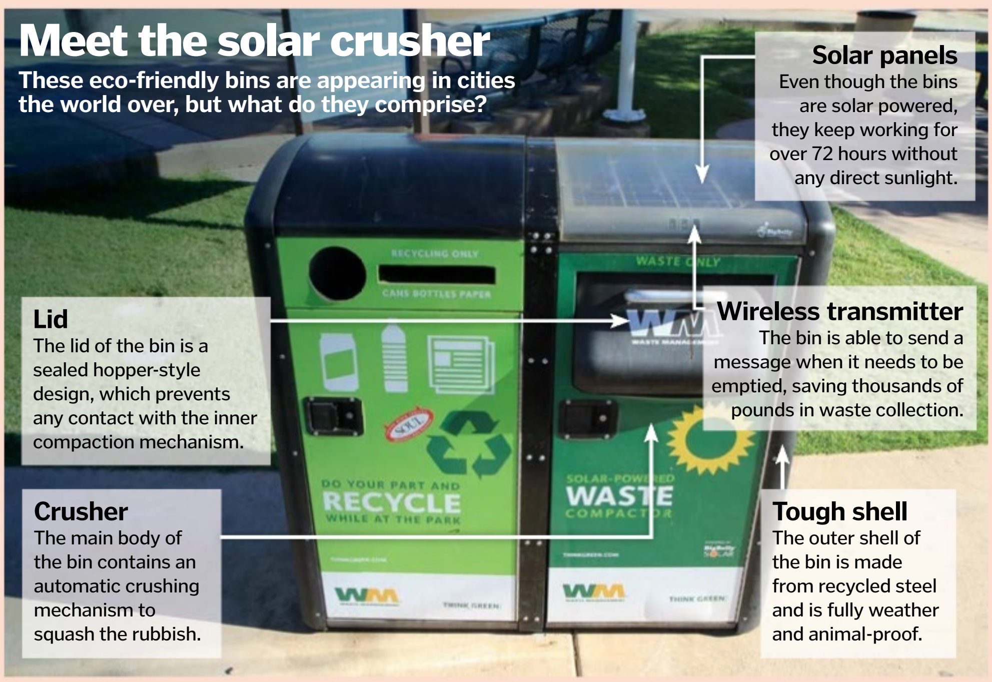
Solar-powered bins contain a sensor to detect when they are full. When litter reaches the level of the sensor, an internal compaction mechanism is activated, crushing the rubbish to make more space. The bins can therefore hold up to eight times more refuse than traditional trash cans, with a capacity of around 800 litres (211 gallons).

The compaction mechanism runs on a standard 12-volt battery so requires very little power. This enables the bins to be used in areas that don't receive much sunlight; in fact, they can even work in the shade – most need just eight hours of sunlight a month to power the compactor and internal electrical components.

Many of these bins also include a sensor connected to a wireless transmitter, which sends a signal to the local waste disposal company when the bin has been filled to 85 per cent capacity. This makes the waste collection process much more efficient.

Meet the solar crusher

These eco-friendly bins are appearing in cities the world over, but what do they comprise?



Solar panels
Even though the bins are solar powered, they keep working for over 72 hours without any direct sunlight.

Lid
The lid of the bin is a sealed hopper-style design, which prevents any contact with the inner compaction mechanism.

Wireless transmitter
The bin is able to send a message when it needs to be emptied, saving thousands of pounds in waste collection.

Crusher
The main body of the bin contains an automatic crushing mechanism to squash the rubbish.

Tough shell
The outer shell of the bin is made from recycled steel and is fully weather and animal-proof.

Robotic surgery

Medical technology in the operating theatre has come on leaps and bounds, but it still needs a helping hand from humans…

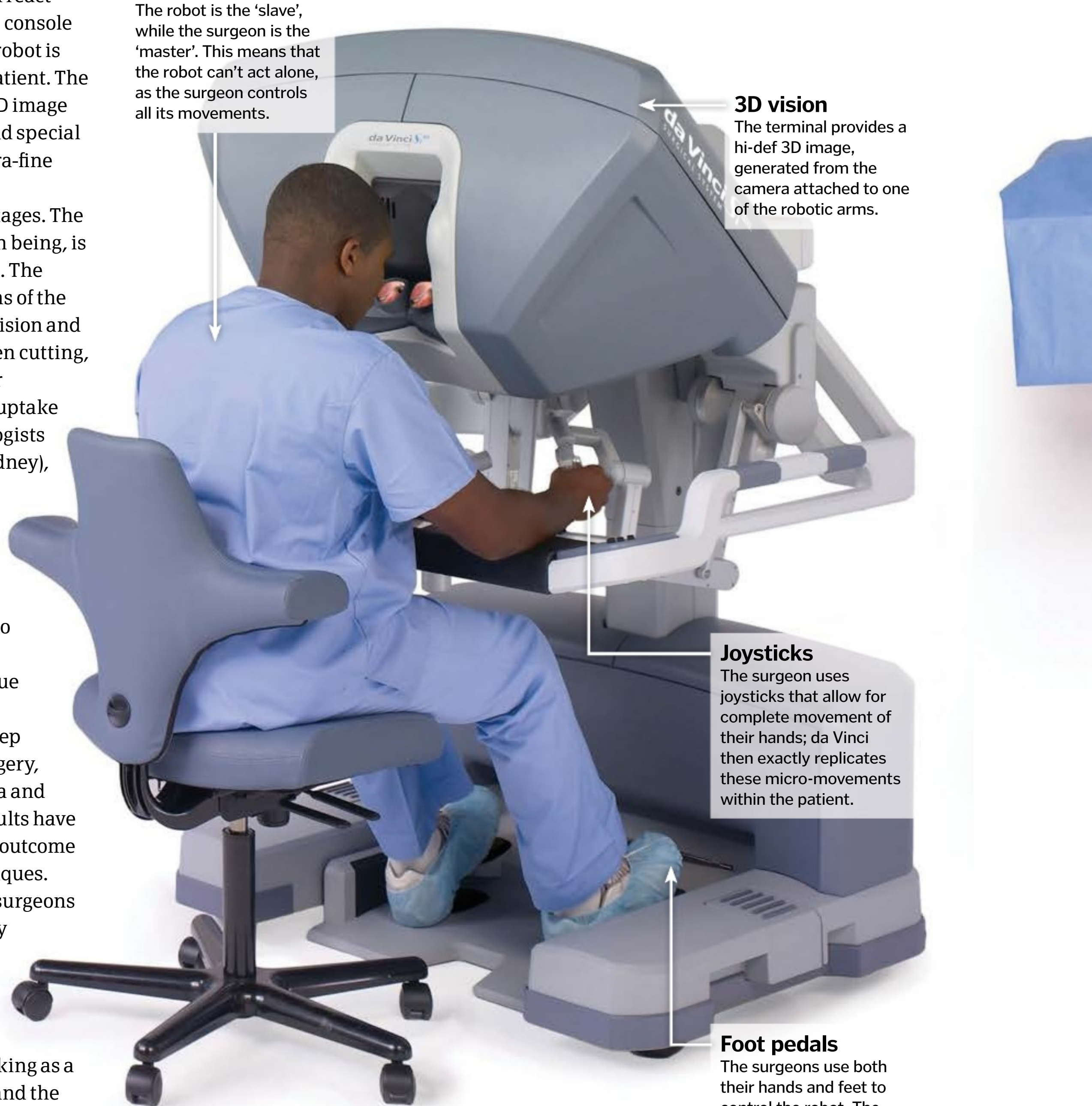
Robotic surgery allows for control and precision previously unknown to surgeons. Contrary to popular belief, the robot does not operate on the patient alone. It is a 'slave' to a human 'master', meaning it is not a true robot (these can work and react automatically). The surgeon sits at a console next to the operating table and the robot is placed around the anaesthetised patient. The surgeon looks at a high-definition 3D image provided by the robot's cameras, and special joysticks are used to control the ultra-fine movements of the robotic arms.

This brings many exciting advantages. The camera, previously held by a human being, is now held perfectly still by the robot. The movements and angles that the arms of the machine provide allow for fine precision and less damage to adjacent tissues when cutting, leading to reduced pain and a faster recovery. This has led to very rapid uptake by some specialists, including urologists (who operate on the bladder and kidney), gynaecologists (who operate on the uterus and ovaries) and heart surgeons. As with most technologies, there are downsides to using robots in operations. They are expensive, large, cumbersome to move into place, and remove the important tactile feeling of real tissue between the surgeon's fingers.

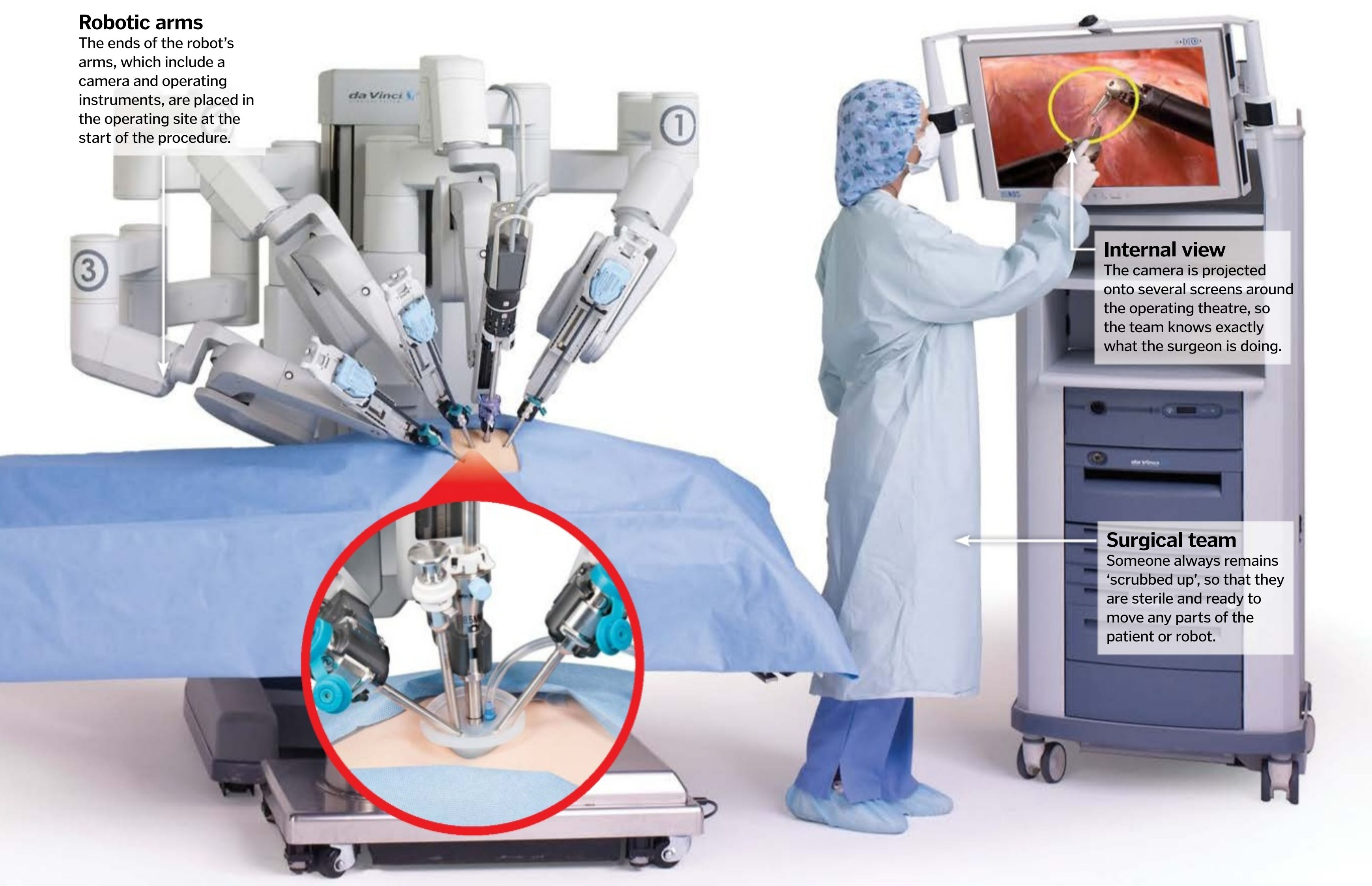
Robotic surgery is considered a step forward from standard keyhole surgery, where the surgeon holds the camera and operating arms. However, early results have shown that there are practically no outcome differences between the two techniques. Combined with higher costs, some surgeons think this means robots are actually inferior to current techniques. This has led to the development of on-going trials, comparing robotic to standard keyhole surgery. Surgeons around the world are working as a single, giant team to deliver these, and the results will determine the future of medical robots for generations to come.

da Vinci in action

This state-of-the-art surgical system works as part of a big team to deliver high-precision surgery. Find out what role it plays now…



DID YOU KNOW? *Surgical robots are incredibly expensive, with current versions costing around £900,000 ($1.45mn) each*

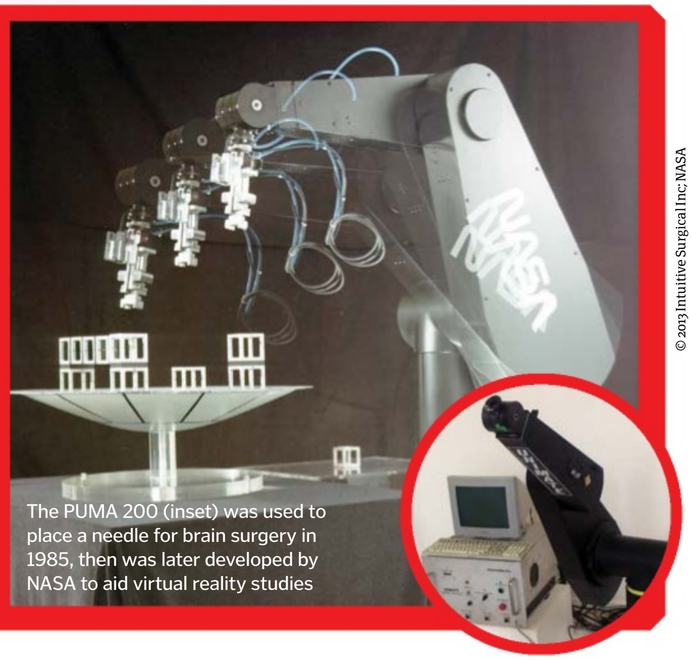


Fluorescence imaging

Fluorescence imaging is still in the experimental stages, and is right at the cutting edge of technological science. Indocyanine green (ICG) is a dye that was initially developed for photography and is now used clinically. It is injected into the patient's bloodstream, and has been adapted so that it sticks to cancer cells – for example, within the bowels. At the time of surgery, the doctor inserts a camera into the patient's body (either using their hands or a robot), and the dye is excited by light at a specific matching wavelength. This creates bright green fluorescence, distinguishing cancerous from normal tissue and allowing the surgeon to make precise incisions.

The evolution of robotic surgery

The current robots in use, like the da Vinci Surgical System, are second generation. The first generation, like the Unimation PUMA developed in the Eighties, had very limited movements and could only carry out specific tasks. The second generation brought a range of fine and varied actions, which surgeons rapidly adapted to. These new-and-improved robots were pioneered and driven forward by North American health systems. Uptake has been slower in Britain due to health budgets, at a time when other treatments have an even bigger impact on patient outcome. There is excitement over development of the third generation of robot, which promises to be more compact, faster and to be packing in even more cutting-edge technology. The future may see telesurgery, where the surgeon in one place (eg a hospital) performs robotic surgery on a patient elsewhere (eg an injured soldier on a battlefield).



The PUMA 200 (inset) was used to place a needle for brain surgery in 1985, then was later developed by NASA to aid virtual reality studies

Compound bows

Discover how new-and-improved technology has transformed the traditional bow and arrow into a whole new beast…

The power of the compound bow comes from its construction, comprising three components: a riser and two limbs. The riser is the central part of the bow that is held and is made of aluminium alloy, or carbon fibre, for maximum strength. The limbs are bolted to the riser and are made of a more flexible composite, allowing them to bend to store energy as the bow is drawn.

The stiffness of the limbs makes the compound bow much more energy efficient than other designs, with hardly any vibration. The composite construction also provides an advantage over wooden alternatives because it is much less affected by temperature and humidity, enabling the archer to shoot accurately in varying weather conditions.

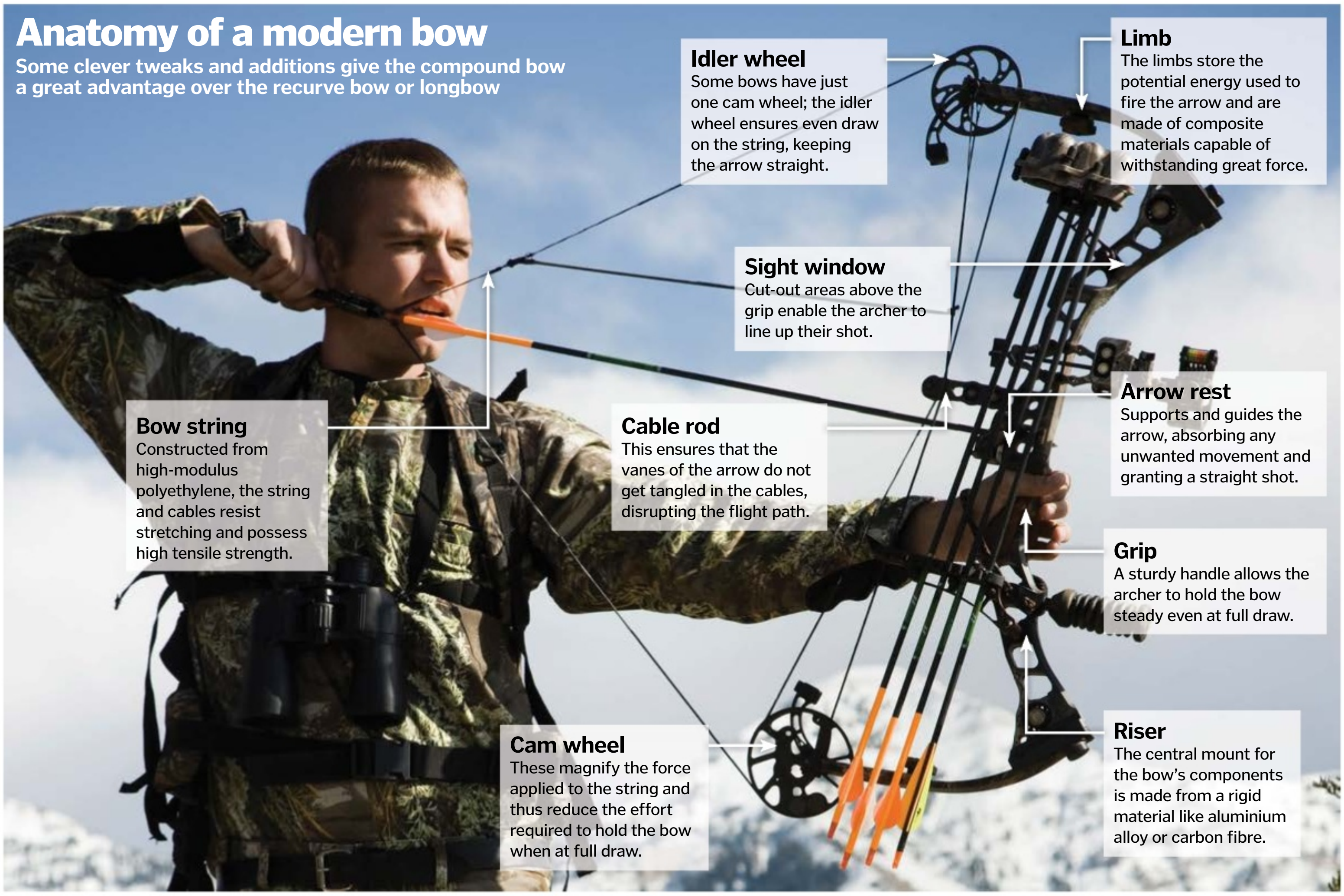
However, the rigidity of the compound bow would make it incredibly hard to draw if the strings were attached directly to the limbs, so a pulley-driven levering system is used. As the string is drawn, the pulleys take in the cables, which draws the limbs of the bow together, storing energy. The system uses asymmetrical cams, so that as the string goes beyond 50-80 per cent of the draw length – towards the point at which the arrow is ready to fire – the amount of force needed to pull the string is reduced. This allows the archer to hold the bow at full draw for longer, granting steadier shooting.

Beyond the bow…

To line up distant shots, archers often use sights with fibre-optic pins – different-coloured pins are set for varying distances, allowing the archer to adjust the shot. Scopes can also be added to magnify the target and increase aiming accuracy. Instead of using their fingers to draw the string, compound bow archers often use a mechanical release. Shaped like a small pincer, the release fits into the hand and pinches the string, enabling the bow to be fired more smoothly; using a release like this makes each shot much more consistent and predictable. Reducing vibration is also important in archery, as any unwanted movement will disturb the path of the arrow. Competitive archers and hunters often attach dampeners to the bow to nullify vibrations.

Anatomy of a modern bow

Some clever tweaks and additions give the compound bow a great advantage over the recurve bow or longbow



Building wax figures

Discover how lifelike models are made step by step

Wax sculptors spend months creating their super-lifelike models

Wax figures have been around since the Middle Ages and are made from a combination of beeswax and Japan wax. To construct a wax figure, first a clay model is made – this model is used to generate a mould. The wax mixture melts at low temperatures and a layer of molten wax is poured into the mould. Once set, the wax remains soft enough to be carved, but durable enough to create a lasting, detailed statue. Heated metal tools can be used to chase away any seams or imperfections in the surface, and to melt sockets in the face for the eyes and teeth. The softness of the set wax also allows individual hairs to be embedded – one of the most time-consuming parts of the process. Finally, layers of oil-based paint are used to create realistic skin colour and texture.

A spotlight on Madame Tussaud

Marie Tussaud was a French sculptor, born in 1761. Her mother worked as a housekeeper for wax sculptor Dr Philippe Curtius, and under his tuition, Tussaud learnt the craft. During the French Revolution, Tussaud made death masks of some of the most infamous victims of the guillotine. Tussaud then travelled to England, and in 1835, she opened her first permanent exhibition on Baker Street in London. It originally had 400 figures, including a popular Chamber of Horrors exhibit still loved today. After Tussaud's death in 1850, her grandson, Joseph Randall, commissioned the move to Marylebone Road.

1. Clay model

To capture a true likeness, wax sculptors use a combination of photographs, video footage and body measurements. First a steel and aluminium skeleton is constructed and a rough outline of the musculature is created using chicken wire and newspaper. The body is then positioned, before being covered in clay and sculpted.

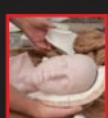
2. Make a mould

Moulds for wax figures are made from different materials. For the head, a plaster mould is often used. For the body, steel supports and hessian sacking are added to the plaster to support the additional weight of the mould. For hands, meanwhile, the moulds can be made of dental alginate.

3. Cast the wax

The plaster mould for the head is filled with molten wax. Wax contracts as it solidifies, so the clay sculptures and resulting moulds are made two per cent larger than the size required. For the hands, a flexible plastic known as 'elvex' is sometimes added to the wax to prevent the digits snapping. The body is cast in resin and fibreglass.

4. Add the hair

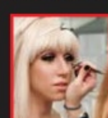


After the wax figure is removed from the mould, any seams are melted away, and further detail is carefully added to the face and hands. Each individual hair is hand poked into the wax figure's head using a fine fork-ended needle; this stage can take up to six weeks to complete.

5. Eyes

Next up is a feature that really transforms the model from inanimate mannequin to realistic human double: the eyes. The glass eyes are carefully painted with watercolours, using silk thread to build up the patterning on the iris. Teeth are constructed using dental acrylic, with a silicone mould taken from the subject's mouth.

6. Paint the skin



Like skin, wax is translucent, providing the perfect base. Skin colour is built up using oil-based paint. The paint is stippled onto the wax to create a realistic texture. The artists take into account the pose of the statue, as well as the display lighting, to create realistic shadows across the figure.

Ivanpah Solar Power Facility

See how the most advanced solar-powered energy generation site produces electricity

The Ivanpah Solar Power Facility is a brand-new solar thermal power site located in the Mojave Desert in western USA. The facility, which consists of three state-of-the-art thermal power plants lies 64 kilometres (40 miles) south-west of Las Vegas and has a total capacity of 392 megawatts, making it one of the largest of its kind in the world.

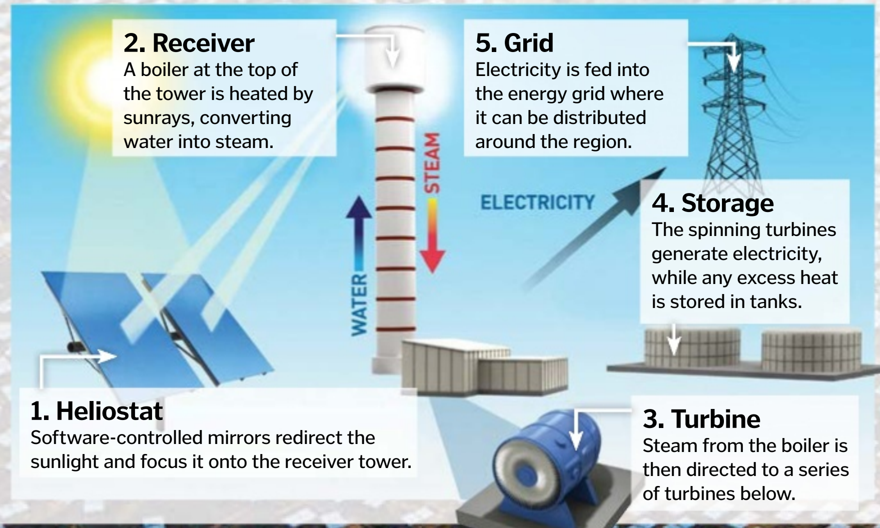
Ivanpah achieves this energy with over 170,000 Sun-tracking heliostats (mirrored panels), which receive a vast quantity of direct sunlight over the 1,415-hectare (3,500-acre) site and redirect it onto steam-producing thermal boilers mounted on top of three receiver towers. This steam is then used directly to power electricity-producing turbines (see 'Ivanpah step-by-step' below to follow the process).

Construction of the Ivanpah project began in October 2010 and is to officially open in the latter part of 2013, with the site set to contribute to California's existing electricity grid.

However, the project has been seen by some environmentalist organisations as controversial due to its construction over an established ecosystem. In particular over 200 desert tortoises needed to be relocated during the build, with a cost of $55,000 per tortoise needed for the move.

Ivanpah step-by-step

From heliostat to energy grid, how does Ivanpah deliver so much power?

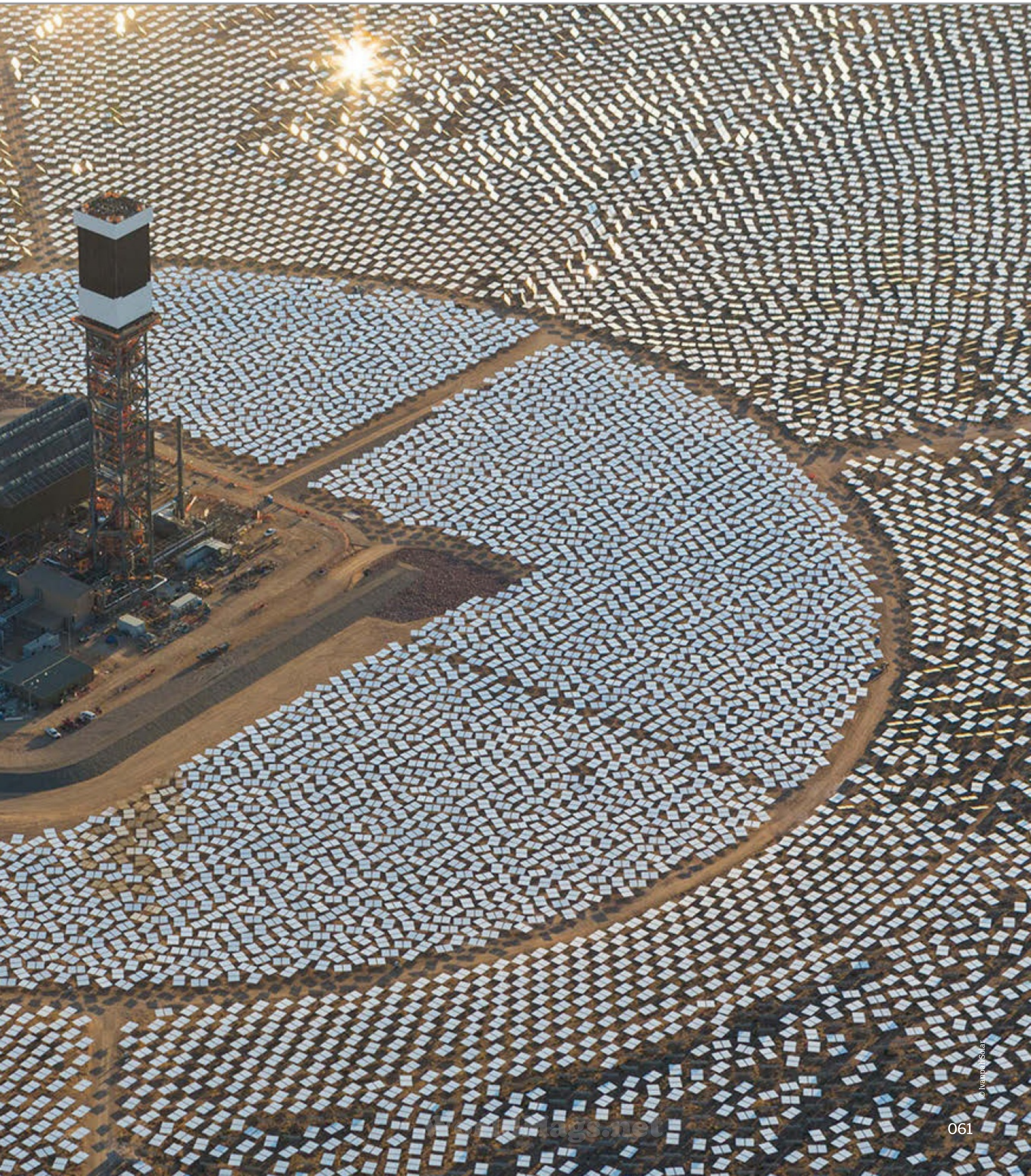


THE STATS
IVANPAH FACILITY

HELIOSTATS 173,500 | LAND AREA **14.2km^2** | REDUCTION IN CO_2 (TONS/YR) 400,000

MAXIMUM CAPACITY **392MW** | ANNUAL POWER GENERATION 1,079,232MWh | THERMAL PLANTS **3**

DID YOU KNOW? *The Ivanpah Solar Power Facility cost in the region of £1.4 billion ($2.2 billion) to build*



© Ivanpah Solar

The lifesaving water filter

How can a simple straw make even the dirtiest water safe to drink?

To this day dirty water is one of the biggest killers on Earth, particularly in the developing world. However, there now exists a cheap and efficient way to stop dangerous, waterborne bugs in their tracks. Enter the LifeStraw.

The device aims to decontaminate dirty water, making it safe for human consumption. It achieves this by using a 0.2-micrometre tube with a hollow fibre membrane that allows water through, but not dirt and virtually no pathogens like parasites and bacteria, of which over 99.9 per cent are blocked.

As the latest iteration of the LifeStraw doesn't use electricity or any sort of chemical (an earlier version used iodine), it is ideal for remote, impoverished areas experiencing drought or with an unreliable water supply. The device can process up to 1,000 litres (264 gallons) before it has to be replaced.

The LifeStraw aims to reduce the spread of disease by providing clean water to all

It's already helped in the aftermath of many natural disasters and mainly targets diarrhoea and Guinea worm disease, which are leading causes of death in developing countries.

LifeStraw up close

See what's happening inside these pocket-sized water filters

Mouthpiece
Safe water is now ready to drink. You just blow air through to clean the straw out and it's ready to use again.

Filtration
Hollow fibres in the tube trap 99.9999 per cent of bacteria and 99.9 per cent of parasites and filter out any soil particles.

Plastic casing
Weighing in at just 56g (2oz), the straw is very practical for distribution and compact enough to carry with you 24/7.

Dirty water
The potentially contaminated water is sucked up at the bottom of the device.

Trekker cameras

Google Street View can now explore city centres and the remote wilderness with its camera backpacks

A fleet of Google Street View cars – alongside a few trikes, snowmobiles and boats – has been capturing panoramic images of our roads and buildings for some time now, but there are certain areas they haven't been able to reach. Well, until now.

The solution lies in a 1.2-metre (four-foot)-tall, backpack-mounted camera called the Trekker. Kitted out with 15 lenses – each attached to a five-megapixel camera – it takes a photograph every two-and-a-half seconds, sweeping in a full panorama above the user's head.

It weighs a hefty 19 kilograms (42 pounds), but volunteers seem very keen to take the equipment into the wilderness. Charitable organisations, research institutions and the tourism industry are all eligible to apply to borrow the Trekker equipment, giving Google access to areas unreachable by their car-mounted cameras, and eventually allowing people to virtually explore national parks, ruined buildings and other difficult-to-reach areas like canyons and caves.

The equipment has already been used to map several hiking trails, including the Grand Canyon, and in the UK the complex network of canals and waterways that runs up and down the country has been recorded.

Making maps

Google is very selective when it comes to imagery and aims to capture photographs when the weather is clear and the view is unobstructed. Images are recorded alongside GPS information so their exact location is accurately mapped. The camera technology uses a series of lasers to measure the distance from the lens to the image subject, creating 3D models of the landscape. This enables the best image to be selected depending on where the user 'stands' in Street View.


Using a backpack-mounted camera, Google Street View explores parts of the world only accessible on foot

DID YOU KNOW? *The first commercial waterproof mobile phone was the LG CanU 502S released in 2005*

Waterproof smartphones

How do these electronic devices carry on working even when underwater?

Today there are two main methods for waterproofing a smartphone: physical barriers such as port covers and sealed seams that prevent liquid entering externally, and nanocoatings that penetrate the device entirely and actively repel water. While both techniques are used, the most effective is the latter, enabling devices to be water resistant without compromising on size and aesthetics.

There are different types of nanocoating, but one of the most commonly used is that made by P2i. This company's waterproofing process involves subjecting any electronic gizmo to a plasma-enhanced vapour in a vacuum chamber at room temperature. The vapour contains a gaseous polymer, which when brought into contact with the device's surfaces – both external and internal – forms a super-strong covalent bond and waterproof barrier 1,000 times thinner than a human hair.

Once on the phone, the ultra-thin polymer layer then dramatically reduces its surface energy, forcing any water that comes into contact with it to bead up and be repelled.

Simply put, the coating acts in a similar way to the waxy feathers on a duck's back, preventing water from infiltrating the top layer and forcing it to run off the sides. Obviously, in the case of a smartphone, this action would prevent water from penetrating the delicate internal components. However, due to the vapour disposition process, even if water were to penetrate the mobile's casing, each internal component would also be coated with the polymer, protecting them until the water evaporated or was dried off manually.

A phone worth splashing out on

We pick out the key components that keep the Xperia Z Ultra super-dry

Waterproof phone rivals

1 Motorola Defy

With a single-core 800MHz CPU, 512MB of RAM, a 1,540mAh battery and a small 9.4-centimetre (3.7-inch) screen, the Defy is very much an entry-level water-resistant phone.

2 Samsung Galaxy S4 Active

With a quad-core 1.9GHz Snapdragon CPU, 2GB of RAM and Android 4.2.2 installed, the S4 Active is a decent-spec, good all-round smartphone that can take the plunge.

3 Sony Xperia Z Ultra

With a huge 16.3-centimetre (6.4-inch) screen, 2.2GHz quad-core CPU and 8MP camera, the Z Ultra is by far one of the largest and highest-spec waterproof phones.

3D PRINTING

Discover the technology behind the 21st-century industrial revolution being printed layer by layer…

5 TOP FACTS
3D PRINTING TECHNIQUES

Stereolithography
1 A liquid plastic called a photopolymer is 'cooked' with a focused beam of ultraviolet light. The model is lowered deeper into the photopolymer bath as each layer sets.

Fused deposition modelling
2 A spool of plastic filament is fed through a heating element to melt it. A platform is moved beneath the element to paint the liquid plastic on.

Selective laser sintering
3 A laser heats a thin layer of fine metal or plastic powder to fuse it solid. New layers of powder are added on top of each other to build up the finished model.

Binder jetting
4 This is like selective laser sintering, except that the powder is plaster-of-Paris and an inkjet head delivers a liquid binder to glue the plaster instead of melting it.

Laminated object manufacturing
5 A sheet of paper is cut using a laser or tungsten knife. The excess is pulled away before another sheet is glued on top and the process repeats.

DID YOU KNOW? *An F-18 fighter jet contains about 90 3D-printed parts – it's cheaper to create maintenance spares this way*

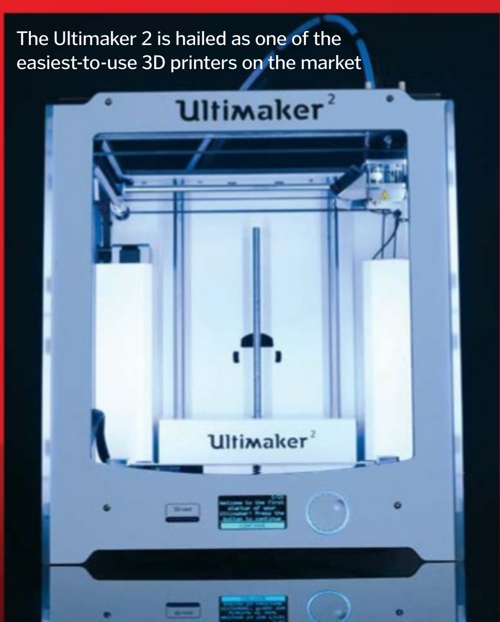
Over the 18th and 19th centuries the Industrial Revolution took manufacturing out of the hands of the common man and into the factories. The 3D printer has the potential to reverse this.

The automated production of intricately shaped objects from a 3D computer design isn't new. Computerised numerical control (CNC) milling machines have been around since the Fifties. But CNC works by cutting material away from a solid block and there are lots of shapes that are physically impossible to make in this way. Imagine trying to make a hollow sphere, for example; unless the cutting tool can reach the inside, there's no way to do it. 3D printing works in reverse: you start with nothing and progressively add material in layers to build up the shape you want. This places far fewer restrictions on the design. Depending on the 3D-printing technique, it is possible to build intricate honeycomb structures that save weight without sacrificing strength and even objects that have moving parts – such as a working gear train – all printed in a single pass, with no need for assembly afterward. The 3D printer has been compared to the printing press, but, in fact, it's a good deal more revolutionary than that. The printing press brought reading to the masses but it wasn't until the word processor and the dot-matrix printer that ordinary people could actually write words of their own in any quantity. Now 3D printers are poised to democratise manufacturing. This isn't just about copying existing factory-produced objects. For the first time in history, we all have the power to physically create and manufacture just about anything we can imagine ourselves.

3D printing is also called additive manufacturing because it works by adding new material in layers. There are several different techniques, depending on the material you want to build from. The earliest system, called stereolithography, was invented in 1986 by Charles Hull. He used a special resin that hardens on exposure to ultraviolet light.

By scanning a beam of UV light over the surface of a bath of the resin, he could create a thin layer of plastic. The floor of the bath was then lowered slightly to sink the completed layer below the surface of the liquid resin and the light beam made another sweep. Each layer was bonded to the one below and eventually the completed object emerged.

Stereolithography is still in use but if you want to build from metal, you need a different system. Instead of a bath of liquid, you shake a thin layer of metal powder onto the floor of the printer and use a high-power laser or electron beam to liquefy certain areas. The powder melts and fuses, you shake a new layer of powder on top and repeat. Because the object is always surrounded by a deepening bed of metal powder, you don't need special struts to support the object as it builds. For decorative figurines, powder bed printers can even create objects in full colour. These use a plaster powder and a printer that combines ink and a glue binder. At **www.figureprints.com** you can have your character from the online role-playing game *World Of Warcraft* printed out in this way as your own full-colour memento. ▶



The Ultimaker 2 is hailed as one of the easiest-to-use 3D printers on the market

3D printers: the rivals

MakerBot Replicator (5th generation)

The pioneer

MakerBot has been at the forefront of desktop 3D printing since 2009 and already is into its flagship product's fifth generation. This version is cloud and app enabled, letting you plan your model from your phone, tablet or laptop. The 100-micron layer resolution offers a spectacularly detailed print.

Cube

The toymaker

Another market-leading 3D printer designed for the domestic market. The Cube lets you print in 16 different colours and objects up to 140 x 140 x 140mm (5.5 x 5.5 x 5.5in) in size making a 3D toy town a real possibility.

Fortus 900mc

The office worker

The Fortus 900mc seems to be a great choice for businesses. It's large at a shade over 0.5m³ (18ft³) but can still print with an accuracy of 0.09mm (0.0035in). It's been used to make ergonomic airline seats and gas tanks, among many other practical things.

Foodini

The private chef

Ever got home from a hard day at work and wished you could just press a button for your dinner to be made? 3D printers like Foodini are making *Star Trek*-style replicators a reality. They aim to take the complicated, time-consuming preparation off our hands and can whip up both sweet and savoury snacks.

Home printing

All of these 3D printing techniques use machinery costing tens or hundreds of thousands of pounds. The real revolution has been the development of 3D printers cheap enough for the home user. To make your own 3D print, you have to start with a computer model of the object. This is a computerised drawing that specifies the precise positions of each corner, or vertex, and the radius and centre of every curve. You can create this in a computer-aided design (CAD) application or you can download an existing CAD file from sharing sites such as **www.thingiverse.com**.

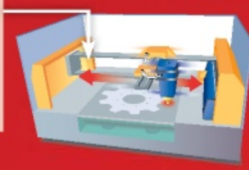
The 3D model allows you to visualise and edit the design but you can't print from it directly. It must first be digitally processed to break it down into a series of virtual horizontal slices that will form your object when they are stacked one on top of the other. These slices are then further processed into instructions that move the print head so that it creates each slice without any gaps or unwanted bridges. Home 3D printers use fused deposition modelling (FDM), which works rather like a hot glue gun. A spool of plastic wire or filament is fed to a heated print head that draws a line of melted plastic onto the object. By moving the print head horizontally past the stage with the model on it, the shape of a single slice is traced out. The stage then moves down by the height of a slice and the printer repeats for the next layer. The end result has a stepped effect, a bit like the pixels in a computer image, but modern 3D printers can work to a high enough resolution to make the steps almost invisible. ▶

Printing with metal

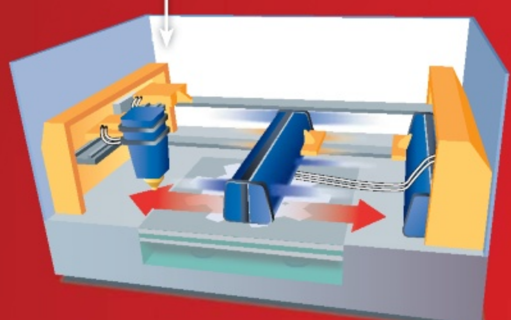
Selective laser sintering is a 3D printing technique that can make things with steel or even titanium

1. 3D design
The process begins with a digital model that is used to direct the movements of the 3D print head.

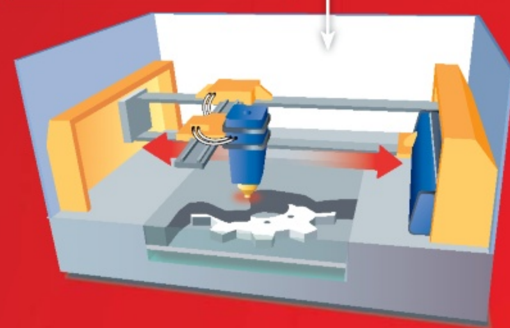
2. Laser sintering
The laser partially melts tiny grains of metal powder so that they stick together – a process known as sintering.



3. New layers
After each pass of the laser head, a new layer of metal powder is applied by a roller.

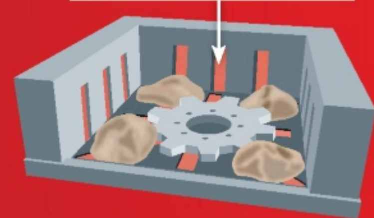


4. Deep powder
The process repeats, layer by layer. Delicate parts of the object are supported by the surrounding powder.

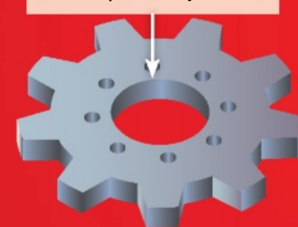


5. Rough draft
The object is removed from the loose powder. The basic shape is there but it's still quite porous and weak.

6. Heat treating
To strengthen it, the object is fired in a 2,000°C (3,632°F) furnace with other metals that melt and soak into the pores.



7. Final touches
Polishing and surface etching or coating provide a high-quality finish for the completed object.



How expensive is additive printing?

A 1kg (2.2lb) spool of plastic filament to print objects in a single colour costs around £25 ($41). If you use this to print LEGO bricks, they will cost 5-20 pence (8-33 cents) in plastic. That's about a third of the cost of buying bricks directly from LEGO, but of course it doesn't take into account the cost of the printer itself, which is around £1,000 ($1,640) for a basic model. For a one-off, **www.shapeways.com** will let you upload a 3D design (or even design it directly on the website) and they will 3D print for you in your choice of materials. If you want an object printed in metal, this is the only economical method currently available to the home user. A silver ring, for example, can cost around £70-£100 ($115-164).

As with so many other inventions, 3D printing can be used for both good and bad

3D printing's dark side

3D printers can make almost anything, even guns. In 2012, the US libertarian organisation Defense Distributed published the files to print a plastic handgun called the Liberator. Since then, lots of different designs have emerged for plastic guns, and even plastic ammunition. These guns aren't very accurate and they don't last for many shots, but they are still lethal. Of course, it has always been possible to make your own gun at home, using easily available metalworking tools. However, 3D printing makes the process that much easier for the casual anarchist and attempts to outlaw the digital blueprints are unlikely to be effective.

RECORD BREAKERS
MAN-MADE ORGAN

4mm

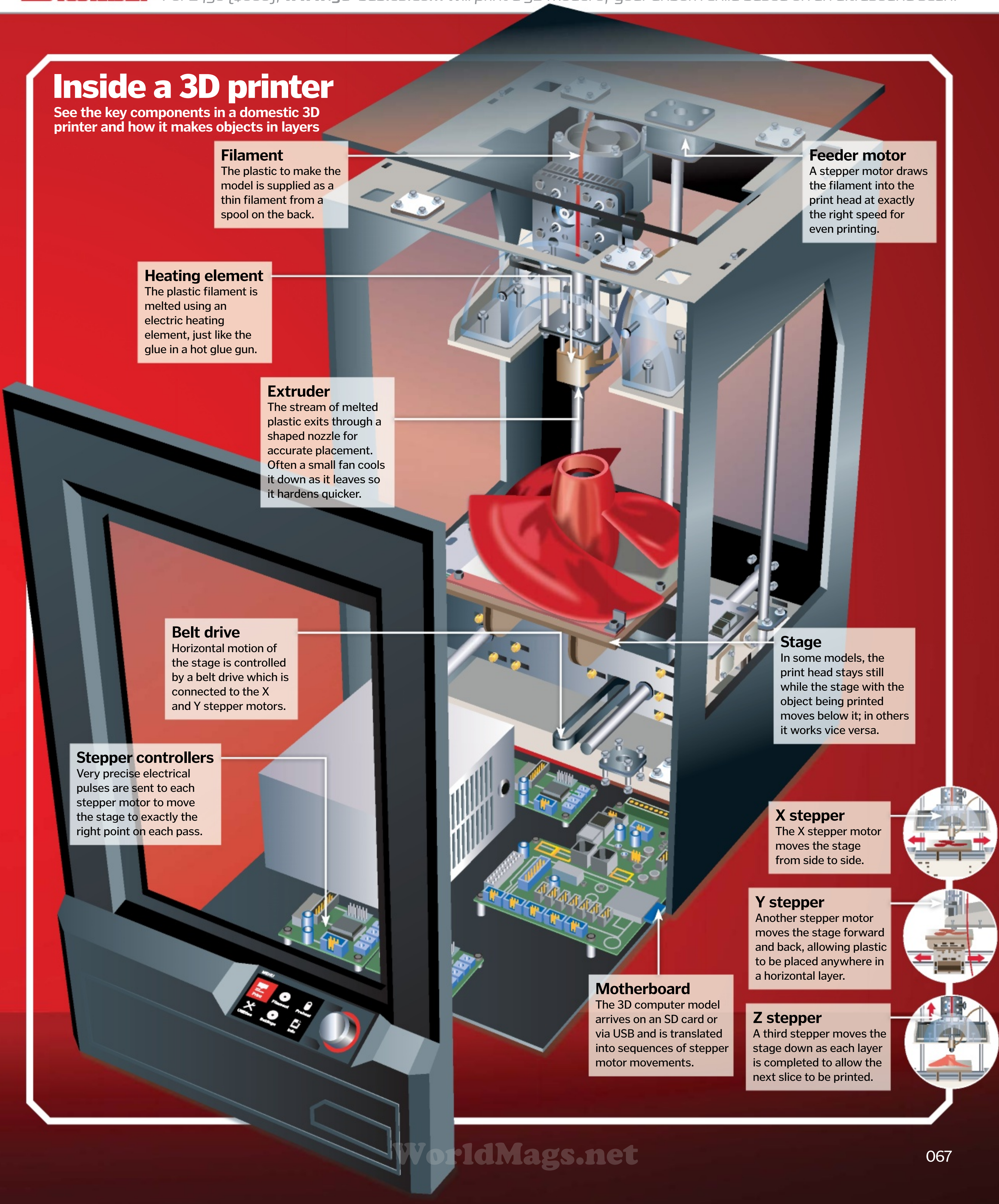
SMALLEST ARTIFICIAL LIVER

US scientists used a 3D printer in 2013 to build a functioning human liver from living cells. Made up of 20 layers of hepatocyte cells, it measured just 4mm (0.16in) across and 0.5mm (0.02in) thick and survived for 40 days in the lab.

DID YOU KNOW? *For £490 ($800), **www.3d-babies.com** will print a 3D model of your unborn child based on an ultrasound scan!*

Inside a 3D printer

See the key components in a domestic 3D printer and how it makes objects in layers



Printing tomorrow

The future of 3D printing will proceed on two fronts. At the industrial scale, new techniques will allow manufacturers to print with more and more materials. Electronic circuits can be built from an aerosol spray of powdered semiconductor materials. Optomec in Albuquerque, New Mexico, has developed wallpaper with LED lighting printed directly onto the pattern and British firm GKN Aerospace is printing physical buttons and switches using a piezoresistive ink that changes its electrical resistance when squeezed. In the home, though, the 3D-printing revolution will be just as dramatic. As prices continue to fall and systems get constantly easier to use, a home 3D printer could ultimately become as common as a regular inkjet 2D printer. This won't just be a way for us to express our own creativity though. It could eventually become a sort of teleporter, where it is quicker and cheaper to email someone the 3D plans for an object and let them print their own than to pop the original in the post.

Medical

In 2012, an 83-year-old Belgian woman had an infected jawbone replaced with a custom-made 3D printed prosthetic. This technology is also used to make prosthetic limbs and other reconstructed organs (eg facial features) are close to reality. In the US, Align Technology makes 17 million 3D-printed, customised clear-plastic braces for children every year. 3D printers can even print customised drugs for patients by combining active ingredients with a binder to form tablets.

Food

The website **www.cubify.com** sells cool sugar cubes, 3D printed into elegant geometric shapes. They are too delicate to ship outside California, but soon you'll be able to buy the printer that makes them. The ChefJet 3D from 3D Systems can also print in chocolate and is expected to cost under £3,000 ($5,000). Systems & Materials Research is developing a pizza printer for NASA, while Foodini is targeting domestic kitchens to make everyday food like burgers (pictured) and pasta without getting our hands dirty.

Clothing & fashion

In 2013, Nike released the Vapor Laser Talon, a set of 3D-printed boot studs for football players, and Belgian company Kipling is soon launching a handbag that looks like a mesh of interlocking monkeys, printed with stereolithography. The Continuum N12 (above) is a ready-to-wear, 3D-printed bikini, made from thousands of interlocking nylon discs. Design studio Nervous System has gone one step further with an articulated dress that can be 3D printed while folded up.

Transport

Right now the largest 3D printers in the world are printing titanium fuselage and wing parts for Chinese passenger airliners. But the technology isn't just for new planes. Ageing McDonnell Douglas MD-80 jets are still in use, but spare parts are hard to come by. Rather than ground its fleet due to leaky toilets, one US airline has 3D printed replacement plumbing. And while BMW cars are still made on traditional assembly lines (for now), 3D printers are being increasingly used to make custom tools.

Space

NASA and Made In Space have been conducting trials during parabolic flights to test the effects of microgravity on 3D printing. This could soon be used onboard the ISS to manufacture spare parts. China uses 3D printing to create customised shuttle seats for their astronauts, and parts are also being printed for rocket engines (right). Architects A-ETC working with the Jet Propulsion Laboratory have proposed a Moon base that could be 'printed' with a robot that uses microwaves to fuse the lunar soil (see below).

The cutting edge of printing

Arjen Koppens, from technology innovator TNO in Holland, reveals his predictions for 3D printing

What are the drawbacks of metal 3D printing?
Arjen Koppens: The accuracy and reliability is just not good enough yet. We had a part that took eight hours to print and we had to throw away the first five before the sixth one was okay. That's a week's work and a lot of wasted material.

Is wastage worse in 3D printing than with traditional casting? Is this improving?
AK: Yes, it's worse. It's a modelling problem. The thermal and mechanical stresses that build up in the chamber of the metal printer are really, really hard to completely understand. We are looking at ways to make this better with a simulation tool. It will tell you the settings to use to print it right on the first try… [by controlling] the laser power or the scan strategy or the [ambient] heat in the printing chamber.

What is the most exciting new technology for printing with plastic in your view?
AK: It is inkjet technology. This prints with small droplets of the same [resin] used in stereolithography. So you don't work with a bath of the material but you selectively spray it and then directly cure [each layer] afterwards.

Will this be available in the average home?
AK: We have already seen very small tabletop stereolithography machines. They are not as cheap as the FDM machines, which you can now buy for less than £830 ($1,360) but the accuracy you can achieve is much better.

We have a machine that can go down to four microns, so you get a very smooth surface with very small details in it. We believe that stereolithography is the way forward because of the high resolution you can achieve.

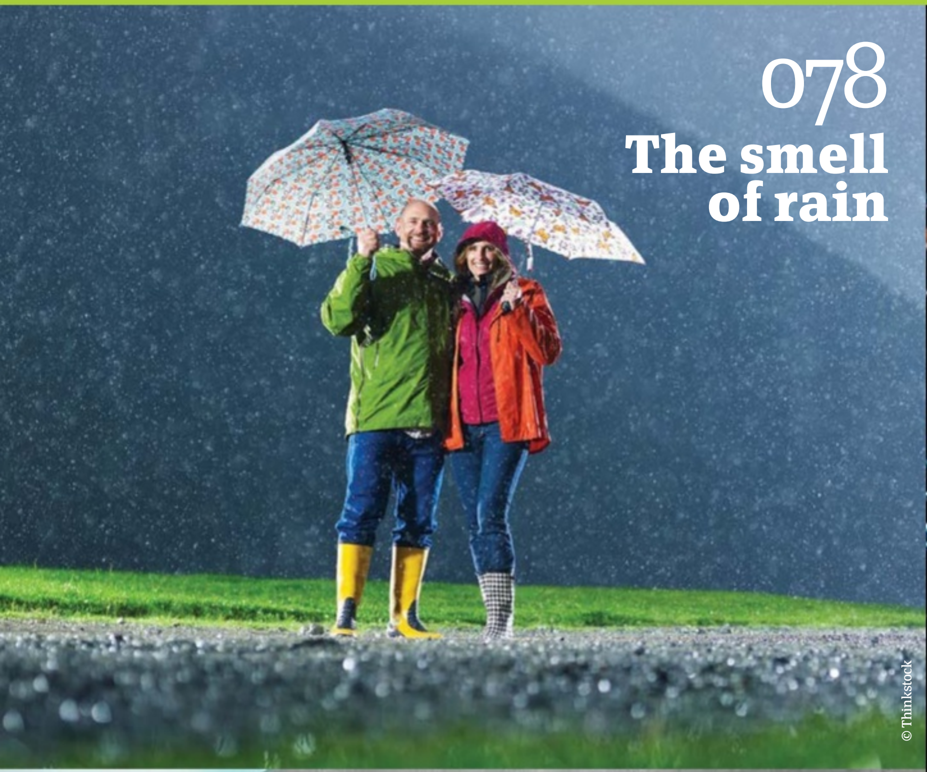
Is there anything that can't be 3D printed?
AK: No. The only thing I don't see the sense in printing is very simple products, like a paperclip or a coffee cup. You can't reduce the weight and you can't print a shape that is more attractive or useful [than the existing ones].

ENVIRONMENT

072
Incredible insects

092
Meerkats

086
Surviving the Antarctic



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7 DAYS A COCKROACH CAN LIVE WITHOUT A HEAD

30 ORDERS OF INSECT

INCREDIBLE INSECTS

Discover the amazing adaptations that have allowed insects to colonise almost every corner of the Earth

RECORD BREAKERS
WEIGHT WATCHERS

100g

THE WORLD'S HEAVIEST INSECT

Goliath beetles are the world's heaviest insects, the biggest weighing in at a colossal 100g (3.5oz), and measuring up to 11cm (4.3in) in length.

DID YOU KNOW? *The combined mass of all the ants inhabiting the Amazon is more than all of the other mammals there combined*

85% OF ALL ANIMAL SPECIES ARE INSECTS

OAKLEAF BUTTERFLY

CAMOUFLAGE	10
AGILITY	6
BITE	0
POISON	0

Also known as the dead leaf butterfly, these insects are masters of disguise. The top sides of their wings are brightly coloured, but underneath, the ragged edges and mottled brown colouring perfectly mimic a fallen leaf.

Insects outnumber humans 1.4 billion to one, and make up an estimated 85 per cent of all animal species. They might look similar to other arthropods, like spiders, centipedes and scorpions, with their segmented bodies, jointed legs and tough armour plating, but what sets them apart is their unique body plan.

All insects share the same basic parts: a head, a thorax and an abdomen, three pairs of jointed legs, compound eyes, and a pair of antennae. For the last 400 million years, insects have been constantly evolving and adapting these simple components, and there are now an estimated five million different species, each slightly different from the next.

There are over 30 orders of insect, divided up according to their evolutionary relationships, each have their own unique anatomy and their own specialities.

On the ground, insects have adapted their six jointed limbs for a variety of tasks. Mole crickets use legs as shovels, grasshoppers have enlarged hind limbs specifically adapted for jumping, and water boatmen use theirs as oars. Many insects also have wings, and in the air, the diversity is just as evident. True flies are the most accomplished aerial acrobats, while other insects, such as beetles, have sacrificed their top set of wings for a tough armour shell, allowing them to spend more time on the ground. Butterflies and moths often use their wings as colourful billboards for mating, or cryptic camouflage for evading predators.

Their incredible ability to travel by land, air and water has allowed insects to take advantage of almost every imaginable habitat and food source on the planet. Their mouthparts are also highly specialised. Grasshoppers have two large, scissor-like mandibles adept at cutting stems, while ants use similar structures as fearsome weapons.

Other species cannot bite at all, having instead adapted to a liquid diet; moths and butterflies have long straw-like mouths used for drinking nectar, while mosquitoes have a hypodermic needle capable of piercing flesh and drawing blood.

Insects are scavengers, parasites, farmers, hunters, builders and masters of chemical warfare. They have a built-in suit of armour, reproduce quickly, adapt rapidly to changes in their environment and are by far the most successful animals on the planet.

SAFETY IN NUMBERS

Raising young is a time-consuming business, and most insects do not tend to their offspring, preferring to lay their eggs on a suitable food source and leave the next generation to fend for themselves. However, this strategy results in a lot of casualties.

Some insect species, including certain types of bees and wasps, dig burrows for their developing offspring and bring food back for the larvae as they grow, but the most successful insects of all are those that work as a team to get things done.

Ants, termites, bees and even some wasps live and work together in colonies that can number in the thousands of individuals. They are accomplished architects and build intricate structures within which to live, segregating special areas for storage and for raising young. They often incorporate natural defences, waterproofing and even air conditioning into their elaborate homes.

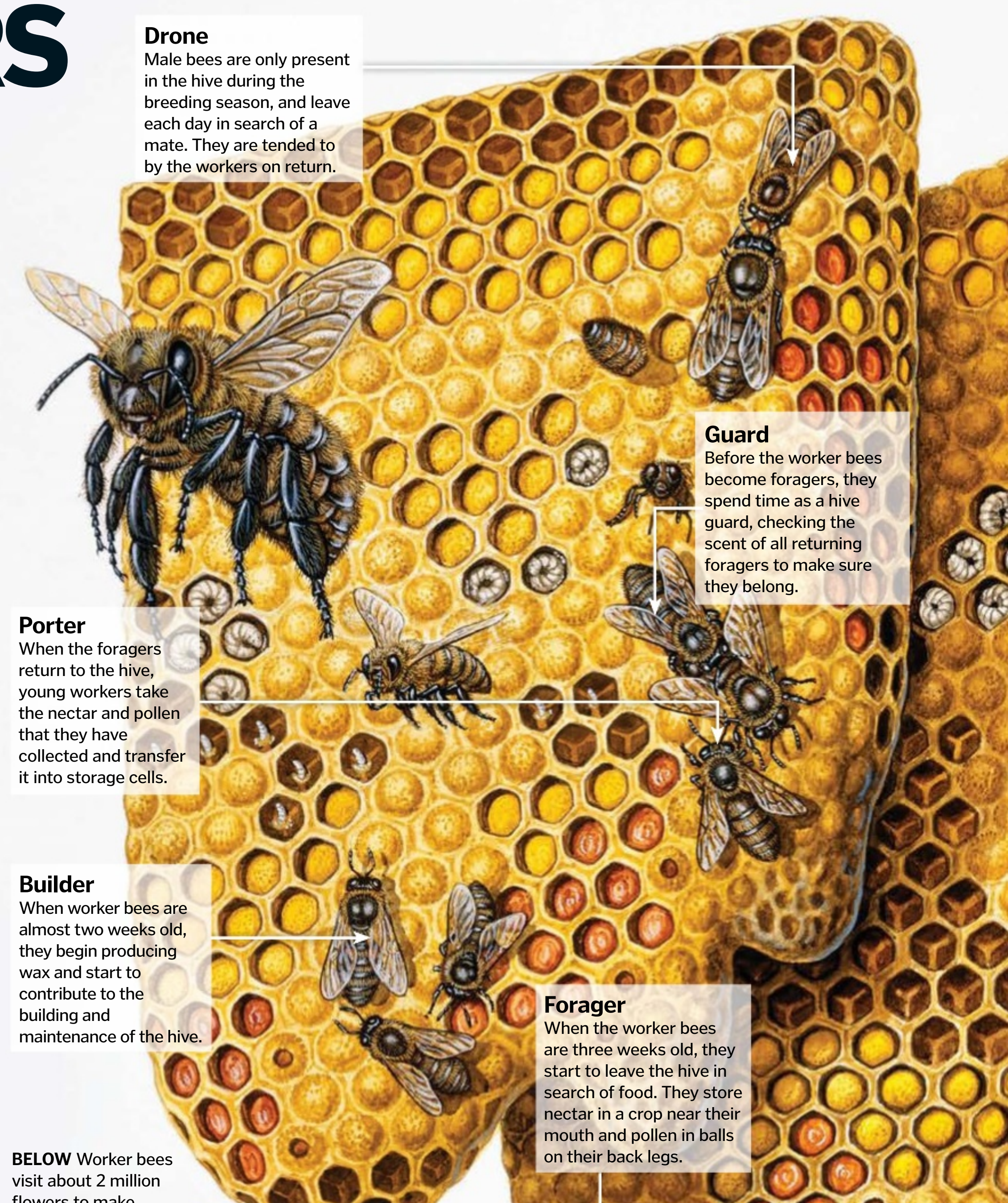
The female workers take responsibility for the maintenance of the colony. Some take on the role of builder, others are nurses and tend to the brood, some are guards, while yet others are cleaners. Older workers leave the nest site in search of food, scouting out the best locations and relaying their location to the foragers, either using a pheromone trail (ants and termites), or with an intricate waggle dance (bees). Any food collected is stored and shared among the colony and their resources are fiercely defended; among some species, workers even form living doors at the entrances, blocking the passage of intruders.

In order for this system to work, all of the individuals in the colony need to collaborate; if each worker were trying to raise her own eggs at the same time, the society would quickly fall apart as the insects fought over food and nesting sites. Honeybee queens produce a cocktail of chemical signals that switch off the reproductive systems of their sisters, so instead of wasting time mating and laying their own eggs, with all the foraging, feeding and fighting that entails, the workers divert all their attention to caring for the offspring of their queen.

Life in the hive

Worker bees take on many different jobs during their lifetime

3-5 YEARS A QUEEN BEE LIVES



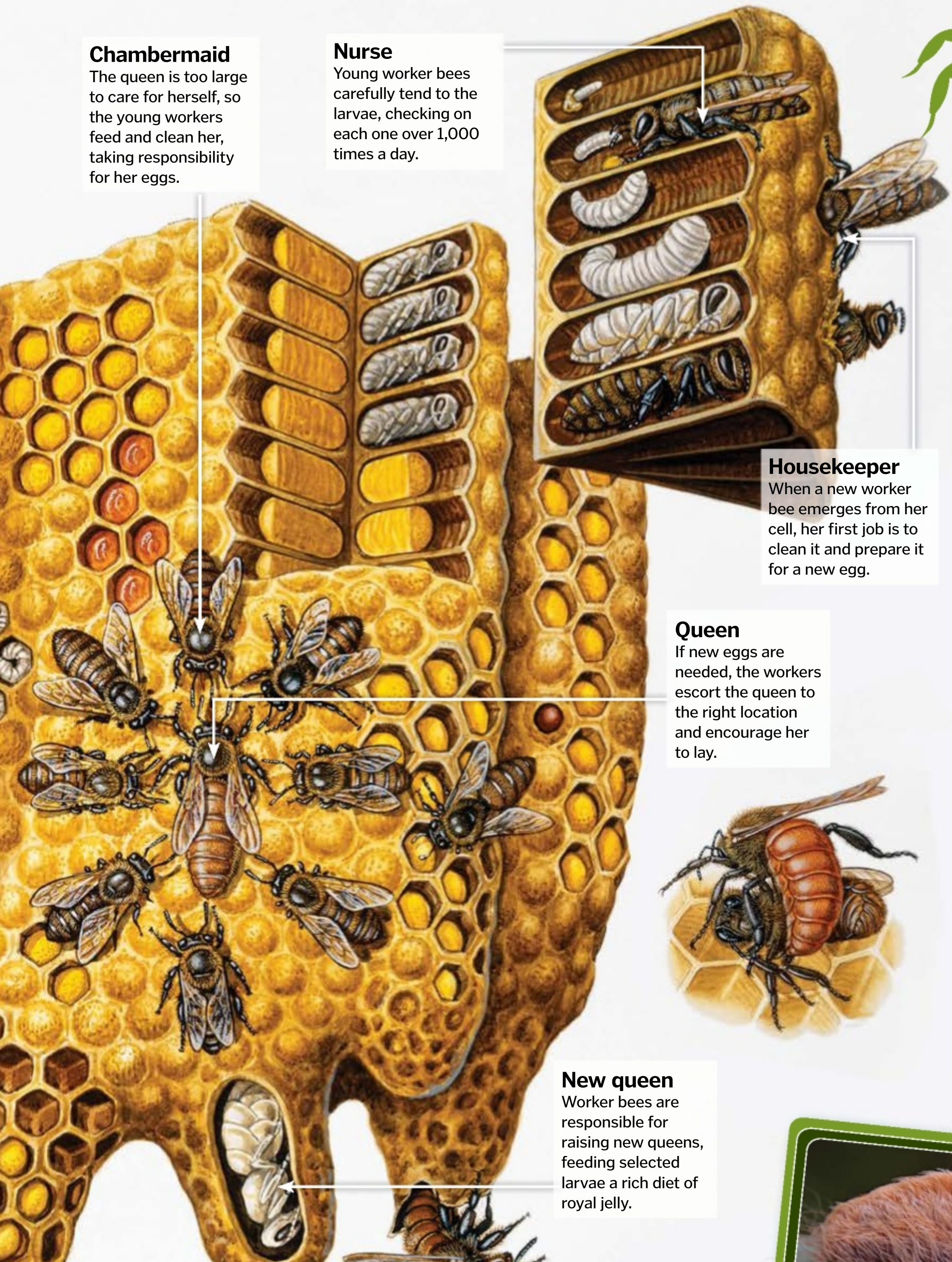
BELOW Worker bees visit about 2 million flowers to make 450g (1lb) of honey

Which are the deadliest insects?

A Fruit flies **B** Africanised honeybees **C** Mosquitoes

Answer:
Honeybees have a painful sting, but mosquitoes are easily the deadliest insects on the planet, if not the deadliest animals. The female anopheles mosquito carries the parasite that causes malaria, responsible for over a million of deaths every year.

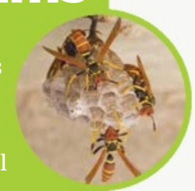
DID YOU KNOW? *There are an estimated 10 quintillion (10,000,000,000,000,000,000) insects alive at any one time*



RIGHT There are 50,000 or more bees in a hive

5 Industrious insect teams

1 Paper wasps



Paper wasps build delicate nests out of wood pulp and saliva. Their social structure is particularly advanced and each wasp individual looks different, allowing them to recognise one another by face.

2 Argentine ants

These aggressive little ants have built a global megacolony. This vast family of related insects spans three continents and includes the three largest ant supercolonies in the world in Japan, the USA and Europe.

3 European honeybees

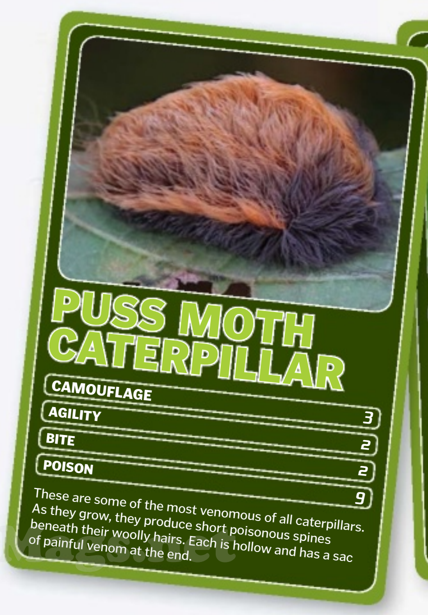
Honeybees colonies are responsible for the pollination of 80 per cent of the flowering plants that we rely on for food. Without them, around a third of the groceries on your table would disappear.

4 Macrotermes bellicosus

These are the largest termites in the world; the queens measure over 10cm (4in) in length. Their enormous mounds can dwarf an adult human, measuring several metres in height.

5 Leaf-cutter ants

These industrious insects spend hours every day gathering grass, but they do not eat it themselves. They are farmers and feed the grass to enormous underground fungus.



INSECT HABITATS

5,000 SPECIES OF LADYBUG

The ancestors of modern insects came from the sea. Around 475 million years ago, plants started to creep across the landscape and within 100 million years, the first insects were scuttling among them. These were similar to modern-day silverfish; small, wingless invertebrates, with a tough exoskeleton and a waxy layer that helped keep them damp. However, as primitive insects started to colonise the land, so too did other arthropods, including spiders, centipedes, millipedes and scorpions, and some of these invertebrates were predators.

Needing to escape these new dangers, insects were the first animals to take to the skies. The first wings were simple, like those of a dragonfly; large, delicate membranes held out from the insect's body. They were good for flying, but their bulky shape made walking on the ground challenging and they were easily damaged. Over time, some species developed more advanced wings that could be folded neatly backward.

The evolution of flight did not just benefit insects, as plants were quick to take advantage. They spend their lives rooted to the floor, so transferring genetic information to other plants can be challenging. Insects are the perfect couriers for genetic material and for millions of years, flowers and insects have evolved side-by side, in a mutual agreement that has allowed both to spread across the globe.

With the arrival of reptiles and mammals and the emergence of flying predators, the world became increasingly inhospitable. But insects are small, reproduce quickly and have had a head start of millions of years, giving them time to adapt to every ecological niche.

Dominating the environment

Insects are adaptable and diverse, and you don't have to look far to find them

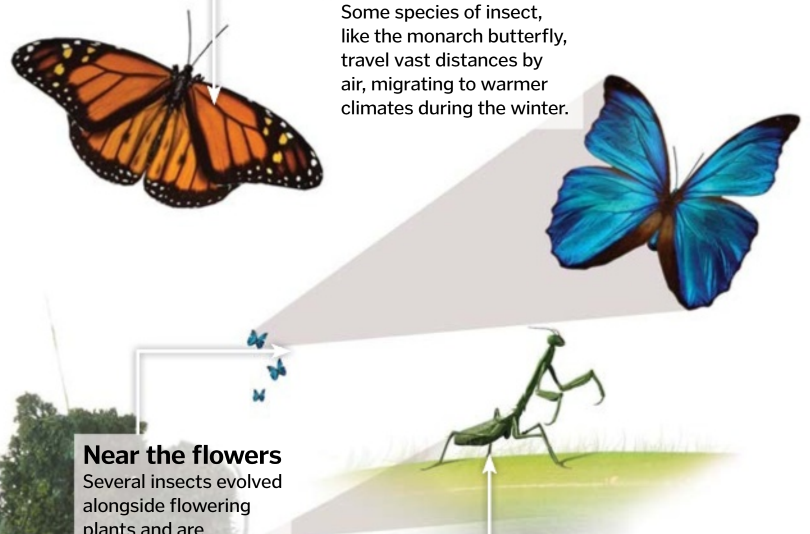
How to build an insect hotel

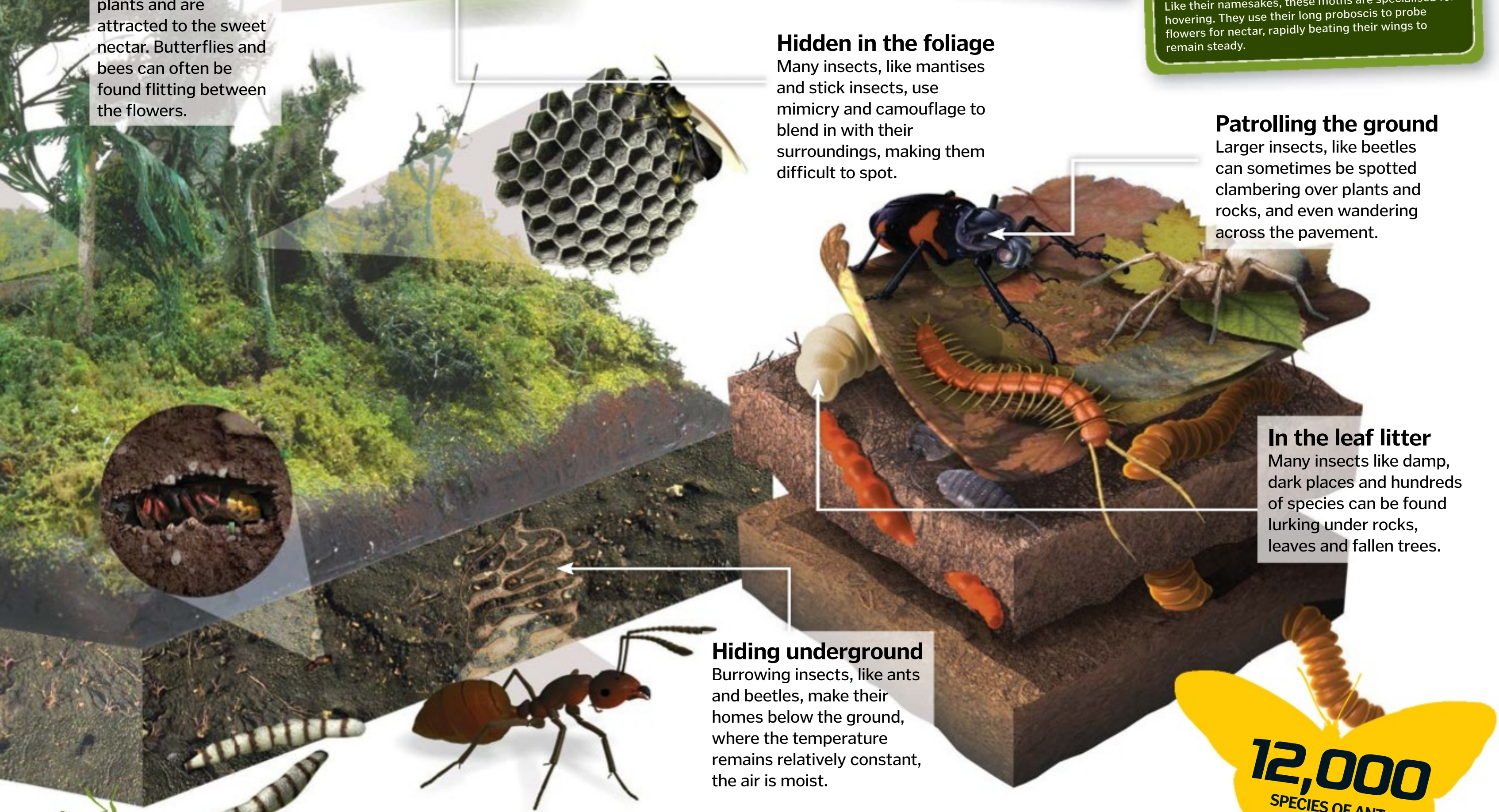
01: Find twigs
Insects like dark, damp crevices, so all you need are some natural materials with lots of nooks and crannies. Twigs, bamboo canes, pine cones and bark are great. You'll also need string and scissors.

02: Tie together
Collect your materials together into a bundle and tie them firmly with the string. Don't worry about being too neat, strange holes and bits sticking out will make great hiding places for the insects.

03: Hang it up
Choose a spot out of direct sunlight to make the most of the dark and damp that insects prefer. Brace it against something so the wind won't blow it about, and use a loop of string to tie it in place.

DID YOU KNOW? To date, 950,000 species of insect have been identified and classified, but millions remain undiscovered





In the air
Some species of insect, like the monarch butterfly, travel vast distances by air, migrating to warmer climates during the winter.

Near the flowers
Several insects evolved alongside flowering plants and are attracted to the sweet nectar. Butterflies and bees can often be found flitting between the flowers.

Hidden in the foliage
Many insects, like mantises and stick insects, use mimicry and camouflage to blend in with their surroundings, making them difficult to spot.

Patrolling the ground
Larger insects, like beetles can sometimes be spotted clambering over plants and rocks, and even wandering across the pavement.

In the leaf litter
Many insects like damp, dark places and hundreds of species can be found lurking under rocks, leaves and fallen trees.

Hiding underground
Burrowing insects, like ants and beetles, make their homes below the ground, where the temperature remains relatively constant, the air is moist.

12,000 SPECIES OF ANT

How to make an ant farm

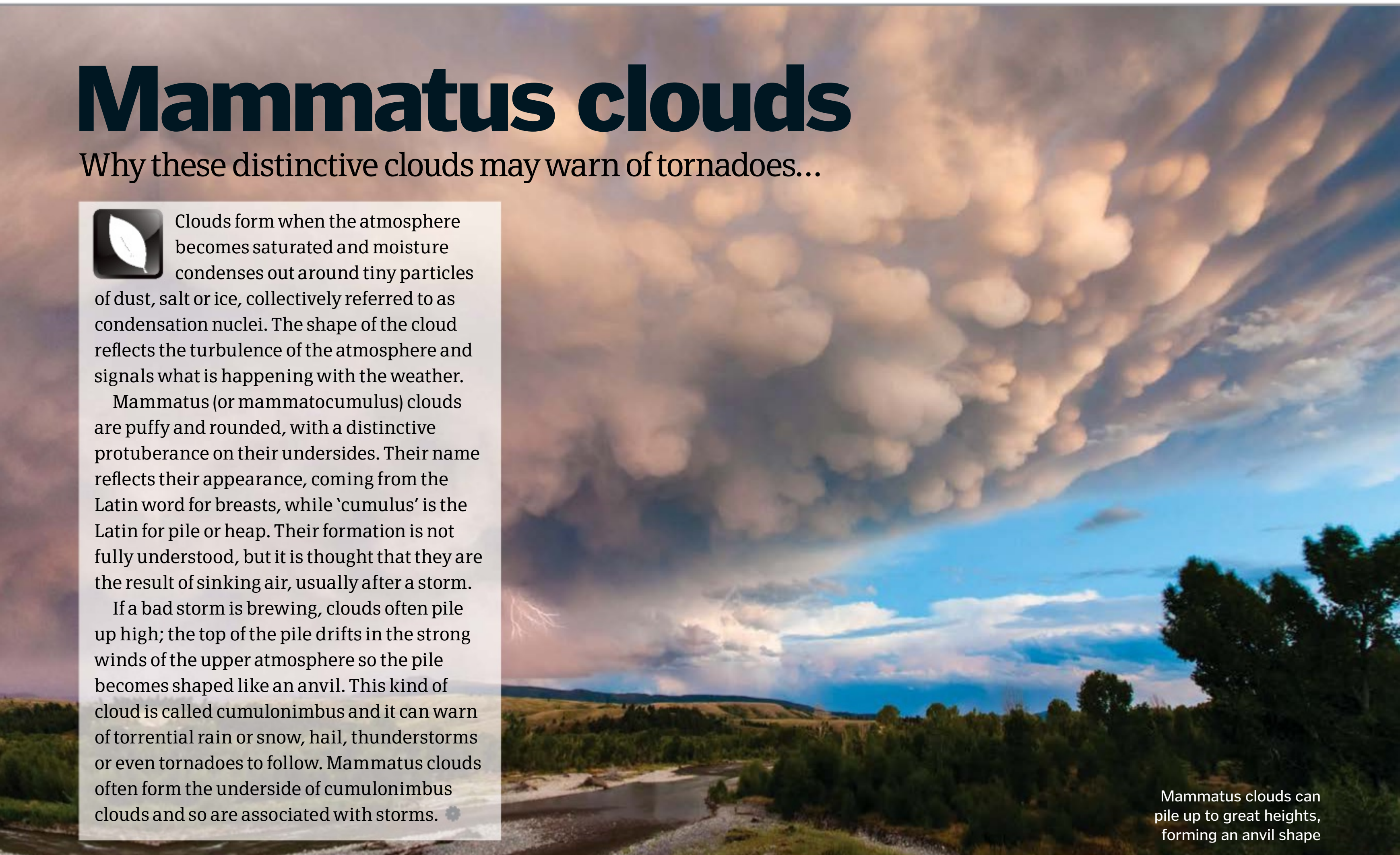
01: Two jam jars
To make this simple ant farm, all you need are two jam jars, one smaller than the other. The small jar sits inside the bigger one, and the ants live in-between, making visible tunnels around the edge.

02: Add soil
Put the small jar inside the big one and carefully tip some soil into the gap between the two. The soil needs to be nice and loose so the ants can dig tunnels, so it may be good to sieve it first.

03: Collect ants
Ants are attracted to sugar and water. Leave some on a cotton ball in the garden and you'll soon have inhabitants for your new farm. Pierce tiny holes in the lid before fastening it on so the ants get some air.

Mammatus clouds

Why these distinctive clouds may warn of tornadoes…



Clouds form when the atmosphere becomes saturated and moisture condenses out around tiny particles of dust, salt or ice, collectively referred to as condensation nuclei. The shape of the cloud reflects the turbulence of the atmosphere and signals what is happening with the weather.

Mammatus (or mammatocumulus) clouds are puffy and rounded, with a distinctive protuberance on their undersides. Their name reflects their appearance, coming from the Latin word for breasts, while 'cumulus' is the Latin for pile or heap. Their formation is not fully understood, but it is thought that they are the result of sinking air, usually after a storm.

If a bad storm is brewing, clouds often pile up high; the top of the pile drifts in the strong winds of the upper atmosphere so the pile becomes shaped like an anvil. This kind of cloud is called cumulonimbus and it can warn of torrential rain or snow, hail, thunderstorms or even tornadoes to follow. Mammatus clouds often form the underside of cumulonimbus clouds and so are associated with storms.

Mammatus clouds can pile up to great heights, forming an anvil shape

The smell of rain

Find out why precipitation creates a distinctive aroma that's the same all over the world

It's possible to smell rain before it has even fallen. Lightning has the power to split atmospheric nitrogen and oxygen molecules into individual atoms. These atoms then react to form nitric oxide, which in turn can interact with other chemicals to form ozone – the aroma of which is a bit like chlorine and a specific smell we've grown to associate with rain. When the scent carries on the wind, we can predict the rain before it falls.

Another smell associated with rain is petrichor – a term coined by a couple of Australian scientists in the mid-Sixties. After a dry spell of weather, the first rain that falls brings with it a very particular aroma that is the same no matter where you are. Two chemicals are responsible for the production of this indescribable odour called petrichor. One of the two chemicals is released by a specific bacteria found in the earth; the other is an oil secreted by thirsty plants. These compounds combine on the ground and, when it rains, the smell of petrichor will fill your nostrils.

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Inca Empire
1 The Inca civilisation of South America was largely built off the back of terrace farming, with great cities such as Machu Picchu supported by the food they produced.

Hanging Gardens
2 The legendary Hanging Gardens of Babylon are often depicted in art as terraces, with a series of staggered layers supporting tropical vegetation and animals.

Rice mania
3 Terrace farming is used to grow a variety of crops around the world. These include olives and wheat, however the most common by far is rice in China and South-east Asia.

Andes origin
4 Terrace farming has been used for many centuries but is thought to have been developed originally by the Wari peoples of the Andes mountains in South America.

Making a comeback
5 A large restoration programme is currently underway in Peru, South America, aiming to revive terraces which have long fallen out of use.

DID YOU KNOW? *The rice terraces of the Philippine Cordilleras are a UNESCO World Heritage Site*

Farming on mountains

How does terrace farming help us work around natural gradients?

Terrace farming is an ancient technique used to both cultivate crops and maintain a hilly terrain's soil health, with the system ensuring moisture and minerals remain locked within the land. As such, farmers in arid, steep or high-rainfall regions can increase their crop yields and prevent damaging erosion.

A terrace system consists of multiple tiers of planting beds, each stepped above another on the side of a hill or mountain. Each area is supported against the incline by a wall – typically a dry-stone structure, which ensures the soil remains level and packed with minerals by limiting runoff. Alternatively, in dry regions, the walls also help to maintain what limited moisture there is.

There are two main types of terrace. The first are retention terraces, used in low-rainfall areas and designed to capture as much runoff water as possible, which is then used to irrigate crops or distributed to lower terraces. The second type is the graded terrace, which is built at a slight gradient and designed to intercept and divert runoff water into protected waterways, preventing it from washing out other levels. In most terrace farms, a combination of these will be used.

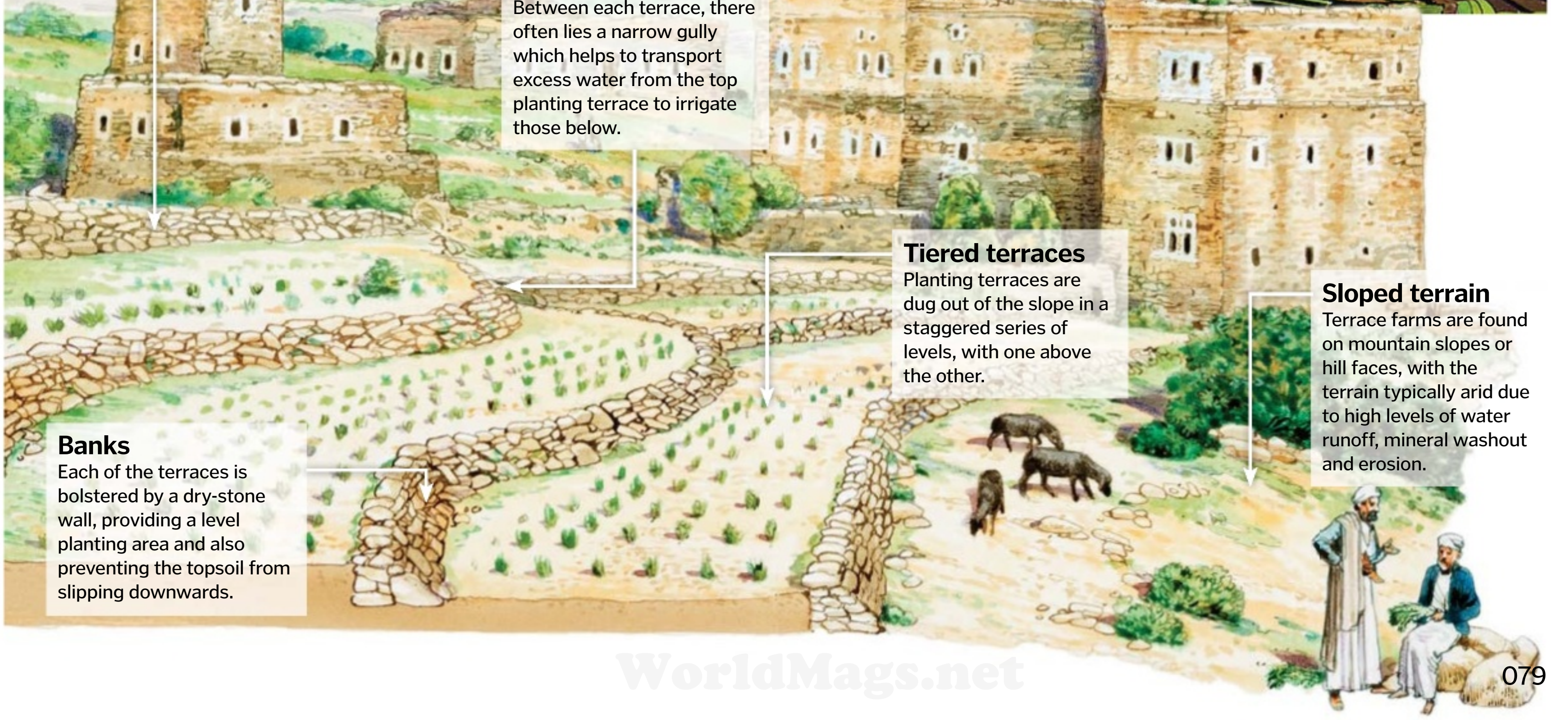
The terrace system also allows for some controlled irrigation of crops within the planting areas. This is achieved through shallow channels that let captured water gradually trickle down through the stepped tiers by the power of gravity.

Hotspots for terrace farming

Multi-level farming

A closer look at the layout of a terraced farm

Farmers in mountainous regions can increase crop yields and prevent erosion using terraces



BIRDS OF PREY

The fastest, the strongest, the most agile – meet the planet's most adept aerial assassins and learn how they survive

Some are manoeuvrable dog-fighting specialists, while others soar high above the ground like stealth bombers. They attack in the air, on the ground and in water. All of them are apex predators, adapted for life at the top of the food chain.

Birds of prey, also known as raptors, may look like feathered dinosaurs, but they aren't any more related to them than any other bird. The physical resemblance comes from their shared carnivorous lifestyle. Most belong to one of two families: the Accipitrids include eagles, hawks, buzzards, kites, harriers and true vultures, while the Falconids consist of falcons, kestrels and falconets. There are also two families of owls and a few species, such as the osprey and secretary bird, that are in families of their own.

Raptors hunt in two main ways. The large Accipitrids and ospreys float high above the ground while they scan for possible targets using their extremely acute vision. They will then dive-bomb or circle around to strike silently and suddenly. Eagles prefer to snatch prey and keep flying in order to minimise the time they spend vulnerable on the ground. Sea eagles, such as the bald eagle, use this technique to catch fish swimming close to the surface. Ospreys, which hunt in freshwater as well as the sea, can spot fish under the surface while flying as high as 40 metres (130 feet) above the water. They drop feet first, and will completely submerge in pursuit of the kill. Uniquely among raptors, ospreys have nostrils they can close to keep water out.

Falcons and hawks hunt other birds in the air. The peregrine falcon attacks pigeons and water birds from high above, dive-bombing – or stooping – from 4.8 kilometres (three miles) up so that they accelerate to over 320 kilometres (200 miles) per hour. At this speed the increased air pressure is enough to burst their lungs, but peregrines have small bones in their nostrils called tubercles that divert most of the airflow to the sides.

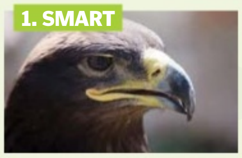
While the peregrine is technically the fastest animal in the world, falling isn't the same thing as flying. The fastest in level flight may be the Eurasian hobby, which actually chases down speedy swallows and swifts.

Species that can't compete in speed rely on their superior agility, like the forest falcons. These sit patiently in dense forest areas, using their extremely sensitive hearing to listen for birds flying nearby. When one passes close

EXTINCT MEGA-EAGLE
THE HAAST'S EAGLE LIVED IN NEW ZEALAND UNTIL IT WAS DRIVEN EXTINCT IN THE 15TH CENTURY. IT WEIGHED 15KG (33LB) AND HAD A 3M (9.8FT) WINGSPAN!

HEAD 2 HEAD
CLEVER BIRDIES

1. SMART

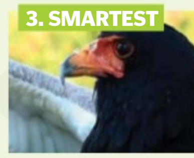


Golden eagle
Golden eagles in Israel have been known to snatch tortoises and drop them onto rocks from a height in order to crack open their shells.

2. SMARTER

Egyptian vulture
These birds can't pick up smooth ostrich eggs, so it has learnt to drops stones on them from above to shatter the shell.

3. SMARTEST



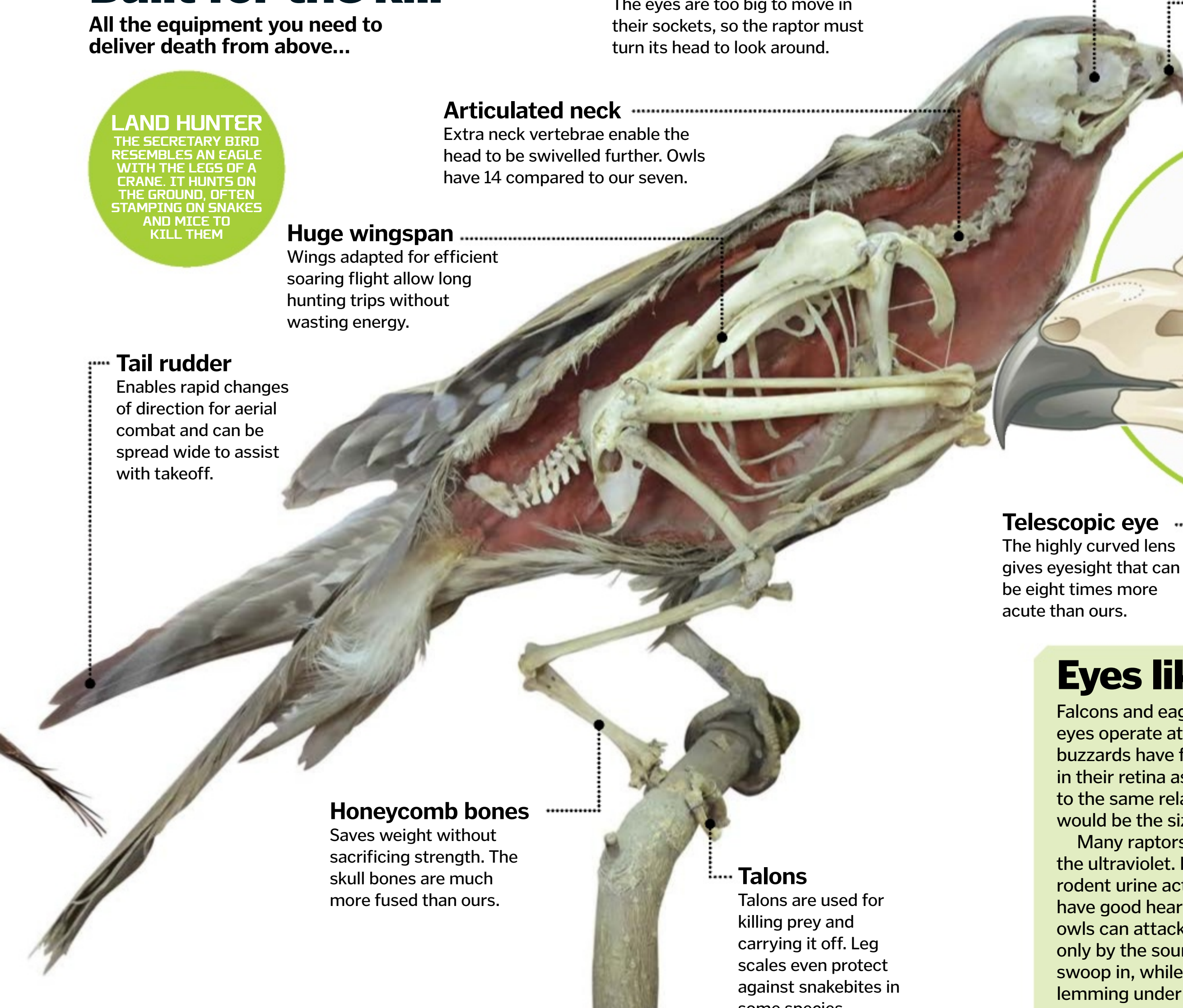
Bateleur eagle
The African bateleur eagle goes one step further and sneakily throws stones at burrows, in the process scaring animals out of their safe shelters.

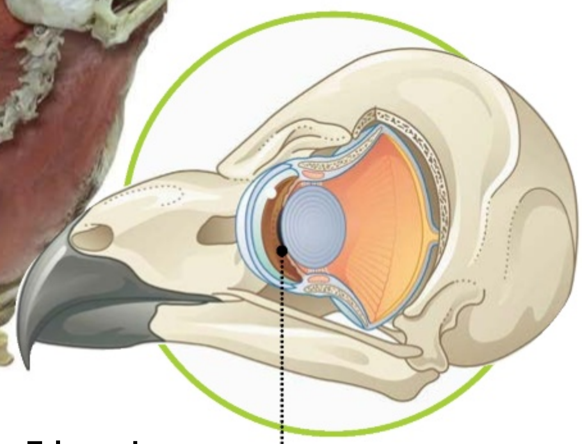
DID YOU KNOW? *The feathers of a bird of prey weigh more than its entire skeleton!*

Built for the kill

All the equipment you need to deliver death from above…

LAND HUNTER
THE SECRETARY BIRD RESEMBLES AN EAGLE WITH THE LEGS OF A CRANE. IT HUNTS ON THE GROUND, OFTEN STAMPING ON SNAKES AND MICE TO KILL THEM





Fixed vision
The eyes are too big to move in their sockets, so the raptor must turn its head to look around.

Hooked beak
Curved for ripping flesh. The colour of the upper part shows off the health of the bird to potential mates.

Articulated neck
Extra neck vertebrae enable the head to be swivelled further. Owls have 14 compared to our seven.

Huge wingspan
Wings adapted for efficient soaring flight allow long hunting trips without wasting energy.

Tail rudder
Enables rapid changes of direction for aerial combat and can be spread wide to assist with takeoff.

Telescopic eye
The highly curved lens gives eyesight that can be eight times more acute than ours.

Honeycomb bones
Saves weight without sacrificing strength. The skull bones are much more fused than ours.

Talons
Talons are used for killing prey and carrying it off. Leg scales even protect against snakebites in some species.

enough they will launch into a short and dangerous slalom run through the branches to catch the bird before it escapes.

Falcons use their beak as a weapon, and some even have a tooth on the upper beak that they use to snap the spine of their prey. For most other raptor species, though, the beak is only used for tearing chunks of flesh from an already downed victim. To kill, they rely on their talons. The exact shape of these depends on the type of animal they hunt: owls have short, heavily muscled toes to squeeze the breath from mice and small mammals, with thin, straight talons to hold them still; while eagles and buzzards have longer, curved talons on the backwards-facing toe and the first forward-facing toe for a powerful pincer grip. The osprey can even rotate its talons so that two toes face forward and two back to hold on to wriggling fish.

> *"The shape of the talons depends on the type of animal they hunt"*

Eyes like a hawk

Falcons and eagles hunt primarily by sight. Their eyes operate at extremely high resolution – buzzards have five times as many cone receptors in their retina as we do. If our eyes were scaled up to the same relative proportions as an owl's, they would be the size of oranges!

Many raptors can see beyond visible light, into the ultraviolet. Kestrels use this to hunt, because rodent urine actually reflects UV light. Raptors have good hearing too, particularly the owls. Barn owls can attack in complete darkness, guided only by the sound of their scurrying prey as they swoop in, while great grey owls can hear a lemming under 0.3 metres (a foot) of snow.

Most raptors have almost no sense of smell, but New World vultures are an exception. The scent of rotting meat has been added to gas supplies in North America because Turkey vultures will detect leaks in pipelines by circling high above the spot.

ON THE MAP

Famous birds of prey around the world

1. Golden eagle
2. Madagascar fish eagle
3. Galápagos hawk
4. Philippine hawk-eagle
5. Bald eagle
6. Great grey owl

Vultures and condors have the weakest talons of any raptor, because their diet consists almost entirely of carrion. Vultures have bald heads to make it easy for them to plunge their entire head into the carcass of a large animal without the blood getting on their feathers.

Judging which is the biggest bird of prey isn't easy. The Andean condor has the largest wingspan at up to 3.5 metres (11.5 feet) and the Philippine eagle the longest body at over one metre (three feet), while the heaviest is Steller's sea eagle in north-east Asia, which can weigh up to nine kilograms (20 pounds).

Because they have no predators, raptors tend to live a long time. Golden eagles last for 25 years in the wild and up to 46 years in captivity, and the Philippine eagle can survive for up to 60 years in the wild! But a long lifespan goes hand-in-hand with a slow rate of reproduction. Bald eagles take four to five years to reach sexual maturity, and usually lay only one or two eggs per season. Even when more than one egg hatches, in many raptor species the strongest chick will kill the others in the nest. This makes many raptors very vulnerable to population crashes from hunting or habitat loss. Around 120,000 Amur falcons are illegally killed by hunters every year in India as they migrate from eastern Asia to South Africa, for example.

There are success stories too though. Red kites have been reintroduced to the UK and Ireland, and peregrine falcons are no longer endangered in Britain now that organochlorine pesticides have been banned.

Home sweet home

Falcons take over abandoned nests of other birds rather than building their own, but other raptors build wide platforms called eyries, or aeries. These are normally high up with a commanding view of the countryside. A golden eagle can see a hare from a mile away, and a sheep from 4.8 kilometres (three miles), so it can search a wide area without ever leaving its nest. Raptors add to their nest each breeding season and can become very big. A bald eagle's nest is strong enough to support a man and can weigh two tons!

On the hunt

How to catch a rabbit from hundreds of metres up

SUSHI SPECIALIST
OSPREYS ARE THE ONLY RAPTORS THAT LIVE EXCLUSIVELY ON FISH. BACKWARDS-FACING SCALES ON THEIR TALONS ACT AS BARBS TO HELP GRIP THEIR SLIPPERY CATCH

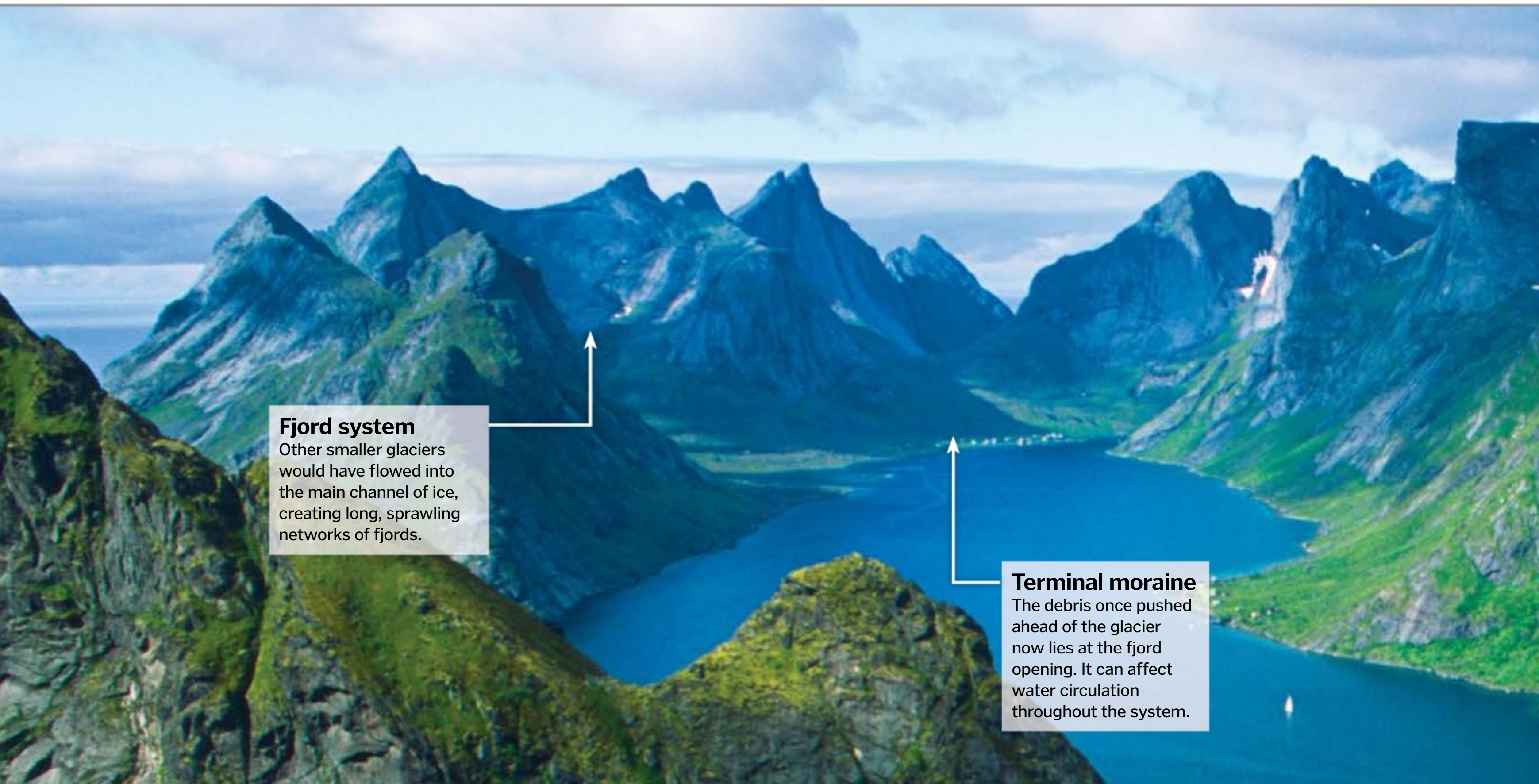
VEGGIE RAPTOR
THE PALM-NUT VULTURE GETS MOST OF ITS FOOD FROM THE FRUIT OF THE OIL PALM. IT WILL ALSO OCCASIONALLY EAT CRABS AND INSECTS, THOUGH

Soaring
Large raptors need to stay aloft for long periods while they search for prey. To save energy, they make use of natural updrafts. In wide-open areas, the Sun heats the ground, which warms the air next to it. Hot air rises, creating a thermal. Another source of lift comes from cliffs and peaks, where the wind is deflected upwards.

Gliding run
The raptor glides from one updraft to another, always scanning the terrain for movement.

Hovering
Kites and buzzards prefer to hover low, near to gaps in ground cover, and drop on anything that moves.

Divebomber
Eagles and buzzards make their attack run from downwind and swoop in at a shallow angle. This minimises the speed lost if they miss their target and allows them to gain altitude again easily. Smaller hawks and falcons aim for maximum speed, with their wings tucked back to increase their freefall speed to over 240km/h (150mph).



How fjords form

As a product of the epic clash between ice and rock, find out how these amazing valleys are created

Fjords are long, steep-sided coastal valleys that are flooded by the sea. The majority of fjords developed during the last ice age, peaking approximately 20,000 years ago. Glaciers dominated the landscape, snaking their way to the ocean and tearing through anything that stood in their path. These massive valleys are typically found in mountainous, coastal areas of the Atlantic and Pacific oceans, and are common in Norway, Sweden, Greenland, Canada, Chile, New Zealand and the US state of Alaska.

As a glacier carved its way through the rock, it cut a distinctive U-shaped valley. The floor was flat and the sides were steep and high. As the massive river of ice – which could reach up to three kilometres (1.9 miles) thick – bore through the valley floor, it picked up rocky debris and carried it along for the ride, adding to the glacier's rock-shattering abrasive power. This rubble eventually made its way to the head of the glacier and was pushed in front of it as the glacier travelled – known as a terminal moraine. Such is the sheer power of the glacier to gouge out rock that the bottoms of fjords are often deeper than the ocean that they open into. For example, the deepest point of the Sognefjord in Norway is approximately 1,300 metres (4,265 feet) below sea level whereas the sill is just 100 metres (328 feet) below sea level. As the ice age came to a close, the oceans flooded into these extra-deep glaciated valleys, forming what we now know as fjords.

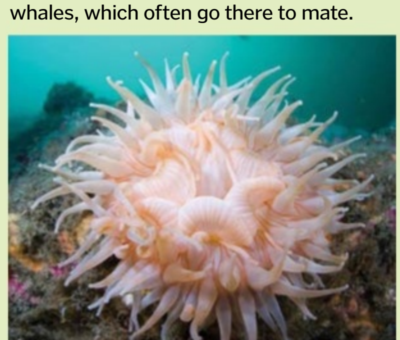
It's the rock formations of a glaciated landscape that are left for us to see today. The glacial moraine will still be present at the entrance of a fjord – a large sill acting as a barrier between fjord and open ocean. There are also other features such as skerries, which are rocky islands within a fjord that can be both large and mountainous or small and treacherous to navigate in a boat.

Life in a fjord

The water in a fjord is distinctly stratified, which affects the animals and plants that call it home. Dense seawater flows over the sill at the fjord's entrance and sinks to the bottom. Hardy deep-water animals such as sea cucumbers live down here in the thick mud, deposited over thousands of years. Deep-water coral reefs can also be found, providing valuable habitats for other species of algae, deep-water fish, crustaceans and molluscs.

Higher up in the water column, algae can thrive on the steep rocky sides of the fjords, providing food for hundreds of fish species. Oxygen-rich fresh water from rivers and meltwater streams runs into the fjord too, which combined with sunlit conditions can serve as the perfect environment for phytoplankton blooms.

The sheltered nature of a fjord can also offer a safe haven for larger marine-mammal visitors such as seals and whales, which often go there to mate.



HEAD 2 HEAD

RECORD FJORDS

1. LONGEST

Scoresby Sund

Located on the east coast of Greenland, the huge Scoresby Sund inlet is believed to be the longest fjord system found anywhere in the world.

2. NARROWEST

Nærøyfjord

Branching off Norway's larger and more famous Sognefjord near Bergen, the Nærøyfjord is just 250 metres (820 feet) wide at its narrowest point.

3. DEEPEST

Fiordo Baker

This fjord in Chile boasts the largest-known over-deepening of 1,344 metres (4,409 feet) – that equates to about three Empire State Buildings!

DID YOU KNOW? *The milky-turquoise colour of the glacier meltwater in a fjord is caused by super-fine debris called 'rock flour'*

Hanging valleys

Fjords often have waterfalls pouring into them, caused by 'tributary' glaciers flowing into the main channel higher up than the current water level.

Steep sides

The flooded valley carved out by the glacier has a classic U-shape, with a flat bottom and high, steep sides.

Deep channels

The deepest parts of the fjord's channel are likely to be slightly farther inland, where the glacial force was strongest.

Skerries

Some fjord systems have islands scattered near the opening of the fjord to the open ocean, which are known as skerries.

SURVIVING THE ANTARCTIC

Why the coldest continent on the planet is a surprising hotspot for both scientific research and wildlife…

Antarctica is Earth's coldest, driest and windiest continent, but many resilient life forms have adapted to survive the harsh environment. Among them is Earth's tallest penguin, the largest mammal and the Antarctic icefish – the only bony animal with transparent blood.

The coldest temperature ever officially recorded was on a high snow plateau in Antarctica, at an altitude of around 3.5 kilometres (two miles) – over twice the height of Britain's biggest peak, Ben Nevis. Around 99 per cent of the land surface is covered with ice and air temperatures can be so extremely cold that atmospheric water vapour freezes to form ice crystals. These crystals catch the sunlight as they fall, and sparkle like diamonds, hence why they've gained the nickname 'diamond dust'.

High altitude renders Antarctica considerably colder than its northern polar counterpart, the Arctic. Air temperature falls by approximately 6.5 degrees Celsius (11.7 degrees Fahrenheit) with each kilometre (0.6-mile) rise in elevation. Antarctica is also Earth's fifth-largest continent, and the vast interior receives little heat from the ocean, which is warmer than the ice.

If the climate wasn't extreme enough, Antarctica experiences 24-hour darkness for a couple of months in midwinter. The continent straddles the South Pole and in late June – southern winter – the pole is tilted away from the Sun. Even in summer, most incoming sunlight is absorbed by Earth's atmosphere before it can warm the ground.

Still, unlikely as it may seem, animals and plants survive in Antarctica's ice-free regions. In the windswept McMurdo Dry Valleys, the continent's biggest ice-free area, fungi and algae manage to thrive inside the insulated blanket of sandstone and granite rocks.

The continental coast and Antarctic Peninsula are host to only two flowering plant species. The biggest creatures include mites and primitive insects called springtails. Just one to two millimetres (0.04-0.08 inches) long, they have natural antifreeze in their blood, and they feed on a variety of moss, lichens and other tiny plant life available to them.

5 TOP FACTS
JUST DESERTS

Antarctic
1 Antarctica is Earth's largest desert with a land area of 14mn km^2 (5.4mn mi^2). The tiny amount of annual snowfall here is equivalent to rainfall in the Sahara Desert.

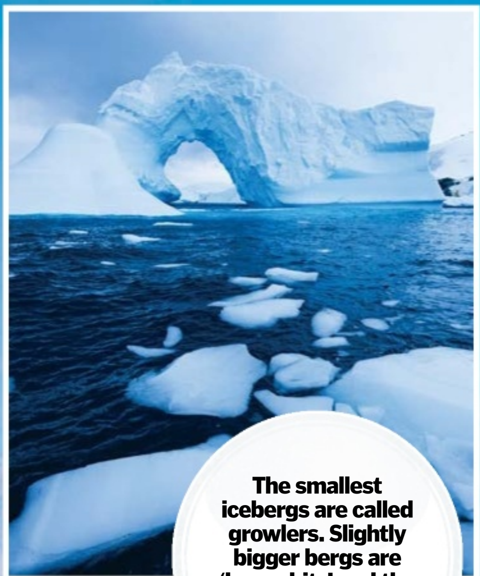
Sahara
2 Earth's biggest hot desert, Sahara covers around 9mn km^2 (3.5mn mi^2) in northern Africa. Around 20 per cent is sand dunes, which can be taller than the Eiffel Tower.

Arabian
3 Summer temperatures in the Arabian Desert can reach 54°C (129°F). It covers 2.3mn km^2 (900,000mi^2) of the Arabian Peninsula, mainly in Saudi Arabia.

Gobi
4 The rocky Gobi Desert covers 1.3mn km^2 (500,000mi^2) of Mongolia and China. Temperatures range between 45°C (113°F) and -40°C (-40°F) in a year.

Kalahari
5 The Kalahari basin has Earth's biggest diamond mines. This southern African desert covers over 900,000km^2 (350,000mi^2) and almost 70 per cent of Botswana.

DID YOU KNOW? *The biggest iceberg on record was the size of Jamaica. It calved off the Ross Ice Shelf in 2000*



The smallest icebergs are called growlers. Slightly bigger bergs are 'bergy bits' and the biggest are 'very large bergs'.

The resilient emperor penguin has made its home in Antarctica

In contrast, the Southern Ocean encircling Antarctica is among Earth's most biologically rich oceans. The melting of sea ice in the spring draws nutrient-rich waters from the depths, feeding phytoplankton. Incredibly, a litre (0.3 gallons) of water can contain more than a million of these tiny life forms.

The phytoplankton are eaten by krill, the powerhouse of Antarctica's ecosystem. These shrimp-like creatures can grow to six centimetres (2.4 inches) long and form swarms big enough to see from space. They are the food source for most Antarctic predators, including the blue whale – Earth's biggest animal. During the feeding season, a blue whale can consume 40 million krill on a daily basis! ▶

Antarctica's climate explained

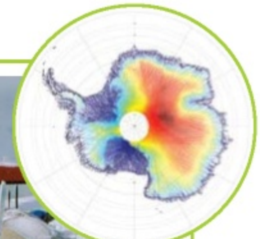
Antarctica is Earth's largest desert, but is covered by kilometres of frozen water. Snowfall accumulates because it can't melt in the cold, but yearly snowfall equals less than 50 millimetres (two inches) of rain. Few clouds form in the dry air. All deserts receive less than 250 millimetres (ten inches) of annual rain.

It's also Earth's windiest continent. The ice reflects away 80 per cent of incoming sunlight, cooling the overlying air, which sinks. This heavy air gusts downhill at speeds exceeding 200 kilometres (124 miles) per hour. Summer temperatures rarely rise above freezing, even at the coast.

The continental interior is colder (around -20°C/-4°F in summer) because it's mountainous and farther from the ocean. Winter temperatures there plummet so low, they could freeze diesel.

Air temperatures have remained stable over Antarctica since the Fifties, except for the Antarctic Peninsula. This peninsula juts into the ocean and is among Earth's fastest-warming places.

Scientists in Antarctica have to cope with some extreme conditions



Tour of the frozen continent

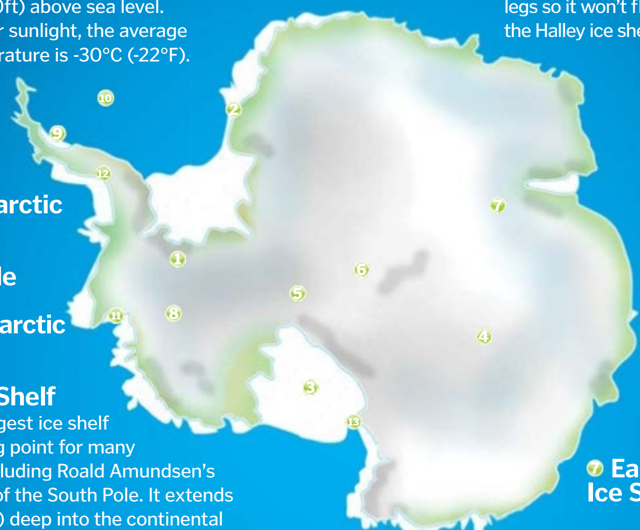
1 Mount Vinson
Just over 1,000 climbers have scaled Mount Vinson in the Ellsworth Mountains, Antarctica's highest summit – fewer than have climbed Everest. The massif is 4,892m (16,050ft) above sea level. Despite 24-hour sunlight, the average summer temperature is -30°C (-22°F).

9 Larsen Ice Shelf

10 Weddell Sea

11 Pine Island Glacier

2 Halley VI
This British research station has hydraulic legs to 'climb' from the 1.2m (4ft) of snow that builds up annually. The station can be towed inland on giant skis fitted to the legs so it won't float off on an iceberg as the Halley ice shelf moves into the sea.



12 Antarctic Peninsula

5 Transantarctic Mountains

6 South Pole

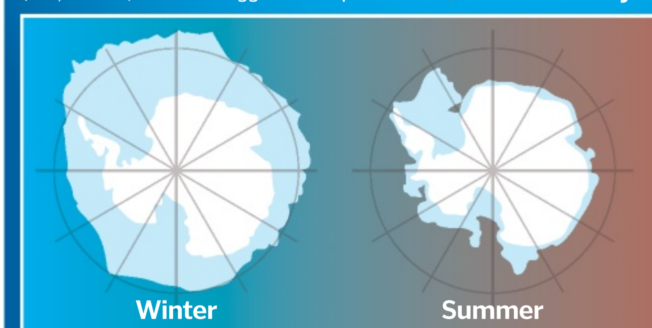
8 West Antarctic Ice Sheet

3 Ross Ice Shelf
The world's biggest ice shelf was the starting point for many expeditions, including Roald Amundsen's 1911 discovery of the South Pole. It extends 950km (600mi) deep into the continental interior. It covers over 472,000km^2 (182,000mi^2) – an area bigger than Japan.

4 Lake Vostok
The icy, dark waters of Antarctica's biggest sub-glacial lake could be teeming with life, despite being buried 4km (2.5mi) beneath the ice for millions of years. In July 2013, scientists revealed that ice collected near the lake waters contained genetic material from 3,507 critters, including bacteria.

7 East Antarctic Ice Sheet

13 McMurdo Dry Valleys



Seasonal variation
During the winter the formation of sea ice around Antarctica essentially doubles the size of the continent compared to summer, from about 18.1 million square kilometres (7 million square miles) to 33.7 million square kilometres (13 million square miles). The ice can grow at a rate of 103,600 square kilometres (40,000 square miles) per day!

Most of the world's seals also live in Antarctic waters. These carnivorous mammals live, hunt and can even sleep underwater. Elephant seals also hold the record for having the biggest relative size difference between males and females of any mammal.

The most common birds in this frozen land are penguins, though of Antarctica's 17 species, only five breed on the continent itself. Emperor penguins – the world's tallest, largest penguin – live exclusively in the Antarctic. Males go without food for nine weeks during winter while incubating their eggs, and the females make a long, perilous journey to seek food for when the chicks hatch.

Islands in the Southern Ocean, surrounding Antarctica are wetter, milder and have more varied vegetation than the mainland. Bird Island, South Georgia, for example, has an average summer temperature of four degrees Celsius (39 degrees Fahrenheit). Its dominant coastal vegetation is tussock grass, which can grow to two metres (6.6 feet) tall.

Even Antarctic icebergs can be home to life. Young icefish hide from predators in holes in the ice. Snow petrels also nest on the bergs, which are generally safer than the mainland.

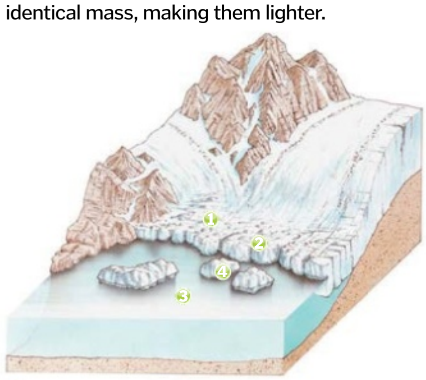
Antarctica was not always an icy desert. Dinosaurs and other megafauna lived in Antarctica when it was warmer. For instance, fossils of a car-sized armadillo, which lived around 45 million years ago, were discovered near the Antarctic Peninsula. Fossilised pollen evidence even shows that rainforests grew on the continent around 52 million years ago, but eastern Antarctica began to freeze over some 34 million years ago, when Earth's climate cooled dramatically.

How icebergs form

In November 2013, the ice shelf attached to Antarctica's Pine Island Glacier shed an iceberg the size of Singapore. Gigantic ice shelves fringe 30 per cent of the Antarctic coast, and thousands of huge blocks of ice break off each year.

Icebergs can be streaked green by algae growing beneath them or bluish if they're made of compacted ice, which scatters lots of blue light.

They float because ice is less dense than the surrounding seawater. As water freezes, the molecules spread out into ice crystals. The crystals fill more space than seawater, but have identical mass, making them lighter.



1 Glacier
Snow builds up in Antarctica's continental interior until it slides downhill under its own weight, forming an ice stream.

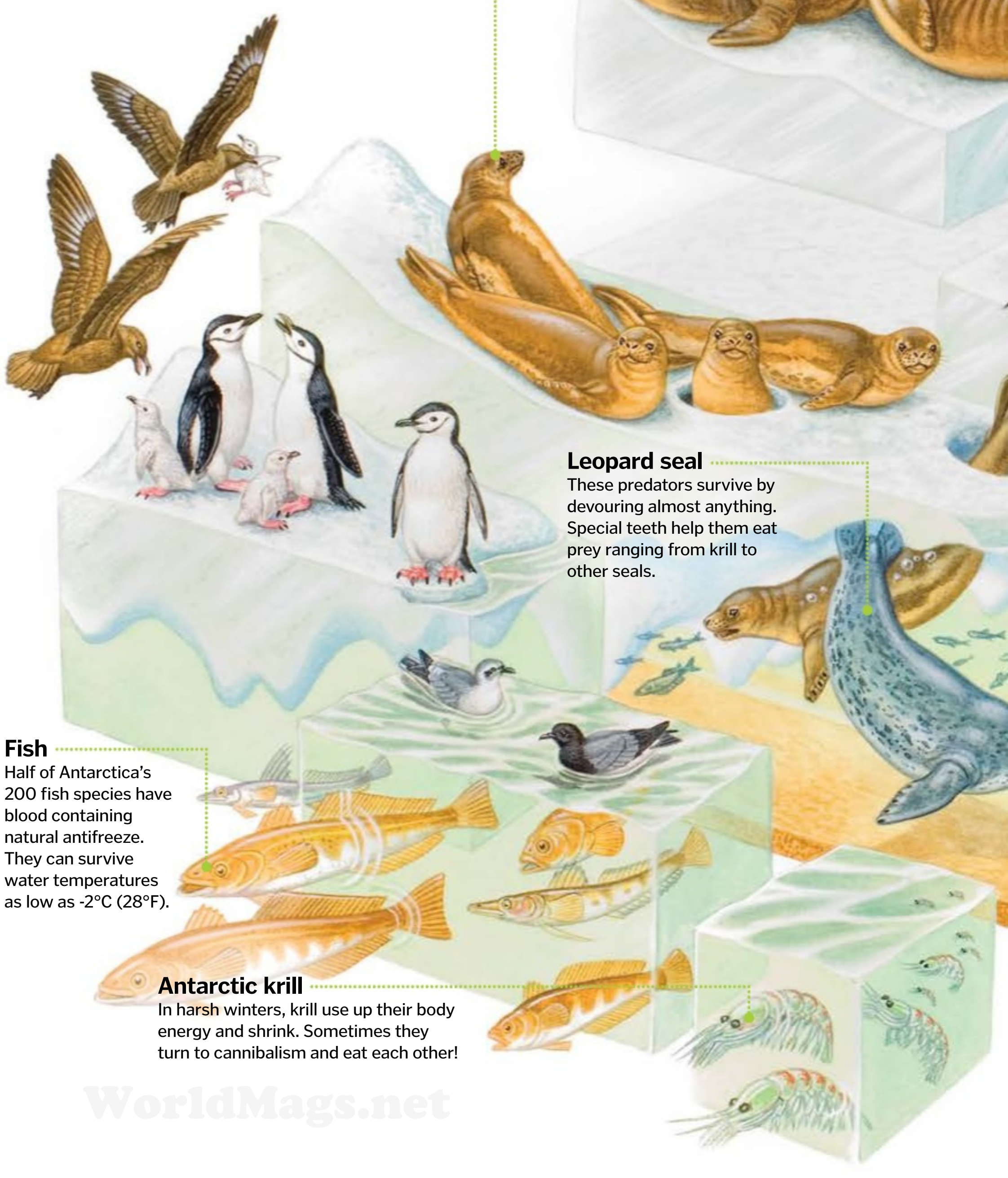
2 Ice shelf
When the glacier reaches the coast, it won't stop there, but extends into the sea to form a floating platform called an ice shelf.

3 Ocean
The ocean's tidal motion raises and lowers the ice shelf, causing cracks. Warm seawater melts and weakens the shelf bottom from below.

4 Iceberg calving
Chunks of ice break off the shelf and crash into the ocean, creating huge waves. Icebergs are born.

Life in the freezer

Discover how a wide range of wildlife has adapted to the bitter Antarctic terrain



Southern elephant seal
Males are up to ten times heavier than females. Elephant seals must live off their fat stores while onshore to breed.

Antarctic fur seal
They have fine fur close to their skin and a waterproof layer on top – like a jumper underneath a wetsuit.

Leopard seal
These predators survive by devouring almost anything. Special teeth help them eat prey ranging from krill to other seals.

Fish
Half of Antarctica's 200 fish species have blood containing natural antifreeze. They can survive water temperatures as low as -2°C (28°F).

Antarctic krill
In harsh winters, krill use up their body energy and shrink. Sometimes they turn to cannibalism and eat each other!

KEY DATES
ANTARCTIC EXPLORATION

1772
James Cook sets sail for the Antarctic Circle, realising rock-strewn icebergs came from an undiscovered continent.

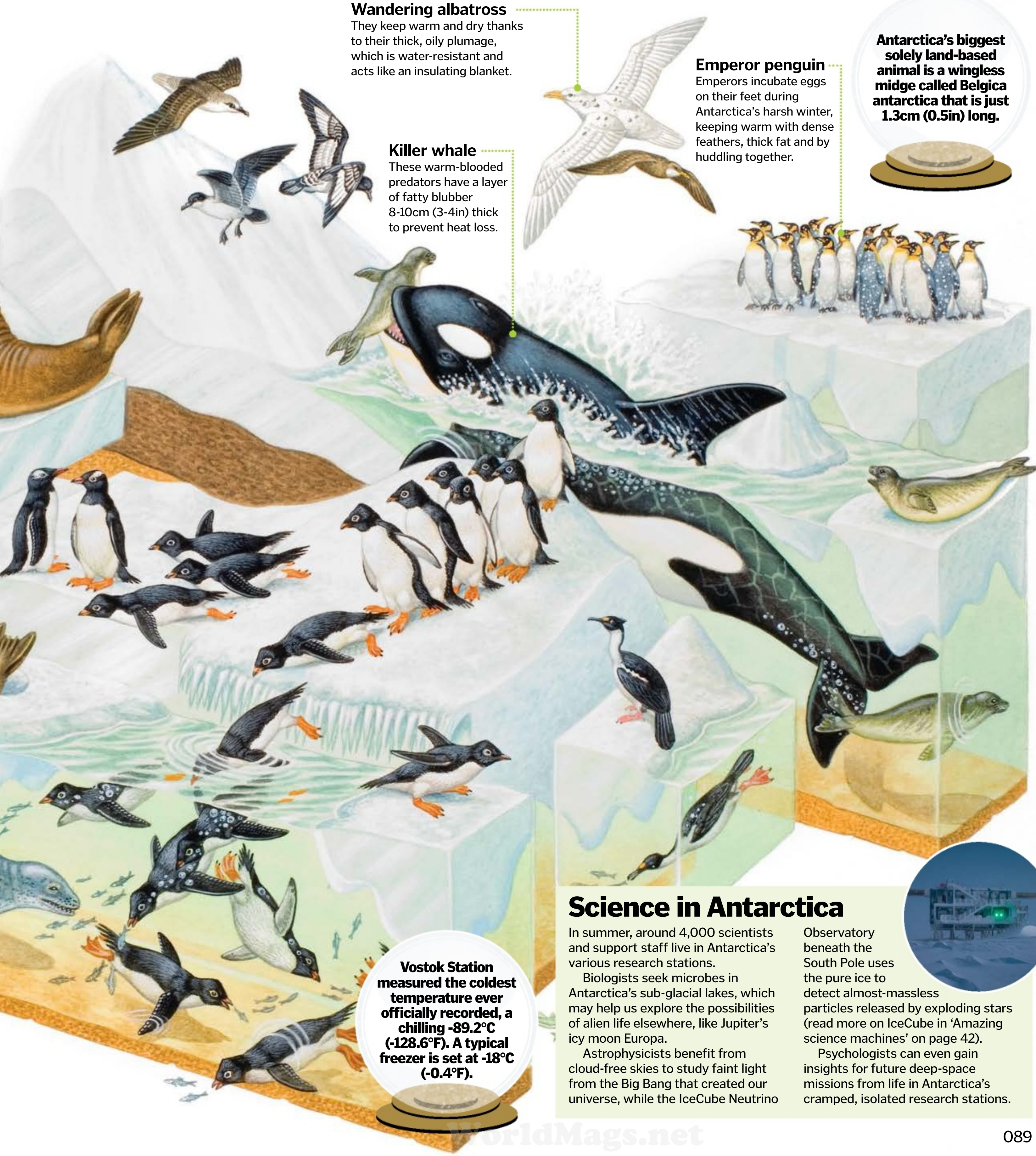
1911
Norwegian Roald Amundsen becomes the first to reach the South Pole, beating the British explorer Robert Scott.

1914
Ernest Shackleton attempts to cross Antarctica, but is stranded for almost two years after winter ice crushes his ship.

1929
US explorer Richard Byrd is the first to fly over the South Pole. He goes on to lead five expeditions to map Antarctic territory.

1996
Borge Ousland makes the first unassisted solo crossing of Antarctica towing a 180kg (400lb) sled with skis and a sail.

DID YOU KNOW? *Blue whales are the largest ever-known animal. As heavy as 24 elephants, they mainly eat paperclip-sized krill*



Wandering albatross
They keep warm and dry thanks to their thick, oily plumage, which is water-resistant and acts like an insulating blanket.

Emperor penguin
Emperors incubate eggs on their feet during Antarctica's harsh winter, keeping warm with dense feathers, thick fat and by huddling together.

Antarctica's biggest solely land-based animal is a wingless midge called Belgica antarctica that is just 1.3cm (0.5in) long.

Killer whale
These warm-blooded predators have a layer of fatty blubber 8-10cm (3-4in) thick to prevent heat loss.

Vostok Station measured the coldest temperature ever officially recorded, a chilling -89.2°C (-128.6°F). A typical freezer is set at -18°C (-0.4°F).

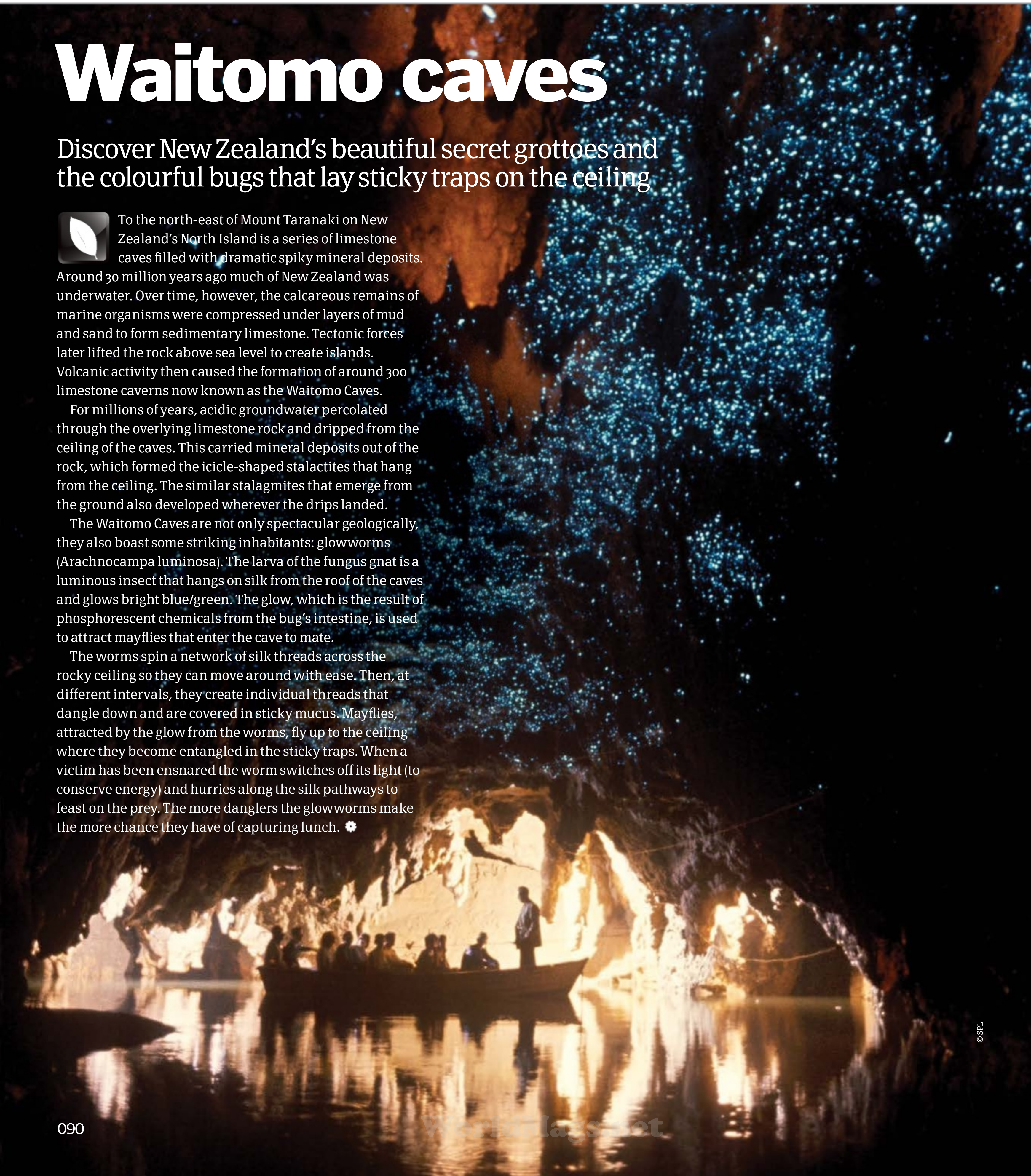
Science in Antarctica

In summer, around 4,000 scientists and support staff live in Antarctica's various research stations.

Biologists seek microbes in Antarctica's sub-glacial lakes, which may help us explore the possibilities of alien life elsewhere, like Jupiter's icy moon Europa.

Astrophysicists benefit from cloud-free skies to study faint light from the Big Bang that created our universe, while the IceCube Neutrino Observatory beneath the South Pole uses the pure ice to detect almost-massless particles released by exploding stars (read more on IceCube in 'Amazing science machines' on page 42).

Psychologists can even gain insights for future deep-space missions from life in Antarctica's cramped, isolated research stations.



Waitomo caves

Discover New Zealand's beautiful secret grottoes and the colourful bugs that lay sticky traps on the ceiling

To the north-east of Mount Taranaki on New Zealand's North Island is a series of limestone caves filled with dramatic spiky mineral deposits. Around 30 million years ago much of New Zealand was underwater. Over time, however, the calcareous remains of marine organisms were compressed under layers of mud and sand to form sedimentary limestone. Tectonic forces later lifted the rock above sea level to create islands. Volcanic activity then caused the formation of around 300 limestone caverns now known as the Waitomo Caves.

For millions of years, acidic groundwater percolated through the overlying limestone rock and dripped from the ceiling of the caves. This carried mineral deposits out of the rock, which formed the icicle-shaped stalactites that hang from the ceiling. The similar stalagmites that emerge from the ground also developed wherever the drips landed.

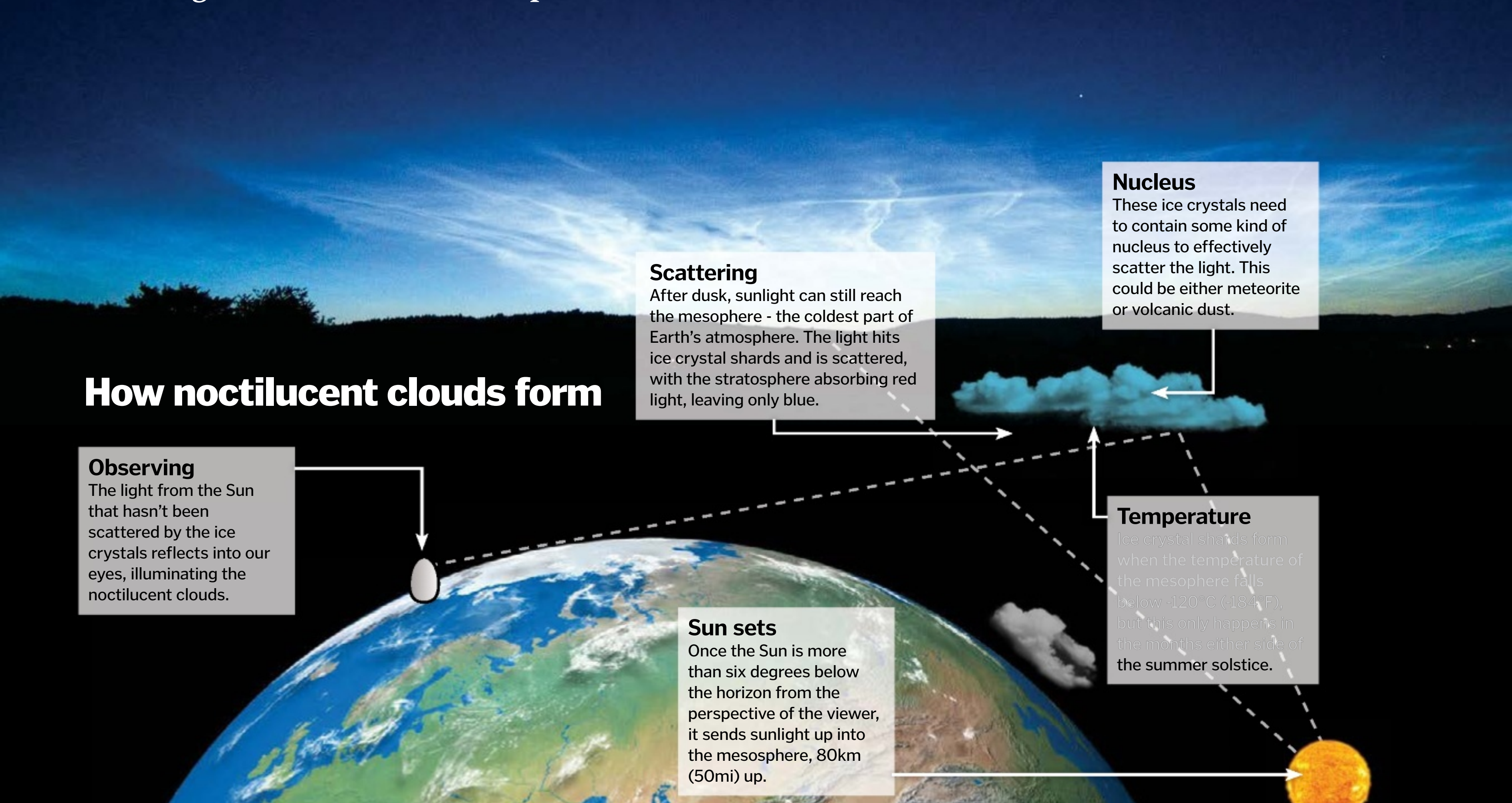
The Waitomo Caves are not only spectacular geologically, they also boast some striking inhabitants: glowworms (Arachnocampa luminosa). The larva of the fungus gnat is a luminous insect that hangs on silk from the roof of the caves and glows bright blue/green. The glow, which is the result of phosphorescent chemicals from the bug's intestine, is used to attract mayflies that enter the cave to mate.

The worms spin a network of silk threads across the rocky ceiling so they can move around with ease. Then, at different intervals, they create individual threads that dangle down and are covered in sticky mucus. Mayflies, attracted by the glow from the worms, fly up to the ceiling where they become entangled in the sticky traps. When a victim has been ensnared the worm switches off its light (to conserve energy) and hurries along the silk pathways to feast on the prey. The more danglers the glowworms make the more chance they have of capturing lunch.

Clouds that shine at night

How do these glow-in-the-dark noctilucent clouds form high in the Earth's atmosphere?

How noctilucent clouds form



The sailing stones

Solving the mystery of the rocks that move by themselves

The Racetrack Playa in Death Valley, USA, has been a massively popular tourist spot for decades, mainly due to the incredible phenomenon in which huge rocks appear to move by themselves. Rocks as heavy as 318 kilograms (700 pounds) have travelled as far as 457 metres (1,500 feet), leaving a trail in the mud behind them. Everything from aliens to pranksters has been blamed for the phenomenon, while other researchers thought whirlwinds that suddenly kick up in the desert might be to blame. This theory was disproved, leaving us scratching our heads for years, until planetary scientist Ralph Lorenz from John Hopkins University cracked the mystery while working on a project with NASA. He discovered that in winter the Racetrack Playa gets extremely cold, allowing ice to form around the rocks. The ice makes even the heaviest rocks buoyant, allowing them to 'surf' along the standing water in only a slight breeze, creating a trail in the sand beneath it.

Meerkat survival tactics

Meet the sociable critters that play to their strengths by living in tight-knit groups

Meerkats might not be the biggest animals on the African plains, nor appear to boast any particularly formidable weapons, like the rhino's horn, or impressive skills, like the cheetah's speed. Nevertheless, through a combination of hardy biology, smart tricks and a unique community spirit, these mammals have adapted perfectly to their harsh environment.

They escape the most extreme temperatures of southern Africa – as well as the vast majority of predators who'd like to make a meal of them – by living in underground burrows. Some of these subterranean networks can play host to up to 50 or so individuals, though an average colony is about half this size, with two or three families living together communally.

A type of mongoose, they are equipped with sharp, curved claws – each about two centimetres (0.8 inches) long – used for digging and self-defence, as well as acute vision, which comes in very handy for spotting danger.

In fact, when they do venture out of their burrows en masse to search for food, there will always be at least one meerkat that stands sentry – often on a rock or in a bush – primarily looking to the skies for their number-one enemy: birds of prey. As soon as any threat is detected, the lookout will give a shrill warning bark and the others will immediately make a dash for a nearby bolthole or other cover. It's thought that meerkats have dozens of different calls to signify a range of threats.

As well as hunting together over a territorial range that can cover as much as ten square kilometres (four square miles), meerkats also share childcare duties. Typically, only the colony's alpha pair will mate, but all the others pitch in to babysit, grooming and feeding the pups, as well as demonstrating valuable life skills, like where to find food, play-fighting and which parts of a scorpion to eat.

Biology of a meerkat

They may be small, but their bodies are tough

Ears
The ears are small and round and can be closed when the meerkat is digging or caught in a sandstorm.

Eyes
Binocular vision helps them detect predators like eagles from as far as 1km (0.6mi) away, while the black eye patches reduce glare. Nicitating membranes act like goggles to keep sand out while digging.

Fur
Varies in colour from light tan to dark brown depending on the terrain, with unique stripe patterns on the back. Fur is thinner on the belly and meerkats will often sunbathe in the morning to warm up.

Tail
Almost doubling the meerkat's length, the long tail is a useful aid for balancing when standing on their hind legs.

Claws
2cm (0.8in)-long claws (four on each paw) are used to dig their burrows as well as to forage for insects and roots in the arid ground.

Are they immune to venom?

Meerkats are renowned for picking fights with creatures that even the most powerful hunters give a wide berth, like snakes and scorpions, but are they really impervious to venom? Well, to some degree this may be true, because mongooses have often demonstrated a much higher tolerance to venom than most animals due to a slightly mutated neurotransmitter, which prevents the toxins from causing muscle paralysis. However, this doesn't mean meerkats are immune – they *can* die if they get stung or bitten several times or by particularly toxic species. But to sway the odds in their favour, they've developed some clever hunting tactics, including 'mobbing', where they encircle an enemy and attack it from all angles. Or in a scorpion's case, they move with lightning-quick reflexes to bite off the stinger before it can do any harm, then rub the toxic outer layer of the exoskeleton on the ground before eating it.


One meerkat will always stand guard while the others are occupied

Meerkats live in colonies of up to 50 individuals and they rely on each other for food, defence and rearing their pups

The statistics…

Meerkat

Type: Mammal

Binomial: Suricata suricatta

Diet: Omnivore, eg insects, fruit, lizards, roots, birds

Body length: 30cm (12in)

Weight: 750g (26oz)

Average life span in the wild: 10 years

How mini monkeys survive

The pygmy marmoset may be Earth's smallest monkey, but it's got plenty of tricks

These minute primates weigh an average of just over 110 grams (3.9 ounces), and measure 135 millimetres (5.3 inches) in body length. Despite their miniature size, they are capable of jumping impressive distances of up to five metres (16 feet) and are highly adapted for a life in the trees.

They live in the Amazon rainforest of South America and, using their long, sharp lower front teeth, gnaw holes in trees and vines to feed on sap, gum and resin. The marmosets choose one tree at a time for this purpose, making a series of holes from the bottom to the top. The sticky sap also attracts insects, which the omnivorous marmosets will eat to supplement their diet.

Pygmy marmosets are social creatures and live in small groups, usually of less than ten, with one dominant male and a breeding female. They are prey animals, and can turn their heads a full 180 degrees in order to keep watch over their surroundings for predators. They also use a series of squeaks, clicks, whistles and trills to communicate with one another over short and long distances.

Pygmy marmosets have adapted claws for clinging to trees while feeding

Bees have an excellent sense of smell, so can sniff out buried explosives

Training anti-mine bees

Swarms of bees have been taught to locate TNT and identify land mines, but how do they do it?

During the Croatian war of independence in the early-Nineties, more than 1.5 million land mines were laid across the country. Although the remaining minefields are marked, de-mining is not yet complete, and over 500 people have been killed and many more injured by land mines since the war ended.

Even once a field has been de-mined and checked, there is a chance that remaining land mines could still be hidden beneath the soil. However, Croatian scientists have developed a rather novel solution to uncovering the remaining mines: bees.

These insects have an exceptionally good sense of smell, which means they can be trained to sniff out trinitrotoluene (TNT) – the explosive used in these devices.

A sugar solution is placed into a glass to simulate nectar and this is placed in soil containing traces of TNT. As the bees fly towards their sugary drink, they smell the TNT and, over a period of three or four days, gradually learn to associate the smell of explosives with the promise of food.

Once the bees are trained, they can be transported to fields and released into the air. Bees are incredibly hard to track visually, but they emit a lot of heat as they fly, and so can be followed with an infrared camera. Their small size also means that, unlike trained mine-detecting dogs, they are not at risk of setting off an undetonated mine.

The research has yet to be completed, but it is hoped the bees will be able to help confirm if fields have been properly de-mined.

Sierra Madre Oriental
1 This mountain range marks the border between the Coahuila and Nuevo León regions in Mexico. Satellite imagery reveals them to look like the spines of fossilised dinosaurs.

Baffin Island sea ice
2 From space these chunks of sea ice floating among tiny ice crystals, known as grease ice, look like swirling wispy white clouds when captured using satellite imagery.

Spider Crater
3 This impact crater in north Western Australia has leg-like ridges of tough sandstone which have stood the test of time better than the surrounding crater.

Polar auroras
4 When the aurora borealis/australis geomagnetic storms are viewed from space they somehow manage to look even more alien than they do when viewed from below.

Great Barrier Reef
5 The magnificent blue-green glow of corals in the Great Barrier Reef off the coast of Queensland are particularly impressive when viewed using satellite imagery.

DID YOU KNOW? Richat's outer rings are the youngest while those at the core indicate significantly older rock

The Eye of the Sahara

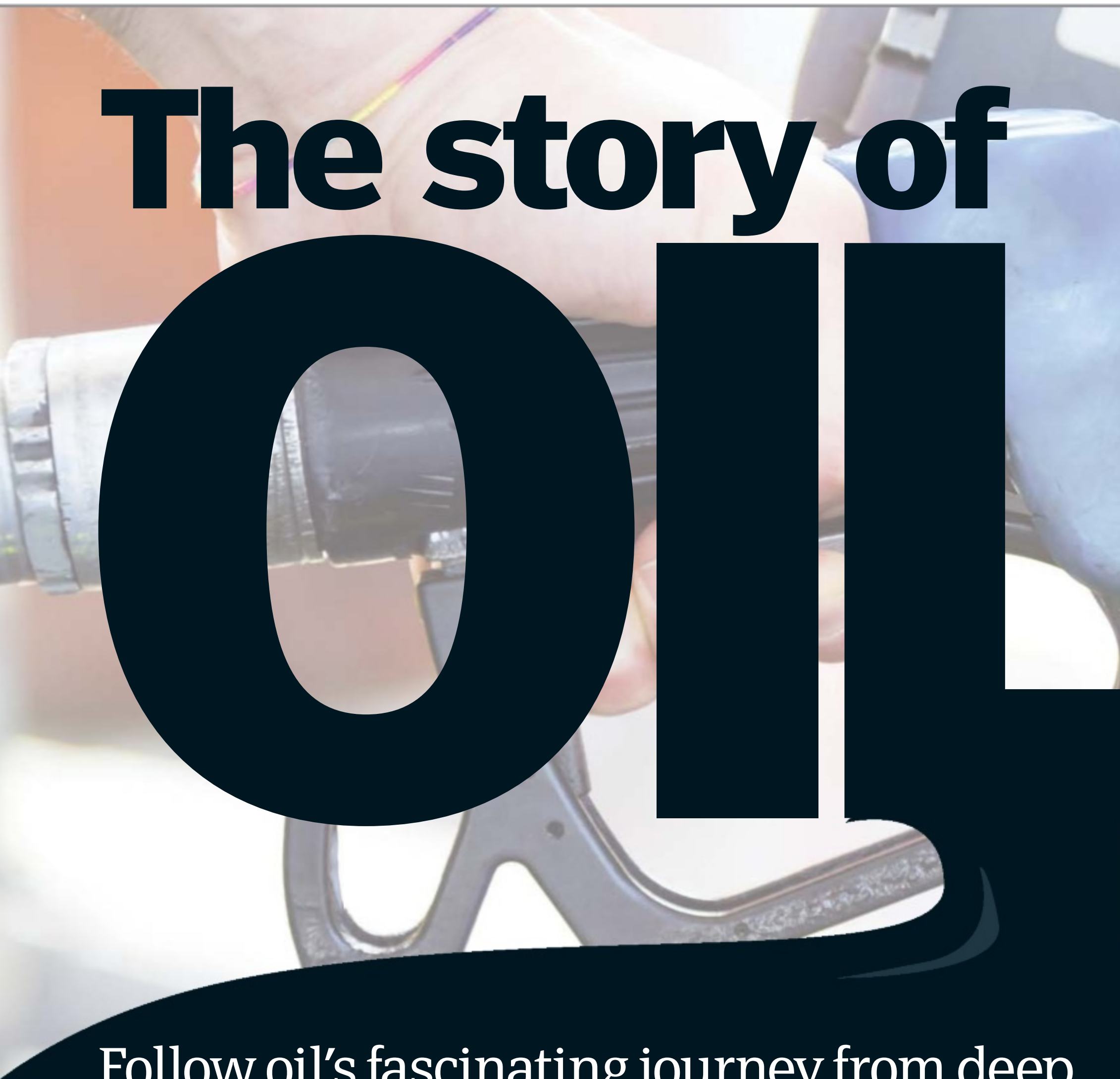
What is the Richat Structure and how did it form?

It might look like the site where a massive ancient meteorite once struck the side of the Earth, but this is no impact crater. The Richat Structure – also known as the Eye of the Sahara – is, in fact, a dramatic geological formation that appears like a giant bull's eye in the otherwise barren desert landscape. Located in the north African country of Mauritania, Richat is a hardened structural dome whose crest has worn away to expose the underlying layers of sedimentary rock and minerals.

All sedimentary rock layers start out horizontal, but due to underground stresses they can get folded – either upwards in a convex shape (anticline) or downwards and concave (syncline). No one knows exactly why, but millions of years ago a circle of rock strata almost 50 kilometres (30 miles) across was uplifted causing an anticline dome to bulge up out of the Earth's surface. We now know this as the Richat Structure. If it helps, try thinking of the dome as the top half of an onion where each layer represents a different strata of rock.

Extremely slowly, the dome was eroded by the elements to expose a ring of concentric circles on the ground that are now clearly visible from space. Like the onion layers, these circles indicate the different bands of rock radiating out from the central limestone-dolomite shelf. Richat's most visible bands of rock (or cuestas) are tilted ridges of resistant palaeozoic quartzite that slope away from the centre and gave it the misleadingly crater-like appearance that long confused scientists.

We know the Eye of the Sahara wasn't the result of an impact because there's no evidence of rock shock, which occurs when the pressure and temperature of an impact deforms the crust



The story of OIL

Follow oil's fascinating journey from deep underground to a petrol pump near you

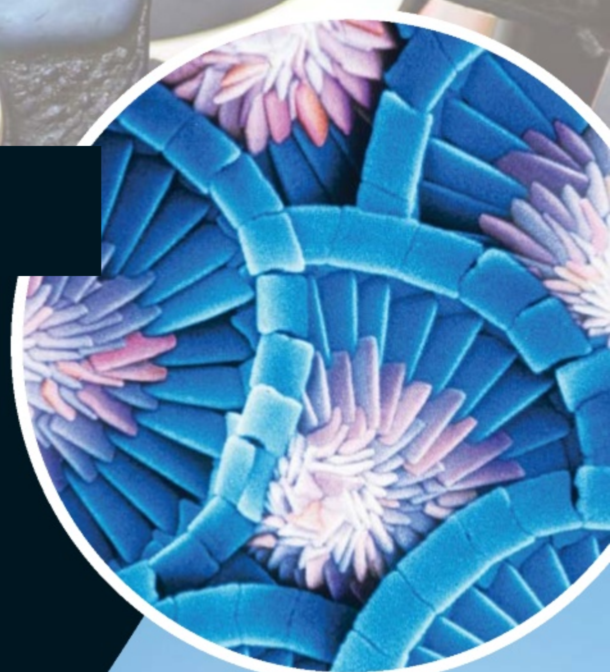
We're all addicted to oil. The fuels on which our cars run, the medicines we take and the plastics we use every day are derived from crude oil. Few of us ever come into direct contact with it, yet it forms the foundations of modern society.

The oil industry took its first steps in the 19th century, driven by the popularity of kerosene-fuelled lamps, but with the advent of the internal combustion engine demand for this energy-dense fuel truly boomed. Humans across the globe now consume 90 million barrels (14.3 billion litres/3.8 billion gallons) of 'black gold' every day.

The story of oil, however, began much longer ago. Crude oil is a fossil fuel formed over millions of years. The process kicked off in prehistoric seas 400 million years ago. As micro-organisms like plankton died, their remains accumulated on the seabed, gradually forming rock. Buried under layers of sediment, the increasing pressure and temperature allowed bacteria and chemical reactions to transform organic matter, first into kerogen and then oil. Collecting in reservoir rock, this oil sometimes got sandwiched between solid rock, creating the oilfields we drill today.

For oil to form, the temperature, determined by the depth at which the source rock is buried, must be just right. Below 80 degrees Celsius (176 degrees Fahrenheit) the organic matter remains kerogen, while above 120 degrees Celsius (248 degrees Fahrenheit), natural gas hydrocarbons develop instead. The exact temperature dictates which hydrocarbons are produced, giving oil from each location its own unique fingerprint.

Three conditions are essential for an oilfield to form. First, a source rock rich in organic material must be buried at the right depth. Then a porous reservoir rock is necessary for it to accumulate. Finally, an impermeable 'cap rock' must prevent oil from escaping to the surface. Predicting where all three conditions may be met allows geologists to pinpoint likely locations for oilfields. ▶



In these cliffs you can see the layers of bituminous shale where oil would have once accumulated (grey) and calcium-rich mudstone (orange); above are coccospheres, one of the millions of tiny marine organisms which decompose to form oil

DID YOU KNOW? *On average the USA has experienced over two oil spills every year in the last decade*

Inside oil

Oil is a mixture of hydrocarbons – molecules composed of only hydrogen and carbon. It also contains small amounts of oxygen, nitrogen, sulphur, salts and water. The covalent bonds between carbon and hydrogen atoms lock away chemical energy reserves that are freed up when burned. Each molecule has different properties depending on structure and length, making oil a very versatile substance. By selecting and cross-linking hydrocarbons, many different products can be made, from plastics to lubricants.

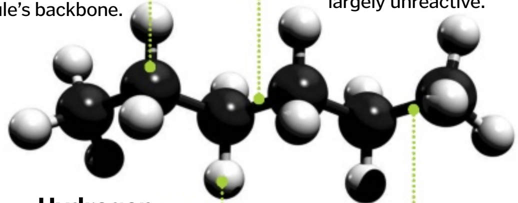
ON THE MAP

Worldwide oil reserves (barrels)

1. Venezuela 298 billion
2. Saudi Arabia 268 billion
3. Canada 173 billion
4. Iran 155 billion
5. Iraq 141 billion
6. Kuwait 104 billion

Hydrocarbon structure

Hexane belongs to the alkane family, one of the most common hydrocarbon types in crude oil



Carbon Six carbon atoms form the molecule's backbone.

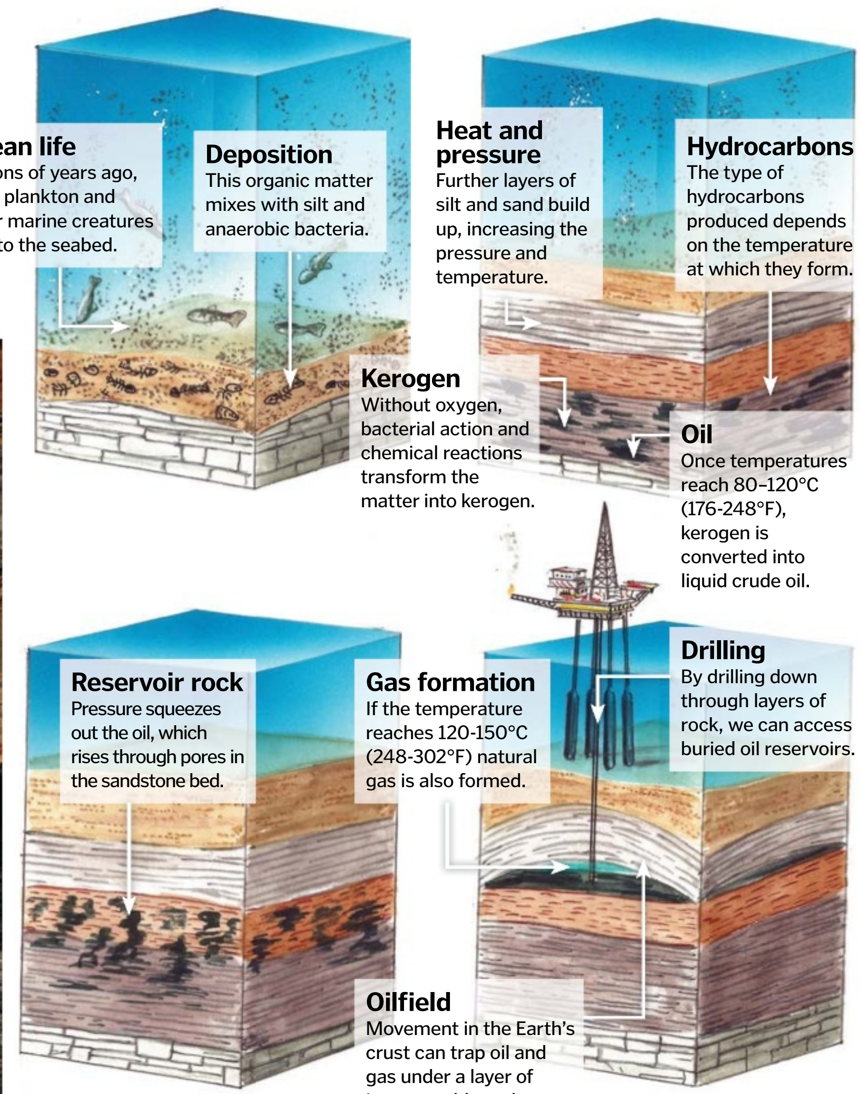
Bonds Single covalent bonds make the molecule largely unreactive.

Hydrogen 14 hydrogen atoms are connected to the carbon atoms.

Combustion Burning hexane breaks these bonds, which creates CO_2 and water.

Oil in the making

See how oil is created in a process spanning millions of years



Ocean life Millions of years ago, dead plankton and other marine creatures sink to the seabed.

Deposition This organic matter mixes with silt and anaerobic bacteria.

Heat and pressure Further layers of silt and sand build up, increasing the pressure and temperature.

Hydrocarbons The type of hydrocarbons produced depends on the temperature at which they form.

Kerogen Without oxygen, bacterial action and chemical reactions transform the matter into kerogen.

Oil Once temperatures reach 80–120°C (176-248°F), kerogen is converted into liquid crude oil.

Reservoir rock Pressure squeezes out the oil, which rises through pores in the sandstone bed.

Gas formation If the temperature reaches 120-150°C (248-302°F) natural gas is also formed.

Drilling By drilling down through layers of rock, we can access buried oil reservoirs.

Oilfield Movement in the Earth's crust can trap oil and gas under a layer of impermeable rock.

▶ The industry uses a variety of techniques to sniff out oil deposits. First, geologists use aerial photography to gather clues on underground rock formations. Measuring the Earth's gravitational pull can also reveal tiny variations that hint at the density of the rocks. Next, a seismic survey is carried out. By firing acoustic waves into the ground and measuring how they bounce off rocks deep underground, a 3D subsurface map is created. Once scientists have located potential oilfields, drilling preparations begin.

Setting up drilling structures on land is fairly straightforward, but at sea, operators must contend with high winds, waves and currents. In shallow waters, jack-up rigs are most common, stabilised by legs that extend down to the sea floor. Beyond depths of 100 metres (328 feet), semi-submersible rigs are towed out and held in place with anchoring systems. Finally, drill ships access the deepest locations. Back on terra firma, rotary drills are most common, using a derrick to raise and lower the drill bit into the ground.

With drilling underway comes the moment of truth: is there any oil? And is there enough to make extraction financially viable? As test wells are dug, scientists retrieve samples that reveal the structure of the rock formation and how much oil is present. Other instruments are lowered down to measure properties, such as the radioactivity or resistance of the reservoir and the pressure and temperature of the gases and liquids. If there is enough oil, production can begin. In the case of offshore sites, this means replacing mobile drilling units with a permanent oil platform.

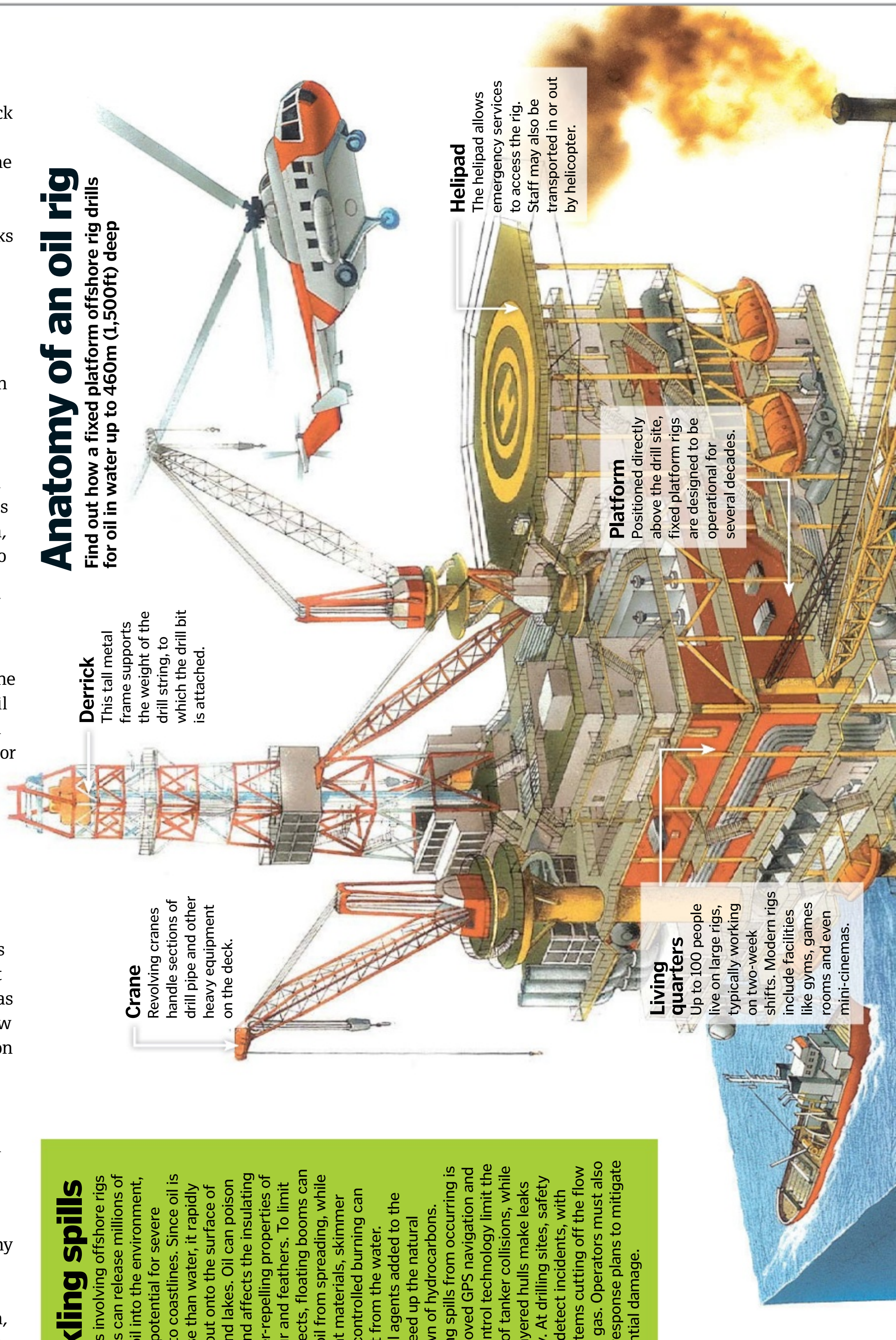
As drilling progresses, cement casing is put in place to keep the hole from collapsing. Highly pressurised pockets of gas or oil can damage rigs and cause explosions or oil spills. To balance out this pressure, a heavy mix of minerals – known as 'mud' – is poured into the hole. Valves called blow out preventers are also fitted under land rigs or on the seabed to seal off the drill line.

When drilling reaches its final depth, a perforating gun makes holes in the casing that will allow oil to enter a narrow pipe. Acid is used to create channels in limestone rock and high-pressure fluid can be used to widen cracks in sedimentary rock. Initially, the oil's pressure may be enough to drive it to the surface, but many other techniques squeeze out the remaining drops. First, waste water is pumped down to build up pressure and keep the oil flowing. Then, steam, gases and other chemicals are injected to make sure no oil is left behind.

The most challenging steps are now over, but crude oil still needs to be refined to be useful… ▶

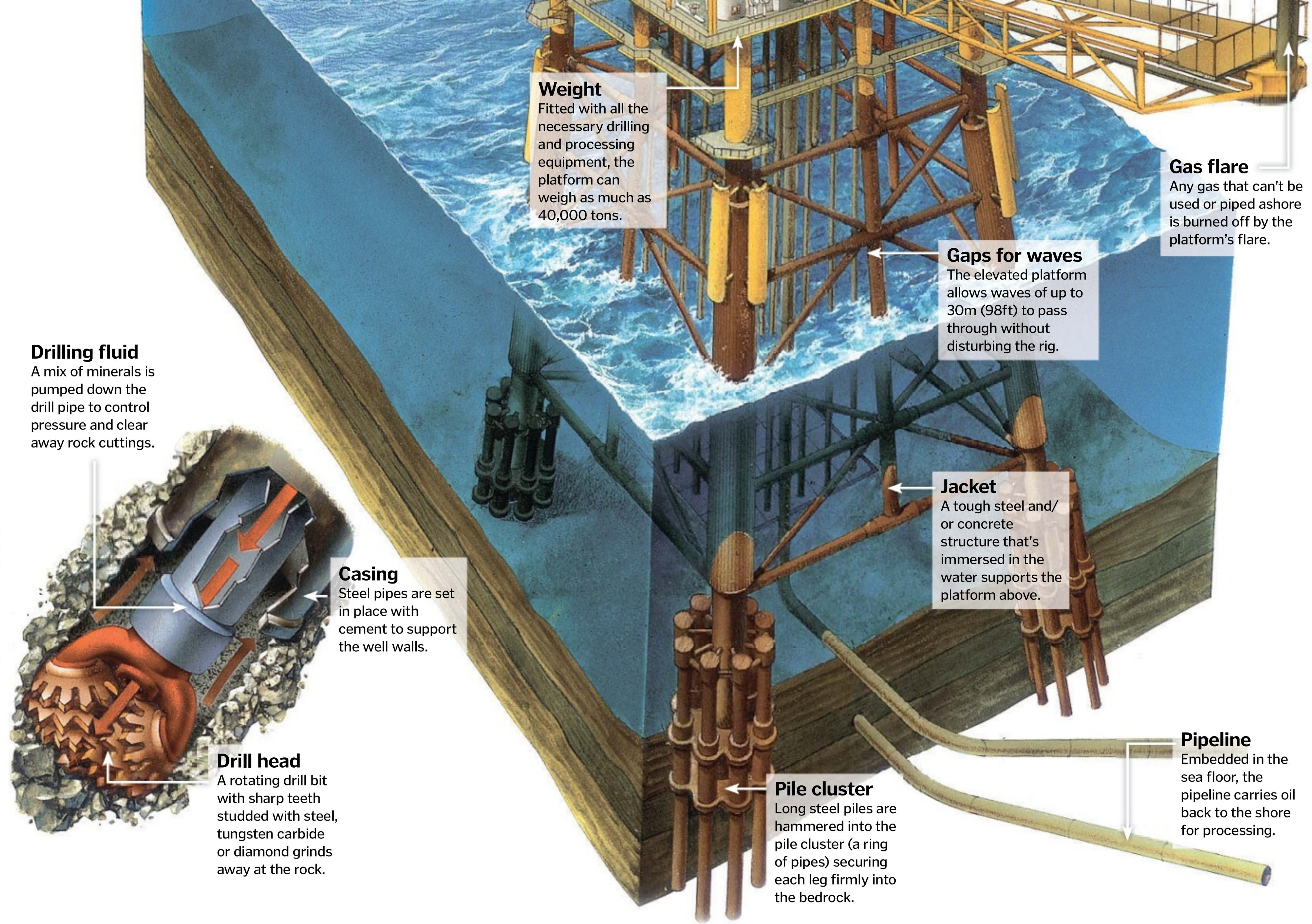
Anatomy of an oil rig

Find out how a fixed platform offshore rig drills for oil in water up to 460m (1,500ft) deep



Tackling spills

Accidents involving offshore rigs or tankers can release millions of litres of oil into the environment, with the potential for severe damage to coastlines. Since oil is less dense than water, it rapidly spreads out onto the surface of oceans and lakes. Oil can poison wildlife and affects the insulating and water-repelling properties of animal fur and feathers. To limit these effects, floating booms can prevent oil from spreading, while absorbent materials, skimmer ships or controlled burning can remove it from the water. Biological agents added to the water speed up the natural breakdown of hydrocarbons. Preventing spills from occurring is key. Improved GPS navigation and traffic control technology limit the chances of tanker collisions, while double-layered hulls make leaks less likely. At drilling sites, safety systems detect incidents, with valve systems cutting off the flow of oil and gas. Operators must also develop response plans to mitigate any potential damage.



Three other types of oil rig

Pump jack

Pump jacks are the most widespread pump design found inland. Converting a motor's rotary movement into the see-saw motion of a beam, the pump jack dips a plunger in and out of the well to draw out oil. Although simple and easy to maintain, pump jacks need to be adjusted manually as the oil pressure fluctuates.

Semi-submersible

Used for mobile drilling and production alike, semi-submersibles rest on two massive hulls. Once the vessel has been towed into its drilling position, the crew fill the balancing hulls with water, allowing them to sink beneath the surface to stabilise the platform above. They can easily be moved between sites.

Spar platform

A spar platform sits upon a cylindrical hull extending 200 metres (656 feet) underwater. The hull's weighted base keeps the platform upright. Further cables moored to the sea floor offer extra stability. Although costly to build, spar platforms can access the deepest sites, down to 3,000 metres (10,000 feet).

DID YOU KNOW? *Quantities of oil are measured in barrels. One barrel is equal to 159 litres (42 gallons)*

Oil extracted offshore is carried to dry land either via pipeline or aboard oil tankers. Crude oil tankers are among the largest ships in the world, some able to carry up to 3 million barrels (477 million litres) of oil. Carrying a highly flammable and corrosive cargo, preventing accidents is vital. Exposed to oxygen, oil vapours create a highly explosive mix. To avoid this, inert gas is pumped into the cargo tanks to keep oxygen levels down.

Pipelines consist of plastic or metal tubes laid on or under the ground or water, with diameters typically from 25-122 centimetres (10-48 inches). Gathering pipelines collecting the oil from wells may be just a few hundred metres long, while transmission lines relaying oil products to consumers can cover many thousands of kilometres. Crude oil or refined products are injected at the initial supply station, with pump stations along the way keeping the oil in motion. Automated probes known as 'pigs' travel down the pipeline, using ultrasound or electromagnetic waves to monitor for damage that could cause leaks.

Although pipelines are generally the most economical form of transport, oil trains sometimes carry oil over long distances. A spate of recent accidents caused by derailments has led to tighter regulations for crude oil trains, including more frequent inspections of vehicles and tracks and stronger braking systems.


Distillation columns tower above a combined oil and gas refinery

The first stop on crude oil's journey to the petrol pump is the refinery. There are hundreds of different hydrocarbons in crude oil, and it is fairly useless until its main constituents have been separated into fractions and processed into different products such as petrol, motor oil or other useful chemicals.

The refining process kicks off with distillation, made possible because hydrocarbon molecules have different boiling points depending on their size and structure. Heated oil forms a vapour that cools as it ascends through a tall distillation column. Longer, heavier molecules condense out first, near the bottom of the column, while light molecules with low boiling points rise to the top. Condensing the vapours at each level gives rise to the full range of oil fractions, from light gases to heavy residual tar and waxes.

Next, chemical processing converts hydrocarbons into the most useful products. The highest demand is for petrol to keep our planet's cars, trucks and other vehicles on the road, so many treatments focus on maximising the amount of petrol and diesel produced. Cracking uses heat to break up larger

From refinery to petrol pump…

Oil's journey from well to tank is anything but straightforward

1. Refinery
Refined oil products are purchased by wholesalers and made ready to leave the refinery.

2. Pipeline
Refined products are usually transported by pipeline, with many different products travelling in batches.

3. Transmix
Where two batches have mixed, the resulting 'transmix' is sent back to the refinery for reprocessing.

4. Pumps
Powerful pumps located every 50-80km (30-50mi) push the oil along.

5. Storage terminal
Petrol and other products await distribution in a storage terminal.

6. Tanker truck
Compartments inside the truck allow it to carry various grades of petrol and diesel.

30mn
CALORIES IN A GALLON OF OIL

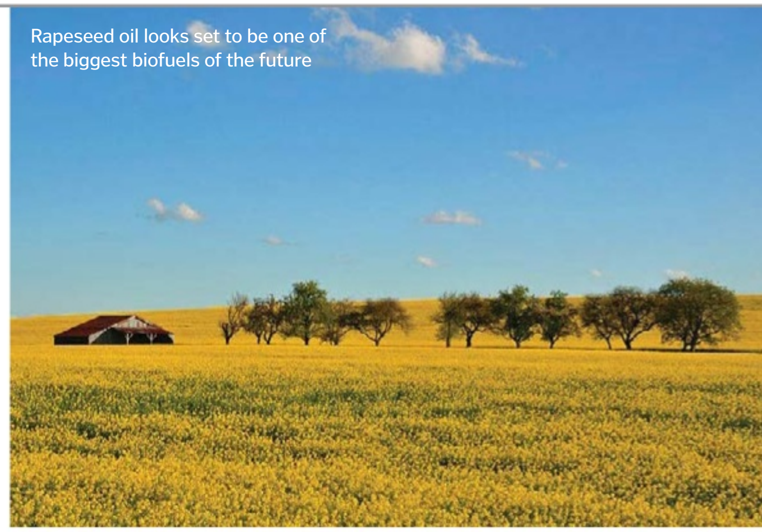
17,000,000,000
LITRES OF PETROL USED EVERY YEAR IN THE UK

4
LITRES OF JET FUEL USED PER SECOND BY A BOEING 747

120,000
NUMBER OF PETROL STATIONS IN THE USA

8km/h
AVERAGE SPEED OF OIL TRAVELLING IN A PIPELINE

Oil is transported on some of the biggest ships in the world



Rapeseed oil looks set to be one of the biggest biofuels of the future

hydrocarbons into smaller, lighter ones. The opposite process, combining smaller molecules to form big ones, is called unification. Finally, alteration is a process which transforms the structure of molecules. For example, alkylation reacts two low molecular weight compounds in the presence of a catalyst to produce high-octane hydrocarbons, which can be blended into petrol to reduce engine knocking.

Once impurities such as sulphur, nitrogen, oxygen, water and other trace substances have been removed, the refinery can then recombine fractions into ready-to-use materials. Petrol and other products finally enter the pipes that will deliver them to the millions of homes and businesses where they are needed.

While oil supplies are running low, it is unlikely that we will ever extract the last drop of our planet's reserves. Instead, experts predict that oil prices will continue to rise over the next few decades until we reach the point where other energy sources are more attractive. We've already exhausted many of the most conveniently located and easily exploitable oil reserves, leaving increasingly challenging environments such as deep-sea beds or oil sands where extraction comes at a higher cost. In a post-oil society, electric cars may replace petrol or diesel-fuelled models. These could charge up on electricity produced by renewable sources such as wind, water or solar power, or draw energy from portable fuel cells. Such fuels could help to address climate change concerns by reducing our carbon emissions. Plant oils could also form the raw materials for bio-polymers and other molecules that will replace the plastics and other essential chemicals we currently obtain from crude oil.

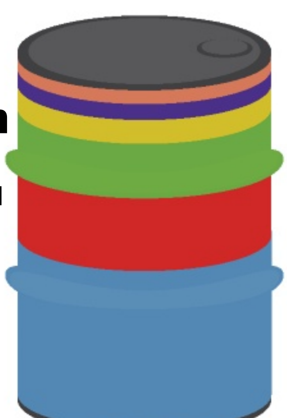
An oil-free world will look very different from today's, but developing the key technologies to wean us off oil now will ensure that the transition is smoother in the future.

8. Petrol station
The end of most oil's journey. In the engine, a spark triggers a small explosion to drive pistons that power our cars.

7. Local distribution
Tanker trucks distribute petrol to filling stations but airports may have a direct pipeline.

£0.03
AVERAGE PRICE OF A LITRE OF PETROL IN VENEZUELA

Crude oil barrel breakdown

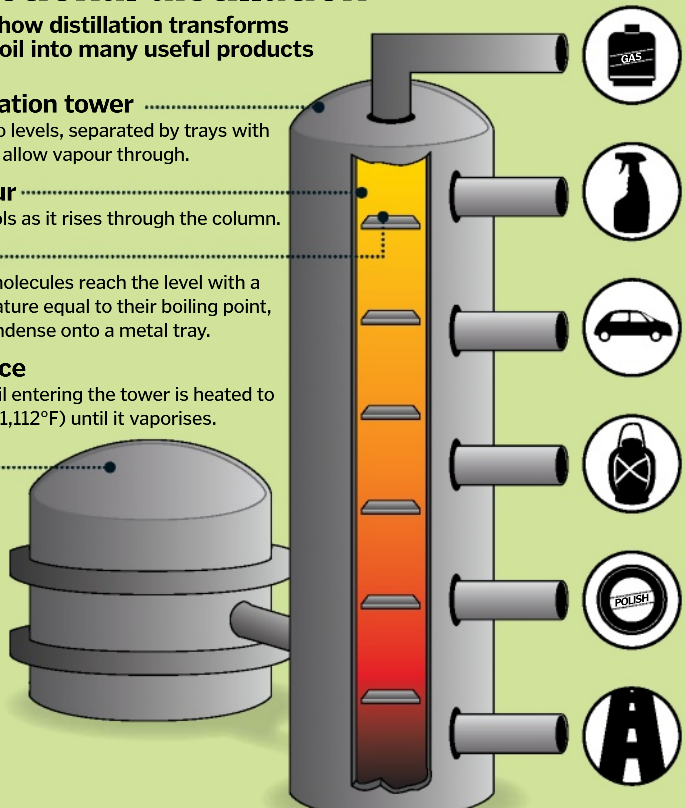


- 3.9% asphalt
- 5% heavy fuel oil
- 5.8% jet fuel
- 15.2% other
- 27.4% diesel
- 42.7% petrol

Source: Statistics Canada

Fractional distillation

Learn how distillation transforms crude oil into many useful products



Distillation tower
Split into levels, separated by trays with holes to allow vapour through.

Vapour
This cools as it rises through the column.

Trays
When molecules reach the level with a temperature equal to their boiling point, they condense onto a metal tray.

Furnace
Crude oil entering the tower is heated to 600°C (1,112°F) until it vaporises.

Liquefied petroleum gas
This light fuel can be used as a method of heating food or homes.

Naphtha
A highly flammable liquid that can serve as a solvent. It can be used as a burning fuel or for cleaning fluids.

Petrol
About half of the crude oil is converted into petrol, which is used to power most of our vehicles.

Paraffin
This hydrocarbon has a lower igniting point than most other fuels, making it ideal for lamps and stoves.

Lubricating oils
Helping to stop moving parts from wearing, it can also be used for waxes and some types of polish.

Bitumen
Also called tar, this heavy material solidifies quickly to provide a waterproof layer for roofs and roads.

SCIENCE

104
25 weird science facts

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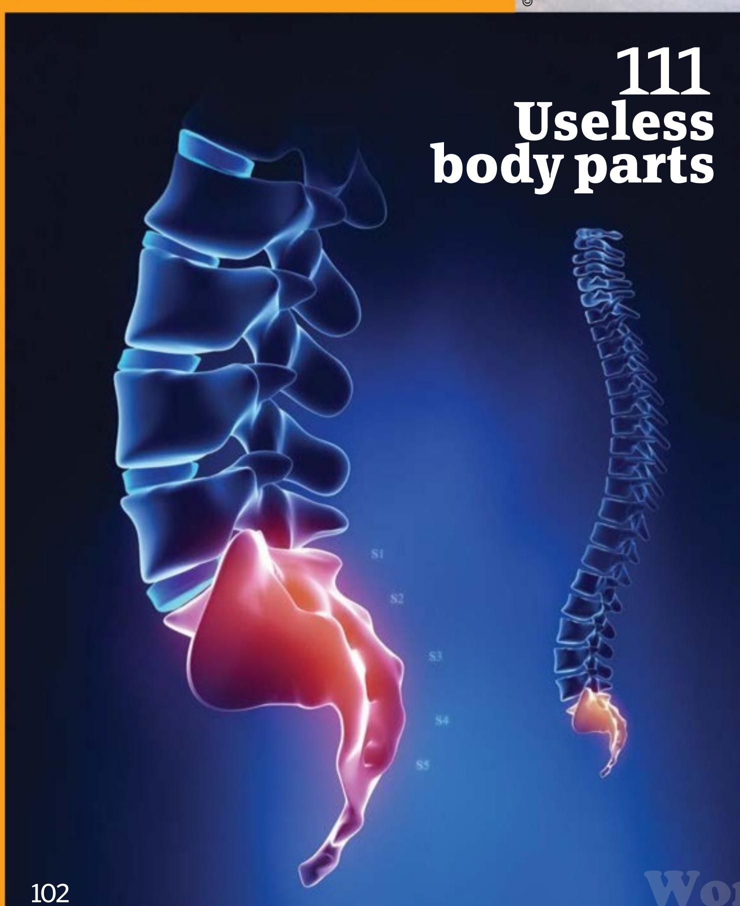
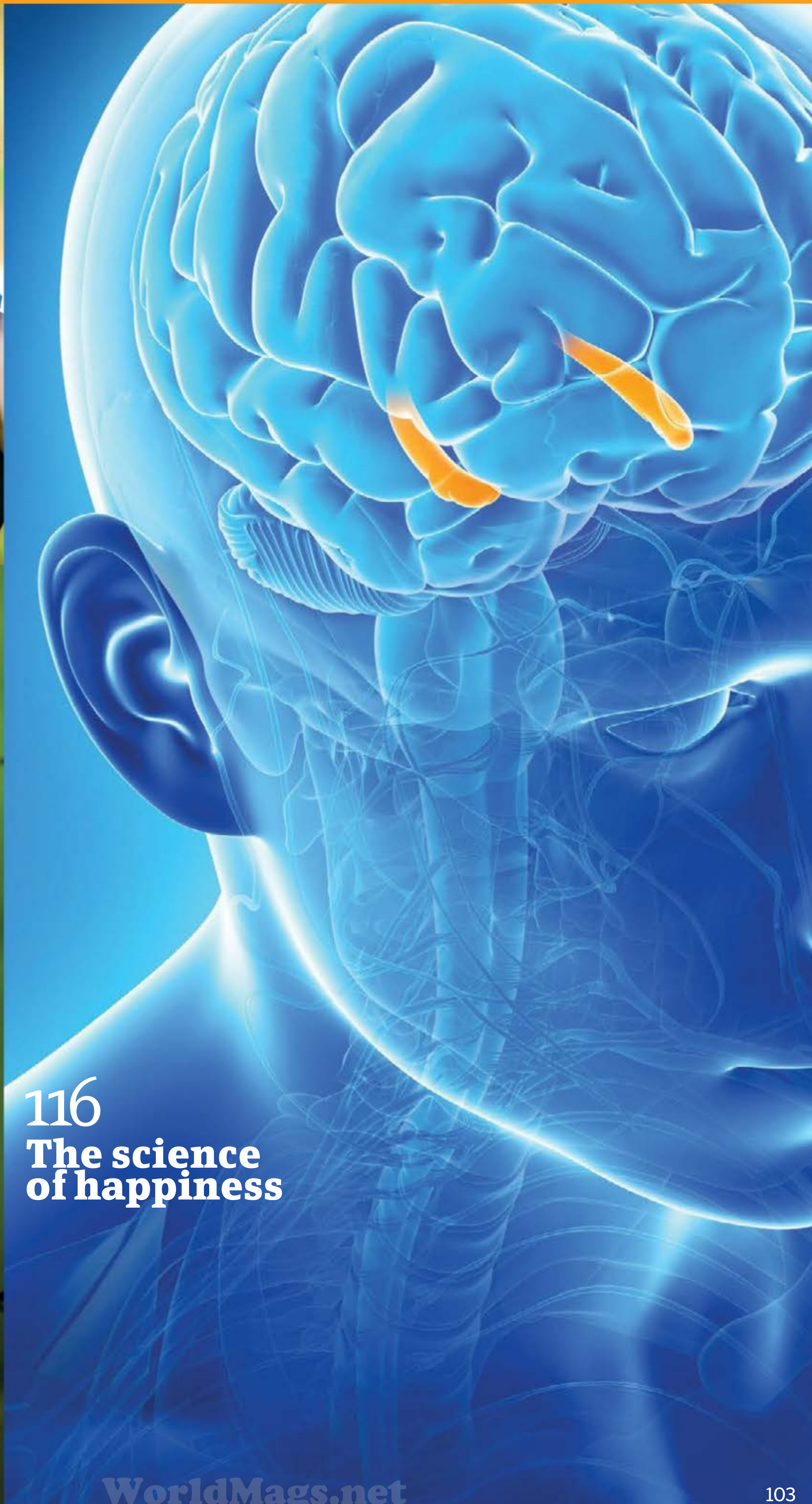


111
Useless body parts

110
72-hour deodorants



COWS ARE MAGNETIC AND 24 OTHER WEIRD SCIENCE FACTS

Science is full of surprises. From the bizarre habits of fruit bats to the average colour of our universe (believe it or not, it isn't black), the weird discoveries uncovered by researchers across all fields of science are a constant reminder that we know far less than we sometimes assume.

Our world, and indeed the cosmos beyond, still has the capacity to shock us, and what's more, it's these anomalies that keep science moving forward, challenging our assumptions and forcing our understanding to new levels. Just think, once upon a time, even cornerstones of the scientific institution like gravity would have seemed crazy.

Funny, intriguing or just plain jaw-dropping, here are 25 of science's strangest findings, from marine biology to mathematics and astronomy. You'll never see the world in quite the same way again…

NO POWER LINES

Bovine north-south tendency
Cows were most likely to be found with their heads pointing due north or south, aligned with geomagnetic fields.

NEAR POWER LINES

Disorder
In the vicinity of power lines the north-south alignment went awry, presumably because the cables' own weak electric fields disrupt magnetoreception.

1. Cows are magnetic

Well, technically they're more like compass needles. Studying satellite imagery from Google Earth, researchers found that cattle (and deer) often align themselves with the Earth's magnetic field lines between the north and south poles. They aren't the only ones believed to sense magnetic fields: bacteria, molluscs and mole rats also display a magnetic 'sixth sense'. But while magnetoreception has a clear advantage for migratory animals, it's not obvious how it could benefit cows. One hypothesis is that it may help them to map their local surroundings.

5 TOP FACTS
JELLYFISH TRIVIA

Ancient jellies
1 The first jellyfish species are believed to have appeared on Earth around 650 million years ago, predating primitive dinosaurs by over 400 million years.

Jumbo jellyfish
2 Native to Japan, Nomura's jellyfish is the largest known jellyfish species, weighing 200 kilograms (440 pounds) and measuring up to two metres (6.6 feet) in diameter.

Beautiful but deadly
3 The box jellyfish's venom is one of the most potent animal poisons, containing toxins that attack the heart and nervous system to kill its victims in as little as three minutes.

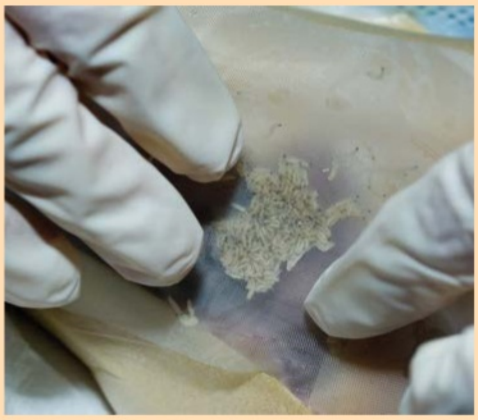
Heartless critter
4 Comprising over 90 per cent water, jellyfish have no bones, brain, heart or respiratory system. Sensory nerves on their tentacles let them see, smell and orient themselves.

Deep-sea glow
5 Some jellyfish species make their own light, known as bioluminescence. Most jellyfish use this light to put off predators, although some also use it to entice prey.

DID YOU KNOW? *Ancient Mayans and Aboriginal Australians are thought to be the first to use maggots to treat wounds*

2. Wounds filled with maggots heal faster

In deep wounds and ulcers, dead or dying tissue needs to be cut out at regular intervals to prevent infection – a process called debridement. Eating dead tissue but sparing healthy tissue, applying maggots to the wound can achieve more precise results than the surgeon's knife in a shorter time. On top of that, maggot secretions have a wide range of benefits, from improving the flow of nutrients to healing tissues to raising the wound's pH level to limit pathogenic bacteria growth.



1 Body
Measuring around a centimetre (0.4in) long, about six maggots are applied for each square centimetre of the wound.

2 Mouth hooks
Maggots use these two modified mandibles to probe and scratch away at dead tissue.

3 Secretions
Enzymes in its saliva and secretions help it to break down its food.

Maggots have proved to be very effective at cleaning wounds

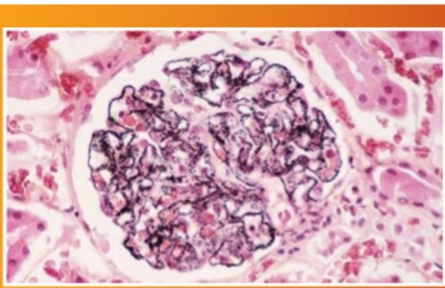
3. Hot water can sometimes freeze quicker than cold water

Observed by scientists as far back as 400 BCE, this uncanny phenomenon is called the Mpemba effect. Several theories attempt to explain it. Concentrations of solutes (which evaporate from hot water) could play a part, or it could be that frost forming on cold water insulates it from further cooling. Convection is also a likely culprit. Inside the freezer, the water touching the container walls cools quicker than water in the centre. This creates convection currents as warmer, less dense water rises. These currents are much stronger in heated water, where the temperature gradient is more extreme, helping it cool faster.

More recent research has implicated that supercooling – the phenomenon in which water doesn't always freeze at 0 degrees Celsius, but continues to cool by several degrees before ice appears – may play a role too. Some believe that initially cold water supercools more than hot water, although why that may be remains to be confirmed.

4. Plants have friends and enemies

Recent studies suggest that plants behave differently depending on who their neighbours are. When surrounded by 'friendly' plants, including genetic relatives or helpful species that limit pests and weeds, they grow slowly, perhaps to share resources. But when they detect a rival such as fennel, which secretes chemicals to inhibit other plants, they grow far more aggressively. Plants recognise these friends and foes thanks to chemical signals emitted from their leaves or roots, and some studies even imply that plants can detect sounds produced by their neighbours. Plants can also alert their fellow flora to attacks from herbivores or parasites. When a tomato plant is attacked by aphids, for instance, it releases volatile chemicals into the air. The plants that pick up on these signals respond by producing their own chemicals to repel the parasites and even attract wasps that prey on aphids. Other species use symbiotic fungi living on their roots as messengers.



5. Too much silver can turn skin blue

Argyria is a condition in which skin turns a blue-grey shade, provoked by ingesting silver. Broken down in the stomach, silver enters the bloodstream as a salt and is deposited in the skin. Light oxidises it, producing blue or grey-silver compounds. Sufferers have usually taken colloidal silver supplements – an alternative remedy with no known benefits.

6. Honey has no expiry date

Honey's low moisture content and high acidity create an inhospitable environment for the bacteria and other microbes that cause food to spoil. It also has traces of hydrogen peroxide, an effective antibacterial agent. If exposed to air, though, moisture can get in, so it needs to be kept in a sealed container to last indefinitely.

7. Straight hair has more knots than curly

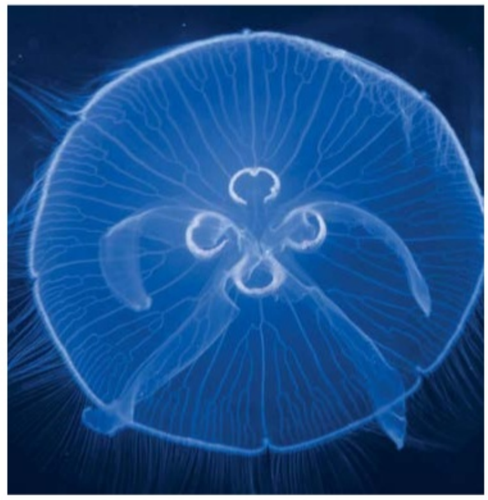
After counting the tangles on hair salon customers' heads, mathematicians found that straight-haired people averaged over five knots, while curly-haired customers had only three. Mathematical models of tangling suggest that although curly hairs brush against each other more often, the angle at which straight hairs meet makes them more likely to become entwined.

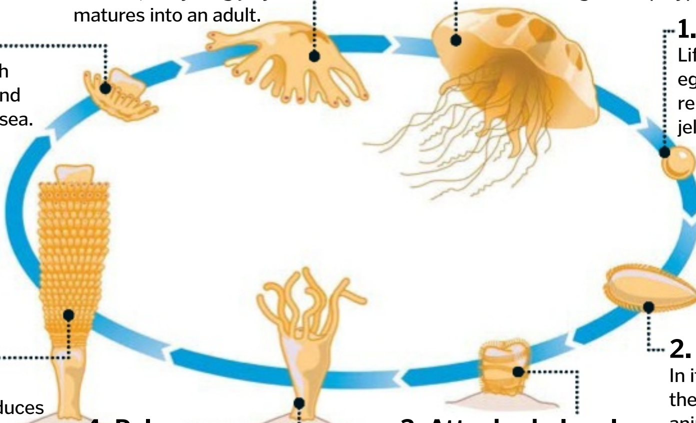
8. The colour of the universe is beige

After adding up the light emitted by 200,000 galaxies, two astrophysicists determined the average colour of universe: a rather bland shade of beige that they nicknamed 'Cosmic Latte'. Ten billion years ago, the universe would have had a pale blue hue, but its colour has shifted with the increasing number of redder stars.

9. Some jellyfish are immortal

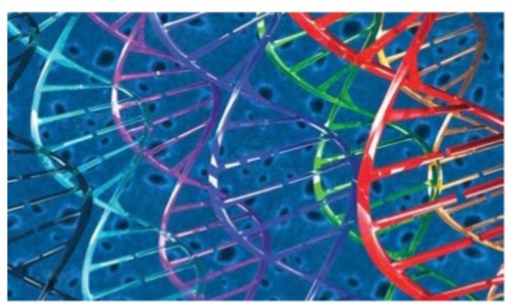
The tiny Turritopsis dohrnii jellyfish has a remarkable life cycle: after reaching sexual maturity it can revert back to a juvenile state. There is no apparent limit to how many times it can do this, meaning it could theoretically live for ever. While most T dohrnii die in the conventional manner, in times of crisis they can transform into a polyp state, a process called transdifferentiation. This lets them reproduce asexually to start a new colony. Unique in the animal world, this has helped them spread to oceans across the world.





10. There is 0.2mg of gold inside us

We absorb small amounts of gold from our environment, but it serves no known purpose. Largely inert, it is non-toxic in small doses. Gold compound sodium aurothiomalate can, however, reduce inflammation in arthritis patients, although its mechanism of action isn't fully understood. Researchers are currently investigating the use of nanoparticles equipped with antibodies which could latch on to cancer cells to help speed up diagnosis.



11. We can have more than one set of DNA

Known as chimerism, this condition can arise when two eggs are fertilised inside the mother. Instead of developing independently to produce non-identical twins, one absorbs the other, taking on its cells and DNA. The outcome is one individual combining cells with two different genotypes. Most chimeras are oblivious to their genetic makeup, but it can create some strange results. Indeed, they may have two blood types or even organs with different genotypes.

RECORD BREAKERS

EGYPTIAN SNACK

3,300yrs

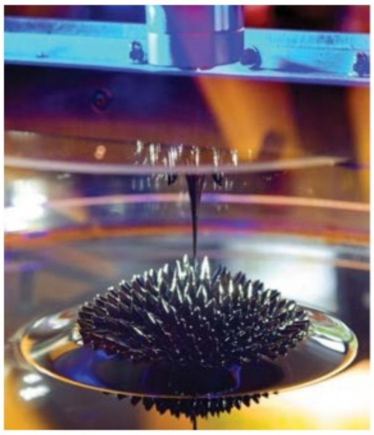
WORLD'S OLDEST EDIBLE HONEY

A jar of honey found in the tomb of Ancient Egyptian pharaoh Tutankhamun is believed to be well over 3,000 years old. And thanks to honey's antimicrobial properties, it's still edible!

DID YOU KNOW? *The water boatman is the loudest creature relative to body size, producing sounds of up to 99dB*

12. A candle flame is full of diamonds

Within a candle's flickering flame, hydrocarbon molecules are converted into carbon dioxide. During this process, the carbon briefly takes the form of diamond nanoparticles. A whopping 1.5 million of these minuscule gems are created every second, but are burnt up almost instantly. Although harvesting these diamonds would be impossible, this recent discovery could lead to new methods for producing cheap jewels. Alongside diamonds, researchers were surprised to find the three other forms of carbon (fullerenic particles, graphitic and amorphous carbon) in the flame.

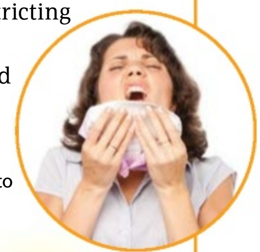


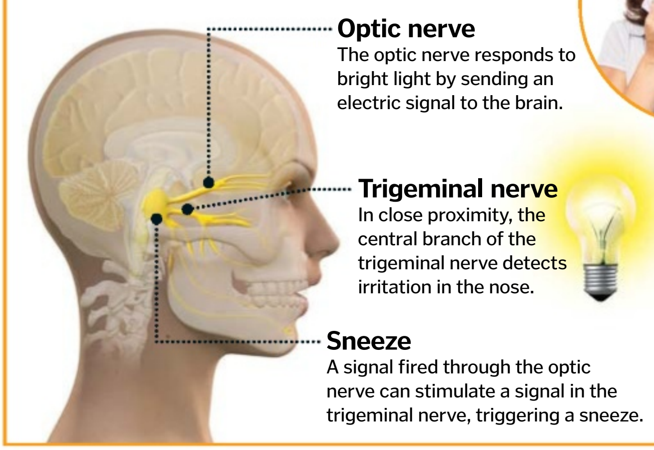
13. Liquids can defy gravity

When cooled down to near absolute zero temperatures, certain substances such as helium become superfluids with zero viscosity, capable of climbing walls or seeping through microscopic cracks. This occurs thanks to a weird quantum effect which makes individual atoms act as one, flouting both gravity and surface tension. Ferrofluid (pictured) is just as mind-blowing; made by suspending tiny magnetic particles of iron in oil, these magnetic liquids form intricate patterns of peaks and troughs when they are placed in a magnetic field.

14. Light can make some people sneeze

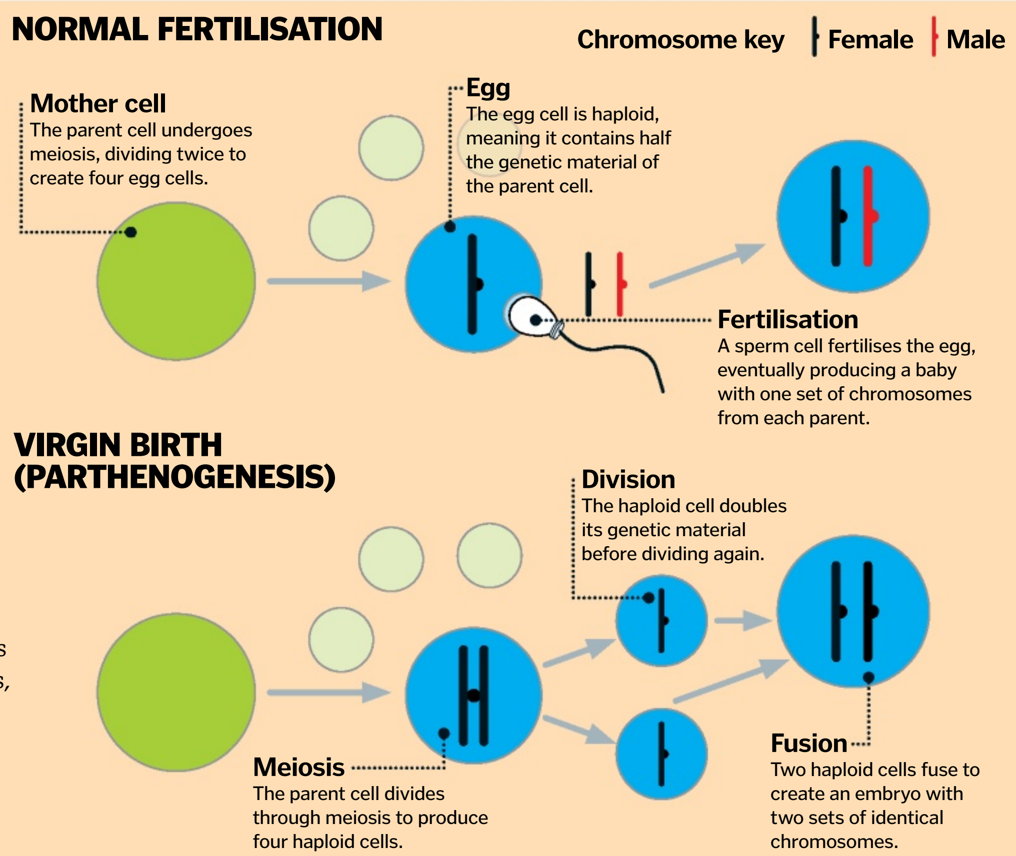
In about a quarter of people, sudden exposure to bright light can bring on a sneezing fit known as the photic sneeze reflex. Normal sneezes happen when something irritates the nose lining. This stimulates the trigeminal nerve and the body expels the irritant with a sneeze. The nearby optic nerve, meanwhile, alerts the brain to changes in light levels, to which it responds by constricting or enlarging the pupils. In photic sneezers, a flood of light creates electric signals in the optic nerve sensed by the trigeminal nerve, triggering a sneeze.





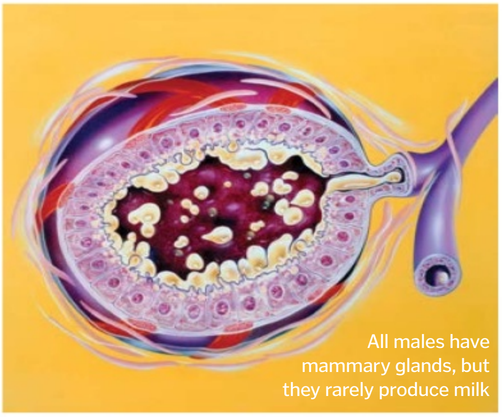
15. Virgin births are not a myth

In some species, a female's egg cell can develop into an embryo without being fertilised. This form of asexual reproduction is called parthenogenesis (Greek for 'virgin birth') and occurs in many plants and insects, as well as certain fish and reptiles, including Komodo dragons and hammerhead sharks. Some species reproduce exclusively through parthenogenesis, while others use it as a back-up option when there are no males. In most species, parthenogenesis produces offspring with two identical sets of chromosomes, making them half-clones of their mother.



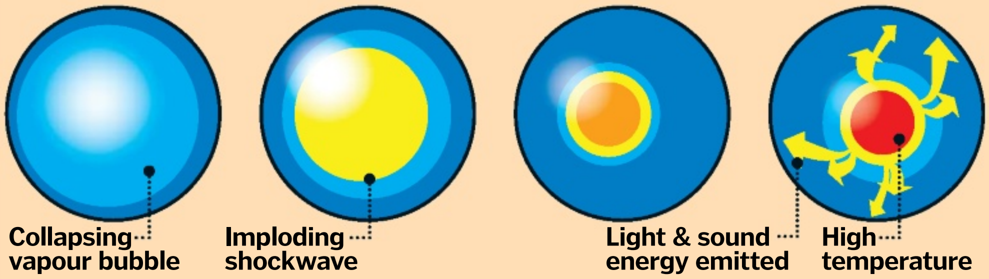
16. Men can lactate too

Male mammals possess mammary glands and can produce milk, although this is rare. Certain disorders involving the pituitary gland, for example, cause it to produce prolactin, which stimulates milk production. The Dayak fruit bat is the only species in which male lactation is widespread. It's unclear whether they actually breast feed or if milk production is a side-effect of a diet rich in phytoestrogens – plant molecules that mimic female hormones.


All males have mammary glands, but they rarely produce milk

17. Pistol shrimp snap their claws louder than Concorde

The diminutive pistol shrimp can snap one of its claws so hard that it tears water apart, creating a high-pressure bubble of gas called a cavitation bubble. As it collapses, the bubble creates a deafening pop as loud as 218 decibels, lasting for just one millisecond. Just before it bursts, the temperature inside the bubble soars to 4,700 degrees Celsius (8,500 degrees Fahrenheit), creating an intense flash of light (see diagram below). The shrimp uses this trick to stun prey.



This map shows how the magnetic north pole has moved over time due to secular variation (ie drift)

18. There is more than one north pole

True (or geodetic) north is a fixed point, located where the Earth's axis of rotation meets the planet's surface, diametrically opposite the south pole. However if you look at a compass needle, it doesn't point to the north pole, but rather to a place a few hundred kilometres south-east: magnetic north. Earth acts like a giant magnet, and the magnetic north is one of its poles. The planet's magnetic field is created by churning molten iron in the planet's outer core. As these currents change, so does the location of the magnetic north pole, which is currently wandering at a speed of about 55 kilometres (34 miles) a year. After drifting through northern Canada, magnetic north is now heading towards Siberia. More dramatic changes could, however, be afoot. In the past, Earth's magnetic poles have switched places every 500,000 years. The reason behind these flips is unknown, but geophysicists predict that the next one could be coming up in a few thousand years.

19. Identical twins are not identical

Although they originate from the same fertilised egg, identical twins still carry small differences in their genes. Examining twin genomes closely, researchers found variations in the numbers of copies of a given gene, possibly caused by mutations during early development. This variation could explain why sometimes one twin develops a genetic disorder while the other is spared.

1 Fertilisation
A sperm cell fertilises an egg, producing a cell called a zygote which combines the parent cells' DNA.

2 Zygote
The zygote soon divides to form a small bunch of cells called a blastocyst.

3 Split
The blastocyst can split into two between one and nine days after fertilisation.

4 Mutations
As the foetuses develop, 'copy errors' in cell division create small variations in the twins' genetic material.

20. The faster you move, the heavier you get

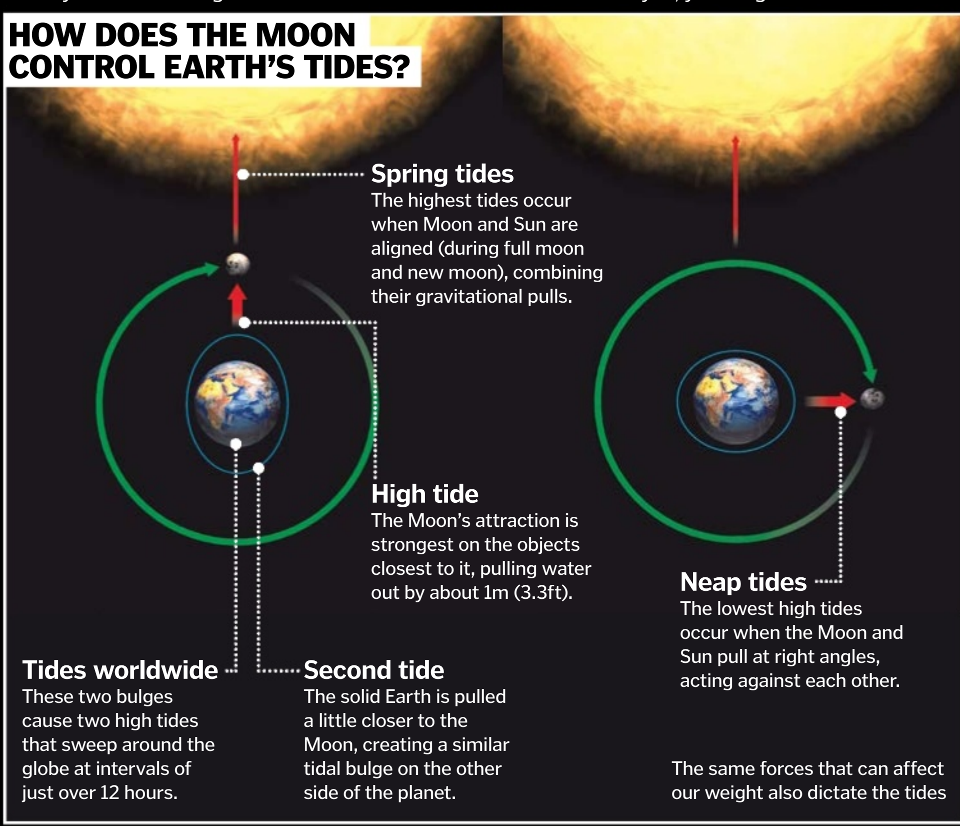
Einstein discovered this with his theory of special relativity. As an object picks up speed it gains kinetic energy, which causes its mass to increase, as described by his famous $E=mc^2$ equation. At the speeds humans travel at the change in mass goes unnoticed, but as an object comes close to the speed of light the effect is undeniable. Particle accelerators like the Large Hadron Collider propelling protons at almost the speed of light, for instance, need to take their increased mass into account. One consequence of this is that no object can travel at the speed of light – the faster it gets, the more mass it acquires and the more energy it needs. In other words, you'd need infinite energy to push it to light speed.

When travelling at high speeds, you become noticeably heavier

21. We weigh less when the Moon is overhead

What we call weight is the downward force resulting from Earth's gravitational pull on our mass. But Earth isn't the only one pulling us towards it. The Moon also exerts a force on us, cancelling out some of Earth's attraction when it is directly overhead. Being much smaller and also farther away from us, the Moon's magnetic field is much weaker, meaning the effect is almost imperceptible: ie a 100-kilogram (220-pound) person would weigh just 0.5 grams (0.02 ounces) less. Conversely, when the Moon is on the opposite side of Earth to you, you weigh a fraction more.

HOW DOES THE MOON CONTROL EARTH'S TIDES?



The same forces that can affect our weight also dictate the tides

22. A mobile phone has more computing power than used on the Apollo missions

The Apollo guidance system that successfully landed man on the Moon had just 64 kilobytes of memory and operated at 0.043 megahertz. Modern-day smartphones, meanwhile, average one to two gigahertz, meaning that they are around 40,000 times faster.

23. There are more molecules in a cup of water than cups of water in the oceans

Earth's oceans contain approximately 1.3 billion cubic kilometres (312 million cubic miles) of water, which equates to 5.2×10^{21} 250-millilitre cups. A cup of water, meanwhile, contains a jaw-dropping 8.4×10^{24} H_2O molecules – that's over 1,000 times more molecules than cups!

24. NASA has a building so big that it can rain inside

NASA's Vehicle Assembly Building's vast interior extends over a whopping 3,665,000 cubic metres (129,428,000 cubic feet). On humid days, it can accumulate enough moisture to form clouds – although in practice 125 ventilators keep humidity levels in check.

25. A single-celled organism can be up to 20cm across

Syringammina fragilissima's one cell branches out into a network of tubes extending over ten centimetres (3.9 inches). As it grows, the deep sea-dwelling creature oozes slime onto the sediment, solidifying its structure.

Why do our muscles ache?

Learn what causes stiffness and pain in our muscles for days after exercise

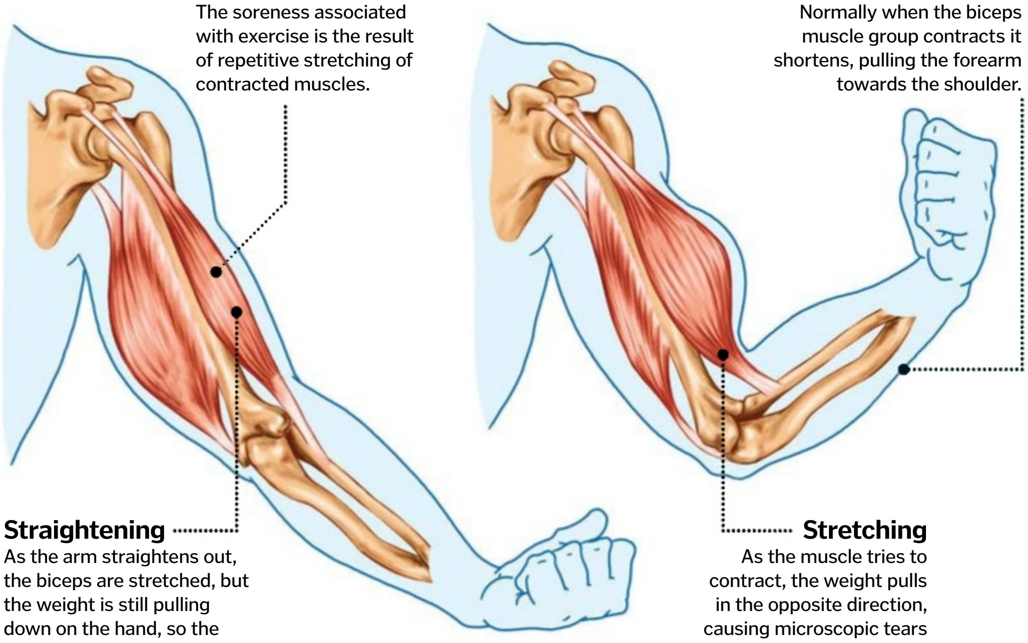
Normally, when our muscles contract they shorten and bulge, much like a bodybuilder's biceps. However, if the muscle happens to be stretched as it contracts it can cause microscopic damage.

The quadriceps muscle group located on the front of the thigh is involved in extending the knee joint, and usually contracts and shortens to straighten the leg. However, when walking down a steep slope, say, the quadriceps contract to support your body weight as you step forward, but as the knee bends, the muscles are pulled in the opposite direction. This tension results in tiny tears in the muscle and this is the reason that downhill running causes so much delayed-onset pain.

At the microscopic level, a muscle is made up of billions of stacked sarcomeres, containing molecular ratchets that pull against one another to generate mechanical force. If the muscle is taut as it tries to contract, the sarcomeres get pulled out of line, causing microscopic damage. The muscle becomes inflamed and fills with fluid, causing stiffness and activating pain receptors – hence that achy feeling you get after unfamiliar exercise.

Weightlifting and the body

What happens to your biceps when you pump iron?



Pain
The soreness associated with exercise is the result of repetitive stretching of contracted muscles.

Bending
Normally when the biceps muscle group contracts it shortens, pulling the forearm towards the shoulder.

Straightening
As the arm straightens out, the biceps are stretched, but the weight is still pulling down on the hand, so the muscles remain partly contracted to support it.

Stretching
As the muscle tries to contract, the weight pulls in the opposite direction, causing microscopic tears within the muscle cells.

How 72-hour deodorants work

Discover the chemistry that helps us combat body odour for up to days at a time

Deodorants prevent the odour associated with sweating, either by masking it, or by killing the bacteria responsible. To make the effects last longer, the active ingredients are sometimes encased within microcapsules. As the capsules take up water from sweat they burst, releasing deodorising chemicals. By including capsules of a variety of sizes, each requiring a different amount of water to burst, the duration can be extended.

Most deodorants also contain antiperspirants, which prevent sweating from occurring at all. These are usually aluminium-based compounds. The aluminium is taken up by the cells that line the openings of the ducts that carry sweat to the surface of the skin.

As the aluminium moves into the cells, it takes water with it, causing the cells to swell and closing off the ducts. Depending on the type of aluminium compound used, the effect will last for different lengths of time.

Antiperspirants cause cells to swell and the ducts to close up, preventing sweating altogether

5 TOP FACTS
VESTIGIAL NATURE

Grounded beetles
1 Certain species of beetle cannot fly at all, despite still being born with wings. In fact, these wings are often fused together, which makes them rather useless.

Leggy snakes
2 Some snakes, such as pythons, have residual pelvis bones formed into spurs, suggesting snakes may once have had legs, or evolved from species that had legs.

Non-flying birds
3 Penguins, ostriches and kiwis are examples of winged birds that can't fly. These birds may have lost the ability because their habitats were once free of larger predatory birds.

Blind salamanders
4 These small newt-like amphibians live out their entire lives in dark caves and now are completely blind. However, they still possess non-functioning eyes.

Whale pelvic bones
5 If you go to a natural history museum and look at a whale skeleton, you'll see residual, non-functioning pelvic bones. This suggests whales may once have been land-dwellers.

DID YOU KNOW? *Your appendix is about 10cm (4in) long but a koala's can grow over 2m (6.6ft) long to digest eucalyptus leaves*

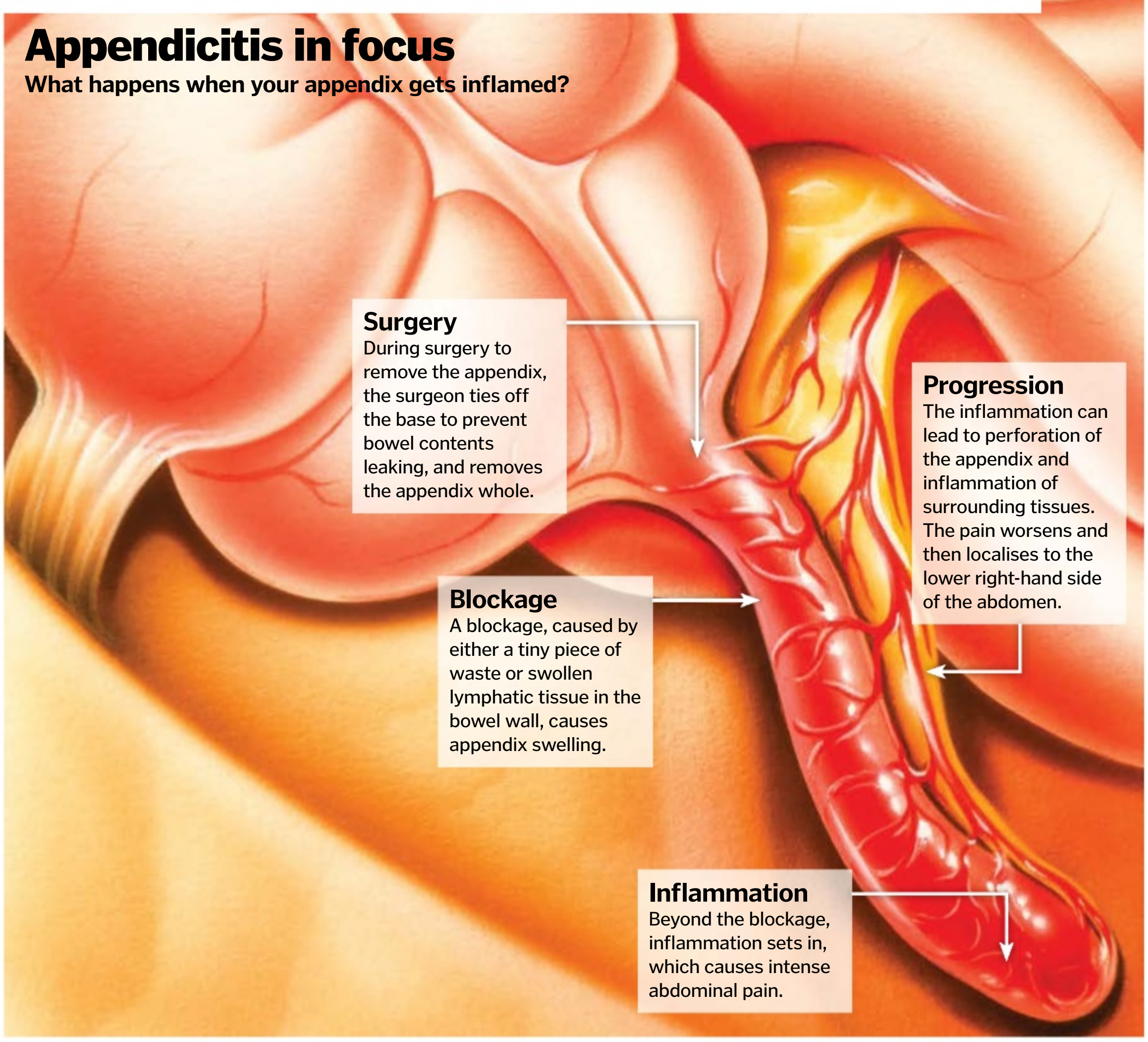
Useless body parts

Why have humans and other animals stopped using certain organs and functions which were once crucial for survival?

Charles Darwin is one of history's most famous naturalists. Living in the 19th century, he became celebrated for his theories on evolution. In his seminal work *On The Origin Of Species* he described how similar animals were likely to be related by common ancestors, rather than be completely unrelated. As subsequent generations are born, traits and features that did not bring a survival benefit to that species were eliminated. That, in a nutshell, is the theory of evolution.

As a consequence, some organs and traits left in the body lose their function and are no longer used. This applies to modern human beings as much as other creatures; some of our physical attributes and behavioural responses are functional in other animals, but they do not seem to be of any benefit to us. These evolutionary remnants that no longer serve any purpose are called vestigial organs, though this can apply as much to behaviour and other body structures as it does to actual organs.

Evolution has also adapted some existing features to help us in new ways, in a process known as exaptation. For example, birds' wings not only help them to fly but keep them warm too. These changes in function may take thousands of years to develop, and in some cases the original role is eventually eliminated from subsequent generations altogether.



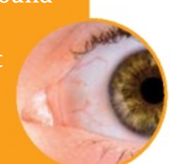
Evolution's leftovers

1 Appendix
The best known of the vestigial organs, the appendix is used in animals to help digest cellulose found in grass, but in humans it serves no clear function now.

2 Tailbone

The hard bone at the bottom of your spine, the coccyx, is a remnant of our evolutionary ancestors' tail. It has no function in humans, but you could break it if you fall over.

3 Goosebumps
Animals use body hair for insulation from the cold, by trapping a warm layer of air around the body. Each hair can stand on end when its own tiny muscle contracts, but as human beings have lost most of their body hair, a jumper is more effective.

4 Plica semilunaris

The fleshy red fold found in the corner of your eye used to be a transparent inner eyelid, which is still present in both reptiles and birds.

5 Wisdom teeth
These teeth emerge during our late teens in each corner of the gums. Our ancestors used them to help chew dense plant matter, but they have no function today. In fact, they can cause a lot of pain so are often removed.

Left or right brained?

Actually, you're neither. Discover the truth behind the way we think

It's true that the different sides of the brain perform different tasks, but do these anatomical asymmetries really define our personalities? Some psychologists argue that creative, artistic individuals have a more developed right hemisphere, while analytical, logical people rely more heavily on the left side of the brain, but so far, the evidence for this two-sided split has been lacking.

In a study published in the journal PLOS ONE, a team at the University of Utah attempted to answer the question. They divided the brain up into 7,000 regions and analysed the fMRI scans of over 1,000 people, in order to determine whether the networks on one side of the brain were stronger than the networks on the other.

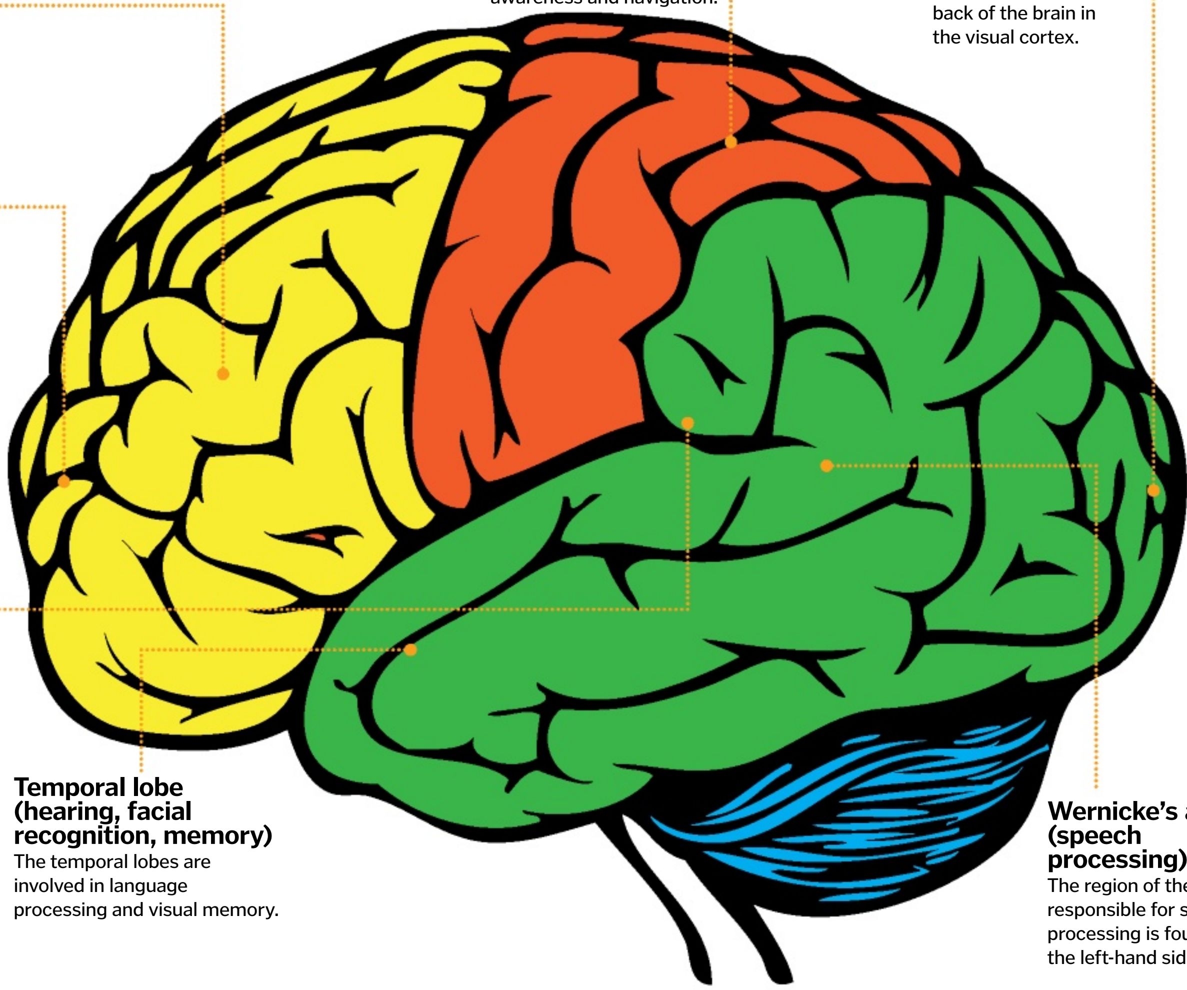
Despite the popularity of the left versus right brain myth, the team found no difference in the strength of the networks in each hemisphere, or in the amount we use either side of our brains. Instead, they showed that the brain is more like a network of computers. Local nerves can communicate more efficiently than distant ones, so instead of sending every signal across from one hemisphere to the other, neurones that need to be in constant communication tend to develop into organised local hubs, each responsible for a different set of functions.

Hubs with related functions cluster together, preferentially developing on the same side of the brain, and allowing the nerves to communicate rapidly on a local scale. One example is language processing – in most people, the regions of the brain involved in speech, communication and verbal reasoning are all located on the left-hand side.

Some areas of the brain are less symmetrical than others, but both hemispheres are used relatively equally, albeit for different things. There is nothing to say you can't be a brilliant scientist and a great artist, too.

Examining the human brain

What do the different parts of the brain actually do?



THE STATS
BRAINY NUMBERS

86 billion NEURONS

>100 trillion SYNAPSES

NERVE IMPULSE SPEED **100 metres per second**

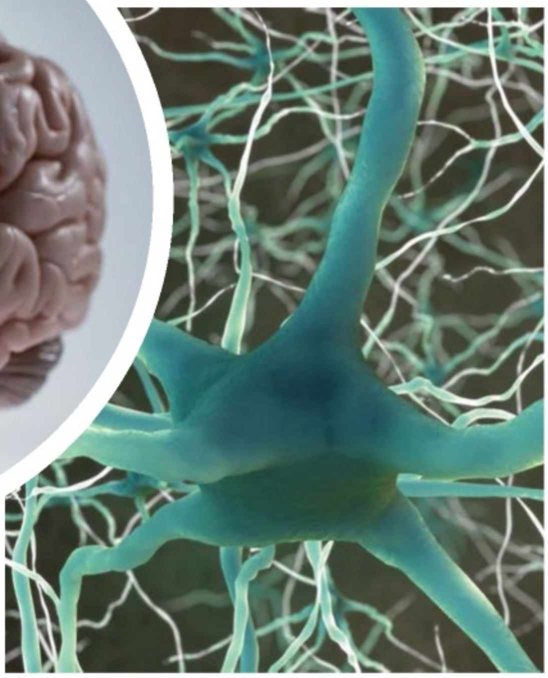
1.4kg MASS

20% OXYGEN USAGE

POWER CONSUMPTION **20W**

DID YOU KNOW? *It is a myth that we only use ten per cent of our brains; even at rest, almost all brain regions are active*

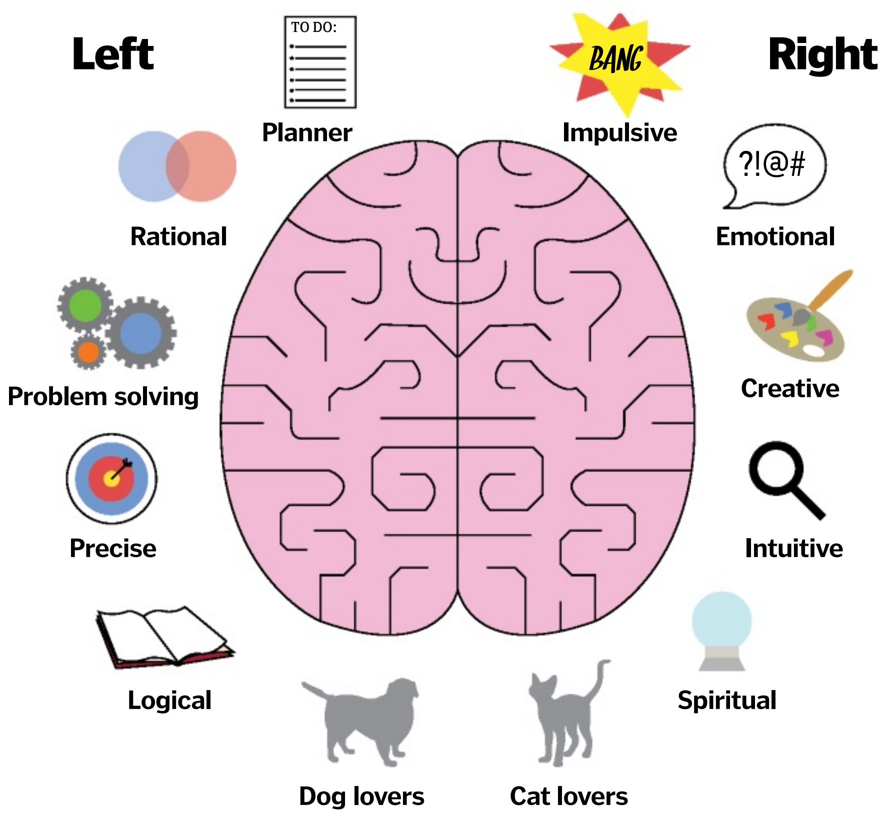
It took 82,944 computer processors 40 minutes to simulate just one second of human brain activity, it's that powerful



A microscopic image of the brain's extremely complex neural network

Myth-taken identity

The left vs right brain personality myth is actually based on Nobel Prize-winning science. In the 1940s, a radical treatment for epilepsy was trialled; doctors severed the corpus callosum of a small number of patients, effectively splitting their brains in two. If a patient was shown an object in their right field of view, they had no difficulty naming it, but if they were shown the same object from the left, they couldn't describe it. Speech and language are processed on the left side of the brain, but the information from the left eye is processed on the right. The patients were unable to say what they saw, but they could draw it. Psychologists wondered whether the differences between the two hemispheres could create two distinctive personality types, left-brained and right-brained.



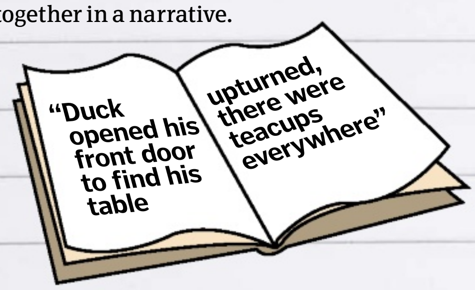
Give your brain a fun workout

1 Boost your memory

Look at this list of items for one minute, then cover the page and see how many you can remember:

Coin	Telephone	Grape
Duck	Potato	Pillowcase
Key	Teacup	Bicycle
Pencil	Match	Table

Difficult? Try again, but this time, make up a story in your head, linking the objects together in a narrative.



...You get the idea. Make it as silly as you like; strange things are much more memorable than the mundane.

2 Slow brain ageing

Learning a new language is one of the best ways to keep your brain active. Here are four new ways to say hello:

- Polish: Cześć! (che-sh-ch)
- Russian: Zdravstvuj (zdrah-stvooy)
- Arabic: Marhaba (mar-ha-ba)
- Swahili: Hujambo (hud-yambo)

Inside our bones

Learn how bone marrow can transform cells into whatever the body needs

The skeleton is not only used as the body's main structural support, it is also home to the largest collective reserve of adult stem cells within us.

Bone marrow is a soft tissue present inside all the long bones of the limbs, and inside flat bones such as the pelvis, skull and ribs and it is jam-packed woth haematopoietic stem cells. These cells are only partly committed to their development pathway, so depending on the signals they receive, can become any of the cells in the blood, from oxygen-carrying red blood cells to bacteria-munching macrophages.

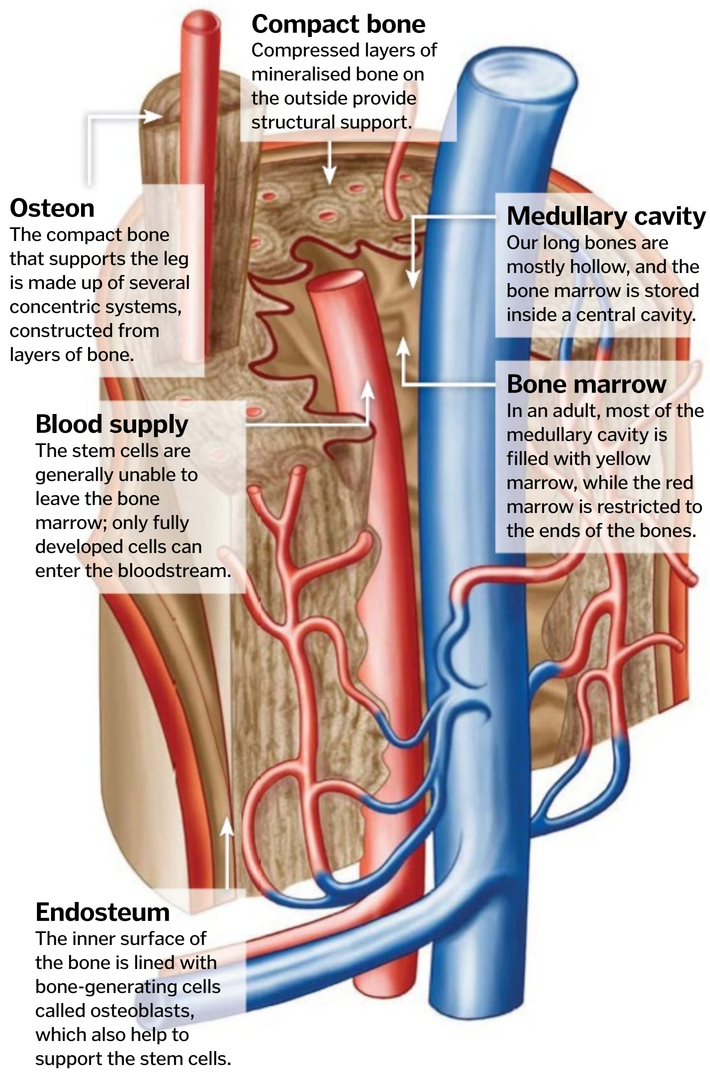
The majority of these stem cells are contained in the red marrow, which gains its colour from a rich network of blood vessels. The stem cells are supported by a range of other cells collectively known as stroma. The stromal cells provide the right microenvironment for the development of stem cells into the blood's components, making a range of growth factors to encourage cells to differentiate down the correct path.

In an adult human, most of the long bones are filled with yellow bone marrow – mostly made up of fat cells – however this can be converted to red marrow for blood cell production should an emergency arise.

Bone marrow also contains a second, less-studied population of stem cells known as mesenchymal stem cells (MSCs). These are able to produce the basic elements that make up the connective tissues of the body, including fat cells, bone cells and fibroblasts.

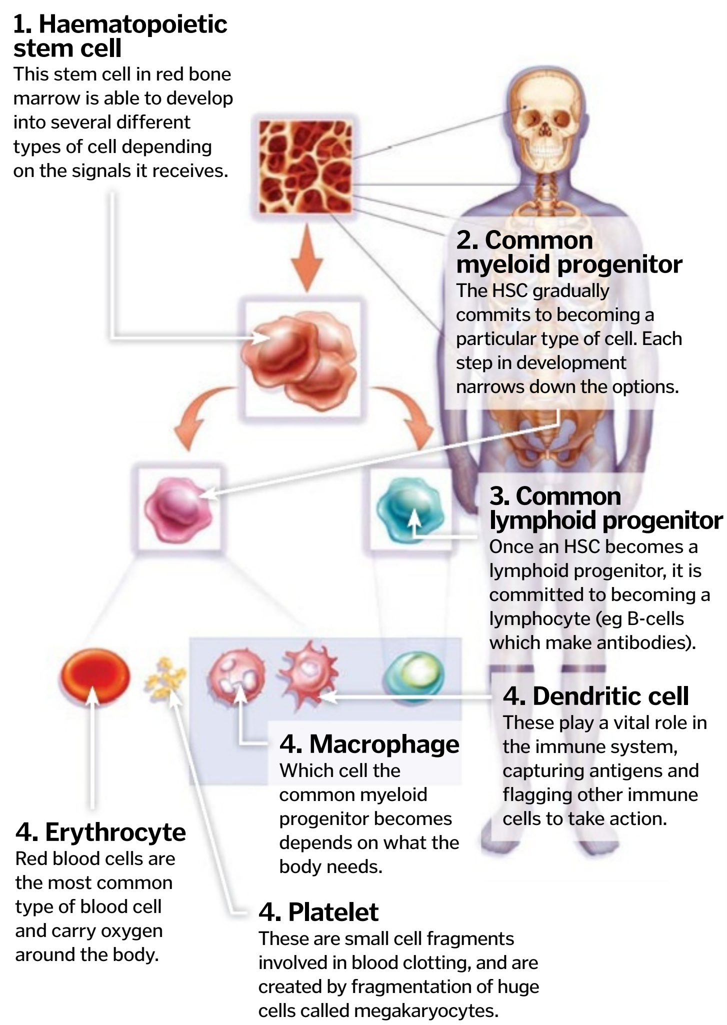
Bone marrow in context

What is going on inside one of the long bones in our legs?



The origins of blood

See how bone marrow is a factory capable of producing all of the components which make up our blood…



STRANGE BUT TRUE
GOING THIRSTY

What is the longest you can go without water?

A One day **B** Three days **C** 70 years

Answer:
Most experts agree three days is the longest a human can go without water. However, Indian Prahlad Jani has claimed he has gone without water for 70 years. The controversial practice is called 'breatharianism' and alleges the body can survive on sunlight alone.

DID YOU KNOW? *Some people get early signs of migraine, like flashing lights. This early-warning system is called an aura*

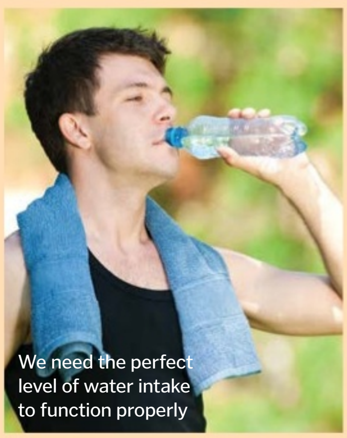
Dehydration and the body

Find out what happens inside us when we don't quench our thirst

Just by breathing, sweating and urinating, the average person loses ten cups of water a day. With H_2O making up as much as 75 per cent of our body, dehydration is a frequent risk. Water is integral in maintaining our systems and it performs limitless functions. Lubricating the skin, flushing out waste and keeping blood pressure and cholesterol levels stable are just a few of its vital roles.

Essentially, dehydration strikes when your body takes in less fluid than it loses. The mineral balance in your body becomes upset with salt and sugar levels going haywire. Enzymatic activity is slowed, toxins accumulate more easily and even breathing can become more difficult as the lungs are having to work harder.

Babies and the elderly are most susceptible as their bodies are not as resilient as other age groups. It has long been recommended to have eight glasses of water or two litres (0.5 gallons) a day. More recent research is undecided, as both slightly less and slightly more have been considered healthy.



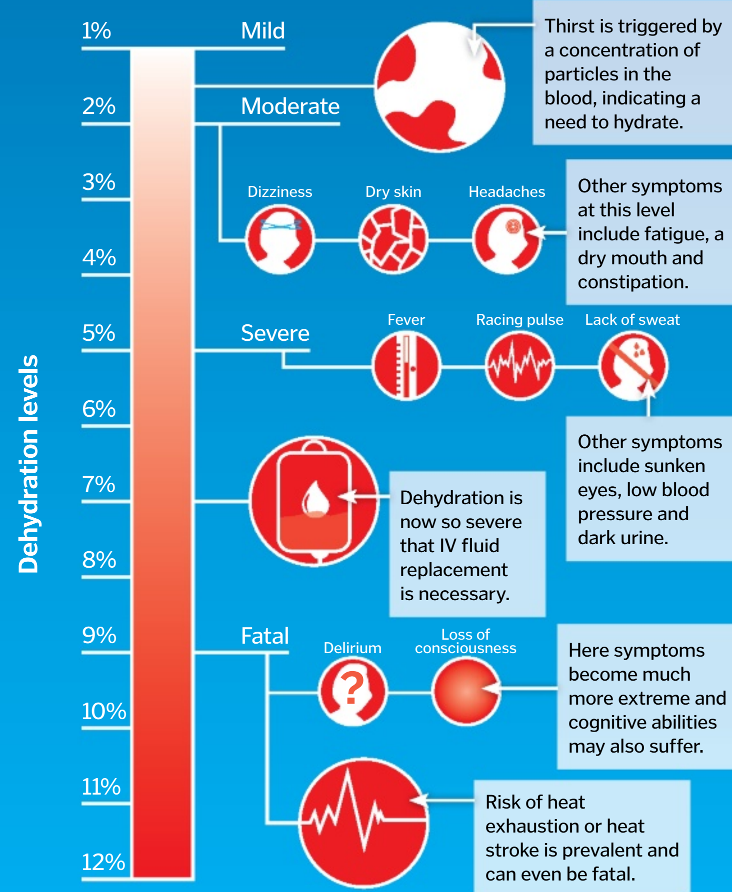
We need the perfect level of water intake to function properly

Too much H_2O?

Hydration is all about finding the perfect balance. Too much hydration can be harmful as well as too little; this is known as water intoxication. If too much liquid is in your body, nutrients such as electrolytes and sodium are diluted and the body suffers as a result. Your cells bloat and expand and can even burst, and it can be fatal if untreated. The best treatment is to take on IV fluids containing electrolytes. Water intoxication is just one type of hyponatraemia, which also includes excessive sweating and liver and kidney problems.

Dangers of dehydration

How does a lack of water vary from mild to fatal?

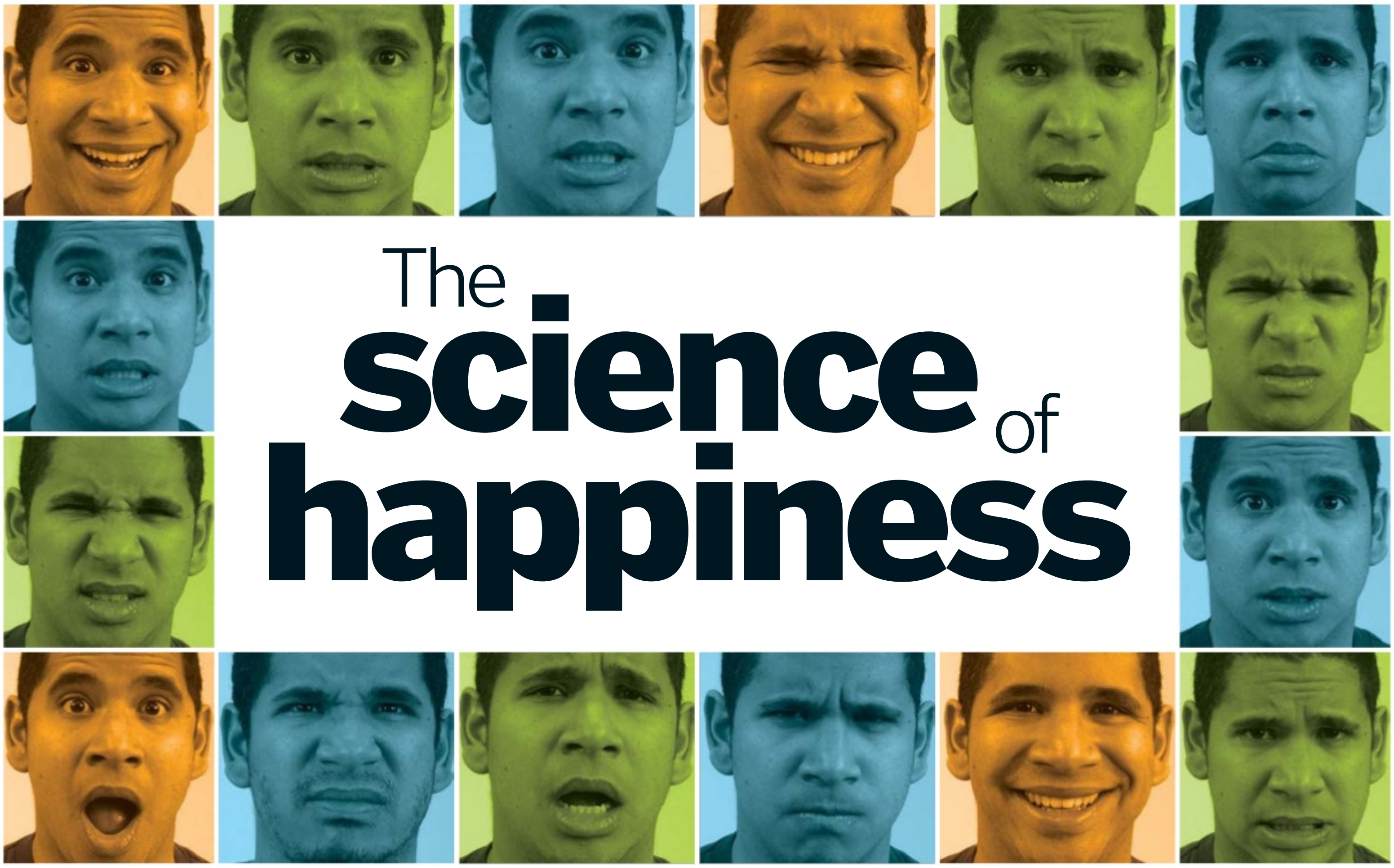


Why do we get migraines?

Discover how these mega-headaches strike

Those who suffer from migraines know they are a constant concern as they are liable to strike at any time. Essentially, a migraine is an intense pain at the front or on one side of the head. This usually takes the form of a heavy throbbing sensation and can last as little as an hour or two and up to a few days. Other symptoms of a migraine include increased sensitivity to light, sound and smell, so isolation in a dark and quiet room often brings relief. Nausea and vomiting is also often reported, with pain sometimes subsiding after the sufferer has been sick.

It is thought that migraines occur when levels of serotonin in the brain drop rapidly. This causes blood vessels in the cortex to narrow, which is caused by the brain spasming. The blood vessels widen again in response, causing the intense headache. Emotional upheaval is often cited as a cause for the drop in serotonin in the brain, as is a diet in which blood-sugar levels rise and fall dramatically.



The science of happiness

Human emotions are governed by a complex mix of chemicals and electricity – learn all about our moody biology now…

The human brain weighs just over a kilogram (2.2 pounds) and plays host to an estimated 86 billion neurons, and at least as many supporting glial cells. Signals are transmitted along each nerve electrically, by gradients of charged ions, and each neuron makes hundreds of connections to those around it.

At each of the 300 trillion synapses in the human brain, chemicals known as neurotransmitters relay messages from one nerve to another. Each neurotransmitter has a set of corresponding receptors, which can be activatory or inhibitory, helping nerves to fire, or suppressing their activity. This enormous chemical and electrical system provides the complex network that enables us to feel emotion, from the all-consuming addiction of love, to the raw devastation of grief.

Techniques like functional magnetic resonance imaging (fMRI) have helped reveal areas of the brain involved in processing different emotional responses. This data, in combination with case studies of patients with damage to certain areas of their brains, and information gathered from investigations in animals, has enabled us to draw up a map of emotional connections in the body.

A notable area of the brain when it comes to mood is the limbic system (see opposite) – a small cluster of interconnected regions involved in memory storage and decision-making. The limbic system is directly connected to the olfactory bulb, which processes incoming smell signals from the nose, providing the biological link that allows odours to recall a memory. Recent research at the Kavli Institute for Systems Neuroscience in Norway suggests smell-based memories are triggered with the activation of corresponding brain waves to those experienced on initially experiencing the scent.

The nucleus accumbens links the limbic system to other areas of the brain also involved in the processing of emotion. For instance, the basal ganglia, at the base of the forebrain, has been well studied for its role in the planning and co-ordination of movement, but certain areas also light up in response to positive emotional stimuli and are thought to be involved in reward and reinforcement. Damage to part of the basal ganglia, known as the ventral pallidum, causes anhedonia – the inability to experience pleasure. The orbitofrontal cortex, located above the eyes, also activates in response to positive experiences, and is thought to play a role in evaluating reward versus punishment.

Another approach to the study of complex emotions like happiness is to break them down into

Compound emotions

New research by Ohio State University has found that we may have as many as 21 distinct and complex emotional expressions – a few demonstrated in the images above. Hybrid emotions include being 'angrily surprised' or 'happily disgusted' and appear when conflicting feelings are experienced simultaneously. For instance, you may be sad something has ended but happy that you have experienced it. Previous studies suggested that we only had six emotions.

5 TOP FACTS
GET HAPPY!

Wear a smile
1 Your body influences your emotions: frowning can make you feel angry, even when you aren't, so forcing a smile even if you don't feel like it can help improve your mood.

Strike a hero pose
2 Psychologist Amy Cuddy has shown that 'power posing' before a challenging situation, like a job interview, raises testosterone, lowers cortisol and boosts confidence.

Laugh out loud
3 The act of laughing triggers the release of endorphins, which act not only as natural painkillers, but also induce feelings of euphoria, so comedy really is good for us.

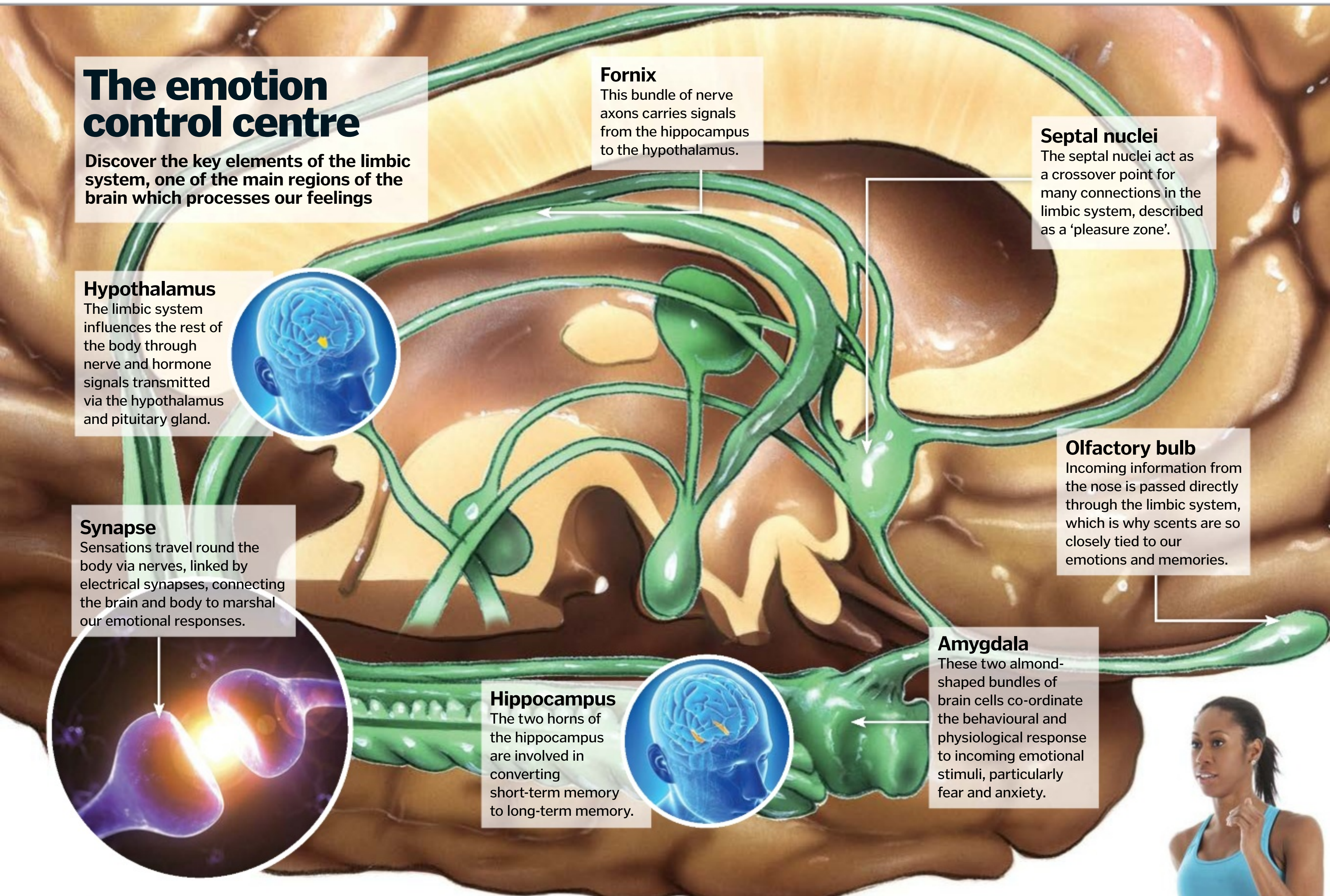
Sniff out happiness
4 The olfactory bulb is connected to the limbic system and smell plays a role in both emotion and memory. Familiar scents can provide an instant mood boost.

Eat the right food
5 Omega-3 fats, commonly found in oily fish and other seafood, are connected with serotonin levels, while folic acid from green vegetables may help fight off depression.

DID YOU KNOW? *Serotonin is found in some insect venom and plant spines; it can cause pain, tingling and nausea*

The emotion control centre

Discover the key elements of the limbic system, one of the main regions of the brain which processes our feelings



Fornix
This bundle of nerve axons carries signals from the hippocampus to the hypothalamus.

Septal nuclei
The septal nuclei act as a crossover point for many connections in the limbic system, described as a 'pleasure zone'.

Hypothalamus
The limbic system influences the rest of the body through nerve and hormone signals transmitted via the hypothalamus and pituitary gland.

Olfactory bulb
Incoming information from the nose is passed directly through the limbic system, which is why scents are so closely tied to our emotions and memories.

Synapse
Sensations travel round the body via nerves, linked by electrical synapses, connecting the brain and body to marshal our emotional responses.

Amygdala
These two almond-shaped bundles of brain cells co-ordinate the behavioural and physiological response to incoming emotional stimuli, particularly fear and anxiety.

Hippocampus
The two horns of the hippocampus are involved in converting short-term memory to long-term memory.

How do drugs alter our mood?

Humans have been modifying their brain chemistry for medical, religious and recreational purposes for centuries, despite the many risks. Stimulants like caffeine, nicotine, cocaine and amphetamine affect the release of the fight-or-flight chemicals adrenaline and noradrenaline, increasing alertness. While euphoriants like MDMA cause a surge of serotonin, which in turn leads to the release of bonding hormone oxytocin, resulting in a sense of euphoria.

Depressants, including sedatives, hypnotics and alcohol, work on the GABA receptor system to dampen brain activity. GABA is an inhibitory neurotransmitter, and blocks nerve activity, resulting in relaxation and reduced anxiety. Some depressants have anti-convulsant effects, so are used as a treatment for epilepsy.

Opioids also modulate nerve signals. Opium, along with related drugs like morphine, have a similar structure to natural endorphins and bind to their receptors in the brain and spinal cord, resulting in pain relief and euphoria.

Emotional messengers

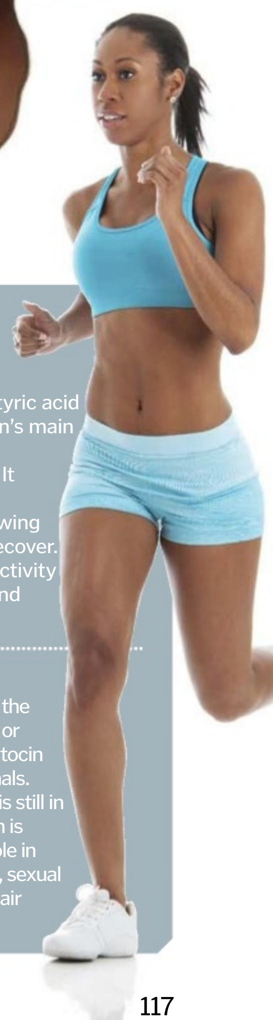
Dopamine
This neurotransmitter feeds the reward pathway in the brain and is involved in motivation, drive, pleasure and addiction. Abnormally high levels of dopamine are linked to loss of contact with reality, delusions and lack of emotion, while low levels are linked to addictive behaviour and risk taking.

Noradrenaline
Related to adrenaline, this neurotransmitter is a stress hormone that co-ordinates the fight-or-flight response. It mediates many of the physical components of emotion, including raised heart rate, and also acts in the brain to enhance alertness, cognition and decision-making behaviour.

GABA
Gamma-aminobutyric acid (GABA) is the brain's main inhibitory neurotransmitter. It subdues nerve transmission, allowing neurons time to recover. Increased GABA activity reduces anxiety and stress.

Serotonin
First recognised for its ability to constrict blood vessels, serotonin has since become widely regarded as the 'happiness hormone'. Chemically known as 5-hydroxytryptamine (5-HT), increasing the serotonin level in the brain is the main goal of medical antidepressants.

Beta-endorphin
Endorphins are natural opioids, produced in response to pain, excitement and exercise (pictured). Beta-endorphin binds to the same mu receptors as pain-relieving morphine. Present on nerves in the brain and spinal cord, they modulate neural activity, causing mild sedation, relieving pain and inducing joy.



Oxytocin
Often described as the 'bonding hormone' or 'love hormone', oxytocin is unique to mammals. Although research is still in its infancy, oxytocin is thought to play a role in intimacy, childbirth, sexual arousal, trust and pair bonding.

smaller parts. Pleasure is evolutionarily ancient and is based on a chemical reward system that acts as an incentive to repeat beneficial behaviour. There are several 'reward pathways' in the brain, but the most studied is the mesolimbic pathway.

The pathway transmits dopamine signals from nerves in the middle of the brain, upward and forward, to the limbic system and the prefrontal cortex, which are involved in emotional processing. Under normal conditions, this pathway serves as a motivator for positive actions, producing pleasurable feelings that reinforce beneficial behaviour like eating high-calorie food, social interaction and reproduction. Activation of the pathway also aids in memory retention, increasing the likelihood that the action will be repeated in the future.

Unfortunately, the pleasurable feedback is so strong that abuse of the pathway is common. Many illicit substances, including cocaine, amphetamine and MDMA, affect the mesolimbic pathway, resulting in a pleasurable reward, but also contributing to habituation and addiction.

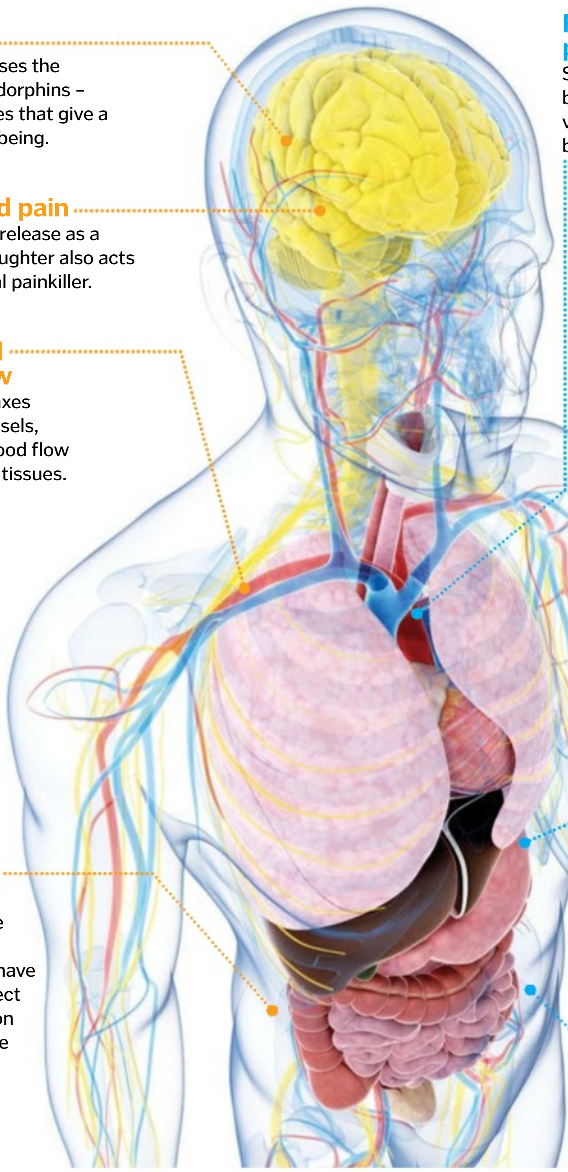
It's not all about the brain though. The feelings associated with emotions are the result of a complex mixture of incoming sensory messages that come from all over the body.

Can we fake a smile?

Faking emotions is harder than it seems. Humans are social animals and have evolved extremely good facial recognition skills – so if something isn't quite right, we are quick to notice. The muscles around our mouths are under fine voluntary nerve control, which not only provides the range of motion required for speech, but also enables us to fake a smile. But people are not easily deceived. Facial expressions involve a multitude of subtle, involuntary muscle movements, and re-creating them is incredibly difficult. The forehead and eyebrows are particularly challenging, as the muscles are mostly under subconscious control. It is hard to achieve the same expression with voluntary muscle contraction, and our eyes are often the biggest giveaway when a smile isn't genuine.

Laughter vs stress

These two opposing states have very different effects on the body, as we reveal here...



Euphoria
Laughter causes the release of endorphins – natural opiates that give a sense of wellbeing.

Reduced pain
Endorphin release as a result of laughter also acts as a natural painkiller.

Increased blood flow
Laughing relaxes the blood vessels, increasing blood flow to the body's tissues.

Improved immunity
There is some evidence that laughter can have a positive effect on the function of the immune system.

Raised blood pressure
Stress causes the heart to beat faster and the blood vessels to constrict, raising blood pressure.

Muscle tension
In response to stress, the body prepares the muscles for activity; very strong emotions like anxiety and anger can lead to shaking.

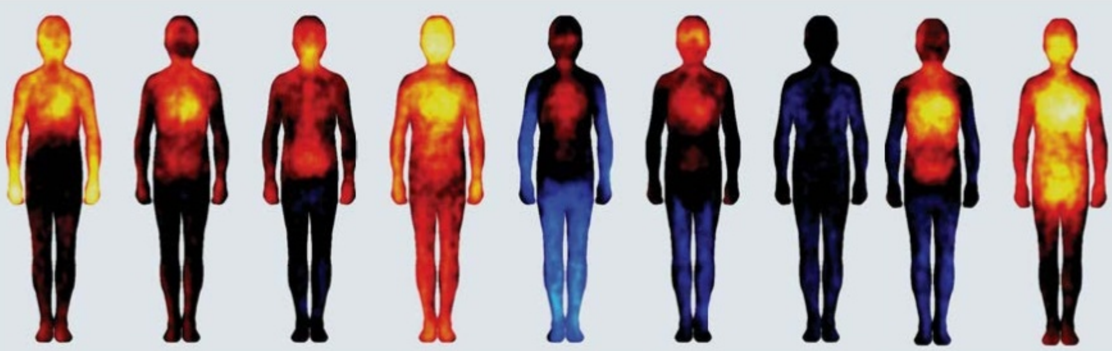
Stomach cramps
In emotionally challenging situations, the brain diverts blood away from the digestive system, prioritising the muscles and brain.

Sweaty palms
As part of the fight-or-flight response, the sympathetic nervous system activates sweat glands on the hands, feet and in the armpits.

Lowered immunity
The stress hormone cortisol (which is produced in the adrenal glands; not shown) suppresses the activity of the immune system.

Mapping out emotions

The complex human emotions are the result of sensory signals from the rest of the body. Researchers at Finland's Aalto University charted the areas of the body most commonly associated with different feelings to produce maps of where we experience the major emotions. The images demonstrate how different emotions trigger different levels of sensation around the body. Here high levels of sensation are represented with warmer hues, and vice versa.



Anger Fear Disgust Happiness Sadness Surprise Neutral Anxiety Love

Can money buy you happiness?

A Yes B No C Sometimes

Answer:
Studies show that money does buy happiness, but only if you don't have too much of it. Being rich might seem appealing, but once a comfortable standard of living has been reached, additional wealth offers little improvement in mood.

DID YOU KNOW? Two-thirds of close couples can smell each other's emotions and detect a difference between fear and happiness

Emotions are often influenced by physical stimuli, be it food, behaviour or environmental factors like sunlight

The autonomic nervous system (more commonly known as ANS) is the subconscious arm of the peripheral nervous system, and is responsible for bodily functions that are not under our voluntary control, such as heart rate, digestion and sweating; it too is wired in to the limbic system.

The ANS has two distinct components with opposing functions. The sympathetic nervous system uses the neurotransmitters adrenaline and noradrenaline to prepare the body for 'fight or flight', raising the heart rate and mobilising resources to fuel the muscles. The parasympathetic nervous system uses acetylcholine to allow the body to rest and digest, slowing the heart and breathing, and diverting the blood supply to the gut.

Sensory feedback produced by the effects of the autonomic nervous system contribute to many of the familiar feelings associated with emotions. Stimulation of the heart by adrenaline and noradrenaline as part of the fight-or-flight response produces the rapid palpitations associated with anger, fear and embarrassment. Its actions on the digestive system cause 'butterflies in the stomach', and activity at the glands on the hands, feet and in the armpits, leads to sweating when nervous.

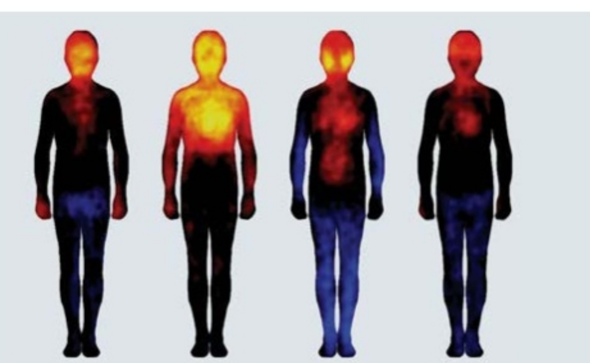
More passive emotions, like sadness or contentment, on the other hand, require little physical response, and the parasympathetic nervous system takes control of the heart, slowing its rate. Feelings of contentment and relief are often accompanied by deep, slow breathing – another indicator of parasympathetic activity.

The limbic system is also connected to the body via the hypothalamus. This small region, located on the underside of the brain, links the nervous system to the endocrine system, which produces hormones – some of which are key mediators of mood and emotion. For example, corticotropin-releasing hormone is produced in response to stress, and leads to the release of the stress hormone cortisol from the adrenal glands above the kidneys.

The regulation of emotion is not just restricted to one area of the brain – it involves almost the entire body. Reducing the bewildering complexity of human emotion down to anatomy, physiology and, ultimately, brain chemistry, might seem clinical and overly simplistic, but in reality, the fact that humans are capable of experiencing such an extraordinary range of abstract feelings is one of the greatest wonders of biology, with many chemical puzzles still waiting to be solved in this area.

Fight or flight

The autonomic nervous system is responsible for the control of heart rate, blood pressure and respiration, and governs the function of most of the internal organs. It's divided into two parts. The sympathetic nervous system is responsible for the fight-or-flight response and is behind raised heart rate, sweating, nausea and shaking associated with action-based emotions like anger and anxiety. While the parasympathetic nervous system has the opposite effect and plays a bigger role in more passive emotions like sorrow and contentment.



5 happiest countries

(based on wealth, economic growth and quality of life, 2013)

1. Norway
2. Switzerland
3. Canada
4. Sweden
5. New Zealand

3 unhappiest occupations in the UK (2014)

1. Publican
2. Elementary construction
3. Debt collection

HAPPIEST and SADDEST states in the United States

(Gallup-Healthways Well-Being Index, 2013)

HAPPIEST	SADDEST
1. North Dakota	1. West Virginia
2. South Dakota	2. Kentucky
3. Nebraska	3. Mississippi

25%

Of 129 gold medal ceremonies at the London 2012 Olympics, 25 per cent of FEMALE ATHLETES CRIED, compared to just eight per cent of male competitors

SMILIEST country Brazil

Travel app Jetpac analysed INSTAGRAM IMAGES BY COUNTRY, ranking photos based on whether the subject had a wide grin or a tight-lipped smile. Brazil finished first, while the USA lagged behind in 33rd place. The UK ranked 62nd and Japan came bottom

23 69

LIFE SATISFACTION peaks at the AGES of 23 and 69, according to the London School of Economics (2013)

Why can't we make water?

Water has such a simple chemical structure, so why can't we replicate it in the lab?

We all know water comprises just two chemical elements – oxygen and hydrogen – both of which exist as gases in Earth's atmosphere. Making water should therefore be as simple as smashing the two together with enough force to overcome the energy barrier keeping them apart – right?

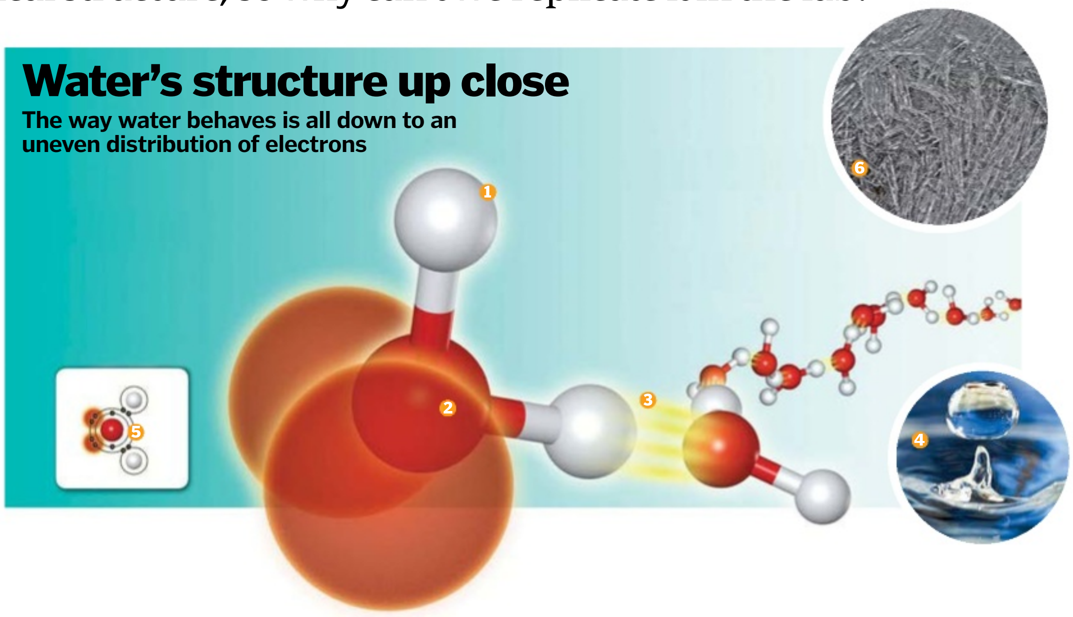
However, this reaction produces a huge amount of energy, as demonstrated in the 1937 Hindenburg disaster, when a hydrogen-containing airship caught fire and exploded. Although this reaction does create water, constructing a facility able to contain the explosion would be both technically challenging and extremely expensive.

An alternative to 'making' new water is to extract the H_2O that is already in the air. Using sheets of cooled metal, the air temperature can be rapidly dropped, allowing the water vapour to condense. The Whisson Windmill is one such invention designed to do just this; as its chilled blades rotate, they condense up to 12,000 litres (2,600 gallons) of water every 24 hours, and at very little environmental cost.

A more portable solution, designed for disaster zones, uses a generator to draw air through a cooled chamber, collecting 545 litres (120 gallons) of condensed vapour per day.

Water's structure up close

The way water behaves is all down to an uneven distribution of electrons



1 Hydrogen
The smallest element in water – hydrogen – has just one electron, which is easily drawn away by the electron-hungry oxygen atom.

2 Oxygen
Oxygen is an electronegative atom. This means it has a tendency to attract electrons.

3 Weak bond
The slight positive charge of the hydrogen atom and the slight negative charge of the oxygen produce a weak bond between adjacent water molecules.

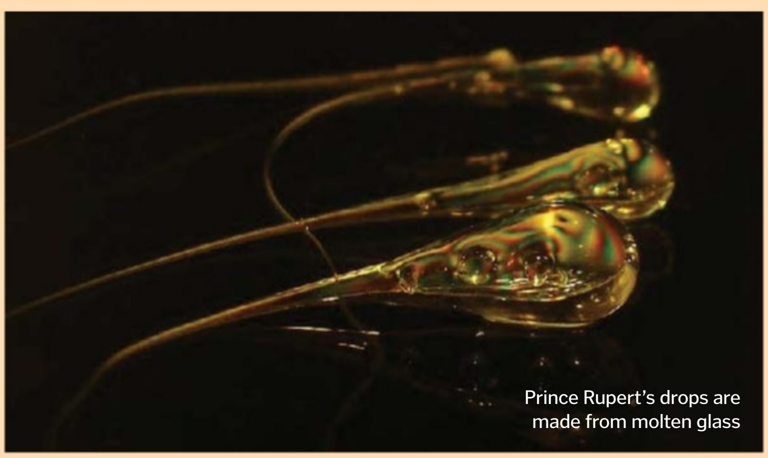
4 Liquid
The network of hydrogen bonds between water molecules holds them closer together than similarly sized molecules, giving it a liquid state at room temperature.

5 Polarity
Oxygen attracts the electrons of both hydrogen atoms, gaining a slight negative charge as a result and leaving the hydrogen slightly positive.

6 Ice
When water freezes, it forms a hexagonal crystal structure, supported by regular hydrogen bonds.

Prince Rupert's drops

Find out why these glass globules are simultaneously tough as nails yet prone to shatter



Prince Rupert's drops are made from molten glass

Hit the head of a tadpole-shaped Prince Rupert's drop (aka Dutch tear) and it seems pretty tough. But tap its tail lightly and the whole thing shatters in a cloud of glass fragments. Prince Rupert's drops are made by pouring molten glass into cold water. The outside of the glass cools and solidifies very quickly, forming a hard casing. The centre shrinks as it gradually cools, but the solid outer shell cannot mould itself to this new shape. This results in a great deal of internal stress as the centre of the drop pulls the outside inwards. This tension makes the tail vulnerable to even the tiniest of cracks, which can spread along the drop's full length in under a millisecond as the built-up stress is released. Curiously, the same structure makes the head of the drop super-strong (ie it can survive a hammer blow) since the internal stress keeps it tightly compressed.

The physics of football

Discover the science that lies behind taking the perfect free kick

The likes of David Beckham and Cristiano Ronaldo are known around the world for their expertise in the art of the free kick. Whether it's a curler into the top corner or a thundering piledriver, free kick taking is a vital part of the modern game. But how does science come into scoring a goal?

The guiding principle is the Magnus effect. Investigated by German physicist Heinrich Gustav Magnus, this law of physics demonstrates that airflow is distorted around any spinning cylinder or sphere in a certain way.

If the ball is spinning anticlockwise, the left side of it will experience less drag as it moves in the same direction as the airflow, while the right side spins against the onrushing air, increasing the drag. This creates a pressure imbalance, with the right side of the ball experiencing higher pressure and the left side experiencing lower pressure. It is this imbalance which forces the ball to move to the area with lower pressure, thus curling to the left.

But the Cristiano Ronaldo or Gareth Bale style of free kicks is a whole different ball game. The idea behind the immensely powerful, swerving free kick is imparting as little spin as possible. As the air flows over the ball, a boundary layer is produced, which is a cushion of air that sticks very tightly to the surface of the ball. If an imperfection in the ball disrupts this airflow, it will deviate in the air.

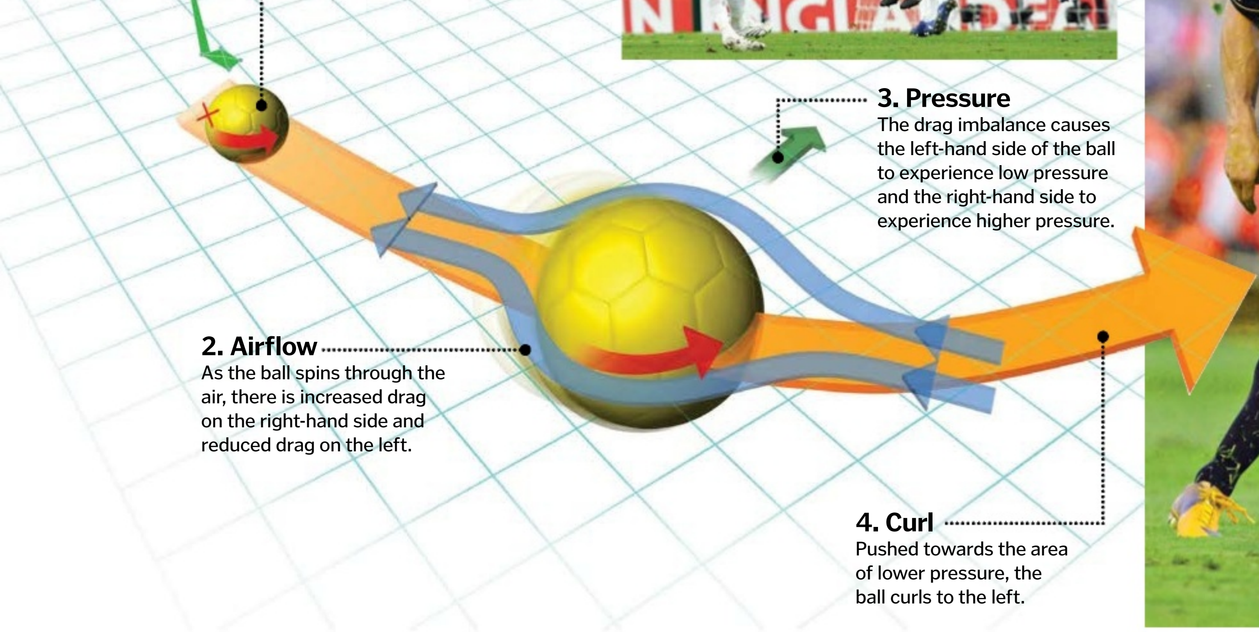
A rapidly spinning football won't deviate much, but a ball hit flatly will, as it will have more time to move in the direction of the disruption. So when Ronaldo strikes the ball with little spin, any minor imperfection in the football will cause it to move during flight and outfox many a poor, bewildered goalkeeper.

Why footballs can be too round

The official match ball for the 2010 World Cup in South Africa, known as the Jabulani, caused consternation with goalkeepers and strikers alike. The lack of panels on the ball and the use of internal stitching made it the roundest ball ever. However, the roundness of the ball caused a lot of confusion among players because of its completely unpredictable swerving. Outfield players didn't like it because the lack of imperfections meant less grip between ball and foot, meaning that they struggled to impart spin on the ball. Meanwhile, goalkeepers couldn't anticipate the trajectory because it would have a habit of suddenly slowing mid-flight or ballooning up, a bit like a plastic inflatable ball.

Guide to the curler

How a curling free kick plays out



David Beckham made the art of the free kick one of his specialities

Physics plays a massive role in football as well as all other sports

Seeing sound

Discover the science of cymatics, which enables us to observe the behaviour of sound waves

The incredible geometric patterns on this page may look artificial, but they are, in fact, the visualisation of how sound waves interact as they travel across a surface. The study of these figures is called cymatics, which derives from the Greek word 'kima' (wave) and was first coined by Swiss scientist Hans Jenny in 1967, but the phenomena had been observed for hundreds of years by the likes of Da Vinci and Galileo.

The patterns are best observed using thin sheets of either metal or glass, known as a Chladni plate after its inventor (see the 'Ernst Chladni' boxout), connected to a signal generator which can oscillate at a variety of audio frequencies. The sheet has set frequencies at which it will naturally resonate as the generated sound waves travel through it. This creates a patchwork of areas where the waves either combine destructively (ie peak meets trough) to cancel each other out, or constructively (ie peak meets peak) forming a larger wave. These sections are called nodes and antinodes, respectively.

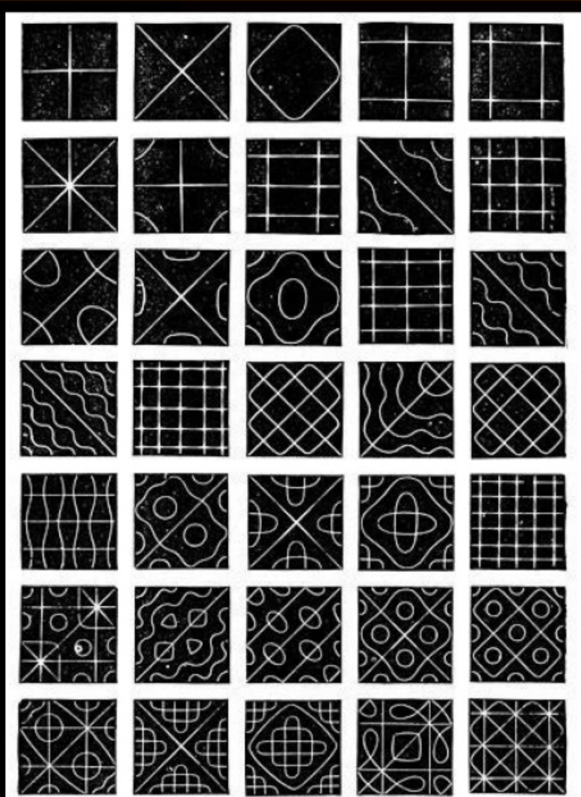
The effect of these vibrations is invisible until a medium – usually a liquid, or fine particles of a solid material such as sand or salt – is added to the plate. When the generator is set to one of the plate's natural frequencies, the water or sand will shift away from the busy antinodes and towards the quieter node regions. The resulting figures vary depending on the rate of oscillation as well as the shape and size of the Chladni plate, but all demonstrate unbelievable symmetry.

This method for visualising sound, as well as being a remarkable form of natural art, can be used across many fields of scientific research. One example is oceanography, where the cymatic patterns of dolphin sonar are being used to better understand how the marine mammals communicate.

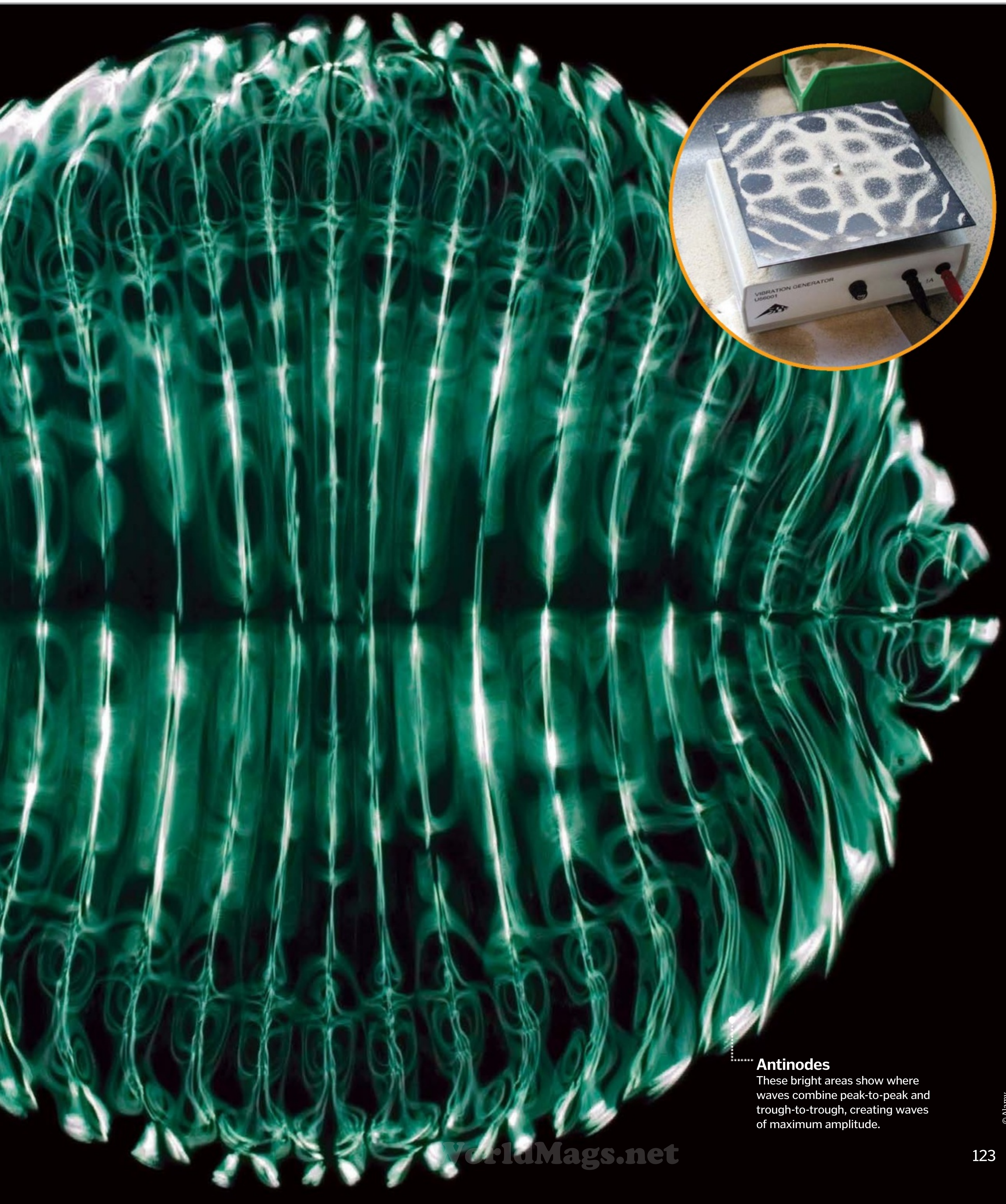
Ernst Chladni

German-born physicist and musician Ernst Florens Friedrich Chladni investigated cymatics around the turn of the 19th century. By running a violin bow along the edge of a metal plate covered in fine sand, he was able to make the plate vibrate at its resonant frequency, producing intricate patterns in the grains. Chladni experimented with a variety of plate shapes and sizes, making extensive sketches of the different sand patterns (right), which were published in his book *Die Akustik* (*The Acoustic*) in 1802. From his studies, he was able to derive a formula known as Chladni's Law, which predicts the patterns that will form on circular plates.


Ernst Chladni was a research pioneer in the field of cymatics



DID YOU KNOW? *Napoleon was so impressed by Chladni's cymatics research he funded a French translation of Die Akustik*



Antinodes
These bright areas show where waves combine peak-to-peak and trough-to-trough, creating waves of maximum amplitude.

Bottling light

Solar bottle bulbs are brightening up thousands of homes in the developing world, but how do they work?

Invented by Brazilian mechanic Alfredo Moser and developed with a little help from MIT students, a solar bottle bulb (or Moser lamp) is simply a soda bottle filled with chlorinated water, fitted into a roof. Refracting and reflecting sunlight downwards during the day, it lights up homes far more effectively than a skylight. Adding a few drops of bleach to the water ensures that it stays clean and free of germs for years. When sunlight meets the water in the bottle it slows down, bending (that is, refracting) downwards. Depending on its angle, some of this light is channelled straight into the room below while some rays hit the opposite side of the bottle and are reflected back in.

This phenomenon, known as total internal reflection, causes light to bounce back and forth inside the bottle until its angle is great enough for it to escape. As light exits the bottle at various directions, it illuminates the home just like an electric light bulb of about 60 watts.


Total internal reflection can be used as a cheap and sustainable light source

What is the Liter of Light project?

The Liter of Light project, initiated by non-profit organisation MyShelter Foundation, aims to bring this sustainable, cheap, but life-changing technology to deprived communities across the world. Living in shantytowns where tightly packed dwellings let in very little natural light, many people are forced to live in near-complete darkness both day and night. Launched in the Philippines in 2011, the project has brought solar bottle bulbs to 140,000 homes in the country.


Creating an effective light bulb out of a soda bottle is surprisingly simple

Making a bottle of light step-by-step

1. Materials
First you need a 1.5-litre PET plastic bottle, a piece of corrugated iron, some rubber sealant, filtered water and bleach. You'll also need cutters to slice through the iron sheeting, sandpaper, a drill and rivets to fix the bottle. This is an adult-only project.

2. Cut
Trace two concentric circles onto the iron sheet: one with the same diameter as the bottle and one a centimetre (0.04 inches) smaller. Cut out the inner circle then make small incisions radiating out. The resulting strips will provide a snug fit for the bottle.

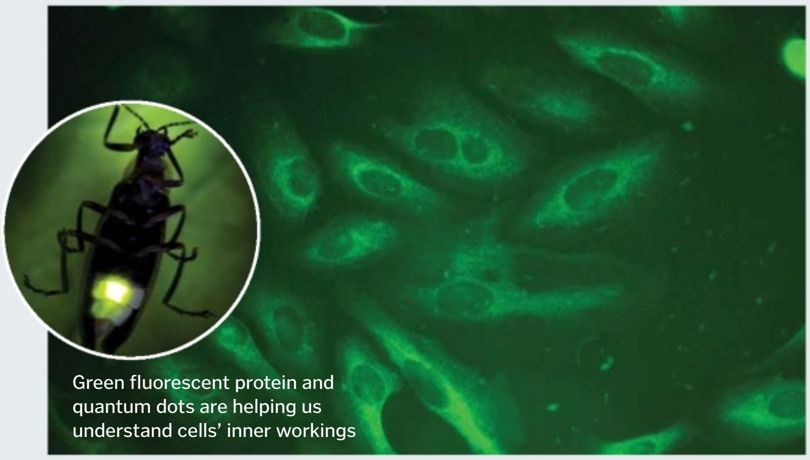
3. Stick
Sandpaper the upper third of the soda bottle to give the sealant a better grip. Then slide the bottle into the corrugated iron so that the smooth upper third sticks out at the very top. Glue firmly into place using the sealant and allow time to dry completely.

4. Fill
Fill the bottle with water, adding 10 millilitres of bleach before screwing on the cap. Mixed with water, the chlorine in bleach forms hypochlorous acid ($HOCl$). Breaching micro-organisms' cell walls, this damages cell proteins and prevents murky water.

5. Install
Cut a hole in the roof just slightly larger than the bottle's diameter and apply sealant. Push the base of the bottle through and make sure it is firmly in place. Drill holes into the roof on each side of the bulb and secure with rivets. Apply sealant to avoid leaks.

Illuminating cells

Find out how GFP and quantum dots are shedding light on medical research…



Green fluorescent protein and quantum dots are helping us understand cells' inner workings

For millions of years, the Aequorea victoria jellyfish held the secret to green fluorescent protein (GFP) – a protein that absorbs the energy from the blue and ultraviolet (UV) range and re-emits it as a green light. Biologists got their hands on the glowing jellyfish in the 1960s, extracting the protein and then uncovering the gene that codes for it.

By inserting this sequence into living organisms, scientists equip them with the instructions required to manufacture GFP, highlighting how genes are expressed in everything from bacteria to human cells. Specific proteins and cell types can be tagged with GFP, allowing researchers to track their movement and interaction. Tagging the HIV virus with GFP, for instance, shows how the infection spreads.

A similar effect can be achieved with quantum dots – nanoscale semi-conductor crystals which also fluoresce under UV light. The dots can be made in many different colours and bound to proteins, allowing scientists to observe complex biological interactions.

Recently, surgeons wearing special goggles identified and removed cancerous cells highlighted with quantum dots. These goggles could also be used to develop diagnostic tests and therapies for other conditions.

Bioluminescence in nature

Hundreds of living organisms produce light, although most do not fluoresce, instead getting their glow from chemical reactions. Most of these are marine creatures and bacteria, although terrestrial invertebrates (eg fireflies, inset) and fungi can also glow. Bioluminescence serves a variety of functions. In many marine animals, it provides camouflage by allowing its bearer to blend in with the surrounding light when viewed from below. In other species it is used as a form of communication or, like the anglerfish, to draw in prey. Researchers aren't certain what the Aequorea victoria jellyfish uses its eerie GFP glow for, but some believe it may be to evade predators.

The science of pepper spray

Discover the eye-watering chemistry behind this weaponised plant extract

The active ingredient in pepper spray – capsaicin – comes from the chilli plant. Produced to protect the plant's seeds from being crushed by the teeth of grazing animals, this molecule binds to TRPV1 receptors on the endings of pain nerves, causing them to fire and inducing a feeling similar to burning.

Pepper spray is a concentrated capsaicin solution that is designed to irritate the eyes, nose and mouth. It is used as a means of self-defence, in police crowd control, by the military and even as a deterrent against aggressive animals like bears in the wild.

Capsaicin does not dissolve in water, so it cannot be easily washed away, but relief from the pain can be achieved using gentle shampoo, which acts as an emulsifier, drawing the chemical into solution and away from the eyes and skin. Capsaicin will dissolve in fat, and milk or oil-based products can also help to soothe the burning sensation.

Turning chillies into a weapon

Capsaicin is a chemical deterrent contained in the fruits of the Capsicum genus, including peppers and chillies, to protect their seeds. It is not water soluble, so in order to extract it from the fruit it is dissolved in ethanol. The capsaicin-infused alcohol is removed and the fluid evaporated off, leaving a resin. To get the resin to mix with water for use as a spray, it is emulsified using propylene glycol, which helps suspend the fat-soluble particles in the watery solution. The concentration of capsaicin is then measured and adjusted before being pressurised in aerosol cans, ready for use.

Science of forensics

What goes on behind the police tape in the real-life CSI?

The area of forensic investigation has captured the public's imagination ever since global smash TV show *CSI: Crime Scene Investigation* first exploded onto our screens in 2000, but incredibly it's a field of criminal investigation that can trace its origins all the way back to the seventh century.

History has it that a market stall owner used the fingerprints of a man who owed him money to prove his identity and, from these inauspicious beginnings, a whole new area of criminology was created.

Today, the first people (after police) at the scene of a crime will be the CSI team, keen to preserve the integrity of the environment to boost the chances of capturing the perpetrator without any evidence being disturbed, although the word 'team' can be something of a misnomer.

Depending on the size of the local force, the CSI team can often consist of a single field officer, trained in multiple areas, who will work methodically around the room, first taking photos, and then collecting clues such as fingerprints, clothing, hair and broken glass which could lead to the culprit. However, for large-scale incidents like murders, up to four people will be involved, including a specialist photographer and a crime scene manager.

Alexandra Otto was a crime scene investigator for 11 years before moving to Bournemouth University, Dorset, UK, to become a demonstrator of forensic science in 2006. In an interview with How It Works she explains the process stage by ▶

At the crime scene…

How does a forensics team approach the scene of a murder?

Forensic toolkit

The must-have gear no CSI should be caught without

Mask and gloves
These essential pieces of protective wear ensure that no investigators contaminate a crime scene with their own DNA.

Evidence bags
All pieces of evidence will be carefully placed in these sterilised plastic bags for later analysis in a laboratory.

Digital camera
A CSI will take hundreds of photographs of the scene as well as the surrounding area to serve as evidence in court.

5 TOP FACTS
FORENSICS MYTHS

Blue light finds blood
1 While an alternative light source (ALS) can find bodily fluids, blood is located using luminol, a chemical that reacts with haemoglobin and causes the blood traces to glow.

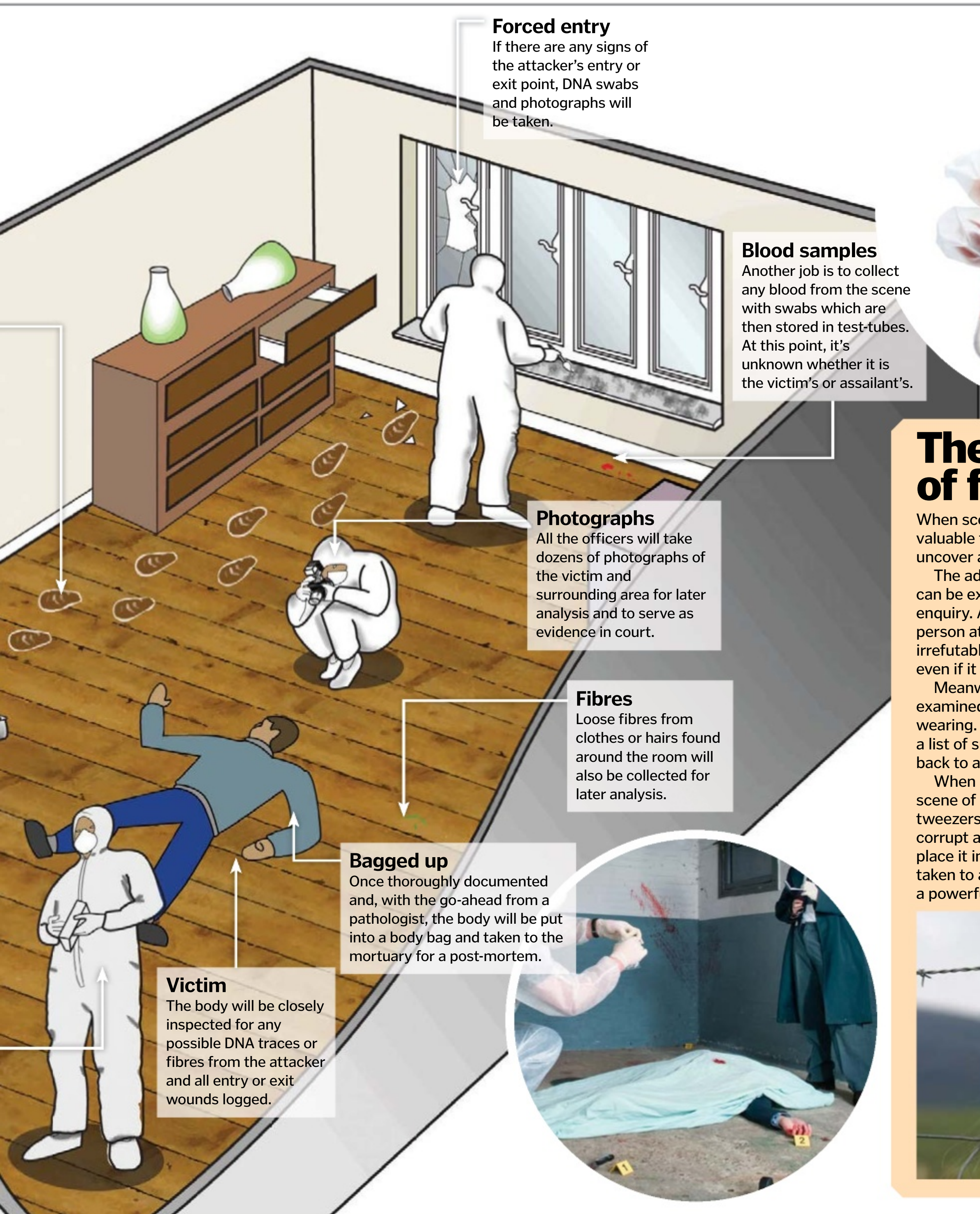
Superfast results
2 In stark contrast to the seconds or minutes that DNA analysis takes on television, a real DNA test will usually take around 7-14 days to return any meaningful data.

Bullet = gun
3 While you can often match a bullet to the gun that fired it, if the bullet has been damaged or the gun has been modified, making a match is much more difficult.

DNA always gets results
4 Even if investigators find DNA, they can't always establish whose it is. Not many people have their DNA on file, so only people with previous convictions get flagged up.

Chalk outline
5 Chalk outlines are not used to mark around dead bodies as doing so may contaminate evidence. Instead, photos and tape markers are used for analysis of the scene.

DID YOU KNOW? *CSI has been named the most watched show in the world five times in the last seven years*



Forced entry
If there are any signs of the attacker's entry or exit point, DNA swabs and photographs will be taken.

Blood samples
Another job is to collect any blood from the scene with swabs which are then stored in test-tubes. At this point, it's unknown whether it is the victim's or assailant's.

Photographs
All the officers will take dozens of photographs of the victim and surrounding area for later analysis and to serve as evidence in court.

Fibres
Loose fibres from clothes or hairs found around the room will also be collected for later analysis.

Bagged up
Once thoroughly documented and, with the go-ahead from a pathologist, the body will be put into a body bag and taken to the mortuary for a post-mortem.

Victim
The body will be closely inspected for any possible DNA traces or fibres from the attacker and all entry or exit wounds logged.

The importance of fibres

When scouring a crime scene, two of the most valuable finds that a forensic officer can uncover are hair and clothing fibres.

The advantage of finding a hair is that DNA can be extracted from it, opening a line of enquiry. Although it can't directly place a person at the scene like fingerprints, it is irrefutable proof that there is a link somewhere, even if it has been planted.

Meanwhile, fibres of clothes can be minutely examined to determine what someone was wearing. This can then be used to whittle down a list of suspects as certain fibres can be traced back to a specific manufacturer.

When anything of this nature is found at the scene of a crime, forensic officers will use tweezers to pick up the item, so as not to corrupt any potential DNA, and immediately place it in an evidence bag. The bag is then taken to a lab, where it can be examined under a powerful microscope and any DNA extracted.

Fingerprinting powder
Two different types of powder are used at the crime scene; which one depends on the type of surface.

Tape
Adhesive tape is used to lift a copy of a fingerprint from a surface.

Luminol
This is a chemical which glows in the dark in the presence of blood, illuminating even trace amounts.

Flashlight
A torch is essential for looking in dark nooks and crannies for crucial evidence or during crime scenes at night.

Tweezers
In order to avoid smudging potential fingerprints or damaging fibres, tweezers are used to pick up small pieces of evidence.

stage from the moment they get the call to the scene to the end of the case.

"First, we'll get a call from the control room that took the report of the incident, head down to the crime scene and talk to any police officers or home owners. Before even entering the room, we will scour the area outside the crime scene to see if there are any clues we can find.

"Then, we will move inside the room, having put on protective suits, gloves and masks. The masks are to avoid any chance of us accidentally contaminating the scene with saliva or anything like that. We will take lots of photos of all areas of the room. These will primarily be for the prosecution, but they are also disclosed to the defence. Next, we go around collecting evidence in bags, such as any blood on a window, fibres from clothes or envelopes the intruder may have opened.

"The next stage is to dust for fingerprints. We will then use tape to lift the prints, which will be bagged in a special envelope and sent to a fingerprints expert, while the rest of the evidence goes to a lab. We would never touch a body until the forensic pathologist has been and studied it. Then the body would get put in a body bag and taken to the mortuary.

"Once all the evidence has been analysed in the lab, we would get the results, which we would pass to the CID who would continue the investigation. We could get called to court to give our side of the investigation, but the detective and analytical work are done by the police and lab teams."

Until fairly recently, much of the laboratory work carried out in Britain was done by the

Anatomy of a fingerprint

What the experts are looking for when trying to match a print

Loops
This pattern will rise up at an angle, curve over and swoop back down, returning back to the starting point of the pattern.

Whorls
These are individual rings, each one encircling the one inside it. Just over a third of fingerprints look like this.

Arches
The least common of all fingerprints, these look a bit like a hill, swooping up from the left, then down toward the right.

Independent ridge
A long ridge which isn't connected to any others.

Enclosure
This is where two ridges split, then rejoin, forming an enclosed loop.

Bridge
A ridge connecting one long ridge with another, bridging the gap between the two.

Bifurcation
Looking like a fork, this is where a ridge naturally splits into two.

Dot
Similar to the independent ridge in that it isn't connected to any other ridges, but it's much shorter.

The process of fingerprinting

1. Collection
Fingerprints can be found in several ways. The most common is taking a high-resolution photograph of a print that is already visible. However, if no prints are visible at a scene, investigators can dust surfaces with powders such as aluminium flakes, take pictures, then collect them by sticking tape onto the powdery surface and removing them along with the imprint. An alternate light source (ALS) can be used in a darkened room.

2. Processing
The print is fed into a computer, which analyses the patterns and tries to find a match with any on its database. If any matches are flagged, fingerprint experts examine the two images by eye.

3. Decision
Examiners use the ACE-V method in fingerprint analysis, which stands for Analysis, Comparison, Evaluation and Verification. The first stage is to establish if there is enough of a print in terms of quality or quantity to verify a match. After that, they look at images of the print and the potential match to see if they are similar. If it's decided that they do match closely enough, the final stage is to bring in a second examiner to perform the same process for verification.

Fathers of fingerprinting

We have a few people to thank for the development of fingerprint forensics

1686
Marcello Malpighi notes fingerprints are unique to the individual, after studying patterns on our fingers.

1858
Magistrate of Indian district Hooghly, William Herschel uses fingerprints to force locals to confess to crimes.

1880
Henry Faulds publishes his reseach in *Nature*, suggesting that fingerprints could be used to catch criminals.

1892
Sir Francis Galton writes the book *Finger Prints* and devises a method to identify and record fingerprints.

STRANGE BUT TRUE
A HUMAN TOUCH

Which Australian animal has human-like fingerprints?

A Kangaroo **B** Koala **C** Wombat

Answer:
Even when viewed under a microscope, it is practically impossible to distinguish a koala's fingerprints from human ones. This is thought to be a recent evolution as fellow marsupials don't have human-like fingerprints.

DID YOU KNOW? *The acid in quicklime is able to erode our fingerprints, although they will grow back in around 30 days*

Forensic Science Service (FSS), which was run by the government, but losses of around £2 million ($3.3 million) per month forced the department to close. The workload for analysing the results of the crime scene then got contracted out to private companies.

"The private companies are very good," reveals Otto. "The only problem is contamination. The great thing about the FSS was that they were world-renowned and their labs were always incredibly clean. Unfortunately the private companies sometimes aren't quite so careful and contaminations do occur. When you're working with DNA, which is obviously such a small thing, you have to be really careful."

After removing a body from a crime scene, it's placed in a sterilised bag and transported to a mortuary where it's kept until the forensic pathologist is able to perform a post-mortem, determining time and cause of death.

Meanwhile, lab analysis of any pieces of evidence is taking place. This can be anything from looking at a piece of thread under a microscope to see what the suspect was wearing to processing any DNA fragments to see if there is a match on the database.

A fingerprint is left on a surface due to the sweat glands in the finger creating a latent mark. Alternatively, if a person presses with enough force in wet paint or other malleable surfaces, this would also leave a print.

"Smooth surfaces like glass will require a flake powder containing aluminium or gold flakes," Otto explains. "Rough surfaces will need a more granular powder. This powder ▶

DNA profiling

The discovery of DNA was a massive milestone in forensics. Watson and Crick proposed the idea of the double helix in 1953, but in 1984 British geneticist Alec Jeffreys discovered a method to use variations in a person's DNA to identify them.

The most common method uses short tandem repeats (STRs). These are structures within the human genome consisting of one to five bases and are repeated half a dozen times through the DNA system. When DNA copies itself, mutations occur, giving each individual their unique code. Profilers will take 10-13 STR markers from DNA found at the scene of a crime and compare that with DNA taken from the person they are interested in.

STRs are useful in DNA identification because the STR markers vary noticeably in humans, reducing the chance of an error, and also because they can be easily magnified when profilers are inspecting the DNA strands.


A CSI will spend a lot of their time in the lab, analysing evidence collected at crime scenes

Putting a face to DNA

Until now, the only clues the police were able to use to physically identify a criminal is witness or CCTV evidence. However, teams from Erasmus University Medical Centre in Rotterdam and Pennsylvania State University have identified five genetic variants that have an effect on the face. This means that the same DNA that can identify who you are on the inside could in the future also help police construct a reasonably accurate re-creation of a face, including the tip of the nose, position of the eyes and general face shape.

This breakthrough was achieved by making 3D images of nearly 600 people from a variety of ethnic backgrounds and linking the differences in face shape to the differences in DNA, isolating the genes that controlled what we look like.

While still not yet fully tested and some way from being able to be used as evidence in court, this new method of forensic profiling has very exciting potential to help investigators drastically narrow down their list of suspects.

adheres to the sweat that creates fingerprints so we can get a clear image of the print."

As fingerprints are unique to the individual, the discovery of fingerprints on a doorframe or a person's body provides irrefutable proof that they were there. While fingerprints found at a scene cannot be dated, and the added confusion of planted evidence the culprit could use to frame someone else, fingerprints provide an invaluable resource to police officers who need to link a suspect with a location.

Once fingerprints have been collected, they are analysed by a dactyloscopy expert and run through a computer that will search its database of fingerprints, collected over several decades, to try and find a match.

The whole basis of fingerprint evidence is centred on the unique pattern of whorls, loops and arches that make up every fingertip. As yet, no one has ever found two people with exactly matching fingerprints, so a positive match is taken as fairly solid evidence of a person's connection with the crime.

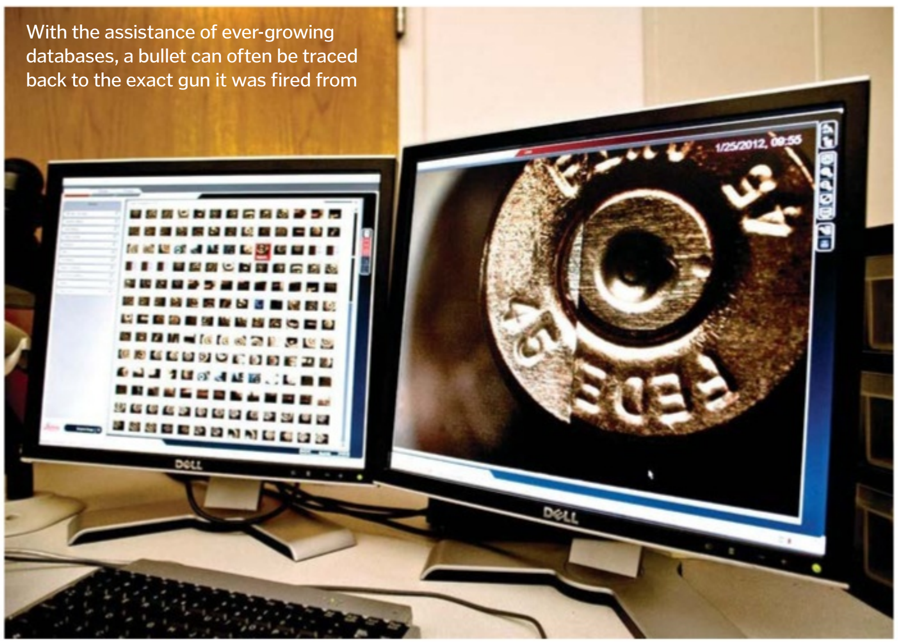
Recent advances in fingerprinting have enabled forensic investigators to even detect high-quality fingerprints from food, a previously tricky area of investigation. A modified form of powder suspension, which is a tar-like substance, will reveal a fingerprint quite clearly even on smooth surfaces, meaning that we now have another way in which to connect people with a crime.

The other key area for forensic investigators is DNA matching. This is a much more recent development, with the technique only emerging in the 1980s, but is able to create matches with incredible accuracy. DNA profiling is where a section of a person's DNA, which is unique to them, is matched with DNA found at a crime scene, which can come in the form of blood, a strand of hair or even oil from a nose print that had been pressed up against a window. If a match is found, you can be fairly certain someone was there, if not when or why.

Obviously though, linking a person with the scene of the crime won't automatically result in a conviction. Now that people are aware of the power of forensic evidence, criminals are able to manipulate the system, planting DNA evidence to throw investigators off the scent. Forensic evidence can go as far as showing who has touched a certain object or whose DNA was found in the area, but it is still up to the police to decide what to do with the evidence put in front of them, much like non-forensic evidence such as witnesses and alibis.

Unfortunately, the other key limitation to DNA and fingerprint evidence is that the person to whom they belong needs to be known to the police. Fingerprints and DNA are run through

Another aspect of crime scene investigation is collecting and examining ballistics evidence, if a gun has been used in the crime



With the assistance of ever-growing databases, a bullet can often be traced back to the exact gun it was fired from

Ballistics in focus

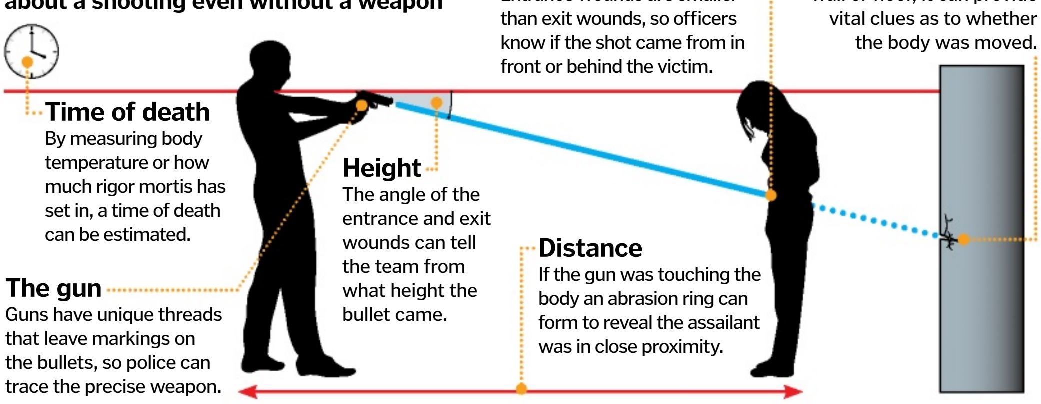
Unless a gun has been modified or the ammunition badly damaged, forensic officers are often able to trace a bullet back to the weapon that fired it, due to marks made by the firearm's unique pattern of grooves and threads.

When establishing the cause of death, ballistics experts and medical officers will work together to determine various aspects of the shooting, such as the distance and angle from which a person has been shot judging by the entry wound and potential exit wound.

Assistance to law enforcement officers now comes in the form of the instant shooter identification kit, which can work out in minutes if a person has recently fired a gun by analysing gunpowder residue on their hands.

Tracking a bullet

The ballistics team can tell many things about a shooting even without a weapon



KEY DATES
HISTORY OF FORENSICS

1788 JC Mayers writes that 'the arrangement of skin ridges is never duplicated in two persons'.

1886 Henry Faulds believes fingerprints could be used to identify criminals. He is rebuffed by Scotland Yard.

1953 Watson and Crick discover that DNA is handed down by a person's parents and is unique to the individual.

1984 Alec Jeffreys develops genetic profiling, which links DNA from a crime scene with DNA taken from a suspect.

1988 Colin Pitchfork becomes the first person to be convicted in the UK using DNA evidence.

DID YOU KNOW? Studying insects at a crime scene is called forensic entomology. Growth of fly larvae can reveal time of death

the national database to find a match, but if the police do not have either on file, they will hit a dead-end in the investigation. An officer can only take DNA and fingerprints when someone is arrested and a recent law in the UK has determined that anyone who hasn't been convicted of a qualifying offence has to have their records destroyed within six months. However, the benefit of the DNA database is that more and more cold cases are being solved, due to people's DNA being taken, fed into the computer and matched with DNA taken from a crime scene years ago, leading to many retrospective convictions.

Forensics alone cannot force a conviction, but they certainly can assist the police in constructing a case for the prosecution.

Whenever a gun is involved in a crime, ballistics is another major area that falls under the forensics team's remit.

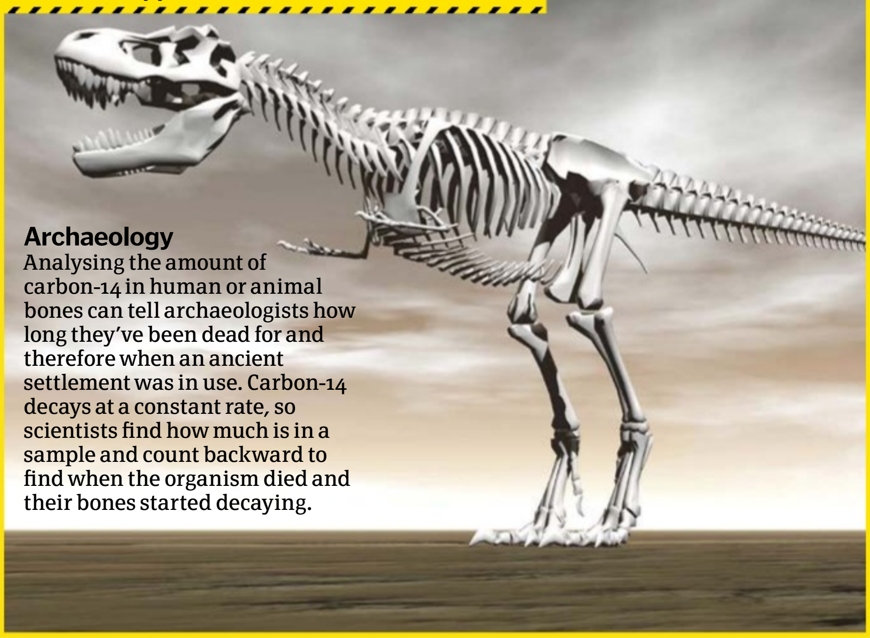
"One of the things we can determine is the directionality of ballistics, so where the bullet came from", Otto explains. "Apart from if a gun is modified, matching the bullet to the gun is a very precise science. Each gun has grooves that are particular to that exact firearm, not just the brand, so we can trace the gun with real certainty. Less reliable is firearm residue. Studies here have shown that there is a real similarity between gunpowder residue and brake dust, for example, so that is an area that needs further investigation."

We have to ask Otto about the influence of *CSI*. The hit US TV show has been phenomenally successful in the 14 years since its premiere and has spawned two direct spin-off series, *CSI: Miami* and *CSI: New York*, as well as inspiring several other detective shows, but is its immense success a boost or hindrance to the world of forensic investigation?

"Of course I watch *CSI*. I need to know what my students are watching. The show is very good, but it does give people a different idea about crime scene investigators. In the show they do everything. They interrogate witnesses, forensically investigate the scene, do the lab work, everything. In reality, we don't do much of that side of things at all. In fact, when my students first arrive I tell them that the life of a CSI is not like on the TV at all.

"It does give the wrong impression about how things work too. Whereas they get DNA results straight away, we generally have to wait about a week to two weeks minimum for results to come back. Having said that, forensics is quick in the courts. It helps to identify the person because of the individuality of DNA, and it has been proven that DNA profiling stands up in the court of law. I don't think the advantages of DNA can ever be overvalued."

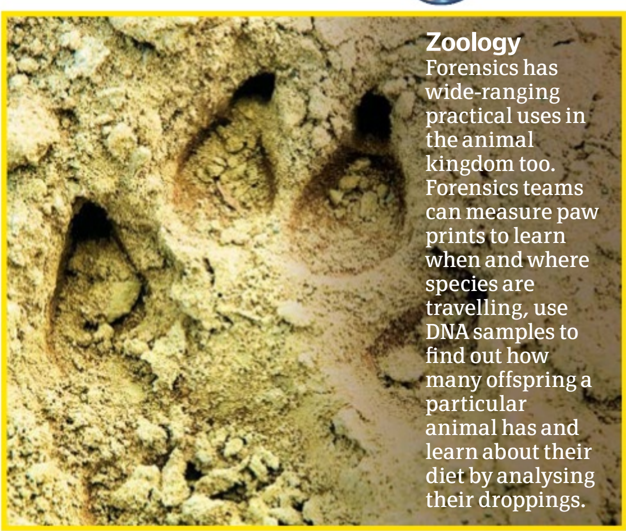
Not just for murder
What other applications are there for forensics?



Archaeology
Analysing the amount of carbon-14 in human or animal bones can tell archaeologists how long they've been dead for and therefore when an ancient settlement was in use. Carbon-14 decays at a constant rate, so scientists find how much is in a sample and count backward to find when the organism died and their bones started decaying.

Reuniting families
Families that have been separated through adoption, abduction or any number of reasons like natural disasters can be reunited through their DNA. By analysing the DNA of child and parent, geneticists can establish a definitive match and provide cast-iron proof of the relationship.

Fraud
Technology is a key part of many criminal investigations, so the field of technology forensics is growing. Experts can determine the last person to use a computer, locate and date emails and even pinpoint a person's current location using IP addresses.



Zoology
Forensics has wide-ranging practical uses in the animal kingdom too. Forensics teams can measure paw prints to learn when and where species are travelling, use DNA samples to find out how many offspring a particular animal has and learn about their diet by analysing their droppings.

SPACE

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ISS medical treatment

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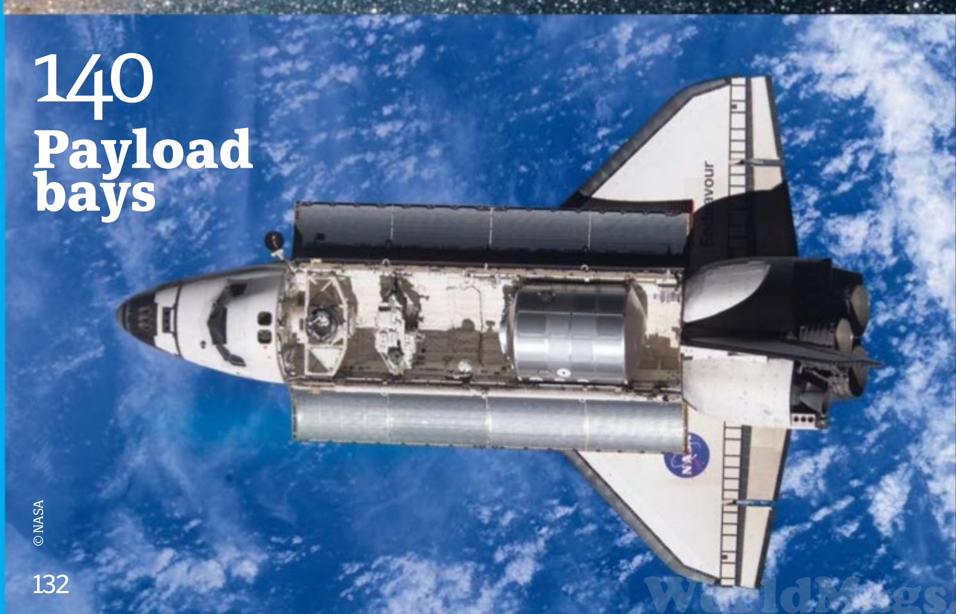
Rogue planets



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Payload bays

144
Hypergiant stars

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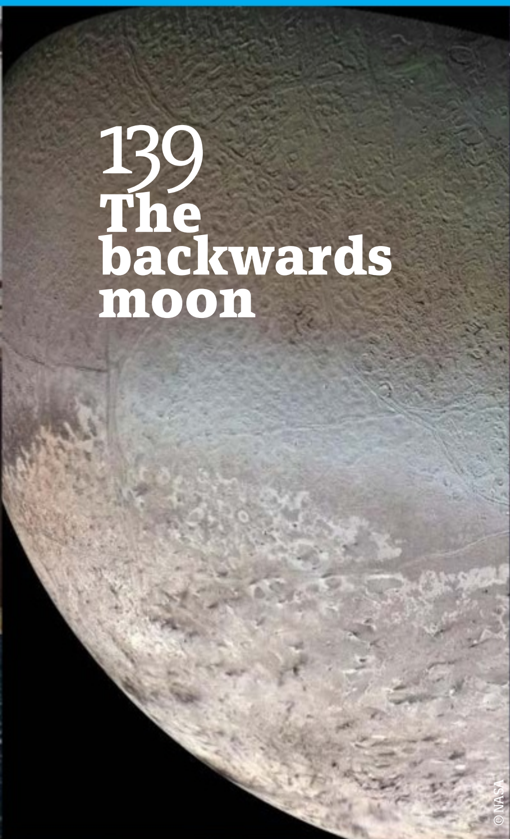

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The backwards moon

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Probe communication

© NASA

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Mega telescopes

© Alamy

Mega telescopes

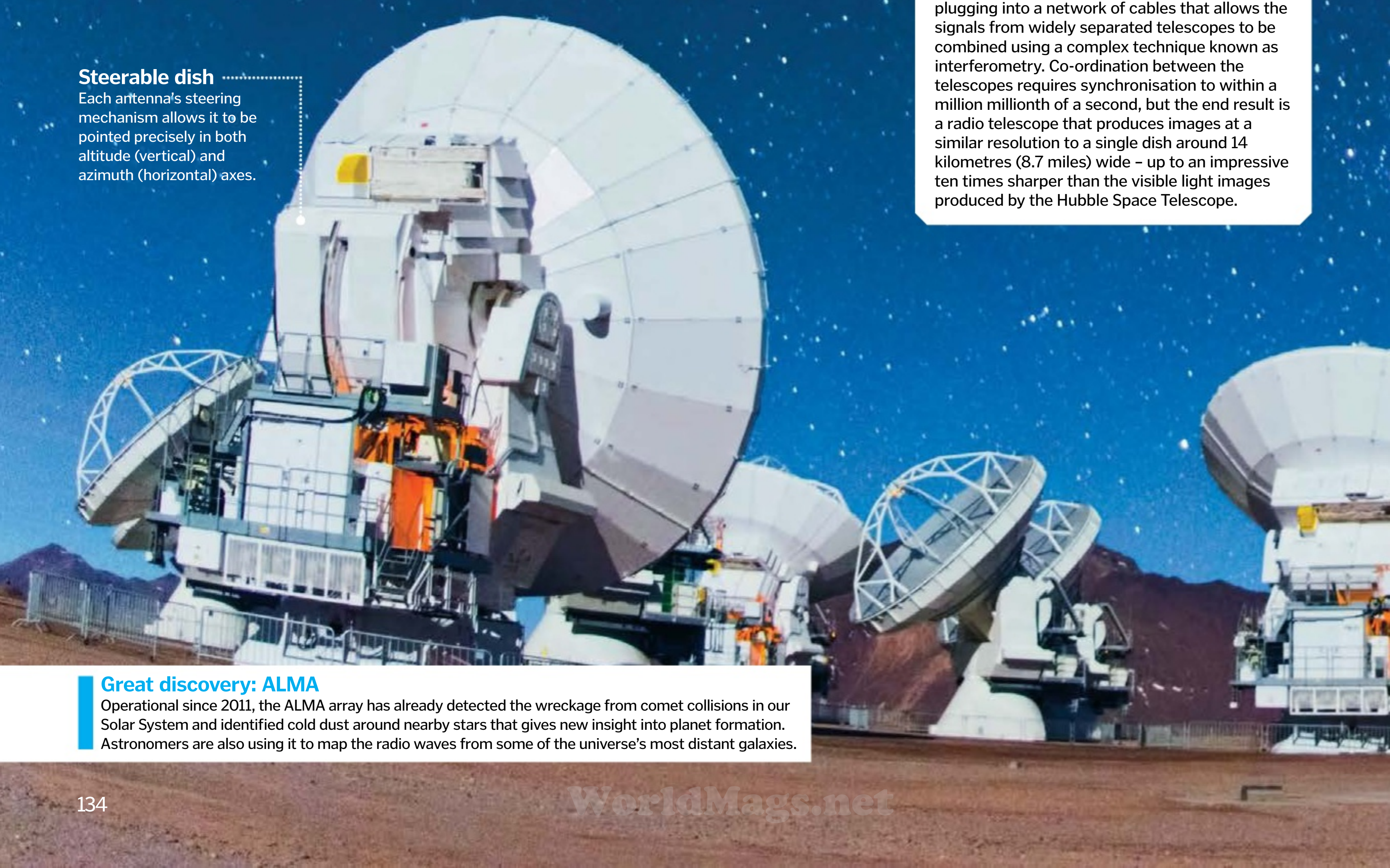
They're our biggest eyes on the sky, but how are these huge mirrors and dishes transforming our view of the universe?

When it comes to astronomy, bigger is always better. A new generation of giant telescopes is pushing the limits of engineering to answer some of our biggest questions about the universe. New technology means that mountain-top monsters like Hawaii's Keck Telescopes can compete with the perfect visible-light views of the Hubble Space Telescope, while the next generation of giants will supersede even Hubble. And when it comes to radio waves (radiation whose long wavelengths can reveal the cool gas and dust of an otherwise invisible cosmos), the engineering challenges of projects such as the Atacama Large Millimeter/submillimeter Array (ALMA) are so huge that they can only be attempted on the ground.

Why go big? There are two reasons. A telescope is essentially a tool for gathering incoming photons of light from distant objects, so doubling the diameter of a telescope's light-collecting primary mirror quadruples its 'light grasp'. Its diameter also affects its resolving power – its ability to separate tightly spaced objects and see fine detail. With a 'single-element' mirror or radio telescope, light grasp and resolving power go hand in hand, but there are tricks for improving resolution if you can't build a single giant collecting surface.

A compound eye on the sky

Depending on how you look at it, the largest telescope in the world right now might be the Atacama Large Millimeter/submillimeter Array (ALMA), in Chile's famously dry Atacama Desert. ALMA is actually an array of 66 individual radio telescopes, a dozen of which are dish antennas some seven metres (23 feet) across, while the remainder are 12 metres (39 feet) across. The telescopes combine to observe the sky in radio waves – electromagnetic radiation that has much longer wavelengths than visible light and so needs a much larger telescope to achieve high-resolution images. ALMA's individual antennas, each weighing up to 100 tons, can be relocated across a flat plain over an area of desert some 16 kilometres (ten miles) across, plugging into a network of cables that allows the signals from widely separated telescopes to be combined using a complex technique known as interferometry. Co-ordination between the telescopes requires synchronisation to within a million millionth of a second, but the end result is a radio telescope that produces images at a similar resolution to a single dish around 14 kilometres (8.7 miles) wide – up to an impressive ten times sharper than the visible light images produced by the Hubble Space Telescope.

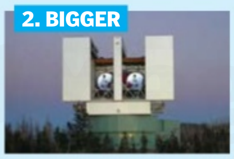


Great discovery: ALMA
Operational since 2011, the ALMA array has already detected the wreckage from comet collisions in our Solar System and identified cold dust around nearby stars that gives new insight into planet formation. Astronomers are also using it to map the radio waves from some of the universe's most distant galaxies.

1. BIG

The Very Large Telescope
ESO's Chilean complex consists of four 8.2m (26.9ft) telescopes that can be combined to mimic a 130m (427ft) telescope.

2. BIGGER



The Large Binocular Telescope
This Arizona desert giant combines two 8.4m (27.5ft) telescopes for an effective 11.8m (38.7ft) diameter.

3. BIGGEST

Gran Telescopio Canarias
The biggest single-mirror telescope, on La Palma, has a 10.4m (34.1ft) mirror with 36 hexagonal segments.

DID YOU KNOW? *In 1974, the Arecibo scope was used to beam our first deliberate interstellar message toward a star cluster*

Land of the giants

Over the past few decades, Chile's Atacama Desert has become the favoured location for many of the world's largest telescopes. The Atacama runs along a 1,000-kilometre (621-mile) strip of coastal Chile and is the driest hot desert on Earth. A more-or-less permanent high-pressure region over the Pacific Ocean to its west prevents rain reaching it from the sea, while the Andes Mountains to the east cast a similar 'rain shadow'. As a result, the average rainfall is less than one millimetre (0.04 inches) a year, and the atmosphere is virtually free of the water vapour that fogs radio and infrared telescope observations. What's more, the desert lies across an elevated plateau with an average altitude of around five kilometres (3.1 miles), above some 40 per cent of the Earth's atmosphere, ensuring stunningly clear skies on almost every night of the year. Telescopes located here include not just the international ALMA radio array, but also the La Silla and Paranal facilities operated by the European Southern Observatory (ESO), whose instruments include the Very Large Telescope, seen by many as the largest Earth-based optical telescope operating at present. The Cerro Tololo Inter-American Observatory and the construction site for the E-ELT all take advantage of similar conditions in the Atacama region.

7,000m²
THE COMPLETE ARRAY OF 12M (39FT) ALMA TELESCOPES HAS A COLLECTING AREA ABOUT THE SAME SIZE AS A FOOTBALL PITCH

Transporter unit
Two heavy-duty transporters called Otto and Lore are used to relocate individual antennas across the site.

Metal surface
The long wavelengths of the radio waves involved mean that they can be reflected precisely using curved metal rather than mirrors.

Dish design
Each antenna collects radio waves arriving from distant space and reflects them to a receiver apparatus where their amplified effect produces electrical signals.

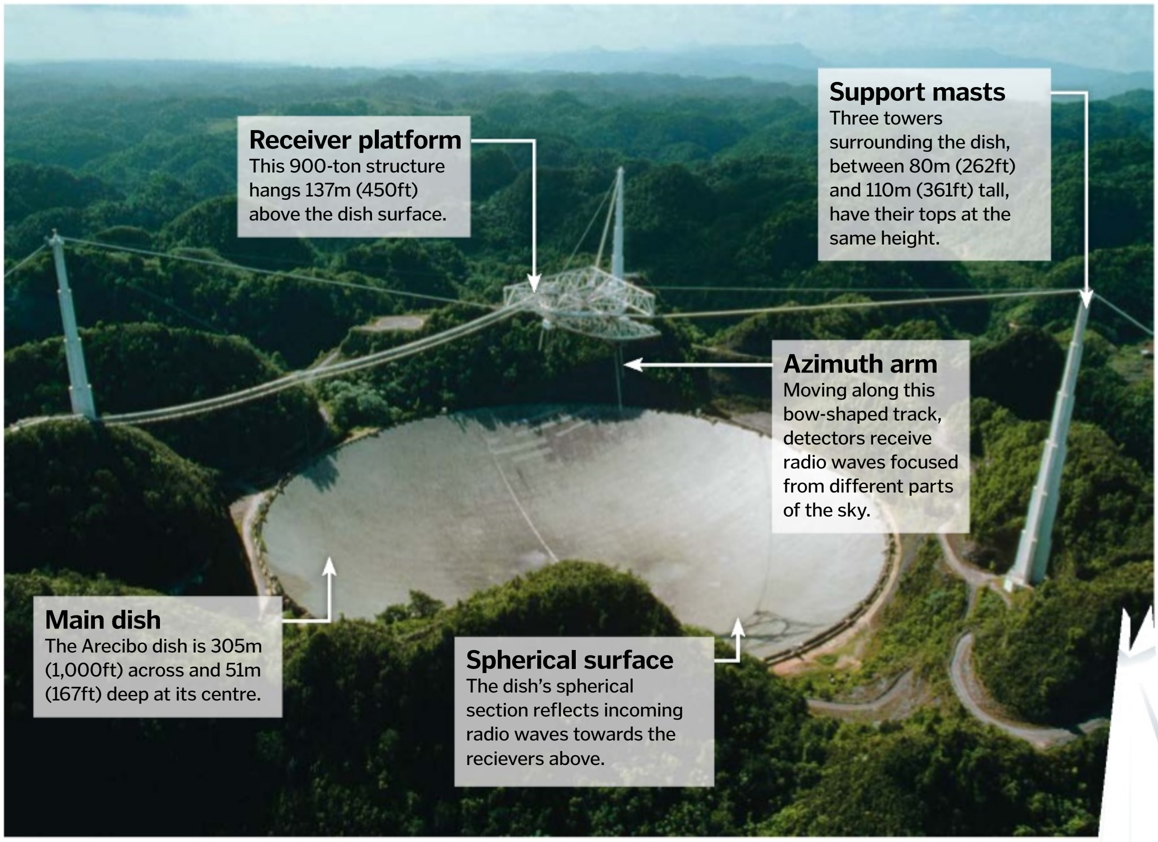
Hard standing
Stable concrete foundation blocks, linked by cable to the central control centre, are scattered across the plateau.

The biggest radio scope

The US National Astronomy and Ionosphere Centre (NAIC) telescope, located at Arecibo on the Caribbean island of Puerto Rico, has become an icon of modern science thanks not only to its spectacular scale, but also to its many appearances in documentaries and movies. With a diameter of 305 metres (1,000 feet), this enormous fixed dish, set within a natural limestone sinkhole, is the largest 'filled dish' telescope in the world (the RATAN-600 radio telescope in the Russian Caucasus is technically even larger, but it consists of a circle of separate, steerable collectors). Arecibo's vast scale means the main dish is not steerable, but a complex detector apparatus suspended overhead can be moved in order to allow detection of radio signals in a 40-degree-wide 'cone of visibility' around the zenith. With the ability to send and receive radio signals, Arecibo was originally intended purely as a giant radio antenna for bouncing signals off the ionosphere region of Earth's upper atmosphere, but amendments built in from the outset have allowed it to be used in many astronomy projects, including the SETI programme, searching for signals from intelligent life beyond our Solar System.

Great discovery: Arecibo

Arecibo's ability to send and receive signals allow it to be used as a planetary radar, sending beams of radio waves towards nearby planets and measuring the signals that returned. In this way, Arecibo was used to make the first maps of cloud-covered Venus, and even to detect the first traces of ice near the poles of Mercury.



The azimuth arm of the Arecibo telescope rotates to direct the reception of signals

The dish's panels are transparent, so plants grow underneath the telescope

305m
AT 305M (1,000FT) ACROSS, ARECIBO'S GIANT DISH IS ALMOST AS WIDE AS LONDON'S SHARD SKYSCRAPER IS TALL

Other astronomical giants of the world

We take a close-up look at five more supersized terrestrial telescopes

Twin giants

With primary mirror diameters of 10m (33ft), each made of 36 hexagonal segments, the twin Keck Telescopes marked a breakthrough in telescope technology when they entered service in the 1990s, introducing techniques such as adaptive optics. They can combine to mimic the resolving power of a single 85m (279ft) instrument.

Giant honeycomb

The Giant Magellan Telescope, being built at Las Campanas Observatory in Chile, has a unique design with a primary mirror with seven hexagonal segments, each 8.4m (27.6ft) across. The combined light grasp will match that of a single 22m (72ft) mirror.

RECORD BREAKERS
MOST SEGMENTS

38,778

PANELS IN THE ARECIBO TELESCOPE

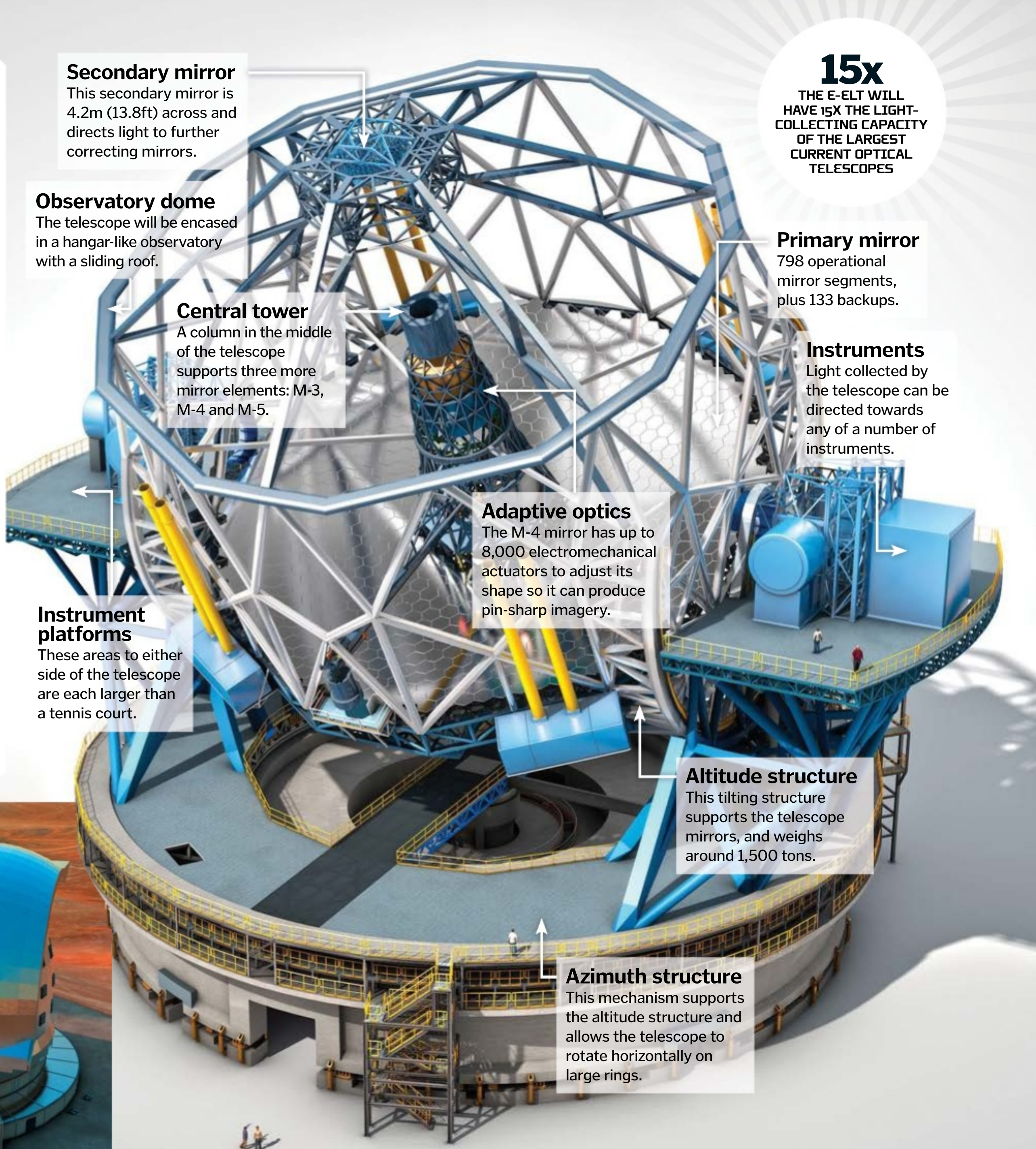
Arecibo's enormous dish is made of nearly 39,000 individual perforated aluminium panels that reflect radio waves to a focus point on a receiver, while letting light through to the forest floor below.

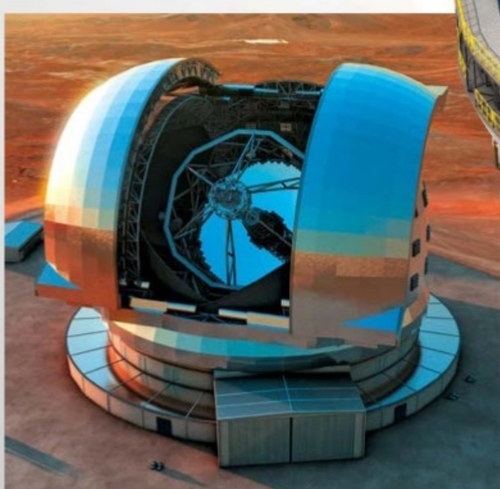
DID YOU KNOW? *Radio telescopes like ALMA can combine signals from telescopes separated by thousands of kilometres*

A new breed of giant

Today's largest optical telescopes are in the ten-metre (33-foot) class, but plans are well underway for the next generation of even more ambitious instruments. For instance, construction should shortly begin on the European Extremely Large Telescope (E-ELT) – a reflecting telescope with a primary mirror surface 39 metres (128 feet) across.

The E-ELT will be built on the summit of Cerro Armazones, a peak in the central area of Chile's Atacama Desert. The telescope's design will involve five separate optical elements, permitting the use of 'adaptive optics' – electromechanical systems that make minute adjustments to the shape of the telescope to correct distortions to the path of light arriving through Earth's turbulent atmosphere. The main mirror itself will consist of 798 hexagonal segments, each 1.4 metres (4.6 feet) across, producing a combined collecting area of 978 square metres (10,527 square feet). Scientists hope the telescope will be operational by the middle of the next decade.





An artist's impression of the ambitious E-ELT

Great discovery: E-ELT

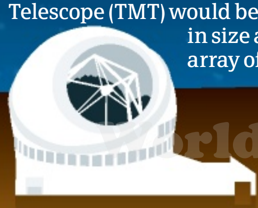
The E-ELT will not be operational for another decade or more, but astronomers at ESO hope it will usher in a new era in astronomy. Sensitive instruments should make the discovery of Earth-like planets around other stars frequent, while the telescope's light grasp will capture the faint radiation from objects closer to the Big Bang than ever before.

Southern behemoth

The Southern African Large Telescope (SALT), sited in South Africa's remote Northern Cape province, is one of the largest optical telescopes operating today, and the largest in the southern hemisphere. It has an 11m (36ft) primary mirror made up of 91 hexagonal cells and saw first light in 2005.

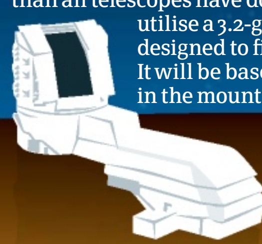
Hawaiian monster

Within the next decade, another giant telescope may join the lineup of international observatories on top of Mauna Kea, Hawaii. Funded by an international consortium, the Thirty Meter Telescope (TMT) would be second only to the E-ELT in size and would contain an array of 492 hexagonal mirrors.



New kid on the block

Expected to enter commission in 2020, the Large Synoptic Survey Telescope will study more of space than all telescopes have done before it. It will utilise a 3.2-gigapixel camera and is designed to find new distant galaxies. It will be based 2,682m (8,800ft) high in the mountains of Chile.



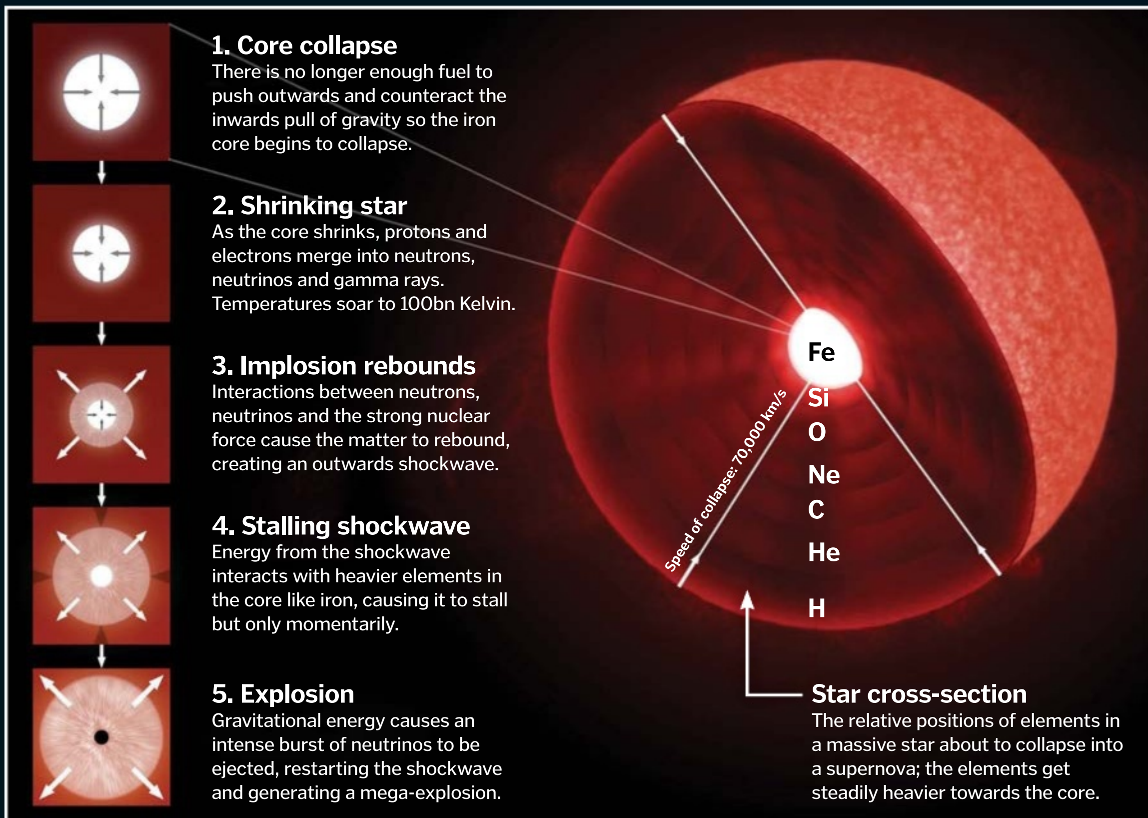
How stars go supernova

Key events at the end of a massive star's life that lead to a cataclysmic explosion

All stars are giant balls of gas trying to collapse under their own gravity. Pressure caused by the collapse generates nuclear fusion – the fusing together of hydrogen and helium nuclei – giving off enough energy to push outwards, so the star doesn't collapse further.

When massive stars eight times the mass of our Sun run low on fuel, the inwards pull of gravity overcomes this outward force, causing the star to shrink. The density becomes so great that further fusion reactions release an immense amount of energy in a matter of seconds, generating the most explosive event in the universe: a supernova.

A large proportion of the star's material is ejected outwards, while an inwards force of equal magnitude causes the remaining matter to collapse into a neutron star or even a black hole.

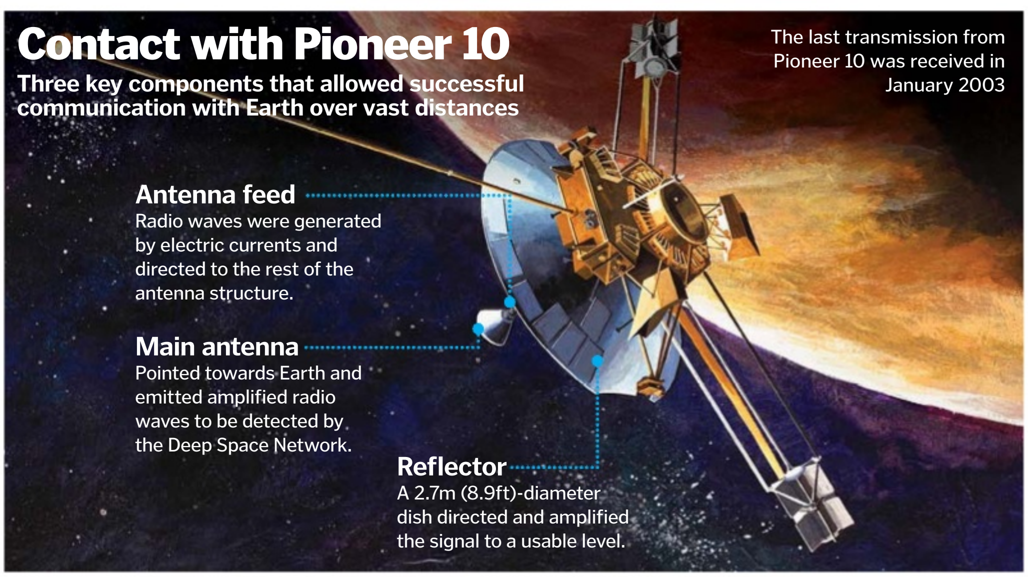


Space probe communication

How do scientists keep in touch with deep-space probes like Pioneer 10 and 11?

Communicating with something over 11.2 billion kilometres (7 billion miles) away is no mean feat, and requires a worldwide network of huge radio antennas. Stations in California, Spain and Australia form the Deep Space Network (DSN) – strategically spread out to ensure there will always be one antenna that can point at any space probe.

Likewise, space probes – like Pioneer 10 and 11 launched in the early-Seventies – need antennas to send pictures, weather data and heading information as radio waves. However power constraints mean that space probes can only send very weak signals, which get weaker the farther away they travel. Antennas on the ground have large dishes to capture the signal, yet greater amplification and noise reduction is needed to boost the signal to a readable level.



THE STATS
TRITON NUMBERS

DISCOVERED **1846** GRAVITY **0.779m/s²** DIAMETER **2,700km**
TEMPERATURE **38K** VOYAGER 2 VISIT **1989** ORBITAL PERIOD **5.87 days**

DID YOU KNOW? *Triton is so massive that if it were orbiting the Sun it would be considered a dwarf planet*

The backwards moon

Why is Neptune's biggest satellite, Triton, the only large moon in the Solar System to orbit its planet in the opposite direction?

Moons usually orbit in the same direction as their parent planet is spinning. Triton's unique orbit indicates it was not formed in the same region as Neptune. Instead, it is believed that it was captured from the Kuiper Belt, an icy ring at the edges of the Solar System that contains thousands of bodies, including Pluto.

For an object to be captured by a planet, it must lose energy, preventing it from escaping the gravitational field. This often occurs as a result of a collision; however, in the case of Triton, this is thought to be unlikely. Instead, Triton may have originally had a companion, like Pluto's moon Charon. As the pair came close to Neptune, their orbital energies were disrupted, being transferred to Triton's companion and expelling it from the system, leaving Triton caught in Neptune's orbit.

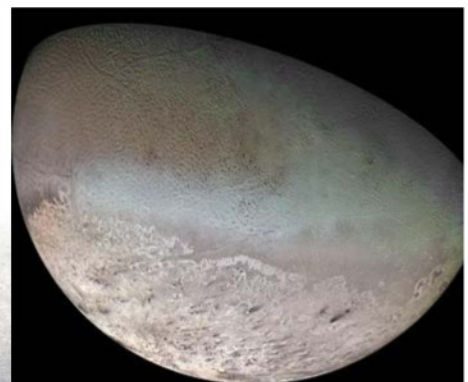
Triton is very similar in composition to Pluto; it has an icy surface primarily composed of frozen nitrogen, water and carbon dioxide. It is the seventh-largest moon in the Solar System, and is more massive than all of the smaller moons combined. Triton's surface shows evidence of having been melted, and icy volcanoes erupt from the crust, spewing gas and dust about eight kilometres (five miles) up.

Beneath the crust are a mantle of water and a core of rock and metal. It is possible that the heat generated by radioactive decay in the rocky core is able to keep the mantle molten, producing a liquid ocean below the moon's outer surface, similar to that on Europa.

Could you spend a day on Triton?

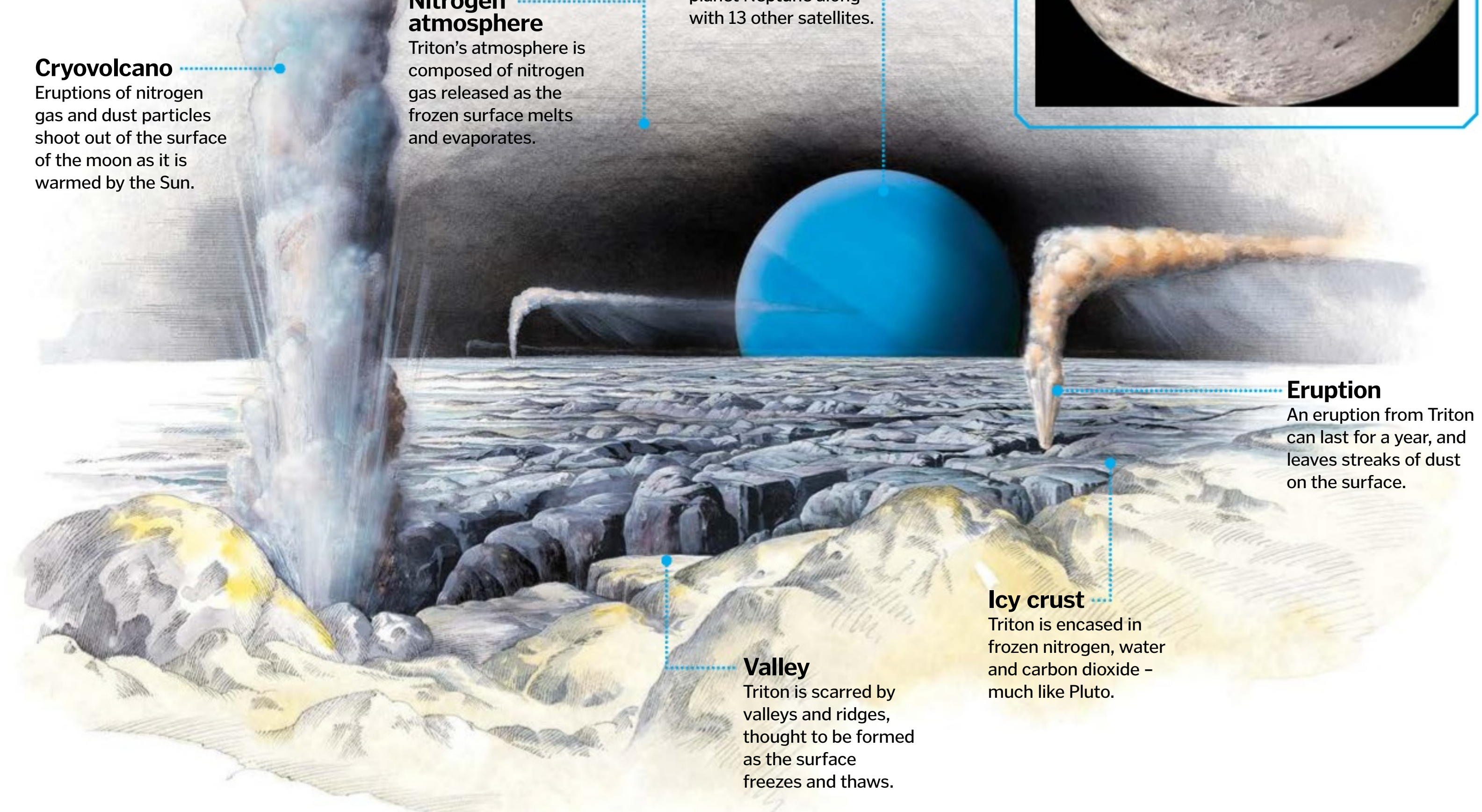
Despite the fact that Triton has a solid, icy surface, it would presently be impossible for a human to step onto the moon. Surface gravity is 12 times weaker than Earth's, and the average temperature is in the region of 38 degrees Kelvin (-235 degrees Celsius/-391 degrees Fahrenheit).

Equally problematic, Triton's atmosphere is very thin. It is composed of nitrogen gas, which is thought to have evaporated from the frozen nitrogen that covers the moon's surface. The atmosphere is so thin that atmospheric pressure is just one-70,000th what it is on Earth.



On the surface

If it were possible to visit Triton, this is what you might see…



Space Shuttle payload bay

How did this colossus deliver tons of supplies and technology into space?

NASA's Space Shuttle launch vehicles undertook over 130 missions during their lifetime, carrying hundreds of tons of technology into space. It had a refined system for delivering payloads to the intended target – be that simply low-Earth orbit or space stations such as the ISS – following a five-step mission profile.

After liftoff, solid-rocket booster separation, external fuel tank separation and orbital insertion, the in-orbit operations could begin. In the case of human payloads, these were delivered via an airlock located at the front of the shuttle, but when dealing with inanimate cargo, that required accessing the internal storage hold, known as the payload bay. Tech and supplies were accessed by the opening of the shuttle's payload bay doors, which swung open from the top of the spacecraft.

Once the bay doors were open, the resources within could be collected either by an EVA (extravehicular activity, or spacewalk), or using a robotic mechanical arm called Canadarm. This arm, 15.2 metres (50 feet) long and 38 centimetres (15 inches) in diameter, had six degrees of freedom and was specially built to manoeuvre cargo from the bay to their final position on the ISS. Once the payload for a mission had been successfully delivered, the Space Shuttle would then be prepared for re-entry and the return trip to Earth.

The STS-133 payload canister is lifted into the rotating service structure on Launch Pad 39A

The Canadarm being used to retrieve cargo from within the Space Shuttle

RECORD BREAKERS
EPIC DELIVERY

22,753kg

BIGGEST PAYLOAD TO SPACE

The heaviest non-commercial payload ever launched – the Chandra X-ray Observatory – weighed in at 22,753 kilograms (50,161 pounds) on Space Shuttle mission STS-93 in 1999.

DID YOU KNOW? *The last Space Shuttle launch – STS-135 – carried a payload of 3,630kg (8,000lb) of supplies*

Endeavour in flight clearly showing its spacious payload bay on STS-111

ISS medical treatment

How is illness prevented and treated when you're out in space?

The human body is adapted to account for the effects of gravity. Muscles and bones respond to impact and resistance, and the circulatory system compensates so bodily fluids don't accumulate in the legs and feet. When gravity is removed, the changes to the body are dramatic.

To compensate for the lack of gravity on the International Space Station (ISS), the crew members have access to an array of specially designed exercise equipment. Treadmills, cycling machines and resistance equipment enable them to limit muscle atrophy. This prevents long-term problems associated with muscle wasting in low gravity and allows the fitness of the crew to be monitored.

The lack of gravity also affects the circulatory system. Fluid redistributes to the upper body, causing the tissues in the head and face to swell. This leads to symptoms similar to the common cold and can place pressure on the optic nerve, distorting vision. Abnormal heart rhythms have been reported on several occasions, so the ISS is equipped with a defibrillator.


Astronaut Sunita Williams works out on the TVIS treadmill on board the ISS

In microgravity, microbes float about in the air, making infection a real danger. Recent studies also suggest that bacteria adapt to space in ways that aren't familiar on Earth, posing an extra threat. On top of that, the immune system itself finds it more difficult to function. In order to protect the crew, the air is filtered and monitored for contamination.

Unfortunately, space crews do get ill, and 75 per cent of astronauts require medication while in space; the ISS carries medication for a range of illnesses. If the medical problem cannot be treated on board, the station is close enough that crew members can be returned to Earth for more specialist treatment.

Common ISS injuries

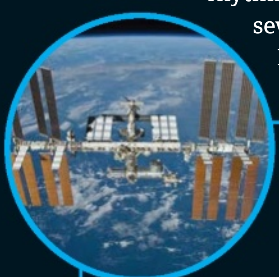
1 Space adaptation syndrome (SAS)
Like motion sickness, it is a reaction of the vestibular balance system to the disorientation of microgravity.

2 Nervous system and sensory organs
Body fluids gather in the head during weightlessness, increasing the pressure on the back of the eyeballs and pushing on the optic nerve. This can result in distortion of vision. Fluid accumulation also leads to nasal congestion, altering smell and taste.

3 Digestive system
Loss of appetite is common and astronauts often complain that food tastes unusual. This is thought to be the result of nasal congestion, much like getting a cold.

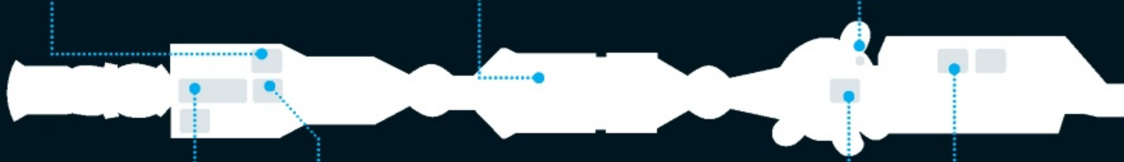
4 Skin
In microgravity the skin undergoes a process similar to ageing, becoming thinner and more fragile. Draughts from the ventilation systems can also dry out the skin, making it more liable to cuts and irritation.

5 General trauma
Living on a space station poses many hazards, including chemical and electrical burns, exposure to toxic substances and physical trauma. During the Space Shuttle Program (1981-98), 141 injuries were reported.



Keeping healthy on the ISS

A tour of the main facilities on the station that keep astronauts fighting fit



Blood/saliva testing
Saliva testing kits and an on-board blood-testing machine help the crew spot any infections early.

Radiation detector
A neutron particle detector allows crew members to monitor neutron radiation levels.

Resistive exercise device
Exercise equipment allows the crew to build up their muscle strength.

Treadmill
The Treadmill with Vibration Isolation Stablilisation (TVIS) had special tech to reduce vibrations that could disrupt nearby scientific experiments. It has recently been replaced with a new model.

Veloergometer
Another machine designed for exercise, this provides both aerobic and cardiovascular conditioning.

Air sampler
Microbes float in the air in zero gravity, so an air sampler is used to keep a close eye on contamination.

Defibrillator
The space station is equipped with emergency medical equipment to restart the heart in the event of a cardiac arrest.

THE STATS
SPACE RUBBISH

500,000 PIECES OF DEBRIS BIGGER THAN A MARBLE

40% JUNK MADE UP OF SATELLITE OR SPACECRAFT BREAK-UPS

30hrs NOTICE REQUIRED TO PLAN AND EXECUTE DEBRIS AVOIDANCE

56yrs OLDEST PIECE OF SPACE JUNK IN ORBIT

13,000 WEEKLY 'CLOSE CALLS'

8km/sec TOP SPEED OF MOST SPACE JUNK

DID YOU KNOW? *Being hit by a coin-sized piece of space debris is akin to being hit by a bowling ball at 483km/h (300mph)!*

Cleaning up space junk

How one aerospace company plans to rid Earth's orbit of dangerous debris

Space junk is a growing problem for satellites in Earth orbit. Currently there are more than 500,000 pieces of debris ranging in size from a marble to a car being tracked, each of which can be travelling at up to 28,000 kilometres (17,500 miles) per hour. These could have devastating effects if they came into contact with a satellite.

Thankfully, Earth orbit is huge, so the chances of a collision happening are quite slim, but not unprecedented. For example, in 2009 a Russian satellite collided with a US satellite, creating over 2,000 new pieces of space junk. As we add more objects into Earth orbit, collisions such as this will inevitably become more and more common.

To deal with space debris, a number of solutions have been suggested, including using lasers to push junk back into the atmosphere where it will burn up. However, a company called Swiss Space Systems (S3) has suggested a more innovative and affordable way of dealing with the larger chunks of debris.

They plan to send up a satellite known as CleanSpace One into orbit on a demonstration mission in 2018. The 30-kilogram (66-pound) satellite will launch on a small spaceplane, also in development by S3. Once it reaches orbit, the satellite will use a four-pronged robotic arm to grab a piece of debris and then, using its onboard thrusters, CleanSpace One will bring it down to a lower altitude and release it to burn up in our atmosphere.

This first mission will cost some £9.7 million ($16 million) and, if successful, the same technology could well be used by satellite operators around the globe in the future to help clean up regions of Earth's orbit.

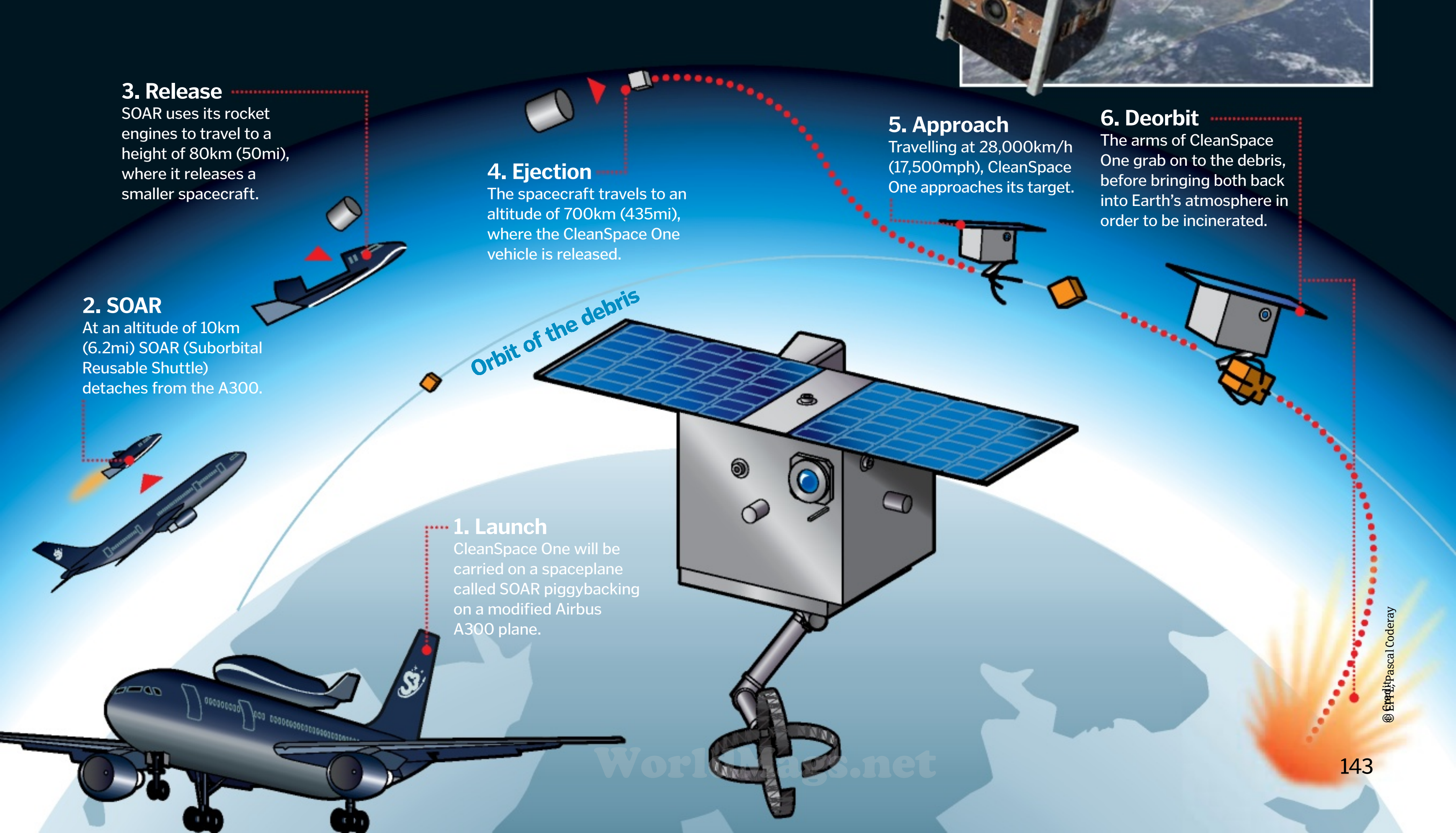
Real-life Gravity

If you've seen the 2013 movie *Gravity*, you might already be aware of the dangers of space junk. In the film, a Russian satellite is blown up by a missile, starting a chain reaction as the debris from the satellite hits other satellites, creating even more debris in the process.

Although the effects were exaggerated in the movie, this is an entirely possible scenario known as the Kessler syndrome. NASA scientist Donald Kessler in 1978 proposed that as the number of objects in orbit increases, the chances of a chain reaction of collisions becomes an ever-likelier threat, hence the urgency to clean up.

CleanSpace One's mission

A step-by-step look at how this spacecraft will remove debris from orbit



HYPER GIANT STARS

Born with the mass of dozens of Suns, hypergiants are enormous stars that live fast, burn brilliantly and die young

Imagine a star so big that if it replaced the Sun, it could engulf the Solar System as far out as the orbit of Saturn. Or one that produces as much energy in one second as our Sun does in a hundred days. These might sound unreal, but both stars exist – they're two examples of hypergiants, the most extreme stars in the universe.

Hypergiants are stars that burn with the brilliance of millions of Suns. Though born from the same clouds of interstellar hydrogen gas as normal stars, their enormous mass (tens or even hundreds of times that of the Sun) creates tremendous internal pressures that heat their interiors and accelerate the rate of the nuclear fusion reactions in their core.

So while a star like the Sun can sustain itself on a relatively small amount of hydrogen 'fuel' for a period of up to 10 billion years, a hypergiant with perhaps a hundred times the available fuel will squander it in a million years or less, blazing away as a brilliant but comparatively short-lived cosmic beacon.

Like all stars, the physical characteristics of hypergiants depend on the delicate balance between the outward 'radiation pressure' from energy escaping their cores, and the inward pull of gravity from their enormous mass. As a result, hypergiants usually change their appearance through their lifetimes. Astronomers on Earth detect these differences through measuring the range of different luminosities and colours from star to star (even though hypergiants live and die quickly on a cosmic timescale, they certainly don't change quickly enough for us to see them evolve significantly over the course of a human lifetime). By plotting these properties for various stars on a Hertzsprung-Russell diagram, they can work out the relationships between them, and the likely paths by which one type of star changes into another.

Hypergiants, it's clear, spend most of their short lives as brilliant blue stars – with temperatures of perhaps 50,000 degrees Celsius (90,000 degrees Fahrenheit), compared to the Sun's 5,500 degrees Celsius (9,930 degrees Fahrenheit). But many later evolve towards the

5 TOP FACTS
HYPERGIANTS

Big babies
1 As hypergiants burn through all of their fuel so fast, most of them can still be found relatively close to their birthplace, embedded in starbirth nebulas.

Rewriting the rulebook
2 Hypergiants are so rare that they weren't included in the standard system of luminosity classes – astronomers had to add a 'Class 0' brighter than the brightest 'Class I' supergiants.

Black hole progenitors
3 Because their cores alone may have the mass of five or more Suns, hypergiants are the most likely stars to leave black holes in their wake when they turn supernova.

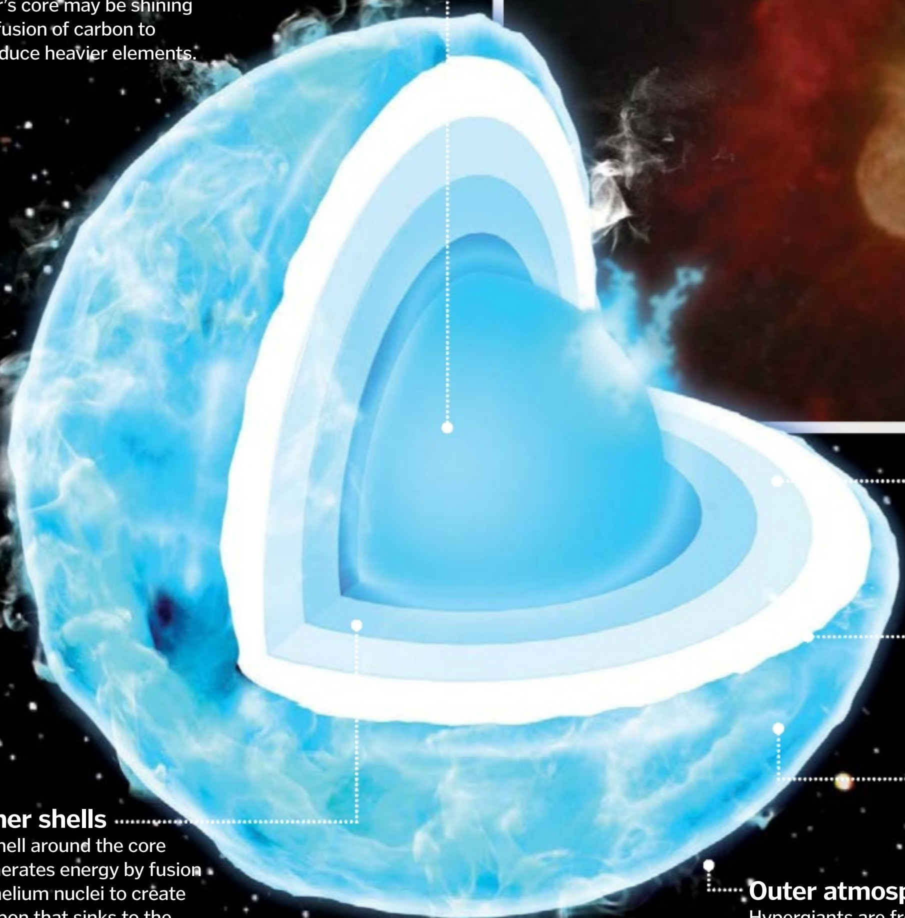
Classification confusion
4 Because of the confusion surrounding the various different types of hypergiant, there are some astronomers who prefer to avoid using the word in the first place.

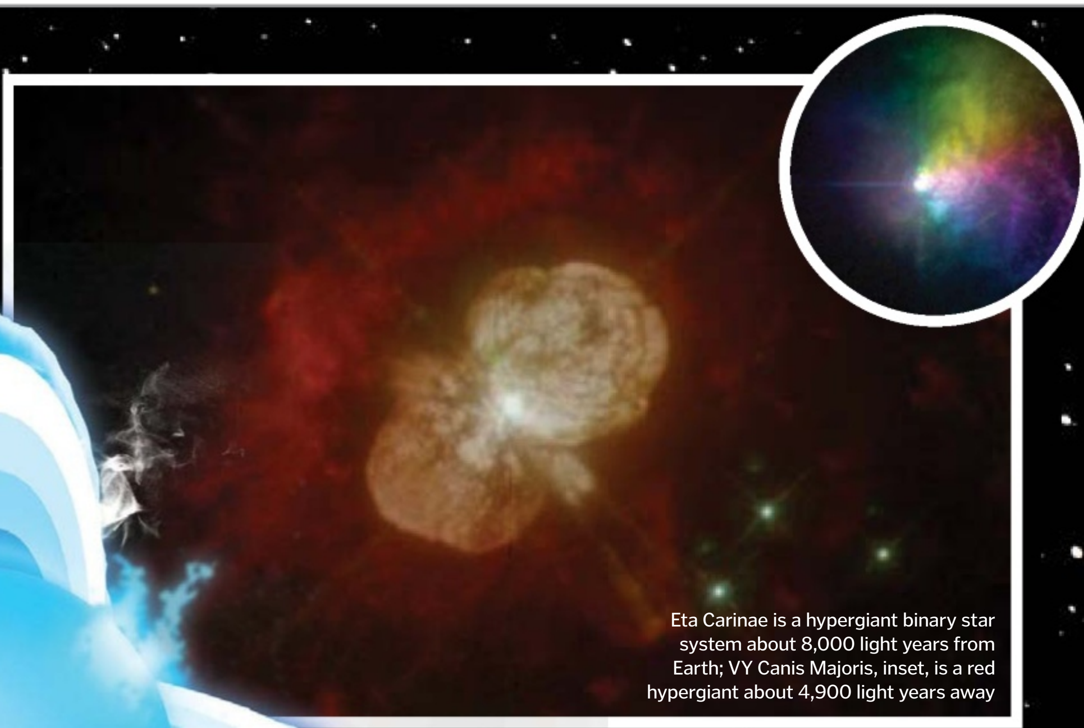
King of the hypergiants
5 There are several candidates for the largest known star, but some estimates suggest the red hypergiant Westerlund 1-26 has a monster diameter equivalent to 2,500 Suns.

DID YOU KNOW? In 2012 astronomers found 'light echoes' – light from Eta Carinae's 1843 outburst reflected off distant nebulas

Inside a hypergiant

What are the main layers that make up a super-bright blue hypergiant?




Eta Carinae is a hypergiant binary star system about 8,000 light years from Earth; VY Canis Majoris, inset, is a red hypergiant about 4,900 light years away

cooler red end of the colour range, with surface temperatures of perhaps just 3,000 degrees Celsius (5,430 degrees Fahrenheit).

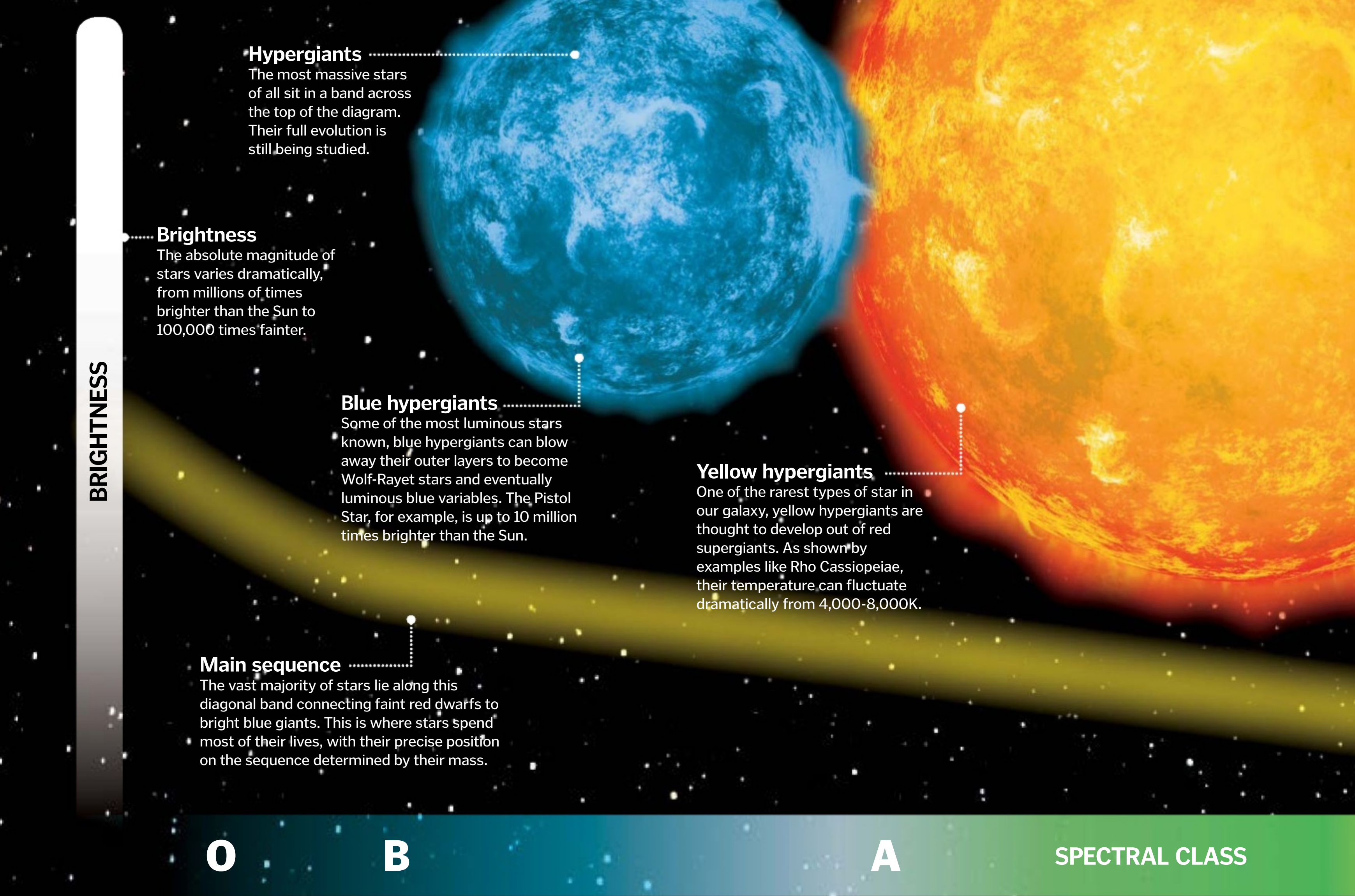
Because a star's surface temperature depends on the amount of energy escaping through each square metre of its surface, there's a direct link between a star's luminosity, colour and size; ie a cool, red star of a certain brightness must be significantly larger than a hot, blue star of the same brightness. The term 'hypergiant' describes a star's luminosity rather than its physical size, so blue hypergiants can actually be smaller than the standard red giants formed by normal Sun-like stars towards the end of their lives, despite being many times brighter. Rare red hypergiants, however, are the biggest stars in the universe. Perhaps the most famous is Mu Cephei in the northern constellation of Cepheus. Known as the Garnet Star on account of its deep red colour, it is large enough to engulf over a billion Suns within it.

The extremes which hypergiants display stem ultimately from their enormous mass. Like all stars, they spend their 'main sequence' life shining through the fusion of hydrogen (the lightest element) into helium (the next lightest) in their cores. But while normal stars fuse hydrogen through relatively long-winded, inefficient chain reactions that rely on random collisions of atomic nuclei, the enormous pressures in a hypergiant's core allow it to use a much faster and more efficient set of reactions called the carbon-nitrogen-oxygen (CNO) cycle.

The rate of reactions in the hypergiant's core generates an enormous outward radiation pressure that swells the star's outer layers. During the main-sequence phase, the inward pull of gravity stabilises the star at few tens of solar diameters – enormous but still compact enough for its surface to remain searing hot and blue-white in colour. Once the core's supply of hydrogen is exhausted, it starts to burn fuel from surrounding shells in an attempt to keep shining. Perhaps surprisingly, this increases the hypergiant's luminosity still further, and the additional pressure of escaping radiation causes the star's outer ▶

How do hypergiants size up?

The Hertzsprung-Russell diagram helps to visualise the main properties of stars



surface to swell and cool, transforming it into a yellow, orange or red hypergiant depending on exactly where the balance is reached.

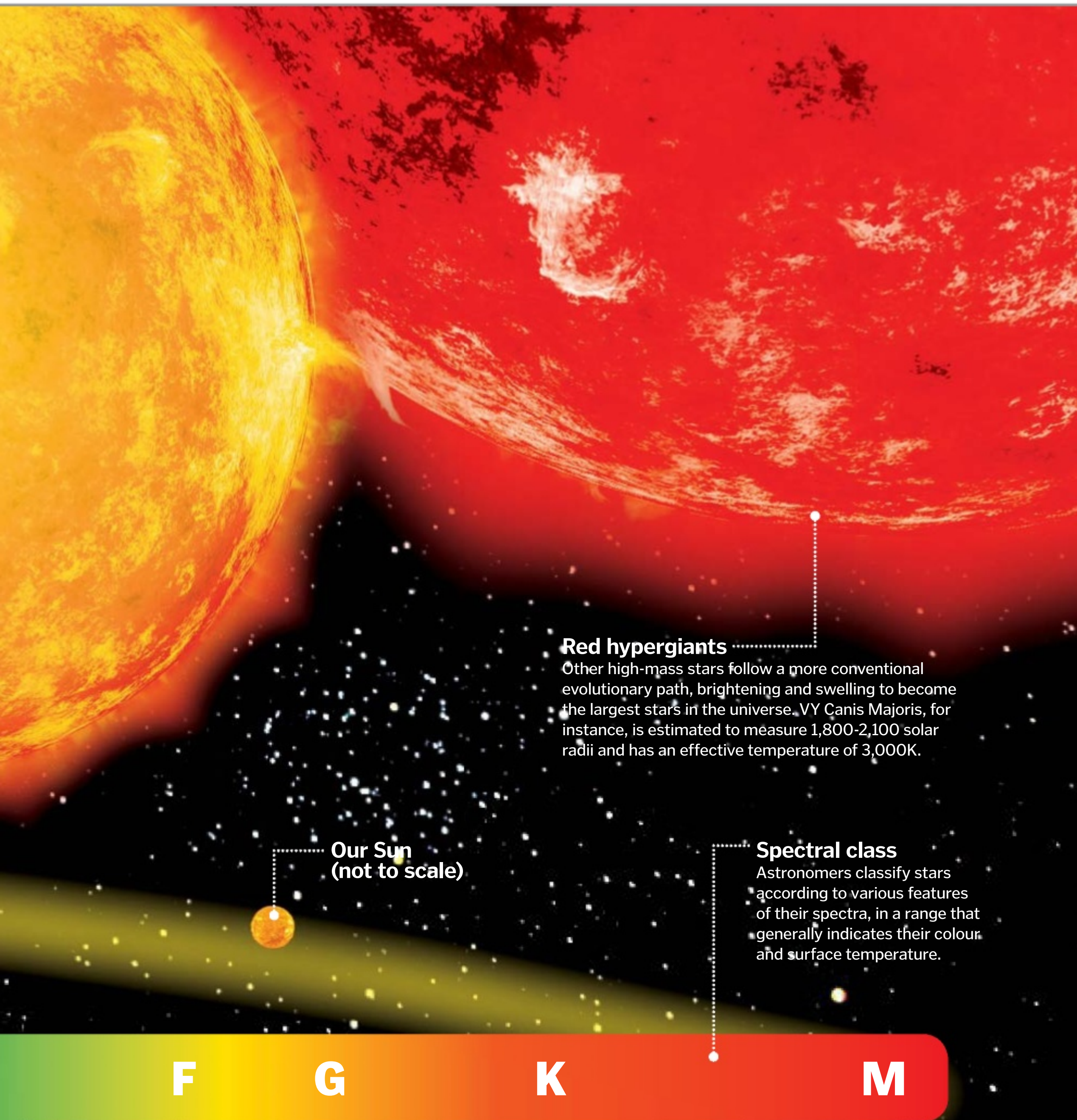
However, many hypergiants never quite reach this stage, staying hot and relatively compact throughout their short lifetime. They do this by blowing away their outer layers on a stellar wind similar to, but much more powerful than, our Sun's own solar wind. So-called 'Wolf-Rayet' stars can shed perhaps a solar mass of material every 100,000 years, exposing their even hotter interior layers.

Towards the end of its life, such a star may become unstable, evolving into a luminous blue variable – or LBV – star which is prone to sudden outbursts. LBVs are often surrounded by clouds of gas ejected from previous eruptions – perhaps the most famous example is Eta Carinae, a double-star system containing a blue LBV of around 100 solar masses, orbited by a blue supergiant of about 30 solar masses. In the early-1840s, a major outburst saw Eta Carinae brighten from its usual position on the borders of naked-eye visibility, to become the second-brightest star in the sky. Today, the system is still surrounded by a cloud of gas and dust ejected from that explosion.

There are many aspects of hypergiant evolution that astronomers still don't fully understand, but one thing that is certain is their fate. Lower-mass stars like our Sun have relatively sedate deaths, in which a short-lived 'second wind' of helium fusion is followed by instability that hurls off the star's outer layers to form a planetary nebula with the burnt-out stellar core: a white dwarf at its centre.

But supergiant and hypergiant stars can keep burning elements to produce heavier ones right up until they reach iron – the first element whose fusion absorbs more energy than it releases. At this point, the star's central power supply is abruptly cut off, and its outer layers collapse inwards before rebounding off the core. The resulting shockwave ignites a tremendous burst of nuclear fusion in the star's upper layers, producing a supernova explosion that dwarfs even the brightest hypergiant – and may even briefly outshine an entire galaxy.

DID YOU KNOW? *R136a1 lies in a tight knot of stars once thought to be a single star with over 1,000 times the mass of the Sun*



5 famous hypergiants

1 Garnet Star
This naked-eye star in Cepheus is one of the reddest stars in the sky and one of the largest stars in our galaxy.

2 VY Canis Majoris
This red hypergiant in the constellation of Canis Major may be the largest known star, with some estimates putting its diameter larger than Saturn's orbit around the Sun.

3 S Doradus
One of the most luminous stars, this blue variable in the Large Magellanic Cloud (a satellite galaxy of the Milky Way) is stable for long periods between sporadic outbursts.

4 Pistol Star
Hidden behind dense star clouds near the centre of the Milky Way, this blue hypergiant is surrounded by a nebula of material thrown off during outbursts a few thousand years previously.

5 Eta Carinae
This binary star system, embedded in the twin-lobed Homunculus Nebula, may possibly erupt soon into a spectacular supernova.

and may even briefly outshine an entire galaxy. In some cases, the shockwave from the explosion can ignite clouds of material ejected from the star thousands of years before, creating an exceptionally bright supernova explosion known as a hypernova.

Hypergiants are the live-fast, die-young rock stars of the cosmos, but recently astronomers have discovered what may be the biggest, baddest star of them all. Catalogued as R136a1, this is a monster 8.7 million times more luminous than the Sun, and with roughly 256 times its mass. R136a1 lies at the heart of the Tarantula Nebula, an enormous star-forming region in the Large Magellanic Cloud, a satellite galaxy of the Milky Way. Discovered in 2010, this distant star tests the limits of how big a star can get without blowing itself apart. It is also undergoing mass loss at a tremendous rate and is thought to have shed more than 50 solar masses of material during its million-year lifespan. When this cosmic giant ends its life, it could detonate in a rare 'pair-instability' supernova, outshining normal supernovas by a factor of 50 and becoming the brightest star in Earth's skies for several months.

When this will happen is anybody's guess – Eta Carinae is most likely to go supernova in the near future, but pair-instability supernovas do not give the same kind of advance warnings as their fainter cousins, so in theory such an outburst might well happen at any time…

Monster problems

The rarity of hypergiants poses problems for astronomers trying to join the dots between the handful of examples they have to study – for instance, they're still not sure of the link between Wolf-Rayet stars and LBVs. They also believe that an entire class of 'yellow hypergiants' has significantly lower masses than their hypergiant cousins and are, in fact, more closely related to red supergiants.

Even the existence of the 256-solar mass monster R136a1 poses a problem, since up until its discovery, astronomers assumed 150 solar masses was the biggest a star could get without tearing itself apart. Still, by searching for answers to questions about these stars, astronomers are building on knowledge of the processes that affect smaller stars like our Sun.

Launch pad at sea

Floating in the middle of the Pacific Ocean is a massive mobile platform for launching satellites, but how does it work?

The Odyssey Sea Launch platform is a commercial satellite launch complex which is situated near the equator in the Pacific Ocean. The system has three segments: the Rocket segment, the Marine segment and the Home Port segment.

On land, the Home Port provides a facility for preparing and fuelling the satellite payload (see opposite boxout for more detail). It also serves as a base to provide support to the marine components of the complex.

At sea, the complex has two vessels. The first is a ship known as the Sea Launch Commander – a mobile rocket assembly unit where satellites are loaded onto the carrier rocket and transported to the launch platform.

The platform itself is a converted North Sea drilling rig. It is self-propelled and semi-submersible, allowing the position, angle and stability of the platform to be carefully calibrated for each individual launch.

Satellites are carried off Earth using a Zenit-3SL rocket, under the guidance of an automated ground control system. The platform is evacuated for the launch, which can either be controlled using the Sea Launch Commander ship – which retreats to a safe distance of five kilometres (three miles) – or from the Home Port in California, USA.

The launch platform is anchored at the equator, where the rotational speed of the Earth is at its greatest. This provides an extra boost to the launch vehicle, and enables rockets to be sent to geostationary orbit without having to correct for launch latitude. In contrast, the same rocket taking off from Cape Canaveral at 28.5 degrees north would have to weigh significantly less to reach geostationary orbit.

The remote ocean location of the Odyssey platform also minimises any interference from overhead air traffic, and provides additional safety over facilities that are nearer to populated areas on land.

On board the Odyssey platform

How does this ocean-going launch pad stay steady when a rocket takes off?

Zenit-3SL up close

Satellites are launched from the platform on single-use Zenit-3SL carrier rockets. The custom-designed rockets are powered by a liquid oxygen/kerosene engine and are designed to accurately carry the satellite payload to geosynchronous orbit around the Earth.

Once in the launch position and fully fuelled, a three-day automated countdown is started, and all personnel are evacuated from the platform. To date, 35 rockets have launched; three of these failed, and a further rocket placed its payload in the wrong orbit.

In 2007, a foreign object in the engine of one rocket at launch led to the entire platform being engulfed in a huge fireball. The automated countdown ensured that there were no casualties, but the failure caused extensive damage to the Odyssey that took a clean-up operation lasting seven months.

1. OLD

Guiana Space Centre
This European-owned spaceport was completed in 1968 near to the equator in French Guiana, South America.

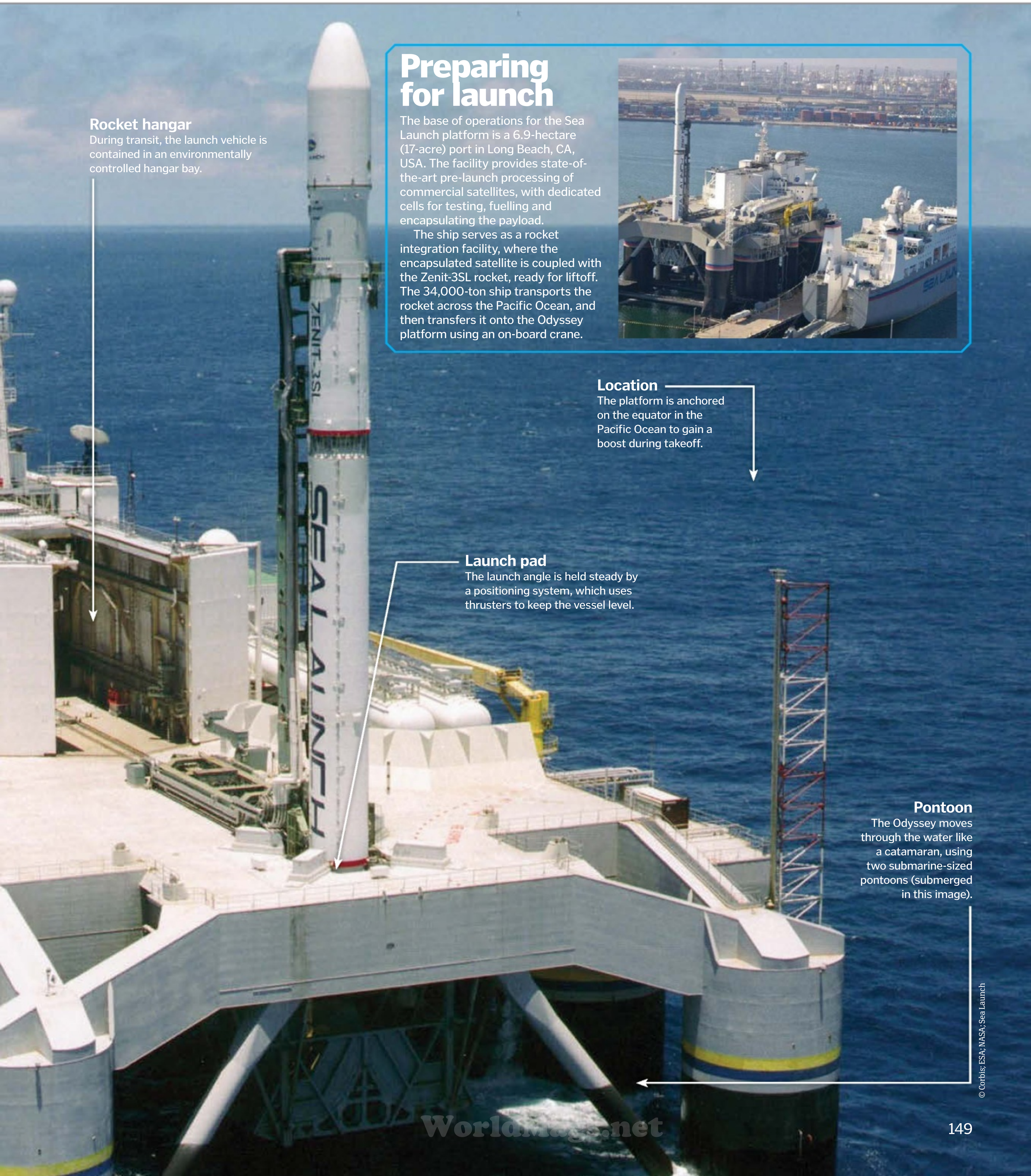
2. OLDER

Cape Canaveral
Originally a missile test centre, Cape Canaveral, FL, was the launch location for the first series of the Apollo missions.

3. OLDEST

Baikonur Cosmodrome
Built back in the Fifties, Baikonur Cosmodrome in Kazakhstan is both the oldest and largest launch facility in the world.

DID YOU KNOW? *The Land Launch platform in Russia uses the same Zenit technology to take smaller payloads into orbit*



Preparing for launch

The base of operations for the Sea Launch platform is a 6.9-hectare (17-acre) port in Long Beach, CA, USA. The facility provides state-of-the-art pre-launch processing of commercial satellites, with dedicated cells for testing, fuelling and encapsulating the payload.

The ship serves as a rocket integration facility, where the encapsulated satellite is coupled with the Zenit-3SL rocket, ready for liftoff. The 34,000-ton ship transports the rocket across the Pacific Ocean, and then transfers it onto the Odyssey platform using an on-board crane.

Rocket hangar
During transit, the launch vehicle is contained in an environmentally controlled hangar bay.

Location
The platform is anchored on the equator in the Pacific Ocean to gain a boost during takeoff.

Launch pad
The launch angle is held steady by a positioning system, which uses thrusters to keep the vessel level.

Pontoon
The Odyssey moves through the water like a catamaran, using two submarine-sized pontoons (submerged in this image).

Nanosatellites explained

How are these pint-sized space explorers levelling the astronomy playing field?

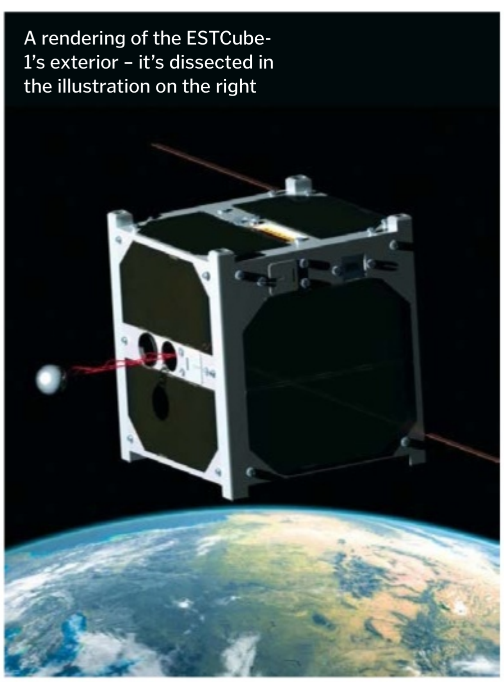
Much the same as cars, satellites come in all shapes and sizes, so in that regard the CubeSat would be the Smart Car of the satellite world.

The standard model is a cube of just ten centimetres (3.9 inches) which weighs no more than a 1.3 kilograms (2.9 pounds), although this design is increasingly being modified.

There are many advantages to going small when it comes to building a satellite. Costs are dramatically reduced and the turnaround time from inception to launch can be a matter of months. It also means that universities, governments with a low budget and other private enterprises can operate them from ground stations anywhere in the world.

Virtually all CubeSats are transported into space on Poly-PicoSatellite Orbital Deployers, or P-PODs, which can hold up to three cubes per trip. The P-POD, developed at California Polytechnic State University, has been designed to be mounted to most rockets as a secondary payload, again helping to reduce launch costs.

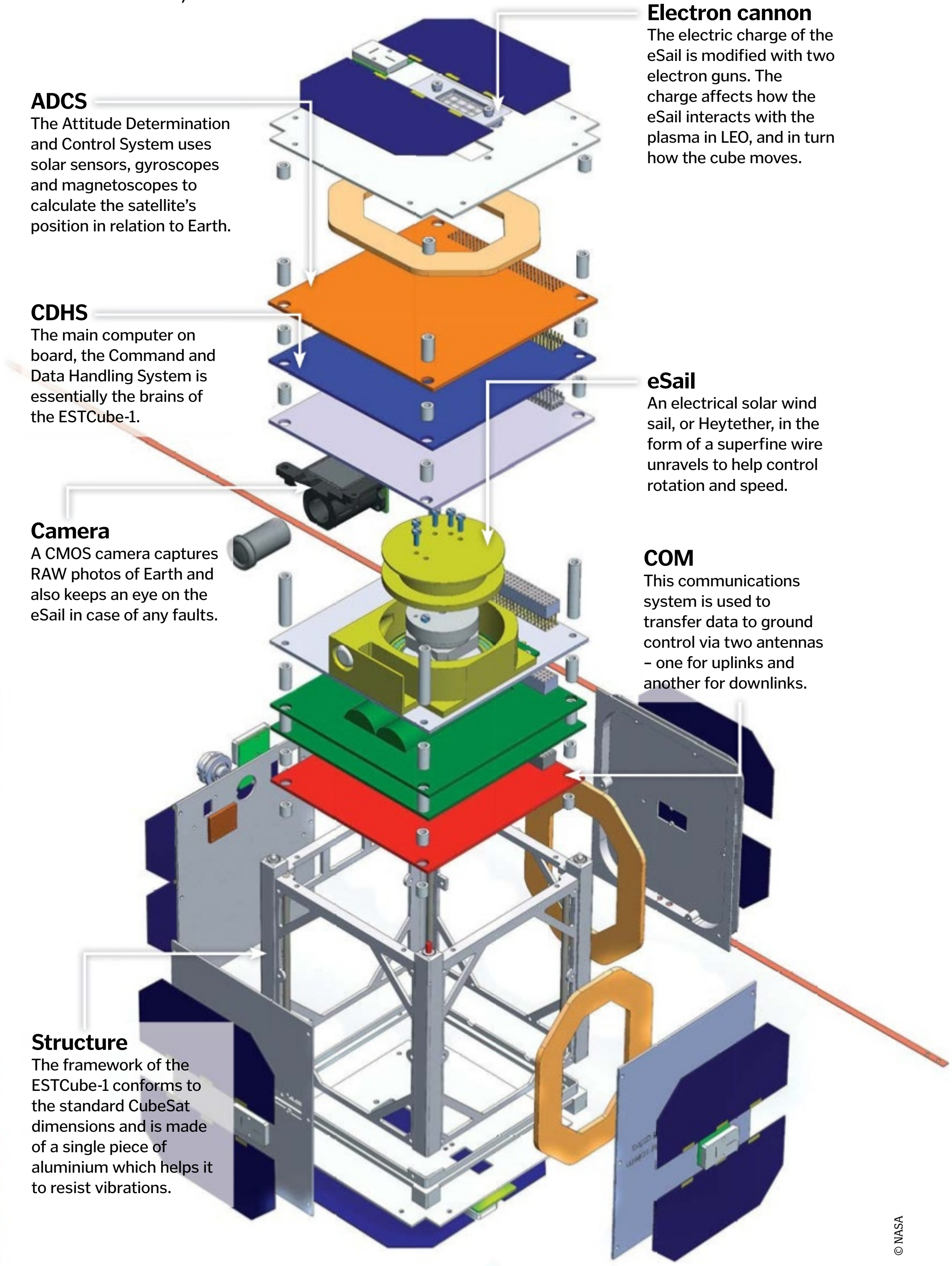
As well as offering invaluable hands-on experience for tomorrow's space engineers, CubeSats are also the perfect testbed for new scientific instruments before trialling them on bigger, more expensive satellites.



A rendering of the ESTCube-1's exterior – it's dissected in the illustration on the right

Inside the ESTCube-1

Marvel at how much technology is packed into Estonia's first-ever satellite, launched in 2013



STRANGE BUT TRUE

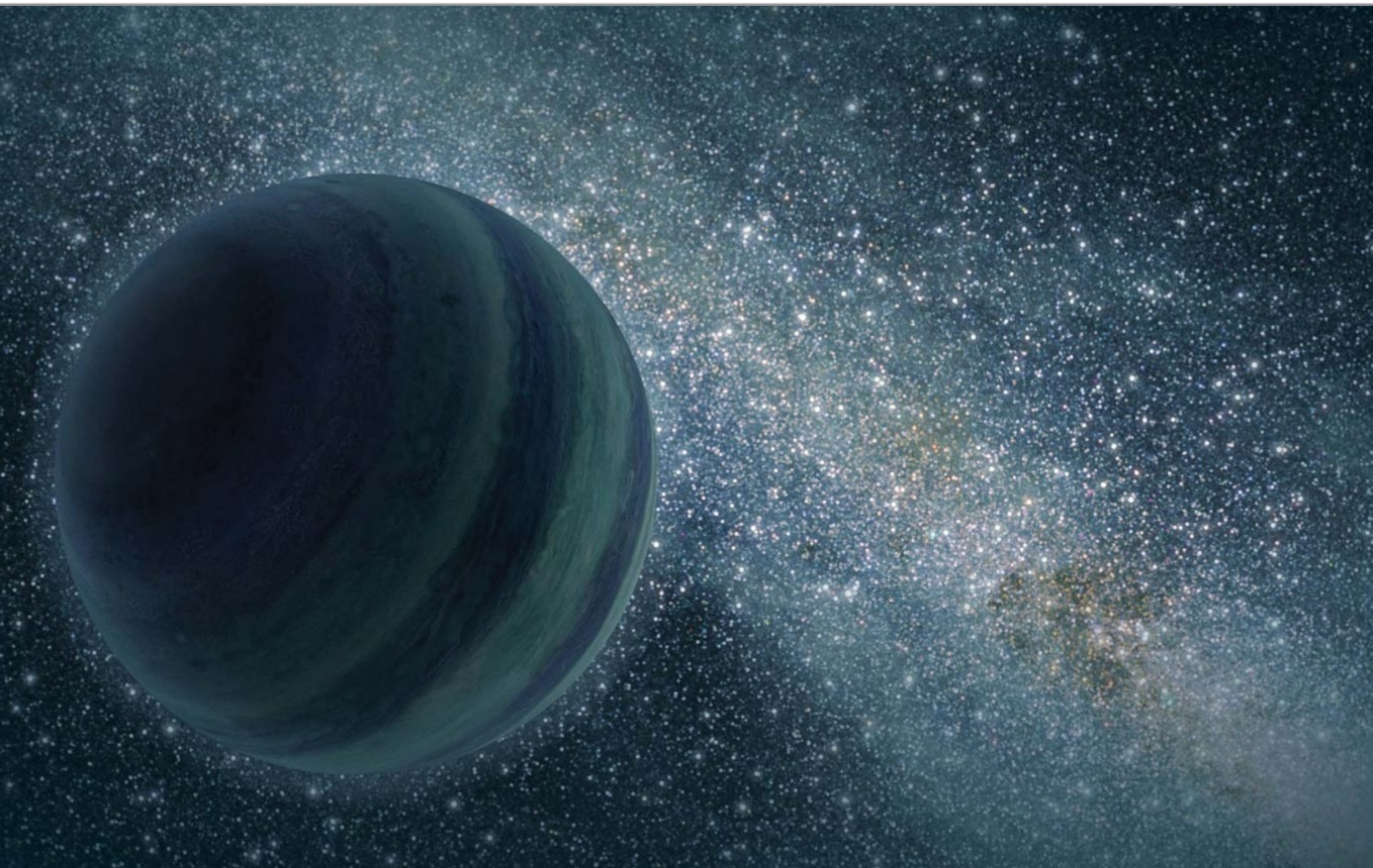
ROGUE DISCOVERY

What was recently found orbiting a rogue planet?

A A moon **B** A black hole **C** A spacecraft

Answer:
The answer is a moon – or exomoon – found outside the Solar System. This satellite is part of the MOA-2011-BLG-262 exoplanet-exomoon system detected in December 2013; its host is estimated to have four times the mass of Jupiter.

DID YOU KNOW? *Estimates suggest there might be twice as many rogue planets as 'normal' planets in the Milky Way*



Rogue planets

Meet the free-floating planets that like to fly solo

Up until the late-20th century the only planets we knew of were those found in our own Solar System. Now, thanks to missions such as NASA's Kepler spacecraft, we know of hundreds more that exist in other planetary systems across the cosmos. But in the last decade, we've started to find some planets drifting freely through space, and estimates suggest that there could be millions more in our Milky Way alone.

First theorised in 1998, several rogue planets have been found since 2012. The predominant theory as to how these planets come to be 'going solo' surmises that these bodies were knocked out of a planetary system by some major event – perhaps a passing star or a nearby unbalanced young system.

Another emerging theory, however, suggests that some rogue planets could be born without a parent star in clouds of dust and gas. These planets would then form in a similar way to stars, except they would be too small to ignite fusion at their cores, so end up remaining as planets rather than developing into stars. Studies indicate free-floating planets may be able to retain some heat, although they are most likely to be cold and barren worlds.

Detecting rogue planets is a tricky business. Our usual methods of finding exoplanets, by noticing their effect on their parent star, is impossible here. Instead, scientists either try to directly image them or notice the gravitational microlensing effect a rogue planet has as it passes in front of a background star.

First sighting

One of the closest rogue planets to our Solar System, and the first to ever be confirmed in 2012, was CFBDSIR2149-0403. Found about 100 light years from us, its proximity has allowed it to be studied in detail. Observed by the European Southern Observatory's Very Large Telescope (VLT) in Chile and the Canada-France-Hawaii Telescope (CFHT) on Hawaii, astronomers have deduced it is between 50 and 120 million years old. It is thought to have a surface temperature of 400 degrees Celsius (750 degrees Fahrenheit) and a mass four to seven times that of Jupiter. Interestingly some observations have also detected water and methane in its atmosphere.

CFBDSIR2149-0403 is the faint dark blue dot in the centre of this shot

© NASA; ESO

Inside a rocket building factory

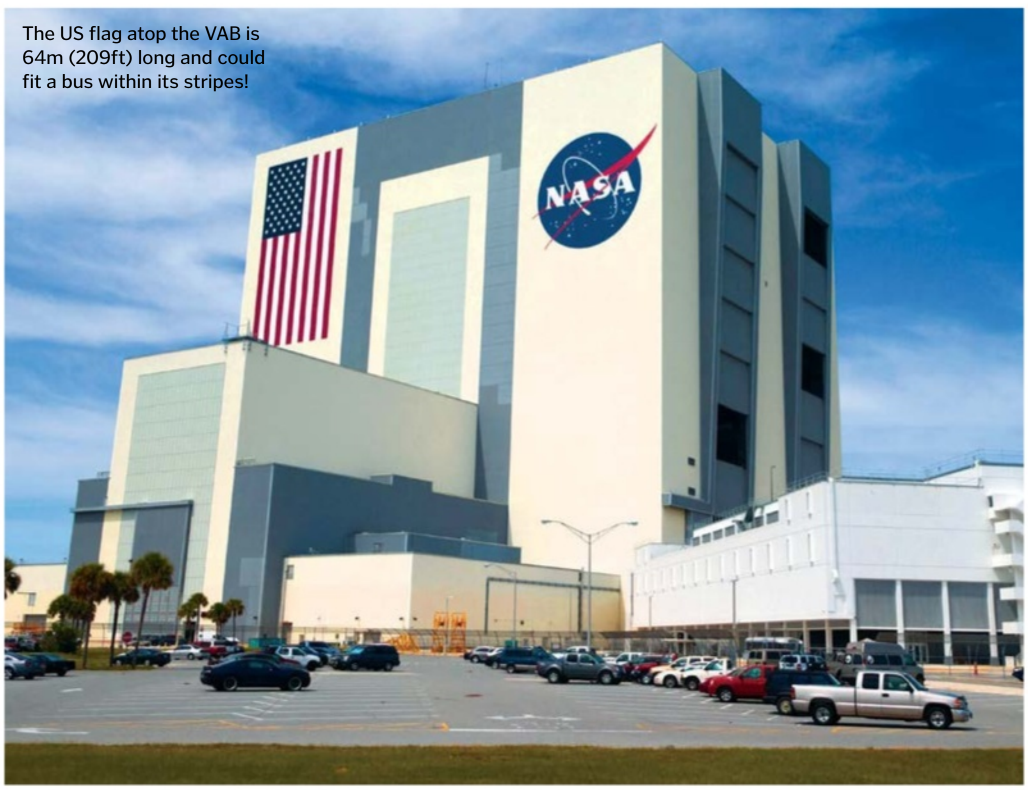
Take a tour around NASA's Vehicle Assembly Building and find out what role it played in the Space Race

Located at the Kennedy Space Center in Florida, the cavernous Vehicle Assembly Building (VAB) helped to build spacecraft used in 135 missions from 1968 until 2011, and is set to do so once again.

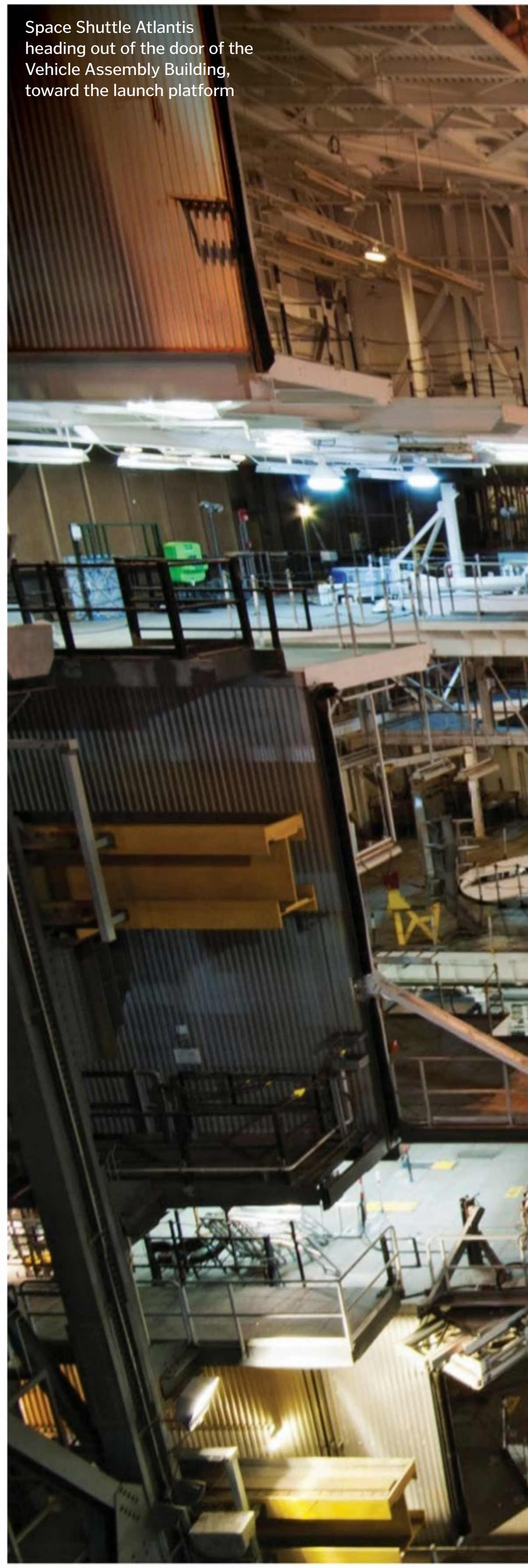
The lower structure of the building was long used for storing rocket components. A transfer aisle connects the sections and leads to a platform which takes vehicles to the launch pad. Overhead cranes inside can hold up to 325 tons and move massive objects with extreme precision. The first rocket assembled in the VAB was the Saturn V, which is still the largest of its kind ever made. Crawler transporters, which are some of the biggest machines ever to move on land, had to be specially engineered to carry the rockets to the launch pad.

Vehicle construction ceased in the VAB after the Space Shuttle was retired in 2011. It was opened to the public for tours around the spaceport to see all the NASA facilities. However, renewed production for future missions has closed the building to the public in February 2014 and it re-opened to begin constructing space vehicles again.

Originally designed to assemble the Apollo and Saturn vehicles, the VAB will now be used to support 21st-century operations. As a result, work is underway to remove old Shuttle-era platforms and introduce ones suited to the new Space Launch System (SLS). The renovation will see a removal of 240 kilometres (150 miles) of Apollo-period cabling in order to update obsolete systems. The first SLS is due for launch in 2017 and will be even larger than the legendary Saturn V. It will be an unmanned Orion crew capsule, which will undertake missions to the Moon and even Mars.



The US flag atop the VAB is 64m (209ft) long and could fit a bus within its stripes!


Space Shuttle Atlantis heading out of the door of the Vehicle Assembly Building, toward the launch platform

160m

BIGGEST SINGLE-STOREY STRUCTURE

At 160m (525ft) tall, the VAB is the largest single-storey structure on Earth. Also the fourth-largest building by volume at 3.7mn m^3 (129.4mn ft^3). As well as all that it can also boast the world's largest doors at 139m (456ft) high.

DID YOU KNOW? *The first launch from the Kennedy Space Center was a modified German V2 rocket in 1950*

5 more NASA facilities

1 Goddard Space Flight Center

NASA's first spaceflight complex was named after Robert H Goddard who built the first liquid-fuelled rocket. The area covers 5km² (2mi²) and comprises 84 buildings.

2 Jet Propulsion Laboratory

Explorer 1 was built here in 1958. More recently, unmanned craft like Voyager, Galileo and Viking were made here. JPL controls all robotic planetary spacecraft.

3 Armstrong Flight Research Center

Previously known as the Dryden Research Center until this year, this is NASA's HQ for atmospheric flight research and operations. It is used for experimental flight tests and contains many of NASA's top research facilities.

4 John H Glenn Research Center

Containing the zero gravity research facility, the centre has facilities for cryogenics, energy storage and advanced materials and played a critical role in the Apollo missions.

5 Lyndon B Johnson Space Center

The home base for astronauts, previously known as the Manned Spacecraft Center. At 6.6km² (2.5mi²), it has over 140 buildings and specialises in manned missions.

The ISS Cupola explored

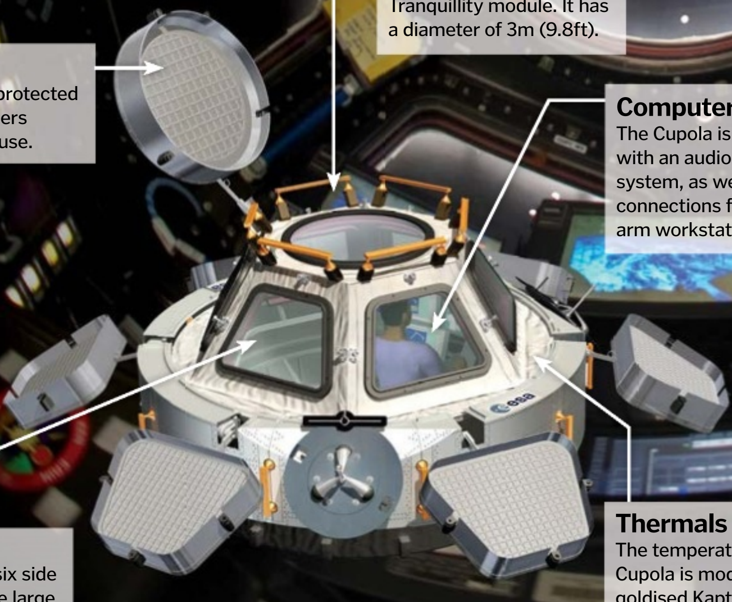
Find out what goes on in the ISS's dedicated space observatory now

The Cupola – named after the Italian word for dome – is an observatory module built by the European Space Agency (ESA) and attached to the International Space Station (ISS). It is fixed to the ISS's Node 3 Tranquillity module and used by astronauts on the station to conduct observations and also aid maintenance operations on the station itself – the latter typified by use of the robotic Canadarm 2 for manipulating payloads.

The Cupola was originally begun by NASA, which entered a partnership with American aerospace company Boeing during the mid-Nineties. Unfortunately, due to funding cuts the project was then shelved until 1998 when the ESA stepped up and took over its development. The Cupola was launched 12 years later and since then has been a crucial tool in day-to-day operations on the space station, with many of the photos and videos we see on Earth of celestial objects taken within it.

Inside the Cupola

Check out the core components of this observatory module now



Shutters
Each window is protected with shield shutters when it is not in use.

Module
The Cupola module is attached to the Node 3 Tranquillity module. It has a diameter of 3m (9.8ft).

Computers
The Cupola is outfitted with an audio, video system, as well as the connections for a robotic arm workstation.

Windows
The Cupola has six side windows and one large 80cm (31in)-diameter window on the top.

Thermals
The temperature in the Cupola is moderated by a goldised Kapton multilayer insulation blanket.

KEY DATES
SPACE FASHION

1961 Yuri Gagarin wore the first-ever spacesuit, the SK-1, during his pioneering trip to space.

1965 The innovative design of NASA's Gemini spacesuit used six layers of nylon for extra protection.

1969 All 12 astronauts who walked on the Moon used the same Apollo A7L suit design.

1977 First used in 1977, Russia's Orlan spacesuit continues to be used by cosmonauts on the ISS today.

1983 NASA's modern Extravehicular Mobility Unit (EMU) spacesuit has been in use since 1983.

DID YOU KNOW? *In late-2009 a mission was proposed to land a Robonaut 2 unit on the surface of the Moon*

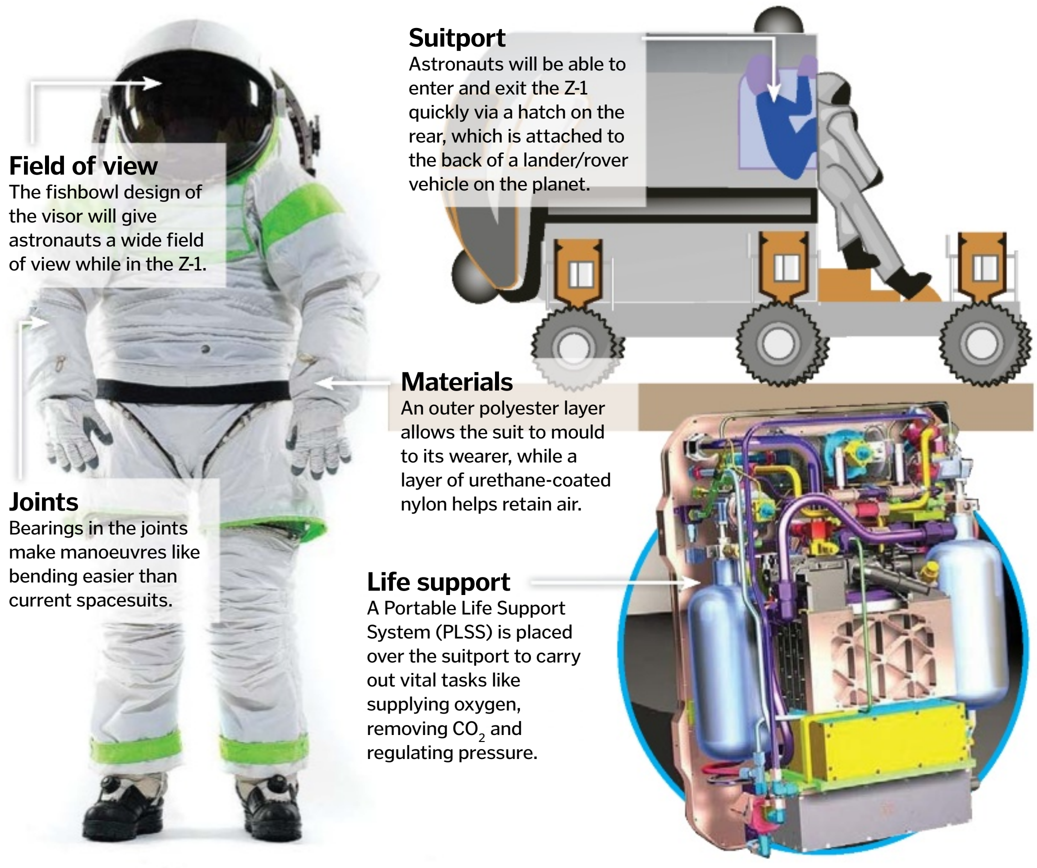
Inside next-gen spacesuits

What will we be wearing when we one day venture onto the surface of Mars?

When humanity ultimately makes it to the Red Planet or an asteroid, our current spacesuits will not be up to the job. They are too rigid, too bulky and lack the protection required to operate on these distant bodies. With that in mind, NASA has been hard at work on a new spacesuit, known as the Z-1, that has a number of innovations to make such ambitious spacewalks possible.

The major breakthrough in terms of technology is a suitport on the back. Already employed by the Russians on their spacesuits, this enables the wearer to climb quickly in and out of the suit, and also allows the Z-1 to be docked externally on a spacecraft for a quick spacewalk (cutting out the time-consuming pre-breathing procedure which helps prevent decompression sickness). Meanwhile the joints of the Z-1 spacesuit contain bearings that make strenuous movements such as bending down to pick up rock samples much easier.

The Z-1 – planned to be first worn on trips to the ISS in 2017 – is expected to be succeeded by the Z-2, with even more cutting-edge tech. This will be the next step to taking us to previously unexplored locations in the Solar System.



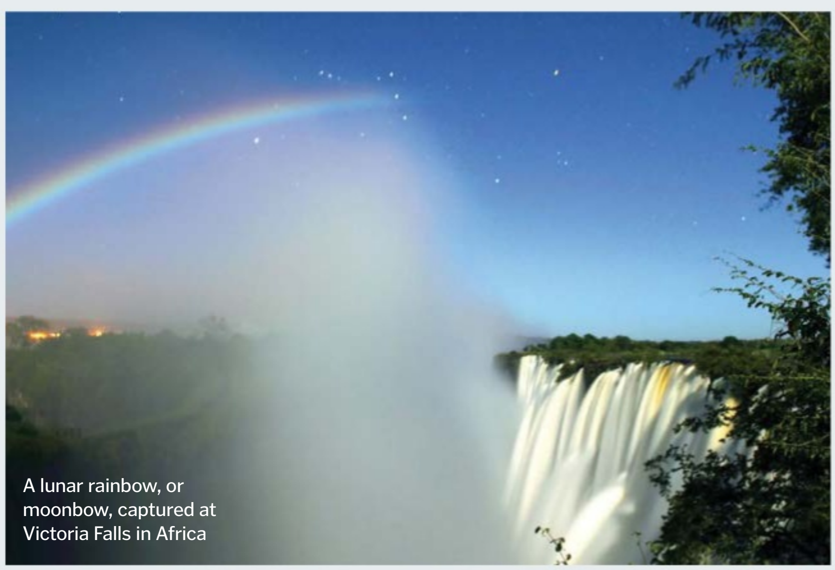
How do moonbows form?

How these beautiful nocturnal rainbows differ from their daytime cousins

For most people, a rainbow is an image exclusively associated with daytime. It is well known that rainbows occur when sunlight refracts off moisture drops in the air, which is why they often appear during and after rainstorms. The change of angle when the light slows as it travels through the water droplets causes the full prism of light to appear, all the way from red to purple.

However, in certain places, moonbows can occur. This is where rainbows are created by moonlight shining through moisture droplets in the atmosphere. As moonlight is much weaker than sunlight, the phenomenon is much fainter than rainbows, but nevertheless provide an incredible sight.

Some of the most vibrant and reliable moonbow sightings appear in Yosemite National Park, USA, during late-spring and early-summer, but they can appear anywhere that a bright Moon catches moisture, such as after a rain shower or near a waterfall.



A lunar rainbow, or moonbow, captured at Victoria Falls in Africa

Spiral galaxies

Discover why our own galaxy and around 70 per cent of our closest neighbours are twisted into the shape of a pinwheel

Tens of thousands of light years in diameter, spiral galaxies revolve around a central point. The farther away from the centre of the galaxy, the longer the material takes to rotate, causing it to wind up into a spiral as the galaxy spins.

The spiral structure is the result of a density wave, which passes out of the centre of the galaxy through the clouds of dust that make up the disc. This wave compresses hydrogen gas as it moves through the disc, forming dust lanes and triggering nuclear fusion. In the wave's wake, new stars develop. As the arms of spiral galaxies age they turn from blue (young stars) to red (old stars) and on to yellow (dying stars); the latter are also called 'fossil arms'.

Spiral galaxies turn very slowly, taking hundreds of millions of years to complete a full rotation – our own galaxy, the Milky Way, for instance, takes approximately 250 million years to turn 360 degrees on its central axis.

At the core of a spiral galaxy is the galactic bulge, a densely packed population of stars that tend to be older – and so redder. It is predicted that the centre of most spiral galaxies also plays host to a supermassive black hole, billions of solar masses in size. They grow by pulling in matter from the galaxy, and dictate the rotation and orbits of all the stars around them.

Spiral galaxies have such huge gravitational pull that they trap a spherical halo of stars and globular star clusters (groups of stars that orbit the galaxy like satellites). These may have formed within the galaxy itself or been stolen from neighbouring galaxies as they collide and merge. These are particularly visible when observing galaxies from the side, and form a hazy cloud that encircles the central disc.

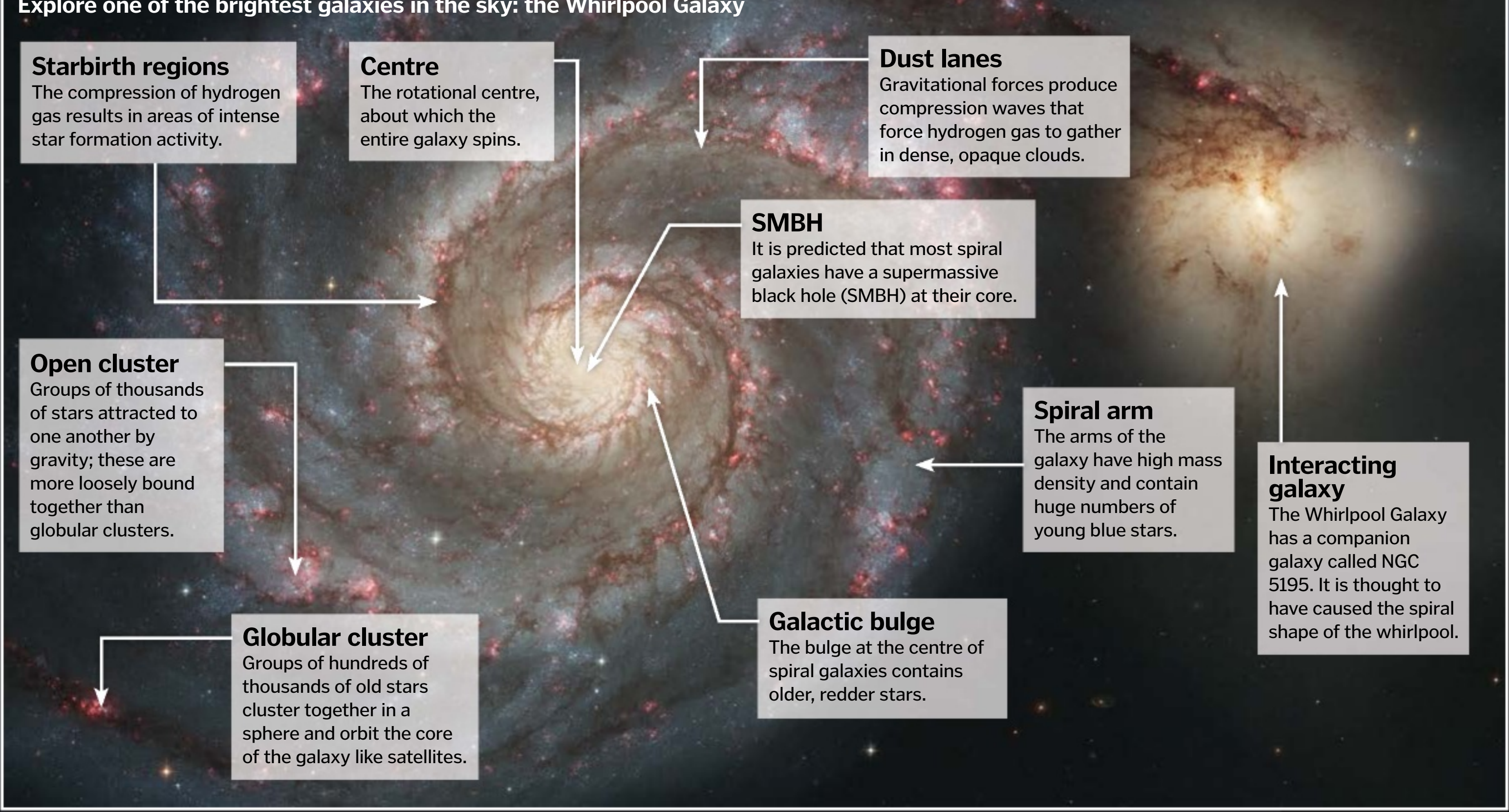
Maths in space

The spiral arms of galaxies are logarithmic; the turns are not a fixed distance from one another – rather the distance between them increases exponentially. A spiral of this pattern allows the galaxy to grow without changing shape.

The Fibonacci sequence (0, 1, 1, 2, 3, 5, 8, 13, etc) is made by adding together the two previous numbers to get the next one. It has long been known that Fibonacci sequences occur in nature, describing the arrangement of leaves on a stem and the petals on a flower, etc. Using tiled squares of sizes following the Fibonacci sequence, a spiral can be drawn (see below). Intriguingly, this ratio can be superimposed over the spiral arms of some galaxies, mapping the trajectory of the dust lanes that swirl around the centre.

Getting in a whirl...

Explore one of the brightest galaxies in the sky: the Whirlpool Galaxy



THE STATS
MILKY WAY

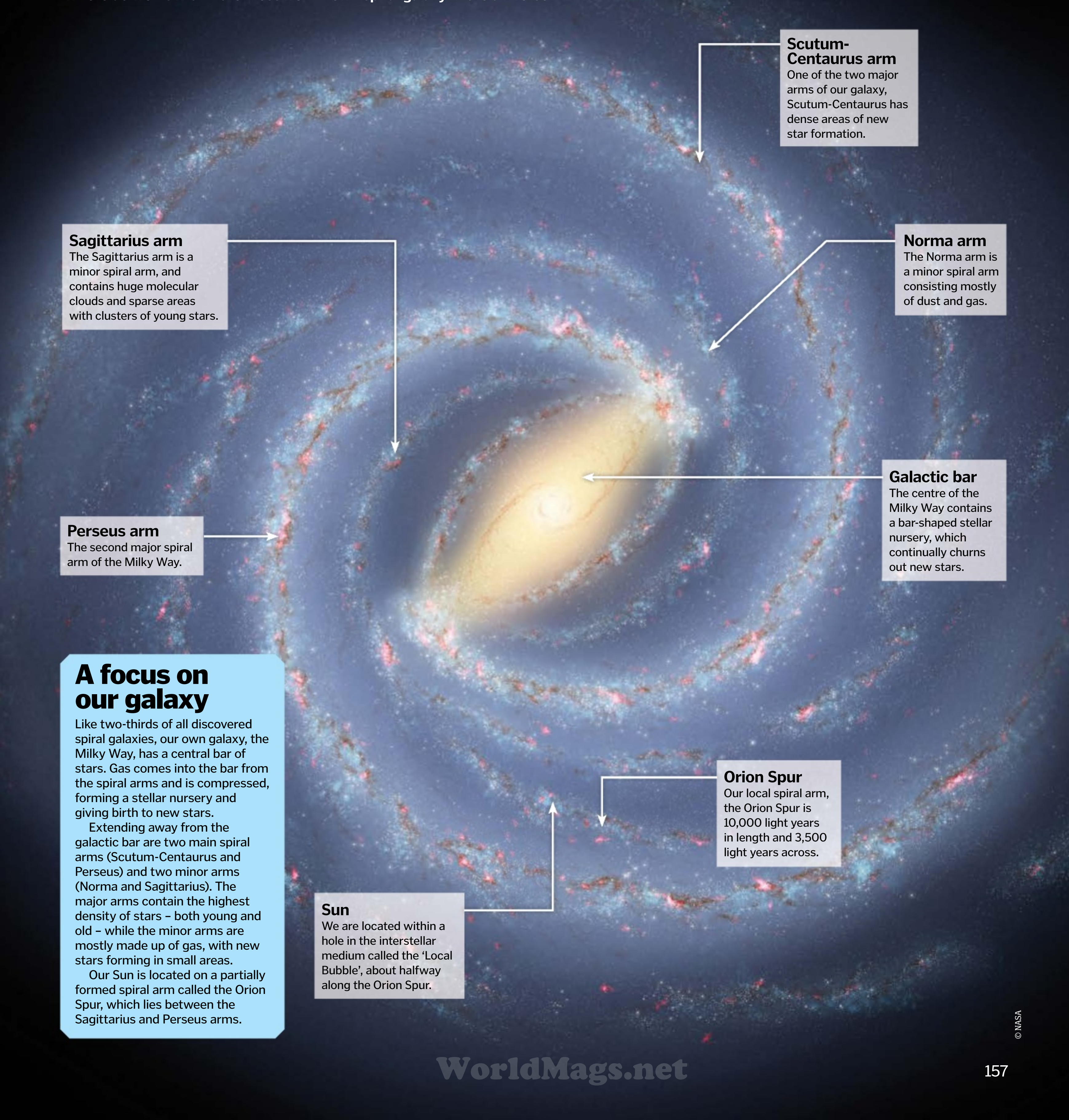
DIAMETER **120,000LY** | MAJOR ARMS **2** | OLDEST STAR (YRS) **13bn**

NUMBER OF STARS **200-400bn** | MINOR ARMS **2** | THICKNESS **1,000LY**

DID YOU KNOW? *At the centre of the Milky Way is a supermassive black hole known as Sagittarius A**

Unravelling the Milky Way

Where do we fit within the most well-known spiral galaxy in the universe?



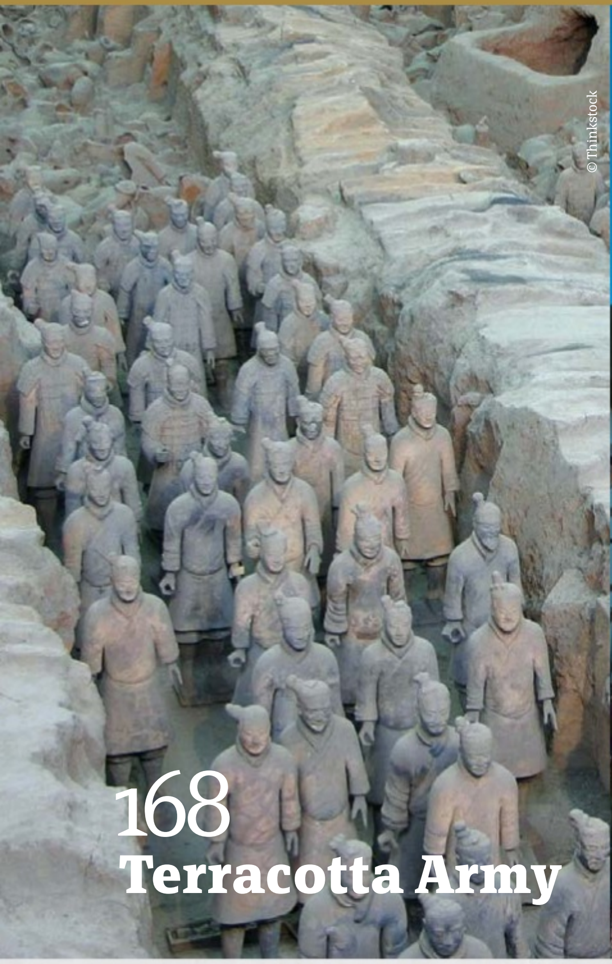
A focus on our galaxy

Like two-thirds of all discovered spiral galaxies, our own galaxy, the Milky Way, has a central bar of stars. Gas comes into the bar from the spiral arms and is compressed, forming a stellar nursery and giving birth to new stars.

Extending away from the galactic bar are two main spiral arms (Scutum-Centaurus and Perseus) and two minor arms (Norma and Sagittarius). The major arms contain the highest density of stars – both young and old – while the minor arms are mostly made up of gas, with new stars forming in small areas.

Our Sun is located on a partially formed spiral arm called the Orion Spur, which lies between the Sagittarius and Perseus arms.

HISTORY



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Life in the trenches

100 years on, why has trench warfare come to define WWI?

World War I represented a major shift in warfare practice. Aircraft and machine guns were two examples, but what truly dictated this conflict was trench warfare.

The first trenches of note were dug by Germans in September 1914 after their charge through France was halted by Allied forces. In order to avoid losing ground, they dug in, creating deep crevasses to hide in. The Allies quickly realised they couldn't breach these defences and followed suit. What ensued was a race to outflank the opponent along northern France. The first trenches were fairly shallow ditches, but evolved into an elaborate system of frontline trenches, support trenches and barbed wire fences.

It would take 450 men six hours to construct a trench of just 250 metres (820 feet), after which sandbags, wooden walkway planks and barbed wire needed to be strategically placed to stop flooding, collapsing and enemy advances. They were dug in zigzag patterns to stop enemies taking out an entire group of soldiers in one attack. The most time-effective method of trench digging was standing on the ground and digging downward, but that left soldiers at the mercy of enemy fire. The alternative was to dig down then along, while still in the hole. This was safer but much slower. ▶

WWI battlefield revealed

See how the complex trench system was laid out

KEY DATES
WWI MILESTONES

Sept 1914
Allied resistance at Marne forces the advancing German army to dig trenches.

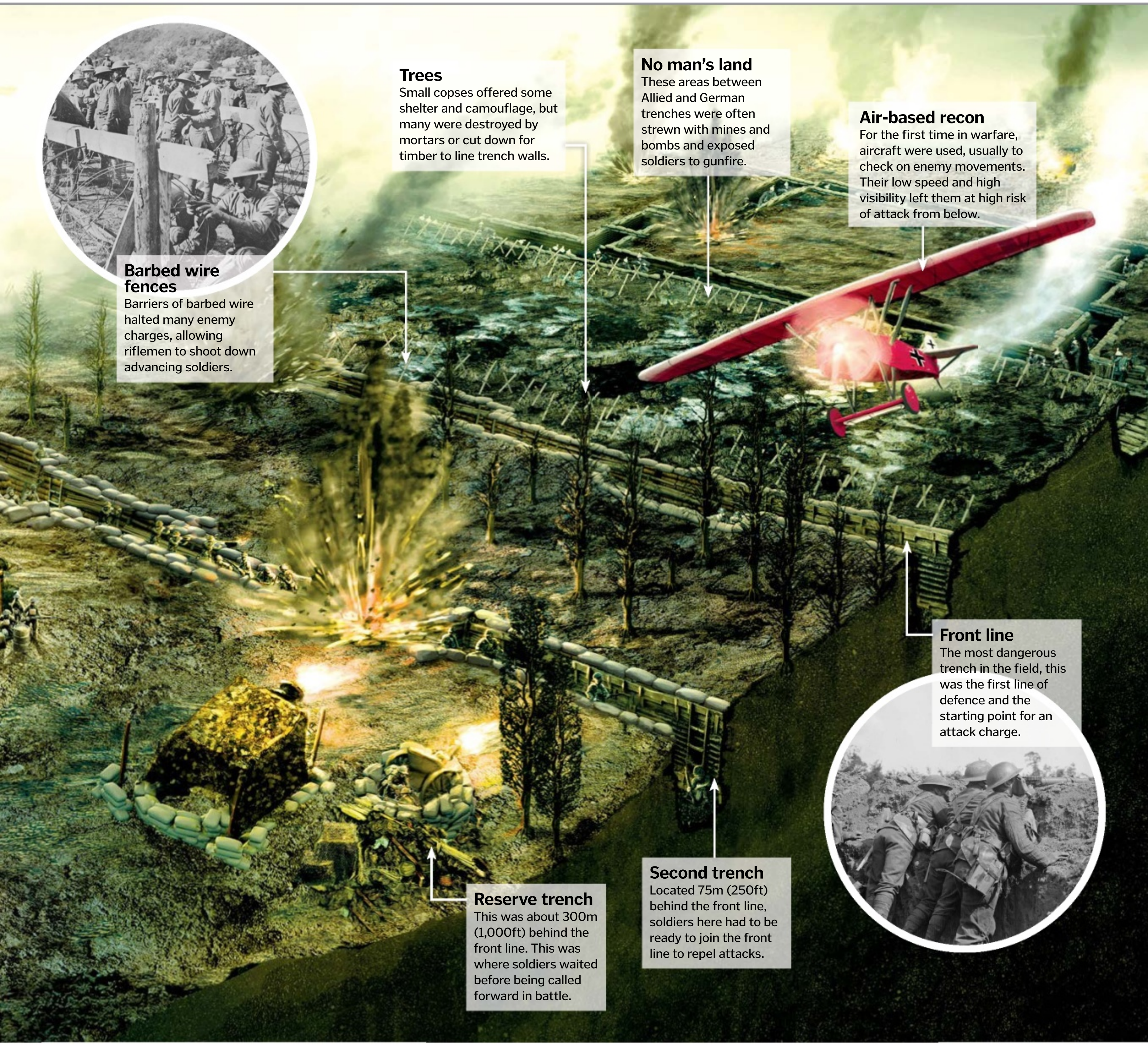
Nov 1914
The first Battle of Ypres in Flanders draws to a close, resulting in a victory for the Allies.

Jul 1916
The devastating Battle of the Somme results in heavy casualties on both sides.

Apr 1917
British and Canadian forces take Vimy Ridge near the town of Arras in northern France.

Oct 1918
Allies break through the so-called Hindenburg Line, gaining a war-ending victory.

DID YOU KNOW? *Around 140,000 Chinese labourers fought in Allied trenches during World War I*



Life in the trenches

▶ Located in north-east France, Marne was the site of the war's first example of trench warfare. German and Allied forces both realised the defensive power of this strategy so engaged in a shovelling 'Race to the Sea', building trenches all the way to the North Sea at Ypres, Belgium.

This then became the location for a bed-in that lasted for the remainder of the war, with attacks and counterattacks barely gaining any ground at all, but at the cost of millions of lives.

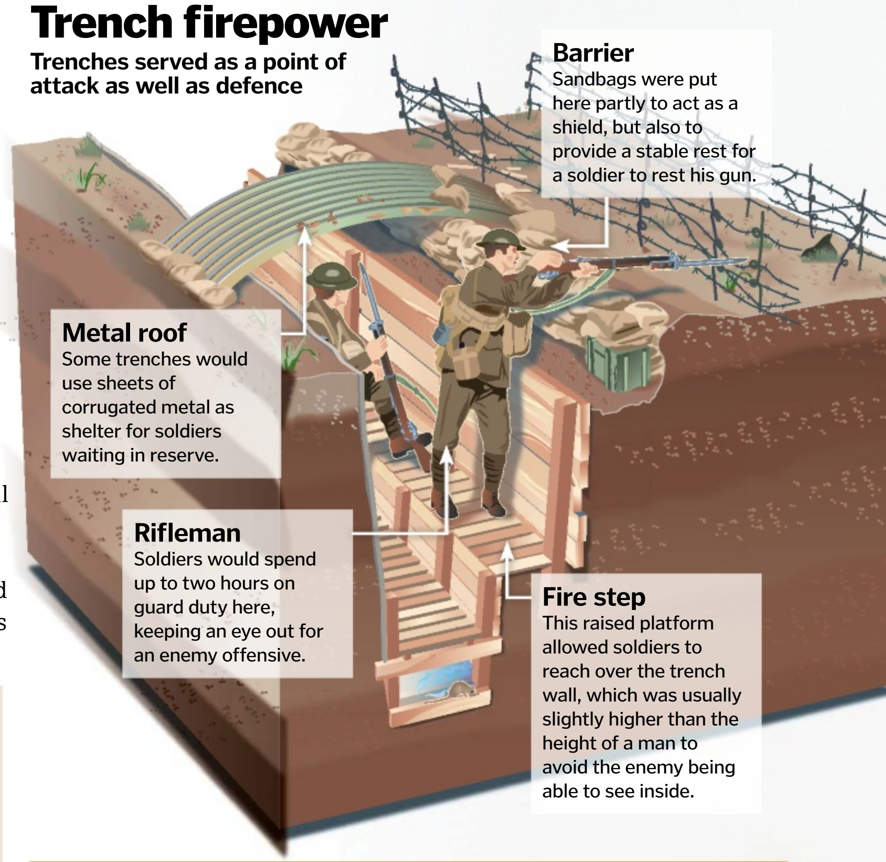
Verdun was another bloody site, with the Germans launching a devastating attack on the fortified town. They broke French resistance but the counter-offensive eventually drove them back to their starting point, resulting in a similarly prolonged trench standoff.

The German forces failed to conquer Verdun because they had to focus on the British army's assault on the Somme. This began with a massive week-long bombardment followed by an infantry attack. However, the German trenches were so well fortified that the British shells barely made an impact, so thousands of Allied troops fell victim to the ruthless German machine guns.

The end came at St Quentin Canal in France. The British managed to storm through the Hindenburg Line, forcing the Germans back and bringing about the first discussions of surrender.

Trench firepower

Trenches served as a point of attack as well as defence



Job roles in the trenches

The majority of soldiers in the trenches were there to directly engage in combat. These soldiers would have a spectacular range of abilities and experiences. Some may have been grizzled war veterans, while others would be fresh recruits, straight out of training. These people would be responsible for day-to-day maintenance, guarding and, eventually, going over the top and launching an offensive on the German trenches.

Officers (1) would also be stationed in the trench. They would be soldiers of higher status and would be in charge of organising and leading night patrols, which tried to keep track of the enemy's location. They had marginally more luxury than the other soldiers, sleeping in a proper dugout in the trench and having first pick of the food.

Medics (2) were stationed in three positions: the collecting zone (right by the battlefield), the evacuating zone (between the front and rear trenches) and the distributing zone (where they would treat the wounded in pop-up hospitals). If a soldier couldn't be moved, they would be treated where they lay. The Royal Army Medical Corps (RAMC) is the only part of the British army in which two members hold double Victoria Crosses.

Listeners (3) would move through tunnels closer to the enemy's front line than the trenches. The idea was to try to hear enemy plans and put a halt to the enemy planting mines close to their trench. This was a very dangerous role as tunnels could collapse at any time.


1


2


3

A day on the front line

Soldiers in the British army would spend about 15 per cent of their active service on the front line and 40 per cent in the reserve trenches.

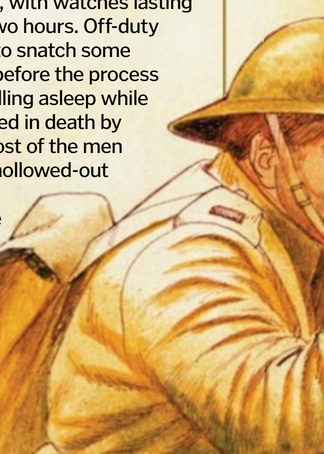
The average day on the front line would begin with a stand to. This would be around an hour before sunrise and involved all soldiers standing on the fire step, rifles ready and bayonets fixed. They would then begin the 'morning hate', firing their guns into the morning mist. This had the dual benefit of relieving tension and frustration, as well as helping to deter a possible dawn raid.

Breakfast would then be served, consisting of biscuits or bread and canned or salted meat. Following breakfast would be a period of chores. These could range from cleaning weapons and fetching rations to guard duty and trench maintenance. The latter would often involve repairing shell damage or trying to shore up the damp, underfoot conditions.

One of the main challenges in everyday trench life was the food. At the start of the war, each soldier received 283 grams (ten ounces) of meat and 227 grams (eight ounces) of vegetables per day. However, as the war wore on, the meat allowance reduced to 170 grams (six ounces) of meat and, if you weren't on the front line, you only got meat on nine out of 30 days. Diets were bulked out with corned beef, biscuits and bread made of dried ground turnips. As the kitchens were so far behind the front line, it was nearly impossible to provide hot food to the troops at the front, unless the men pooled their resources and bought a primus stove to heat their food and make tea. Other common meals included pea soup with horse meat and Maconochie, a weak soup containing sliced carrots and turnips.

As dusk fell, the soldiers would engage in an evening version of the morning hate. Essential tasks like repairing barbed wire and rotation of troops were done after dark, as the enemy was less likely to be able to launch an effective attack.

Guards would look out for night-time raids, with watches lasting no more than two hours. Off-duty men would try to snatch some precious sleep before the process began again. Falling asleep while on watch resulted in death by firing squad. Most of the men would sleep in hollowed-out sections of the trench or on the fire step.



5 TOP FACTS
TRENCHES TODAY

Sanctuary Wood
1 This is a museum and trench network 3.2km (2mi) east of Ypres. You can visit the woodland where soldiers once sheltered and walk in their footsteps in the trenches.

Yorkshire Trench
2 Originally dug by British troops in 1915, the Yorkshire Trench – located north of Ypres – has been restored in considerable detail and is free for all to visit today.

Vimy Memorial Park
3 Free tours to this site are provided by Canadian students. Canada was granted this piece of land after they were instrumental in taking it from Germany in 1917.

The Somme
4 One of the most significant battle sites in the war, where an estimated 60,000 men died in one day. The area is still covered in craters and trench lines to this day.

Verdun
5 Another key site in the battle for the Western Front, Verdun was the location of a bloody battle, with almost 300,000 soldiers killed over ten months of fighting.

DID YOU KNOW? *The machine gun was originally designed by American inventor Hiram Maxim as long ago as 1884*

5 key WWI weapons

1 Machine gun
The machine gun was one of the definitive weapons of WWI. At the outbreak of war, Germany had 12,000 machine guns, while the British and French only had a few hundred between them.

2 Tank

Early tanks were based on farming vehicles, the caterpillar tracks allowing for movement over uneven muddy ground. They were slow and unreliable but once these problems were ironed out and they were weaponised, the British enthusiasm for the tank helped them win the war.

3 Rifle
Despite the advance of long-range or automatic weapons like machine guns and mortar shells, the rifle continued to be an essential piece of military kit.

4 Bayonet

These blades affixed to the front of rifles were only useful in close combat. The French army used needle blades, while the German army developed the saw-back bayonet blade.

5 Flame-thrower

By 1915, German soldiers had portable flame-throwers that terrified the British army at Flanders. The British attempted to come up with flame-throwers of their own, but with little success, while the French developed their own self-igniting, lightweight flame-throwers, with more success than the British.

The Globe Theatre's story

The most famous and historic theatre in Britain – if not the world – the Globe was the original home to William Shakespeare's greatest plays

The Globe Theatre was an Elizabethan-era playhouse part-owned by the great playwright William Shakespeare. Built from the remains of an existing theatre in Shoreditch, London, made by English actor and theatre owner Richard Burbage and his brother Cuthbert, the Globe was constructed over just a few months in 1599. The playhouse became the home of the Lord Chamberlain's Men, a troupe of which Shakespeare and the Burbages were members. The group went on to perform many of the Bard's most famous plays there. Reportedly, the first performance was *Julius Caesar*, with subsequent plays such as *Richard II, Romeo And Juliet* and *A Winter's Tale* also shown there.

The Globe proved a great success, with its 3,000 capacity frequently tested to the limit, both in the cheap standing-only pit area as well as in the more prestigious tiered seating located around the inner walls. Unfortunately, however, on 29 June 1613 during a performance of *Henry VIII*, a theatrical cannon misfired and ignited the wooden beam and thatch roof, leading to the entire building burning down. Luckily, the success of the Globe's owners and its performances resulted in the theatre being rebuilt again in 1614, with the new playhouse continuing to host many acting troupes well after Shakespeare's death in 1616. In fact, it was not until 1642 that the theatre was closed down – a casualty of the English Civil War.

The Shakespeare's Globe standing today (inset) is an accurate reconstruction of the original Globe Theatre

The Globe over time

Check out some of the main events in the theatre's history now

1599: Grand opening
The Globe Theatre is opened on Bankside, London.

1601: *Richard II* runs
Shakespeare's acting troupe, the Lord Chamberlain's Men, are commissioned to stage *Richard II*.

1608: Blackfriars bought
The Globe's co-owner, Richard Burbage, acquires the lease for the Blackfriars Theatre, which is then used for winter performances.

1614: Globe rebuilt
Following a disastrous fire that burned down the Globe, it is rebuilt a year later on the original foundations.

1997: Resurrection
An accurate reconstruction of the Globe is built near to the site of the original building. It stages Shakespeare's works and is a popular tourist attraction to this day.

1644: Globe destroyed
The theatre is razed to the ground again – this time by order of the Puritans. Landowner Sir Matthew Brend builds tenement houses on the site in its place.

1642: Plays suppressed
In the English Civil War, Parliament issues an ordinance that forbids all stage plays. The Globe is shut down.

1616: Mortal coil
William Shakespeare dies aged 52 in Stratford-upon-Avon, where he is buried in the Holy Trinity Church.

A modern-day Globe

Theatre fans today can visit the Globe, but it's not the Globe of Shakespeare's day but instead a modern reconstruction. It was nevertheless made to be historically accurate, consulting the plans, construction methods and materials of the 1599 original, albeit with modern safety standards in mind. Shakespeare's Globe is built from 100 per cent English oak, with components linked with mortise and tenon joints – both features shared by the original – and also has the only thatched roof permitted in all London since the Great Fire of 1666. The attention to historical detail even extends to the pit area, which remains standing only, albeit with a concrete surface rather than the earthen/straw mix of the 16th/17th century. A second Shakespearean play venue, the Blackfriars Theatre, is also being reconstructed and is due to open by 2014.

5 TOP FACTS
GLOBE TRIVIA

Motto
1 The Globe's motto was 'Totus mundus agit histrionem', derived from Roman courtier Petronius' statement that 'all the world plays the actor' – hence its name, the Globe.

Shareholders
2 The Globe was owned by actors who were also shareholders in the Lord Chamberlain's Men. Shakespeare owned a single share, equal to 12.5 per cent.

Breeches on fire!
3 According to reports of the Globe fire in 1613, no one was seriously injured, the only incident involving a man's breeches being set alight and then put out with ale.

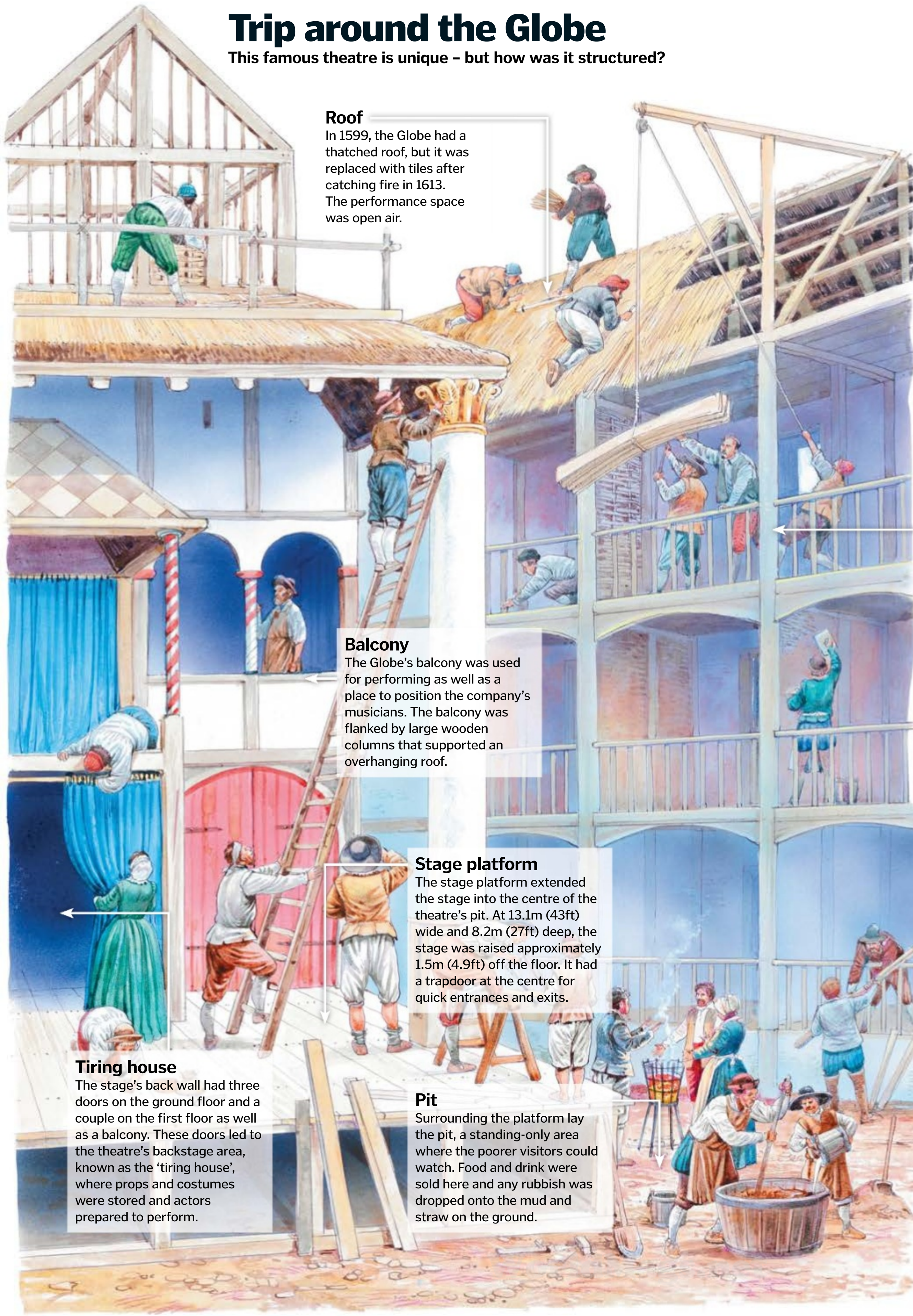
Puritan shutdown
4 Like all other theatres at the time, the Globe was closed down by Puritans in 1642 before being torn down two years later to make way for cheap residential housing.

Car park
5 Today, while an incredibly accurate reconstruction of the Globe exists – named Shakespeare's Globe – the remains of the original are located under a car park.

DID YOU KNOW? *The modern reconstruction of the Globe is located 230m (750ft) from the original site*

Trip around the Globe

This famous theatre is unique – but how was it structured?



Roof
In 1599, the Globe had a thatched roof, but it was replaced with tiles after catching fire in 1613. The performance space was open air.

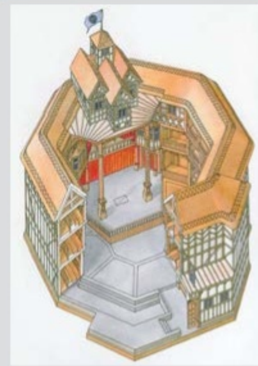
Balcony
The Globe's balcony was used for performing as well as a place to position the company's musicians. The balcony was flanked by large wooden columns that supported an overhanging roof.

Stage platform
The stage platform extended the stage into the centre of the theatre's pit. At 13.1m (43ft) wide and 8.2m (27ft) deep, the stage was raised approximately 1.5m (4.9ft) off the floor. It had a trapdoor at the centre for quick entrances and exits.

Tiring house
The stage's back wall had three doors on the ground floor and a couple on the first floor as well as a balcony. These doors led to the theatre's backstage area, known as the 'tiring house', where props and costumes were stored and actors prepared to perform.

Pit
Surrounding the platform lay the pit, a standing-only area where the poorer visitors could watch. Food and drink were sold here and any rubbish was dropped onto the mud and straw on the ground.

The statistics...



Globe Theatre

Opened: 1599

Capacity: 3,000

Stage width: 13.1m (43ft)

Stage depth: 8.2m (27ft)

Theatre diameter: 30m (100ft)

Closed: 1642

Storeys
The Globe had a three-storey seating arrangement used by the middle and upper classes. Basically the higher the seat, the more expensive it was.

Foundations
Despite appearing circular in design, with a diameter of just over 30m (98ft), the Globe's foundations were actually a 20-sided polygon (icosagon). At the centre of the theatre lay the rectangular stage platform.

Entrance (not shown)
There was one main entrance to the theatre, which was directly opposite the stage and led into the pit. Two sets of stairs near the entrance led into the upper seating tiers.

Biggest ever land mammal

Find out how this prehistoric mega-mammal – eight times the size of a modern-day rhinoceros – used to live

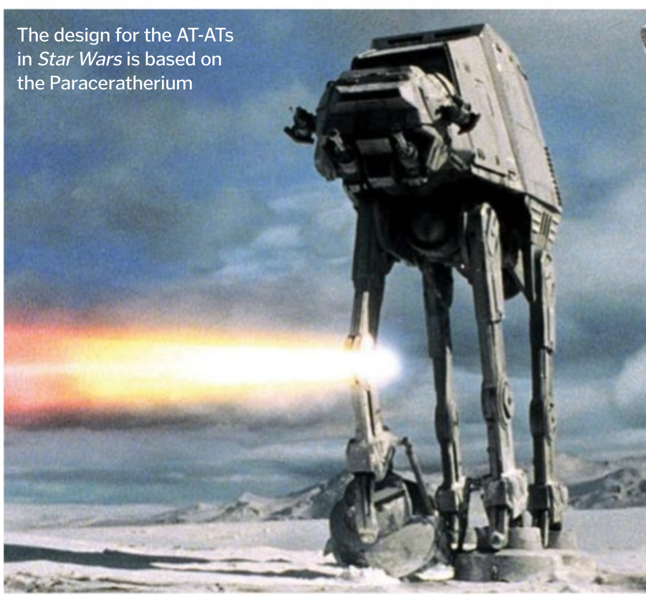
Imagine a beast taller than a giraffe and heavier than two elephants. Paraceratherium was the dinosaur of its day. It filled the same ecological niche as the huge sauropod dinosaurs, like Diplodocus, that lived 120 million years earlier, roaming through lightly forested plains and eating the leaves of trees, which it stripped off the branches with its front teeth. Unlike the dinosaurs, Paraceratherium didn't have a long tail to counterbalance the weight of its neck and head. Instead, it had much more powerful neck muscles, anchored to tall extensions at the top of its spine. This brought its centre of gravity much farther forward, onto the front legs, resulting in a much stockier shape overall.

Paraceratherium lived during the Oligocene epoch, around 30 million years ago. The climate cooled suddenly during this period; Antarctica developed its ice cap for the first time and the Alps began to push upwards to form mountains. As the climate changed, the dense tropical forests were replaced with more open landscapes containing a mixture of trees and grass. These made it harder for medium-sized animals to hide from predators, so natural selection favoured ever-larger individuals able to fend off attacks. Along with competition between males for breeding rights, this drove the evolution of heavier grazing animals. The culmination of this was the Paraceratherium, which weighed a whopping 20 tons.

The largest predators at the time were a kind of marsupial hyena, no more than two metres (6.6 feet) long. An adult Paraceratherium was far too large to be troubled by these animals. Instead, they may have been eventually driven extinct by the rise of early elephant species. These would have knocked down the trees Paraceratherium relied on for food. As the grasslands expanded, Paraceratherium was replaced by smaller grazing mammals.

In a galaxy far, far away…

When Phil Tippett was designing the special effects for *Star Wars Episode V: The Empire Strikes Back*, he needed a reference model for the giant mechanical AT-AT walkers that assault the rebel base on Hoth. Initially, his team studied elephants to animate the leg movements, but the final design is much taller and more menacing. That's because they are based on the Paraceratherium. The AT-ATs portrayed in the film are three times as tall as the prehistoric mammal, but the lumbering gait and joint articulation is probably very close to the way the real Paraceratherium would have moved around.

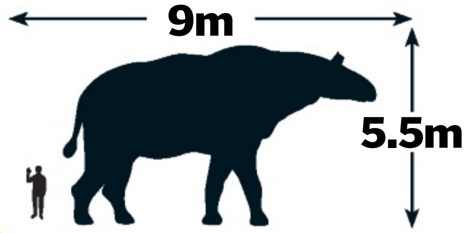

The design for the AT-ATs in *Star Wars* is based on the Paraceratherium

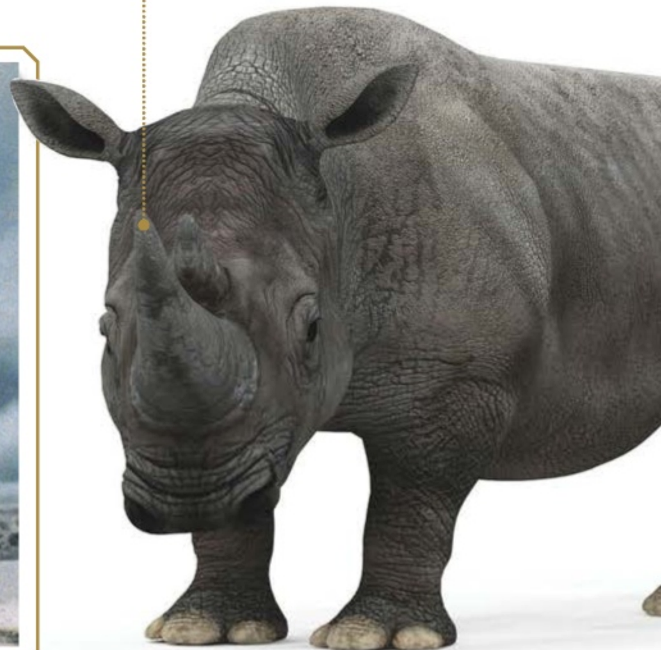
The problems with bone identification

The first Paraceratherium fossil bones were found in 1911 by the palaeontologist Clive Forster Cooper. Two years later, he found more bones he took to be from a related genus and named the animal Baluchitherium because the fossils were found in Baluchistan, in what is now Pakistan. In 1915, Aleksei Borissiak found a third set of bones and named the animal Indricotherium, after the Indrik, a monster from Russian folklore.
None of these fossil finds were anything like a full skeleton, and it can be very hard to decide whether you have found a completely new animal or just a larger example of an existing one based on a single neck vertebra. The scientific consensus is now that all three sets of fossils belong to the same genus, which is called Paraceratherium, because this was the first one to be described scientifically. To date, five species of Paraceratherium have been identified.

Size matters

How would the Paraceratherium have measured up against a person?





5 TOP FACTS
MEGAFAUNA

Toxodon
1 This 1.5-ton hoofed animal looked like a hornless rhinoceros, but had much larger front legs than hind legs. Herds of them roamed South America 20,000 years ago.

Diprotodon
2 The 'hippopotamus wombat' was the largest marsupial ever. 3m (9.8ft) long and weighing 2.8 tons, its fossils may have inspired Aboriginal legends of the 'bunyip'.

Megatherium
3 This ground sloth weighed about four tons. It only went extinct 10,000 years ago and, at the time, only the Columbian and woolly mammoths were larger.

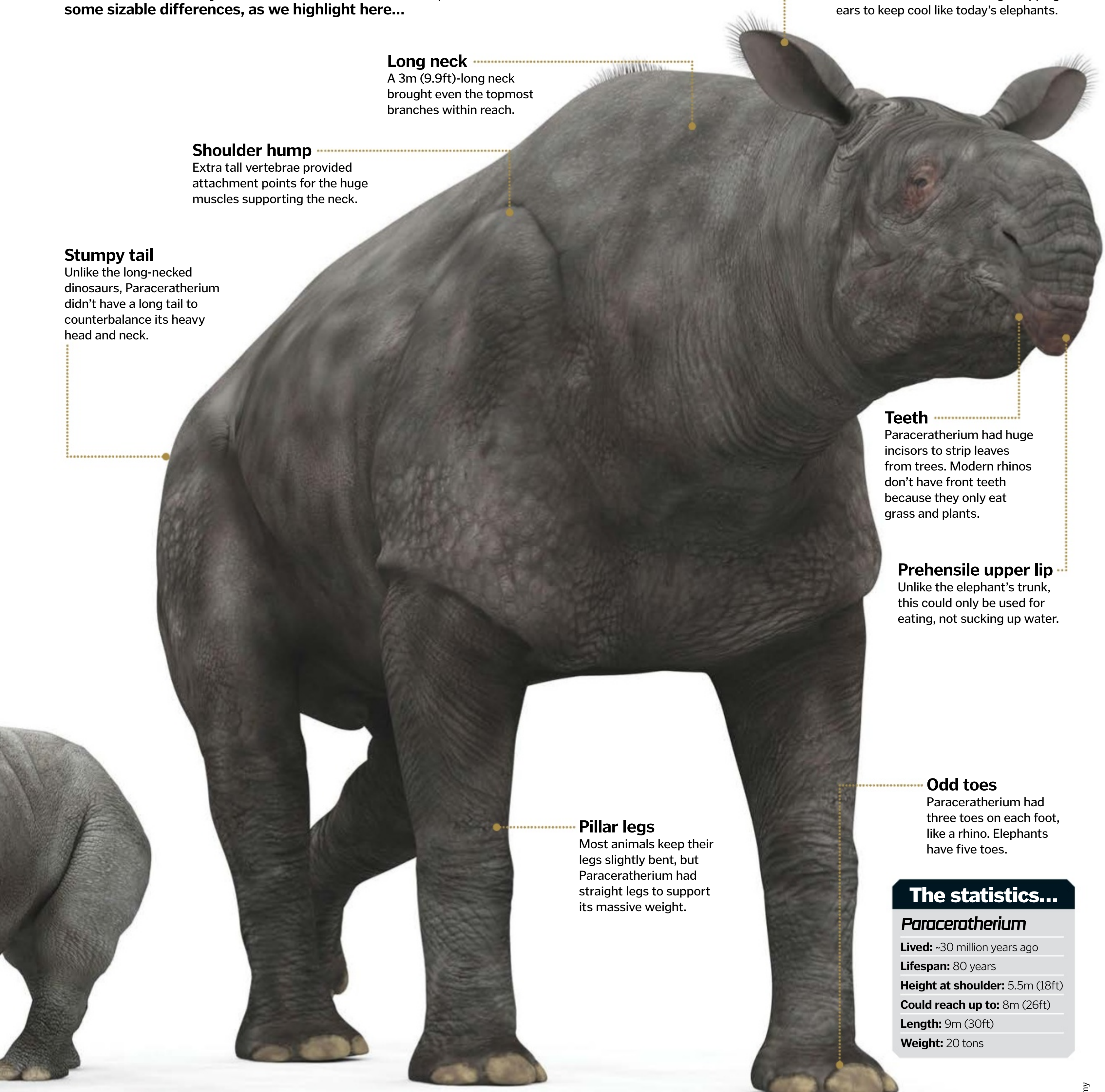
Deinotherium
4 Although they aren't closely related, Deinotherium looked like an overgrown elephant, but with larger front legs and tusks pointing down. It lived about 7 million years ago.

Woolly mammoth
5 At 3.4m (11.2ft) tall and weighing six tons, these ice age relatives of the elephant had tusks up to 4.2m (13.8ft) long that could weigh over 90kg (200lb).

DID YOU KNOW? *Paraceratherium was bigger than Diplodocus; although the dino was longer, Paraceratherium was bulkier*

Anatomy of a mega-mammal

Paraceratherium may be related to the modern rhino, but there are some sizable differences, as we highlight here...



Mystery ears
Soft ears don't fossilise, but it's possible that Paraceratherium had large flapping ears to keep cool like today's elephants.

Long neck
A 3m (9.9ft)-long neck brought even the topmost branches within reach.

Shoulder hump
Extra tall vertebrae provided attachment points for the huge muscles supporting the neck.

Stumpy tail
Unlike the long-necked dinosaurs, Paraceratherium didn't have a long tail to counterbalance its heavy head and neck.

Teeth
Paraceratherium had huge incisors to strip leaves from trees. Modern rhinos don't have front teeth because they only eat grass and plants.

Prehensile upper lip
Unlike the elephant's trunk, this could only be used for eating, not sucking up water.

Odd toes
Paraceratherium had three toes on each foot, like a rhino. Elephants have five toes.

Pillar legs
Most animals keep their legs slightly bent, but Paraceratherium had straight legs to support its massive weight.

The statistics…
Paraceratherium

Lived: ~30 million years ago
Lifespan: 80 years
Height at shoulder: 5.5m (18ft)
Could reach up to: 8m (26ft)
Length: 9m (30ft)
Weight: 20 tons

Making the Terracotta Army

Meet the immortal warriors built to defend the Chinese Emperor Qin Shi Huang and find out how they were constructed over 2,200 years ago

The Terracotta Army comprises a huge collection of sculptures found within the mausoleum of the first emperor of China, Qin Shi Huang. Featuring close to 9,000 figures, objects and weapons, the massive earthenware cohort was built to accompany Emperor Qin into the afterlife.

The terracotta army was manufactured by thousands of labourers and craftsmen during Qin's reign around 220-210 BCE. The material used to build the sculptures was harvested from the site of the mausoleum – Mount Li in Shaanxi Province. According to detailed examination of the figures, their heads, arms, legs and torsos were modelled and fired separately, only being assembled afterwards, so many more were probably made but damaged during production.

While today the excavated figures have reverted to their natural orange-red colour due to exposure to the air, when originally completed these sculptures would have been brightly painted and highly detailed – evidence of which can still be found on a few well-preserved specimens. What does remain unchanged is their original layout, with the thousands of statues arranged in accurate military formations, with generals and other important officers identified.

The Terracotta Army is but one feature – albeit the most impressive one to date – of Qin's larger mausoleum and necropolis, with the emperor's tomb and underground palace yet to be excavated. According to famous Chinese historian Sima Qian (circa 145-90 BCE), all manner of treasures are concealed there, but the site is considered sacred so there are no immediate plans to disturb the tomb.

Beyond the warriors…

Officials

Qin also needed protection from the trials and tribulations of administration work. Terracotta court officials and counsellors can therefore be found throughout his enormous mausoleum.

Acrobats

In contrast to the sombre and serious terracotta soldiers, other pits within Qin's mausoleum have revealed acrobats and dancers, each crafted in animated positions and with strong facial expressions.

Musicians

Music was important in Ancient China, which is represented by the abundance of musicians and instruments. A set of Bianzhong bronze chimes was recently unearthed in very good condition.

Animals

Emperor Qin Shi Huang was clearly a big fan of animals, as a host of sacred creatures, such as cranes and swans, as well as a full-blown imperial zoo, have been found inside the mausoleum.

All about Qin

Qin Shi Huang, the legendary first emperor of China, brought the Warring States period to a close in 221 BCE. His reign was typified by military conquest, with campaigns into modern China's southern lands, as well as massive public projects; examples include the unification of state walls into the Great Wall of China and a national road system. Qin ruled unopposed until his death in 210 BCE – an event he reportedly attempted to avoid by undertaking a search for a fabled elixir of immortality.

Astronomical calendar
1 German mathematician Maria Reiche was convinced that the Nazca lines represented an astronomical calendar, used to document important astronomical events.

Water rituals
2 Peru's Nazca region is extremely dry, so some archaeologists believe that the lines were created as part of a ritual to bargain with the gods for rain.

Ancient astronaut
3 One of the figures vaguely resembles an astronaut, and given that the images are best viewed from above, some people have suggested that the Nazca were able to fly!

Alien airport
4 Due to the abrupt start and finish points on some of the Nazca lines, the idea was put forward that the area was a landing strip for ancient extraterrestrials!

Sports park
5 Many of the figures have a defined entry and exit point and can be walked in one line, like an elaborate set of running tracks in an enormous outdoor sports stadium.

DID YOU KNOW? *The upper layer of Nazca gravel is dark in colour due to the presence of ferrous oxide*

What are the Nazca lines?

Ancient drawings cover the Peruvian plains, but where did they come from?

The Peruvian coastal plain in South America is home to a wonder of archaeology. The ground is scarred by images, or geoglyphs, known as the Nazca lines, thought to have been constructed by the people of Nazca between 500 BCE and 500 CE.

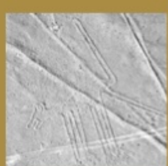
The ancient artworks – most easily viewed from the air – were created by methodically removing dark-coloured gravel from the surface to reveal lighter material below. The plains' unique climate has preserved the lines for thousands of years. Each year, the region receives just 20 minutes of rainfall on average, and the ground is mostly stone and gravel, which prevents the striking images from eroding in the wind.


These intricate patterns were created by using very simple tools and methods


The extremely dry conditions in Peru have preserved the drawings

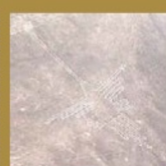

The complexity of the Nazca lines has led to some wild theories as to their origin

Going on a Nazca safari…



Dog
This 51m (167ft) canine is thought to be an image of an ancestor of the hairless Peruvian dog. This was kept by the Nazca people as a pet and used as a watchdog.

Spider
An impressive 45m (150ft) in length, this Nazca arachnid was one of the very first figures to be studied in the region by scientists back in the Thirties.



Hummingbird
The Nazca hummingbird measures 97m (318ft) from beak to tail and was carved on a raised plateau, making it one of the most prominent of the animals.

Origins of chocolate

Why it was more than just a tasty snack…

Chocolate is derived from the theobroma ('food of the gods') cacao tree and was consumed by the Mayans as a drink. Chocolate became a sacred elixir to both the Mayans and Aztecs. Archaeologists have discovered residues of chocolate in ancient jars that were found in Honduras and date to 1100 BCE. Cocoa trees grew in abundance throughout the Mayan territories, and by 600 CE their pods (pictured) were processed in order to produce a frothy, bitter drink. Mayans blended their chocolate with spices like chilli pepper and vanilla; once consumed they were believed to ward off tiredness. Evidence suggests that cocoa beans were also ground to a powder. During this process, other ingredients could be added. In this instance, the resulting powder was mixed with water to create a porridge.

Buckingham Palace uncovered

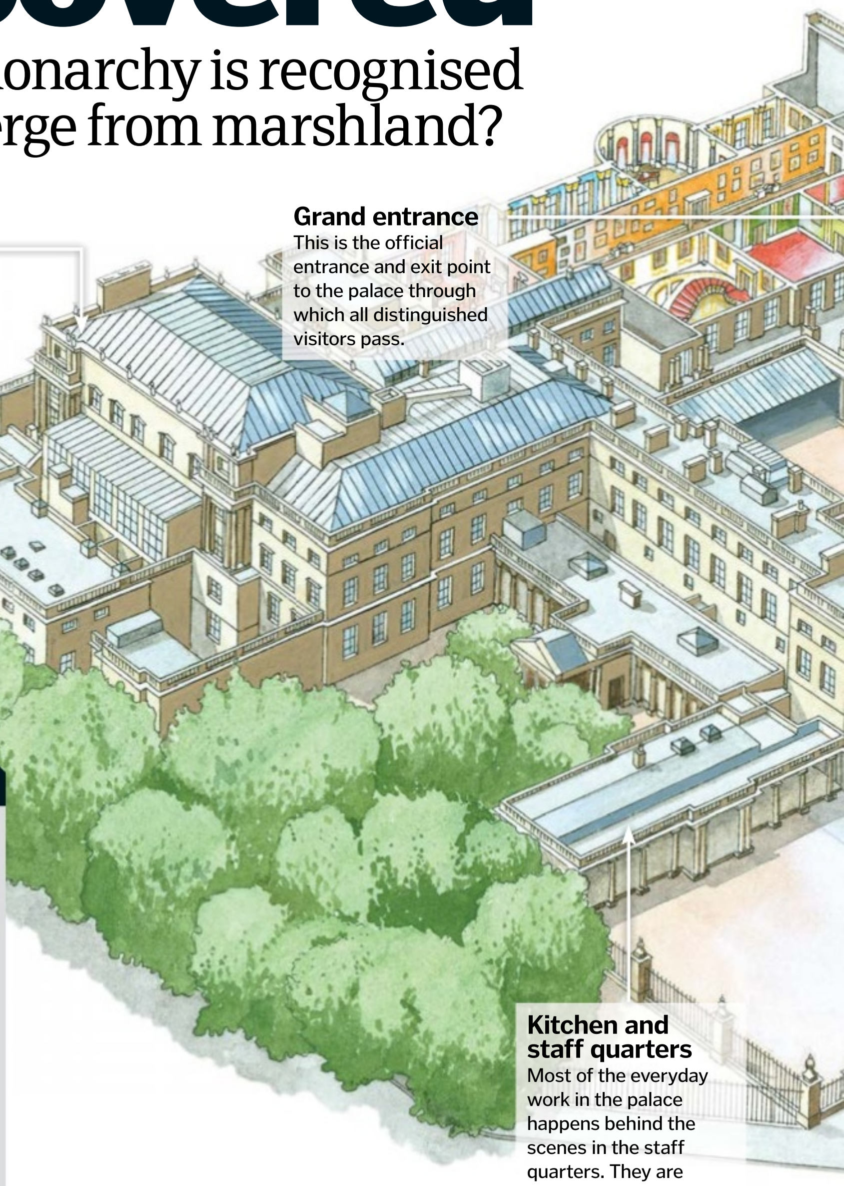
The London home of the British monarchy is recognised the world over, but how did it emerge from marshland?

Although one of London's most popular historic landmarks, Buckingham Palace as we know it today is less than 200 years old. Part of the medieval manor of Ebury, the land on which the palace stands, came into royal possession under Henry VIII.

Planted up as a mulberry garden by King James I (1603-1625) in an attempt to rear silkworms, the site of the future palace passed through various hands before Goring House, Arlington House and then Buckingham House were built on the same site in less than 150 years. Little is known about these houses, but they are thought to have stood where the south wing of the palace is located today.

In 1761 George III purchased Buckingham House for his wife, Queen Charlotte, as a quiet family home close to St James's Palace. A rather simple redbrick building, the king remodelled the house in 1762 and it was redesigned again on the accession of George IV in 1820. In 1826 the king decided to transform the old-fashioned house into a palace. The celebrated architect John Nash doubled the size of the building by adding a new suite of rooms in a French neoclassical style. The north and south wings of the old house were demolished and rebuilt on a larger scale, with a triumphal arch – the Marble Arch – as the courtyard's centrepiece.

With the accession of William IV, Nash was replaced by Edward Blore who finished work on the palace. The king, however, did not care for the building, failed to move in and even offered ▶



The statistics...

Buckingham Palace

Architects: John Nash, Sir Aston Webb, Edward Blore and others

Built: 1762-1914

Area: 77,000m² (830,000ft²)

Height: 24m (79ft)

Number of rooms: 775

Cost: Estimated at over £1bn ($1.7bn) today

The palace over time

Take a tour through Buckingham Palace's history and discover the key events that made it the landmark it is today

1536
Land sold
King Henry VIII takes the Manor of Ebury, which includes the land where the palace now sits, off Westminster Abbey and leases it to royal landlords.

1624
First house built
Sir William Blake builds the first house on the site. Bought by Lord Goring in 1633, the original structure is extended and becomes known as Goring House.

1674
Fire!
Purchased by Henry Bennet, First Earl of Arlington, Goring House burns down in 1674. Its replacement is called Arlington House.

5 TOP FACTS
ROYAL RESIDENTS

Queen Elizabeth II
1 The palace is the Queen's London home. Inhabiting her own quite modest private apartments, she is usually absent during August and September each year.

The corgis
2 The Queen has two corgis, Holly and Willow, and two 'dorgis' (corgi/dachshund crosses), Candy and Vulcan. The royal corgis travel with her throughout the year.

Queen Victoria
3 Britain's longest-reigning monarch, Victoria improved the palace by adding the east wing and state ballroom, but after Prince Albert's death in 1861, she rarely visited it.

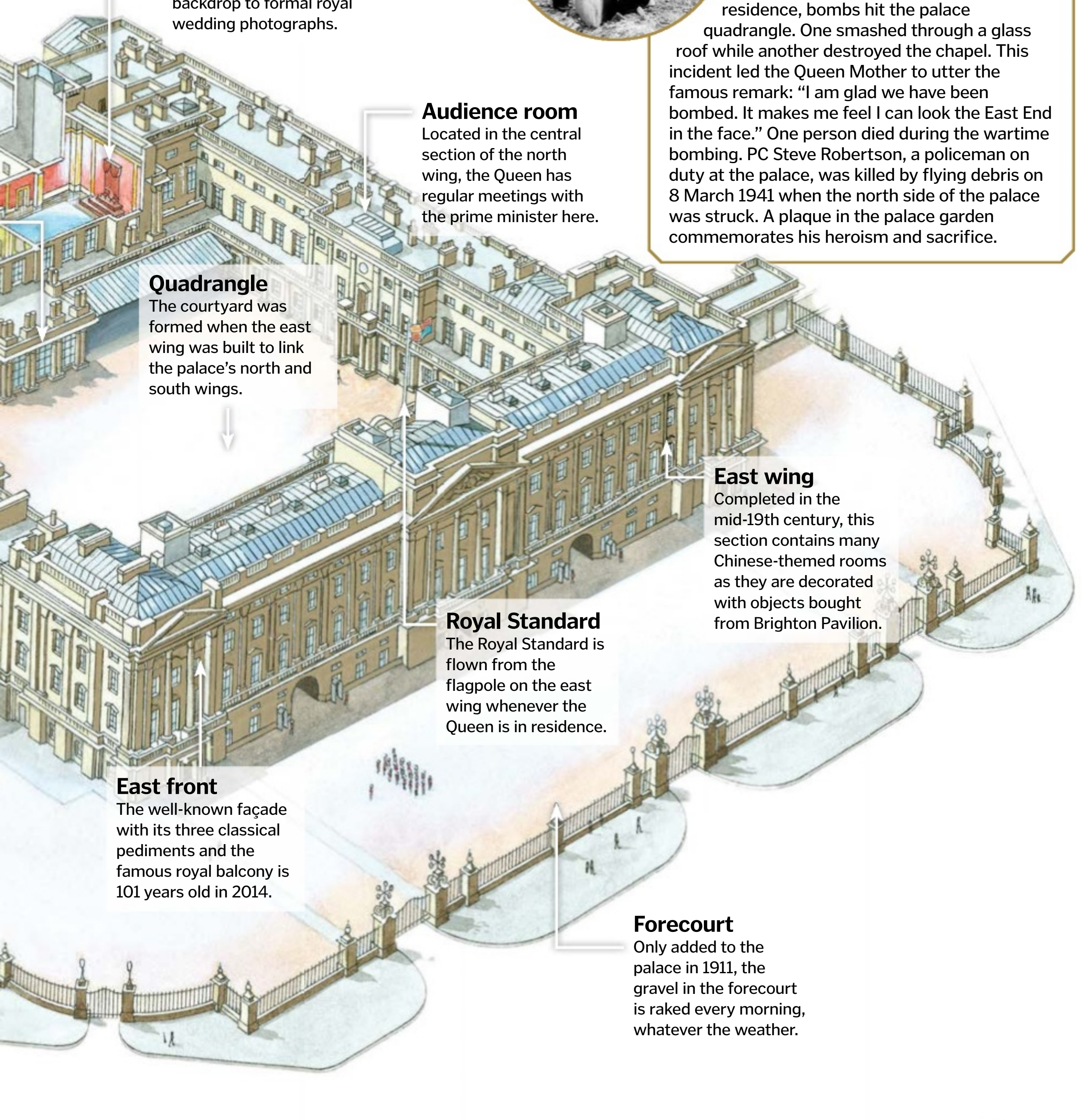
Duke of Edinburgh
4 Since his marriage to Queen Elizabeth in November 1947, Prince Philip has lived alongside her at Buckingham Palace. He has his own private office and apartments.

King Edward VII
5 King Edward VII is the only monarch to date who was both born and died at Buckingham Palace. The king was born there in 1841 and passed away in 1910.

DID YOU KNOW? *There are over 350 working clocks and watches in Buckingham Palace, one of the world's largest collections*

Under fire

The palace suffered nine direct hits from bombs in WWII, but suffered little damage. However, on 13 September 1940, when King George VI and Queen Elizabeth the Queen Mother were in residence, bombs hit the palace quadrangle. One smashed through a glass roof while another destroyed the chapel. This incident led the Queen Mother to utter the famous remark: "I am glad we have been bombed. It makes me feel I can look the East End in the face." One person died during the wartime bombing. PC Steve Robertson, a policeman on duty at the palace, was killed by flying debris on 8 March 1941 when the north side of the palace was struck. A plaque in the palace garden commemorates his heroism and sacrifice.



Throne room
Used for royal receptions, this impressive room is most often seen as the backdrop to formal royal wedding photographs.

Audience room
Located in the central section of the north wing, the Queen has regular meetings with the prime minister here.

Quadrangle
The courtyard was formed when the east wing was built to link the palace's north and south wings.

East wing
Completed in the mid-19th century, this section contains many Chinese-themed rooms as they are decorated with objects bought from Brighton Pavilion.

Royal Standard
The Royal Standard is flown from the flagpole on the east wing whenever the Queen is in residence.

East front
The well-known façade with its three classical pediments and the famous royal balcony is 101 years old in 2014.

Forecourt
Only added to the palace in 1911, the gravel in the forecourt is raked every morning, whatever the weather.

5 other royal pads

1 Windsor Castle
The Queen's official residence and the largest occupied castle in the world. Inside the walls is St George's Chapel, home to the Knights of the Garter and the burial place of ten British monarchs.

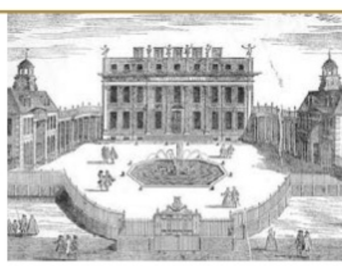
2 Sandringham House
The private home of the sovereign since 1862. The royal family usually spend Christmas here and stay until February each year.

3 Palace of Holyroodhouse
The Queen's official residence in Scotland, founded as a monastery in 1128. Situated at the end of the Royal Mile in Edinburgh, the Queen is usually in residence for a week at the end of June each year.

4 Clarence House
Built in the early-19th century. The Queen lived at Clarence House after her marriage to the Duke of Edinburgh in 1947. Today it's the official home of the Prince of Wales, the Duchess of Cornwall and Prince Harry.

5 Balmoral Castle
The Queen's private home in the Scottish Highlands, the Balmoral estate was bought and the present castle built by Queen Victoria and Prince Albert around 1850.

1703
Buckingham House is built
The house forming the core of the present palace is made for the Duke of Buckingham by architect William Winde.



1761
Royal residence
George III buys Buckingham House for his wife, Queen Charlotte, as a family home close to St James's Palace.

1762
Extreme makeover
King George III employs Sir William Chambers to completely remodel the now old-fashioned house, at a cost of £73,000 – a huge sum in the 18th century.

it to Parliament as their new home after the Palace of Westminster (the Houses of Parliament) was destroyed by fire in 1834. But Queen Victoria decided to make Buckingham Palace her home and, after moving into the house in 1837, decided to have it enlarged as the palace had too few bedrooms for visitors and no nurseries. Blore designed a new east wing and had the Marble Arch moved to its present home at the north-east corner of Hyde Park. The east wing was constructed using French stone and was the last major addition to the palace.

This was not the end of construction work. In 1911, the present forecourt was formed with its impressive gates and railings, where the changing of the guard takes place today (see boxout). Just two years later the stone on the east wing's façade was discovered to have deteriorated so badly due to London's polluted atmosphere that it needed to be replaced. Sir Aston Webb produced a new design and, after a year of preparation, the new Portland stone façade was erected in just 13 weeks.

The palace's most impressive rooms are the state rooms, most of which are in the west wing. These consist of a sequence of theatrically magnificent interiors, designed to impress visitors and magnify the glory of the British monarchy. The state rooms are reached by ascending the grand staircase. The throne room, the blue drawing room and the white drawing room are the principal reception rooms, while the ballroom is frequently used for investitures. Electricity was first installed in the ballroom in 1883 and over the next four years it was extended throughout the palace. Today there are some 40,000 light bulbs in use and since 2005 traditional bulbs have been replaced with LED low-energy bulbs wherever possible.

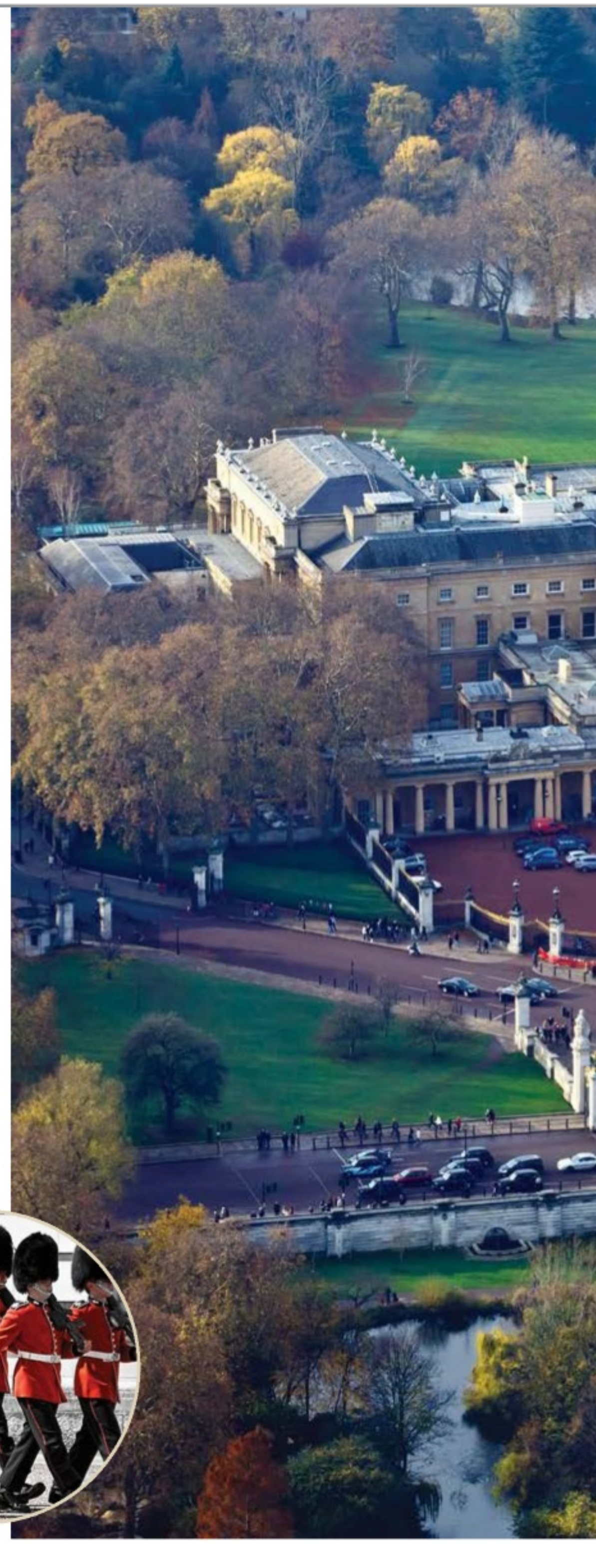
Of the palace's 775 rooms, there are 19 state rooms, 52 royal and guest bedrooms, 188 staff bedrooms, 92 offices and 78 bathrooms. There are some 1,514 doors and 760 windows in the palace; incidentally all the windows are cleaned every six weeks. Aside from the state, private and staff apartments, the palace has its own chapel, post office, swimming pool, staff cafeteria, doctor's surgery and even a cinema. However, despite rumours to the contrary, the palace does not have its own private Underground station!

The gardens are private and surrounded by high walls. They cover 16 hectares (40 acres) and include a lake, tennis court and helipad. Over 99 per cent of green waste produced in the gardens is recycled on site. They are thought to contain about 30 different species of bird and over 350 species of wild flowers. The setting for the annual royal Garden Parties introduced by Queen Victoria in 1868, the gardens have also hosted a charity tennis competition, pop and classical music concerts and a children's party.

Although Buckingham Palace claims to be the world's largest working palace, there are other bigger contenders such as the Apostolic Palace in the Vatican City, Rome, the Royal Palace of Madrid in Spain and the Istana Nurul Iman Palace – home to the sultans of Brunei – which stands on the northern coast of Borneo. Whether or not Buckingham Palace is the world's largest operational palace, it is nonetheless an instantly recognisable symbol of London, the royal family and Britain as a whole.

Changing of the guard in focus

The changing of the guard, or guard mounting, is the process during which the new guard relieves the old guard. Dating back to the 17th century, the household troops stand sentry over the reigning sovereign and have been present at Buckingham Palace since 1837. Taking place at 11.30am each morning from May to July and on alternate days through the rest of the year, the ceremony is accompanied by a guards band, which plays a range of music, including themes from films, musicals and even pop songs. Over 2 million people watch the changing of the guard each year. The guard's uniform of black trousers, red jackets and tall bearskin hats has become synonymous with the British royal family and Buckingham Palace.



1826
House to palace
George IV transforms Buckingham House into a palace. The king employs John Nash and asks Parliament for £450,000 to cover the work.

1830
All change
George IV dies and William IV takes the throne. John Nash is dismissed for having spent nearly £500,000 on the palace and Edward Blore is appointed to finish the job.

1837
Queen Vic moves in
Queen Victoria is the first sovereign to take up residence in Buckingham Palace, in July. It is just three weeks after her accession to the throne.

1847
East wing completed
More space is needed in the palace so an east wing is added to Edward Blore's design. This wing holds the balcony where the royal family appear on special occasions.

201,948

PORTRAIT BY MOST ARTISTS

For three nights in April 2012, an image of the Queen was projected onto Buckingham Palace, made up of 201,948 self-portraits created by British children.

DID YOU KNOW? *Although Buckingham Palace is known the world over, it still has a unique postcode: SW1A 1AA*

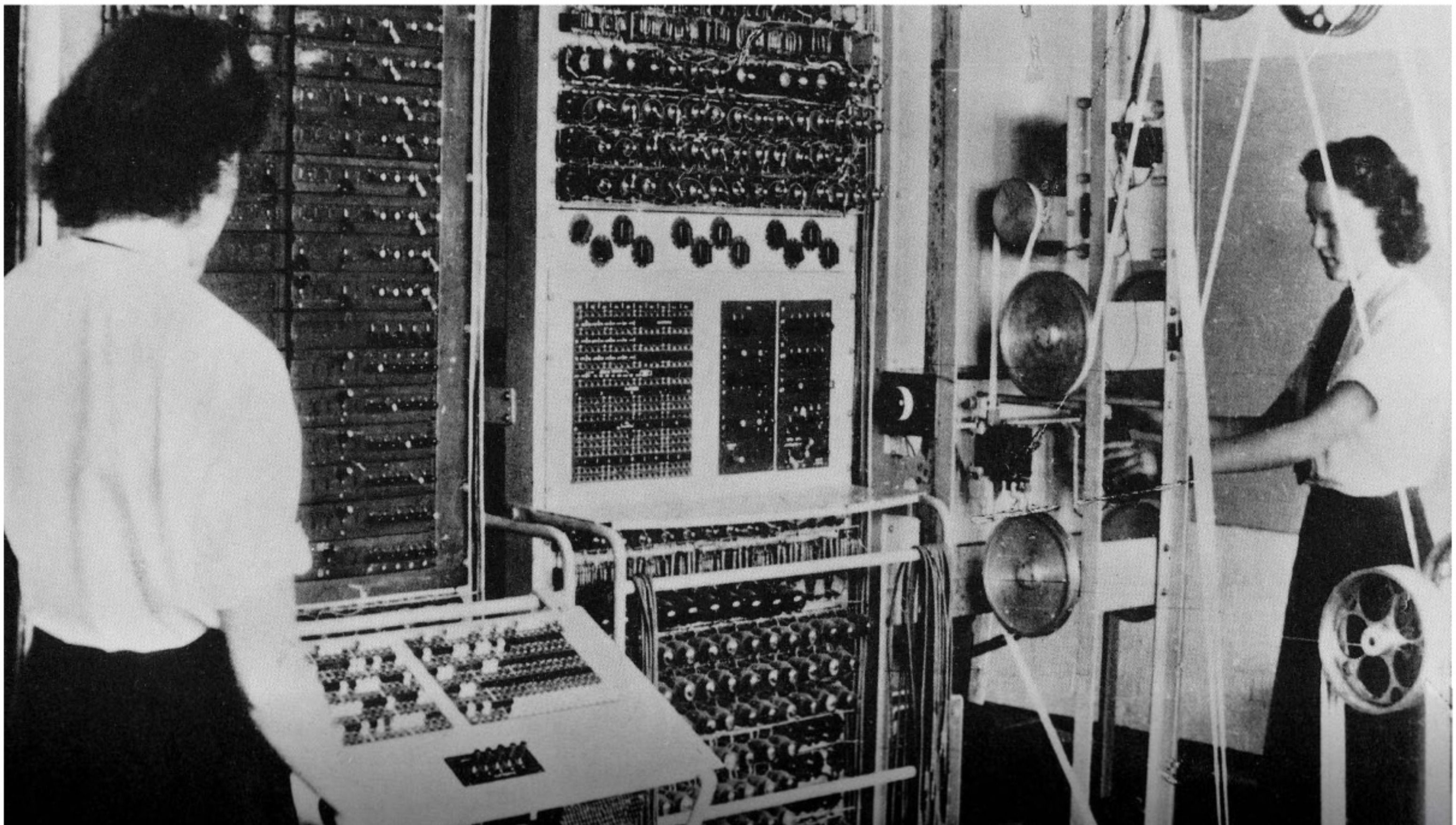
Buckingham Palace with the Victoria Memorial in front, erected in 1911

1911
Changing of the Guard
As part of the Victoria Memorial scheme, the world-famous railings and forecourt in which the Changing of the Guard takes place are laid out in front of the palace.

1913
Face-lift
The soft French stone used on the east front is found to be crumbling, so Sir Aston Webb redesigns the façade and replaces the soft stone with hard Portland stone.

1945
Victory in Europe
On VE Day (8 May), the palace becomes the focus of celebrations, with the Royal Family appearing on the balcony to the cheers of the crowds on the Mall.

1993
Open house
Ever since the summer of 1993 the public have had access to Buckingham Palace's state rooms during August and September, when the Queen is not in residence.



The Colossus computer

How the first programmable digital computer helped bring WWII to an end

The Colossus computer was a machine used by the British intelligence service during World War II to analyse and decrypt teleprinter orders and messages enciphered with a Lorenz SZ40/42 encryption machine by the Nazi Germany High Command. The contents of the messages were of incredible value to the Allies, as they often contained key orders for German generals, including troop movements and tactics.

Prior to the German use of the Lorenz cipher, the Allies had successfully cracked their Enigma code and had for years held the ability to decode messages thanks to Alan Turing's electromechanical Bombe machine. The Lorenz cipher was much more complex, however, with the SZ40/42 enciphering a message by combining its characters with a keystream of characters generated by 12 mechanical pinwheels. As such, without knowing the key characters – ie the position of the pinwheels – no decryption could take place.

The Colossus solved this issue by finding the Lorenz key settings, rather than actually decoding the message – the latter part done manually by cryptologists. The computerised process involved the Colossus analysing the inputted encoded message's characters and then counting a statistic based on a programmable logic function (such as whether an individual character is true or false). By analysing a cipher text in this way a number of times, the initial position of the Lorenz machine's 12 pinwheels could be determined and the keystream established.

Historically, the Colossus proved to be a colossal success, with the Allies decoding many war-changing messages throughout 1944 and 1945 and the generated intelligence used to counter the Nazis' movements in Europe. In addition, after the war, the technological advancements in computing brought about by Colossus led to Britain becoming a pioneering centre for computer science.

A colossal reconstruction

As part of the transformation of Bletchley Park into a museum, a fully functional replica of the Mark 2 Colossus was completed in 2007 by a team of engineers led by electrical engineer Tony Sale. Unfortunately, this was nowhere near as simple as six decades' worth of technological advancement since the war might make you think, with many blueprints and original hardware being destroyed after WWII, leaving those responsible for its reconstruction severely lacking in workable information.

Luckily though, after a dedicated research campaign, many of the Bletchley team's original notebooks were acquired, which when collated delivered a surprising amount of information. As such, by using the notebooks and consulting several original members of the Bletchley team, including the designer of the Colossus's optical tape reader – Dr Arnold Lynch – the reconstruction was completed successfully and is today situated in exactly the same position of the original Colossus at Bletchley Park, where it can be used to crack codes once more.

KEY DATES
COMPUTING MILESTONES

1837 Charles Babbage describes his design for the first mechanical computer – the Analytical Engine.

1936 German engineer Konrad Zuse builds the Z1 (right), which is the first programmable computer.

1943 The original Colossus, the world's first programmable electronic digital computer, is built by Tommy Flowers.

1948 The Small-Scale Experimental Machine (right) is built in Manchester. It can store and run a program from memory.

1975 The first machine to be sold to the public as a 'personal computer' is the Altair 8800.

DID YOU KNOW? *The Colossus was not made public knowledge until the 1970s due to the Official Secrets Act*

A sculpture to commemorate Flowers, with his son (left)

Flowers in focus

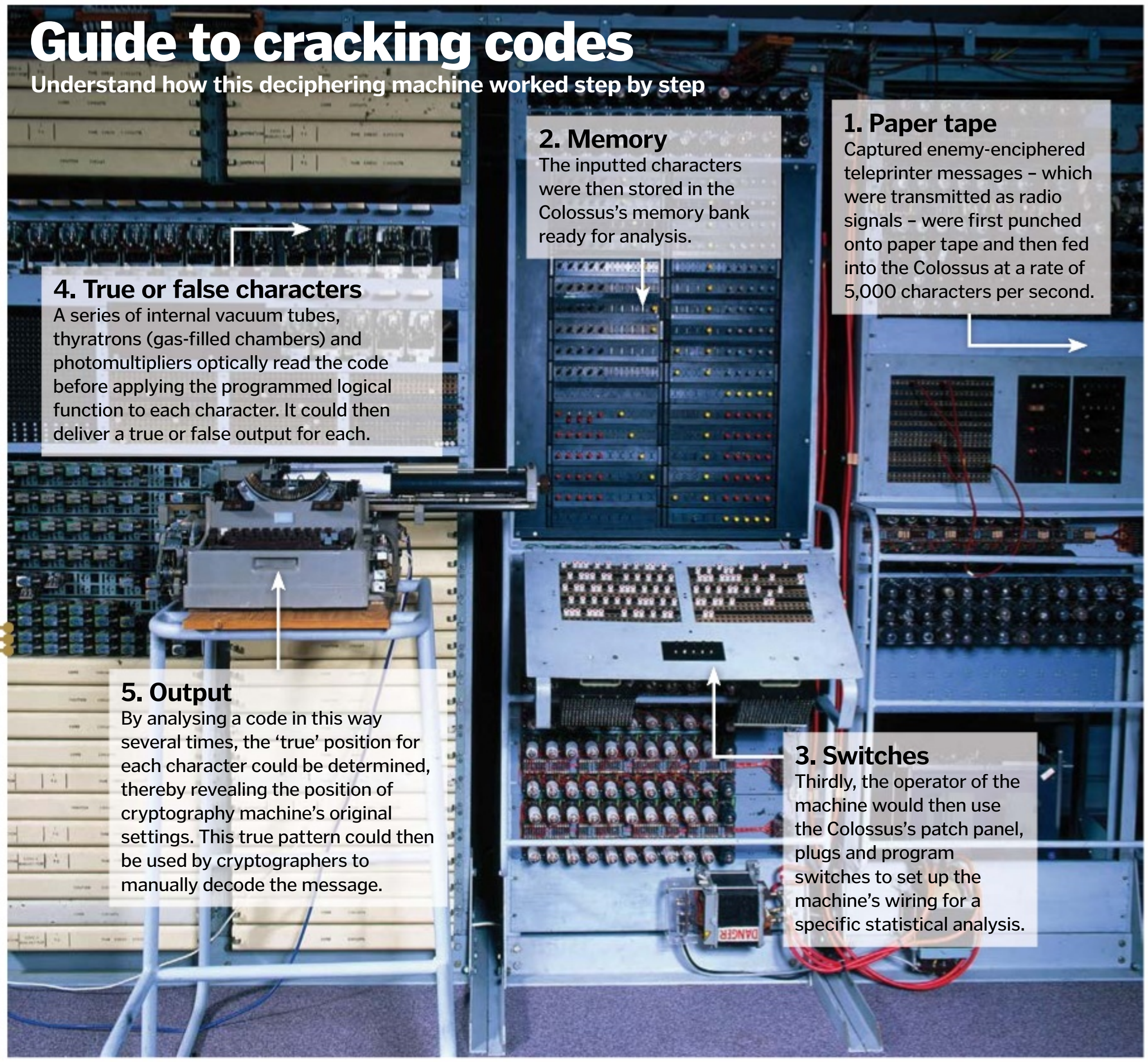
Thomas (Tommy) Flowers was the British engineer behind the design and construction of the Colossus computer. After graduating from the University of London with a degree in electrical engineering, Flowers went on to join the telecommunications branch of the General Post Office, where he explored the use of electronics for telephone exchanges.

Off the back of this work, Flowers was invited to help code-breaking expert Alan Turing to build a machine that could help automate part of the cryptanalysis of Nazi Germany's Lorenz cipher – a high-level cipher used to communicate important orders from the high command.

By 1943 Flowers had built the Colossus, and soon after received funding to create a second improved variant, which went into active service in June 1944. Despite his key role in helping the Allies to victory, Flowers could not talk about his work for decades as he was sworn to secrecy.

Guide to cracking codes

Understand how this deciphering machine worked step by step



1. Paper tape
Captured enemy-enciphered teleprinter messages – which were transmitted as radio signals – were first punched onto paper tape and then fed into the Colossus at a rate of 5,000 characters per second.

2. Memory
The inputted characters were then stored in the Colossus's memory bank ready for analysis.

3. Switches
Thirdly, the operator of the machine would then use the Colossus's patch panel, plugs and program switches to set up the machine's wiring for a specific statistical analysis.

4. True or false characters
A series of internal vacuum tubes, thyratrons (gas-filled chambers) and photomultipliers optically read the code before applying the programmed logical function to each character. It could then deliver a true or false output for each.

5. Output
By analysing a code in this way several times, the 'true' position for each character could be determined, thereby revealing the position of cryptography machine's original settings. This true pattern could then be used by cryptographers to manually decode the message.

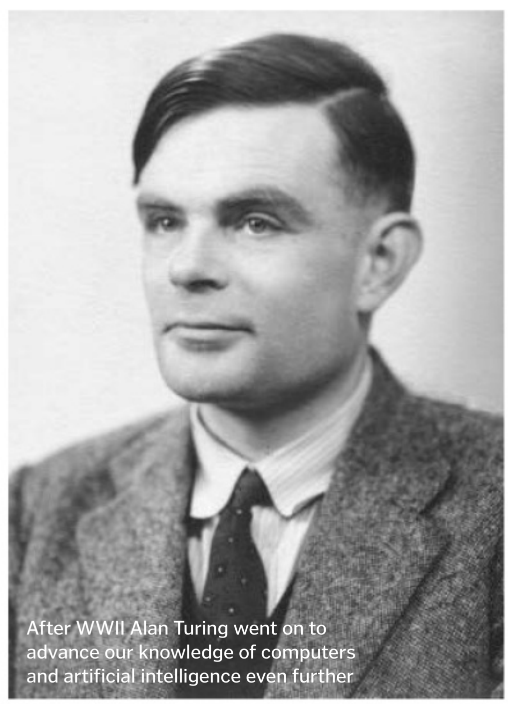
In 1993 Bletchley Park was re-opened as a museum devoted to code breakers

Bletchley's role in WWII

Bletchley Park was the British government's main decryption headquarters throughout World War II. Located in Milton Keynes, Buckinghamshire, England, Bletchley was a top-secret facility for Allied communications, with a diverse team of engineers, electricians and mathematicians working manually – and later with the help of decryption machines – to break the various enemy codes used to disguise orders and private communiqués.

Among the many decoders – also known as cryptanalysts – working at Bletchley, Alan Turing became by far the most famous, with his work in breaking the Enigma and then Lorenz codes earning him the nickname the 'Father of Computer Science'. Indeed, between them Turing, Flowers and the rest of the Bletchley team's efforts arguably were crucial to the Allies' eventual victory in 1945, with the intelligence gathered by them – intel which was code-named 'Ultra' – speculated by some to have shortened the war by up to four years.

Today Bletchley Park is run by the Bletchley Park Trust, which maintains the estate as a museum and tourist attraction, with thousands of people visiting the site every year. Among the Trust's many activities is the reconstruction of many of the machines that helped to break the Axis codes – as discussed in more detail in 'A colossal reconstruction' opposite.



After WWII Alan Turing went on to advance our knowledge of computers and artificial intelligence even further

Brooklyn Bridge

One of New York's most recognisable landmarks, the Brooklyn Bridge was the first-ever steel-wire suspension bridge

Built between 1870 and 1883, the Brooklyn Bridge links Brooklyn and Manhattan by spanning the East River in New York City. Designed by a German immigrant, John Augustus Roebling, it was his son, Washington Roebling, and daughter-in-law, Emily, who actually oversaw most of the construction after John's unexpected death just months before building commenced.

The bridge consists of two main elements. Firstly, there are the two anchorages that are positioned either side of the river and between them are two towers (also known as piers) which stand some 84 metres (277 feet) high. Consisting of limestone, granite and cement, the towers – designed in a neo-Gothic architectural style – stand on concrete foundations that run 13.4 metres (44 feet) and 23.8 metres (78 feet) deep on the Brooklyn and Manhattan sides, respectively.

Secondly, the bridge itself is constructed from iron and steel-wire cables, with a layer of tarmac on the main deck. At 26 metres (85 feet) wide and 1,825 metres (5,989 feet) long, the Brooklyn Bridge was the longest suspension bridge in the world when first built and held the record for over 20 years. Roebling's design includes many redundancies, such as a diagonal stay system between cables and stiffening trusses, which make the bridge very safe; indeed, even if one of the main support systems were to fail altogether the bridge would sag, rather than completely collapse.

More unusually, the bridge also has its own nuclear fall-out shelter built into one anchorage. Having fallen out of use and been forgotten, the shelter was rediscovered in 2006, along with provisions from the Cold War era. Designated a National Historic Landmark in 1964, since the Eighties the bridge has been floodlit at night to highlight its distinct architectural features. Initially intended to carry motor vehicles, trains, street cars, bicycles and pedestrians, since the Fifties, the bridge has only taken cars, cyclists and foot traffic. Over 120,000 vehicles, 4,000 pedestrians and 3,100 cyclists cross it every day.

1,991m

LONGEST SUSPENSION BRIDGE

When completed in 1883, the Brooklyn Bridge's was a record holder, but today it has been superseded by the Akashi Kaikyo Bridge in Japan, with a main span of 1,991 metres (6,532 feet).

DID YOU KNOW? *In 1884, showman PT Barnum paraded 21 elephants over the Brooklyn Bridge, proving its stability*

The origins of suspension bridges

In a suspension bridge the deck – the load-bearing portion – is hung below suspension cables on vertical suspenders which bear the weight. Although bridges of this design first seem to have been invented in 15th-century Tibet, it was really the 19th century which saw their application on a massive scale.

The materials used in the construction of the Brooklyn Bridge were sourced in the US. The granite blocks were quarried in Maine and delivered to New York by boat. The wire rope and steel cable were produced in local factories, while the pigment used in the red paint with which the bridge was originally covered came from the mines at Rawlins, Wyoming.

The design and construction techniques employed in the Brooklyn Bridge have changed little in their essentials over the last century or so. Although at least 81 suspension bridges today are longer than the Brooklyn Bridge, they are all fundamentally the same – except that now the materials tend to be drawn from all over the globe rather than sourced locally.

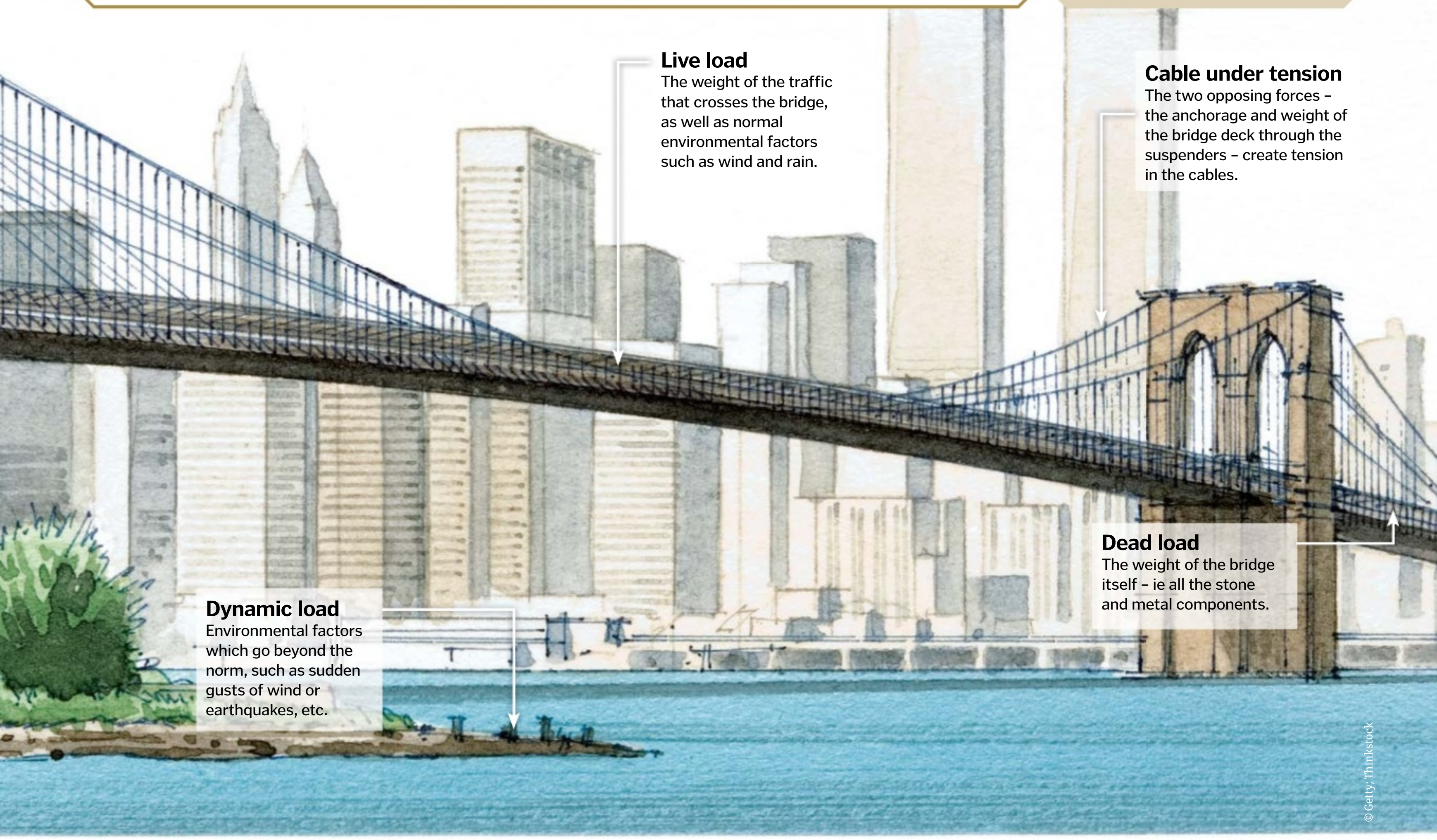
The Brooklyn Bridge during construction in the late-19th century

Cultural impact

Since its completion, the Brooklyn Bridge has inspired many an artist and poet. The modernist American poet Hart Crane, for example, famously published the ode *To Brooklyn Bridge* in 1930. Regarded as a wonder of its age, people flocked to see the structure's opening with a spectacular fireworks display and regatta in 1883 – a celebration which was repeated on its 100th anniversary.

Many people have jumped off the bridge as publicity stunts or suicide attempts, while others have got married on it. In 1919 the Caproni heavy bomber, which was then the world's largest aeroplane, was flown under the deck, while in 2003 it was the intended target of an Al-Qaeda terrorist plot.

The Brooklyn Bridge has also frequently appeared in Hollywood movies, such as *I Am Legend*, *The Dark Knight Rises* and *Godzilla*; most recently the bridge featured in *The Great Gatsby*.



Ancient Egyptian cosmetics

Makeup was once an important part of everyday life in Egypt – find out why now

In Ancient Egypt, the image of an individual often acted as a substitute for the body in the afterlife. Therefore, in funerary paintings, both males and females are shown in their best clothes, wigs and makeup.

In life, the Egyptians utilised a variety of pigments to adorn the face. The most predominant of these was kohl, which was used to line the eyes. Kohl came from two sources: a green eye paint made of mineral malachite and a black liner derived from galena, a form of lead ore. Women used red ochre to form a light blush for cheeks and lips, while henna was used to paint the nails and dye the hair. Cosmetics were also applied for practical reasons – the military wore it to protect their eyes from the intense glare of the African Sun. Moreover, it had a religious resonance – each day, in the holy sanctuary of the temple, the god was anointed with makeup as a symbol of celestial regeneration.

Applicator
The applicator was used to add rouge to the lips. It was made of wood, ebony or ivory.

Bronze mirror
The Egyptians used mirrors of polished bronze. The handle was often carved in the form of an Egyptian goddess.

Wig
Because of lice infestations, Egyptians often shaved their head. They wore elaborate wigs of real human hair, which were adorned with flowers and braids.

Cosmetic spoon
These spoons are highly decorative – the one shown here is fashioned in the shape of a swimming girl.

Cosmetic jars
The Egyptians' special oils and unguents were stored in containers made from glass, faience ceramic and stone.

How did we make candles?

Shining a light on the manufacturing process behind this valuable source of illumination

Long before the advent of the light bulb, candles were our primary form of artificial light, with the art of candlemaking, or chandlery, both celebrated and profitable for those with the necessary tools and expertise. Indeed, while today candles are made en masse by machines, right up until the early-20th century teams of workers harvested the raw ingredients, prepared them in industrial workshops and moulded them into the finished product. Of course, with the arrival of the electric light bulb, the industry went into decline. Take a closer look at a typical Victorian candlemaking workshop in this annotated illustration.

1 Rending the fat
Before modern-day wax varieties were produced candles were made with tallow, which was rendered by melting animal fat.

2 Storing the tallow
The melted tallow was put in large vats for easy transport. Metal kettles were used to scoop it up for pouring into moulds.

3 Preparing the wicks
Professional makers spun wicks out of strands of cotton. Amateur makers used strands of any material they could acquire.

4 Dipping the wicks
Prepared wicks were dipped in tallow repeatedly to build up a base layer and lend the wick some strength.

5 Pouring the tallow
Often piston-powered moulds took a wick through a small hole before melted tallow was poured in around it.

6 Hanging the candles
Once extracted from the mould, the candle would be cleaned and hung from a rack to harden before being sold.

What were pneumatic tube systems used for?

Discover how these unusual machines transported messages in a flash

Pneumatic tube systems were a novel form of transportation popular in the late 19th and early 20th century, in which cylindrical containers were transported through a network of metal tubes via compressed air or by partial vacuum.

The systems were developed as an alternative form of courier for objects, letters and even – for a short, experimental time – people, with banks, post offices, telegraph exchanges and offices all connecting themselves via an intra or extranet of tubes.

The most common use for pneumatic tubes was in post offices and telegraph exchanges, with large city-based postal centres connected to local branches by miles upon miles of tubing. These systems greatly sped up the delivery of physical mail, reducing the need for human postal workers to cross large areas of a city, only making the final short connection between local branch and target destination on foot. The same largely became true for banks, with money, deposits and even withdrawals actioned via pneumatic tube.

Indeed, the uptake of pneumatic tube systems was so great that in the latter decades of the 19th century it was even attempted to extend the principle to carry people, with projects such as the 1869 Beach Pneumatic Transit Company in New York building hundreds of metres of subway-style tube networks. While these systems worked, the upscaling in size largely eradicated the efficiency and speed of smaller, post-sized networks, leaving them to be abandoned in favour of traditional rail networks.

Down but not out

Despite pneumatic tube systems garnering widespread popularity and usage through late-19th and early-20th-century cities worldwide, the advent of the digital computer, internet and World Wide Web meant that by the turn of the 21st century, they were almost all redundant. After all, no pneumatic tube system could run a message from London to New York in a matter of seconds like an email can.

However, despite email's dominance, pneumatic tube systems are still used today in select areas – foremost of which is in the medical sphere. Many large hospitals and medical research laboratories have extensive pneumatic tube networks, allowing drugs, tools, blood packs and biological samples to be rapidly transited around typically large and warren-like facilities. To gain a better understanding of how these amazing systems work, be sure to take a look at the video link above.

Telegraph exchange step-by-step

Follow the journey of a telegraph and find out the role pneumatic tubes played

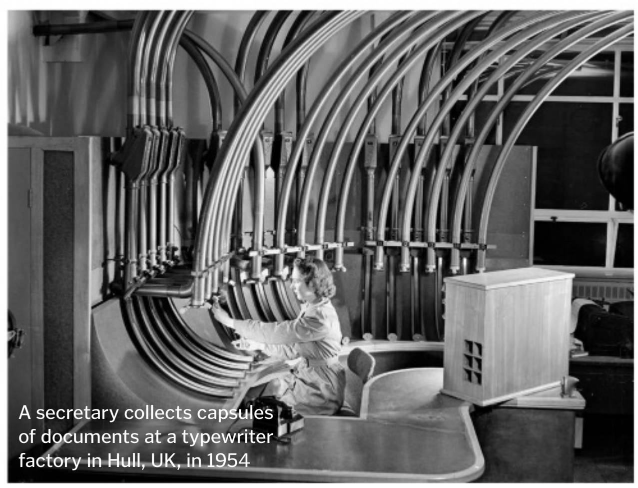
1. Telegraph in
Telegraphs would enter the exchange from their point of origin – ie another post office branch – via manual mail or pneumatic tube delivery.

2. Sorting
The telegraph would be sorted, with its destination logged by human operators.

3. Re-routing
The telegraph would then be re-routed in the exchange, being sent to the relevant dispatch area via an intranet of internal pneumatic tubes.

4. Telegraph out
Once at the dispatch area, the telegraph was sent out by pneumatic tube. This network was extensive in major cities, transporting the telegraph over hundreds of metres.

5. Receipt
The sent telegraph would arrive at its destination's local office or exchange, with the communiqué delivered in person to the recipient.



A secretary collects capsules of documents at a typewriter factory in Hull, UK, in 1954

A tube used to transport airmail between a post office and the airport in the Thirties

Jerusalem under siege

From Roman battles to WWI, this city has seen more than its fair share of conflict

In its long history, the city of Jerusalem has been besieged over 20 times. One of the oldest cities in the world, it has been the scene of Roman civil wars, holy crusades and even a world war.

The first siege of the Common Era was when the city was under Roman rule in 70 CE. Started by the Great Jewish Revolt in 66 CE, the Jews were incensed when a Roman official stole from the synagogue. Jews rose up against their oppressors' rule and established Jerusalem as the centre of rebellion. Subsequently, Emperor Vespasian ordered a force led by General Titus to retake the city. Battering rams, catapults and siege towers were used to destroy the walls and sacred relics from the city's temple were stolen. The Arch of Titus in Rome was built to commemorate the victory.

Perhaps the most famous of all Jerusalem's conflicts, though, were the Crusades. In the First Crusade of 1099, a Christian army with 12,000 infantry and 1,500 cavalry took the city. Siege towers and scaling ladders were used to overwhelm the defences of one of the best-defended metropolises of the age.

This victory led to a counterattack in 1187 from Saladin of the Ayyubid Dynasty. The city, still under Christian rule, was defended by Balian of Ibelin. At first, Saladin negotiated for a peaceful surrender but after it was rejected he began besieging Jerusalem.

He focused his attacks on the Tower of David and the Damascus Gate. The assault was repelled so the attention was turned to the Mount of Olives, which had no gate. This proved to be a tactical masterclass and, just as the Christian stronghold was about to fall, Balian offered a negotiated surrender to which Saladin eventually agreed. The later Third Crusade led by Richard the Lionheart and Philip II in 1189 aimed to reclaim the city, but ultimately failed.

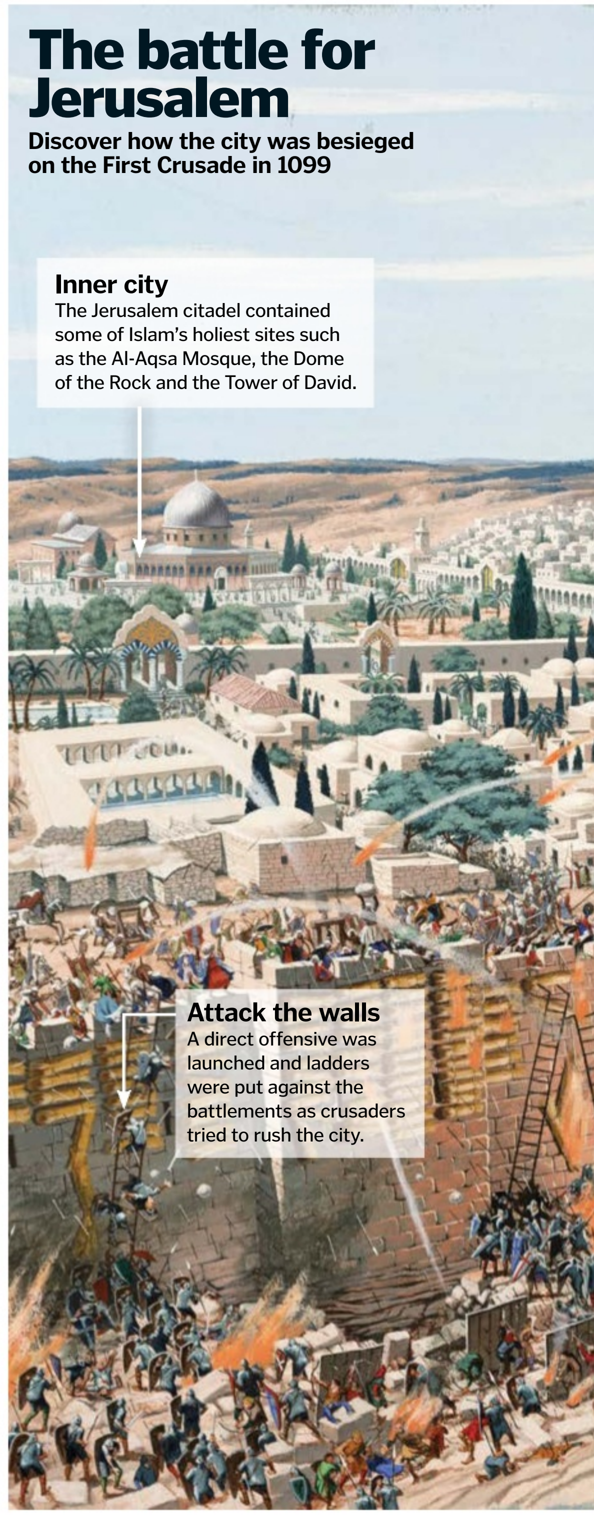
The next major siege was centuries later in 1917 during World War I. A battle between the British and the Ottoman Empire, the city fell into Allied hands after several days of fighting. The city remained under British rule until 1948, when the Arab-Israeli War divided Jerusalem between Israel and Jordan, leading to decades of internal conflict. Today, it is the capital of two sovereign states: Israel and Palestine.

Why is Jerusalem so sought after?

Jerusalem has been regarded as a city of religious significance for Jews, Christians and Muslims for over 2,000 years. For Crusaders, the city needed to be recaptured from Muslim rule, as it was essential to pilgrimages. In Judaism, Jerusalem is considered holy and is often known as Zion. Jews believe the city was designed for them by God. For Islam, the city contains one of the holiest mosques after that in Mecca and is known as Al-Quds. Jerusalem was also geographically important for different empires to get a foothold on the Middle East for military campaigns and trade.

The battle for Jerusalem

Discover how the city was besieged on the First Crusade in 1099



Road to Jerusalem

Jerusalem was the main target for the First Crusade – here's how the conquest unfolded

Nov 1095
Christian armies from the West, encouraged by Pope Urban II, decide to recapture the Holy Land from the Muslims.

Dec 1096
Western forces arrive in the Byzantine capital of Constantinople to begin the war.

Jun 1097
The Anatolian city of Nicaea is captured, followed by an eight-month siege of Antioch (right).

5 TOP FACTS
FAMOUS SIEGES

Gibraltar
1 The Great Siege of Gibraltar was a French and Spanish attempt to take over the British stronghold. Lasting over three years, the British held out despite navy blockades.

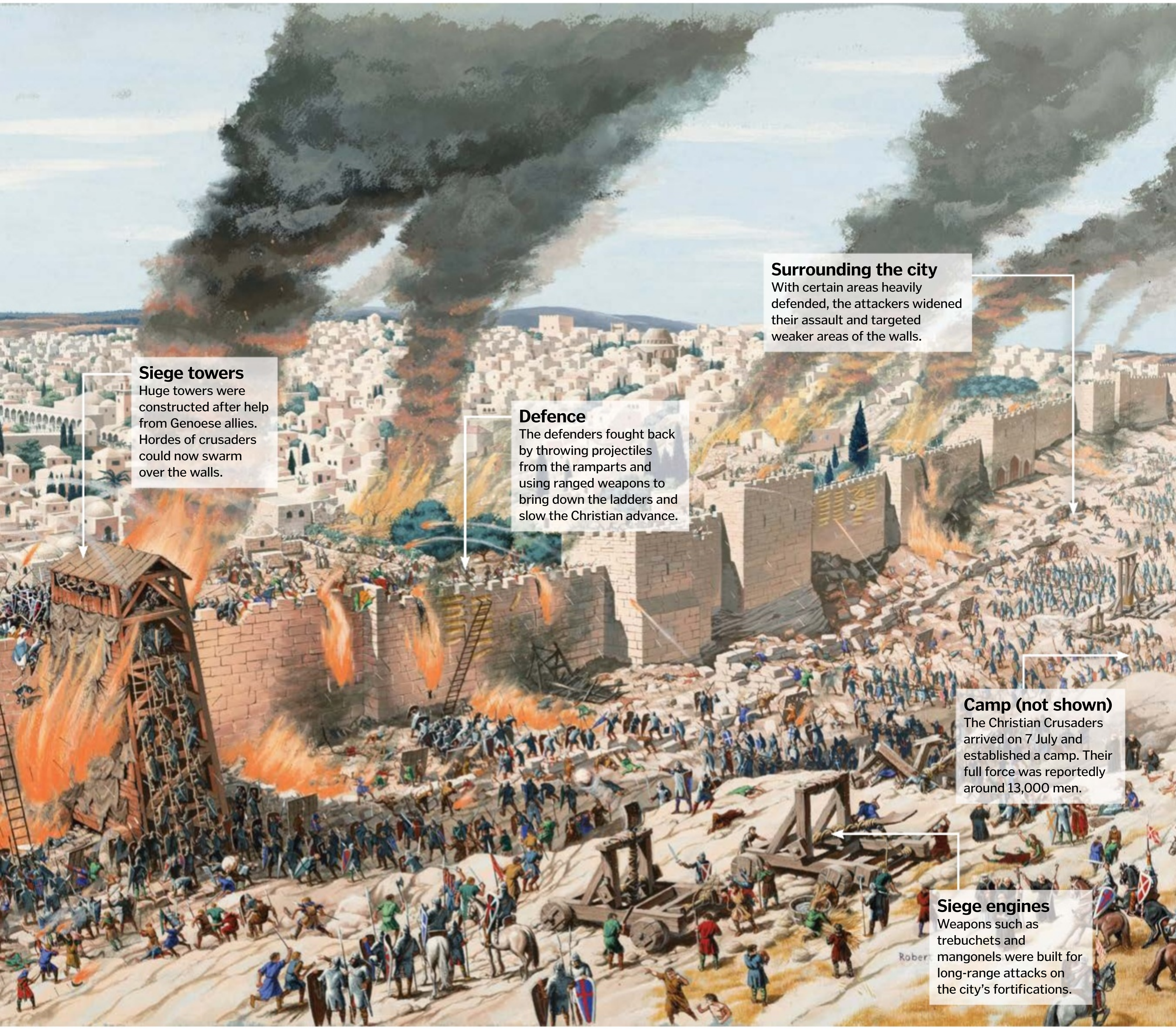
The Alamo
2 Fought during the Texas War of Independence in 1836, the Alamo is renowned for the bravery of 200 Texans who held out over a 13-day siege against 6,000 Mexicans.

Candia
3 Lasting for two decades, the Siege of Candia is the longest in history. 60,000 Ottomans attacked the Venetian city in Crete in 1648 and it eventually succumbed in 1669.

Constantinople
4 In 1453, just 10,000 men stood against 100,000 Ottomans. Cannons and warships led to not just the city's demise but also the fall of the Byzantine Empire.

Stalingrad
5 In 1942, Soviet city Stalingrad was surrounded by German forces. Fierce street-to-street fighting ensued, eventually resulting in a Russian victory and a turn of the tide in WWII.

DID YOU KNOW? 2005's Hollywood blockbuster film Kingdom Of Heaven is based on the 1187 Siege of Jerusalem



Jul 1097
The first big skirmish of the campaign at Dorylaeum results in heavy losses but a Christian win.

Dec 1097
The Muslims, led by Duqaq and Ridwan, strike back in two battles at Harenc but are repelled.

Jun 1098
The Battle of the Orontes sees a 75,000-strong Islamic army, low on morale, defeated by 15,000 Christians.

Jun 1099
The Siege of Jerusalem begins and the Crusaders are victorious by July (right).

Aug 1099
At the Battle of Ascalon, an Egyptian force of 50,000 is defeated by the Crusaders. With Jerusalem still under Christian control, the First Crusade ends.

Saint Mark's Basilica

Why does Venice's most storied and famous church have so much treasure within its walls?

An eye-catching mix of Eastern Byzantine, Western Gothic and even Islamic styles of architecture and art, Saint Mark's Basilica in Venice, Italy is testament not just to the wealth and power of the Medieval Republic of Venice in northeastern Italy, but to its swashbuckling adventures in the Mediterranean – not just as traders, but as conquerors.

In 828, two rather unscrupulous Venetian merchants stole what they believed were the remains of Saint Mark the Evangelist from Alexandria in Egypt. Declaring Saint Mark their home city's patron saint, they then built a church to house the body. Instead of hiding its origin, one mosaic in Saint Mark's Basilica even boasts of the theft – showing the Venetians in question hiding the stolen saint in barrels of pork, which the Muslim Egyptians were forbidden from touching, so that the customs officials wouldn't inspect their cargo too closely.

After the original church was damaged in a fire in 976, it was restored and then rebuilt some time before 1094 around the striking central dome that still stands there today. With Venice at the height of its powers in the 11th to 14th centuries, the city provided naval support to European armies in the Crusades and actually led the Fourth Crusade against Constantinople (now Istanbul in Turkey, but then the Greek Orthodox Christian capital of the Byzantine Empire) and took the opportunity to loot its many religious relics, gold and chalices, as well as four bronze horse statues, to further embellish their Basilica. The Venetians even stole mosaics, columns and carvings from various churches and houses of worship across the Middle East to pile onto their own back in Venice.

Not everything that found its way into the Basilica was taken by force, though, for it was also a tradition for Venetian merchants to bring back gifts from their travels, making Saint Mark's Basilica – or to give it its 11th-century nickname, Chiesa d'Oro, or 'Church of Gold' – one of the most beautiful cathedrals in not only Italy, but all of Europe.

Inside the Church of Gold

The many origins of St Mark's interior

KEY DATES
ST MARK'S STORY

832
The original Saint Mark's Basilica is constructed to house the saint's pilfered remains.

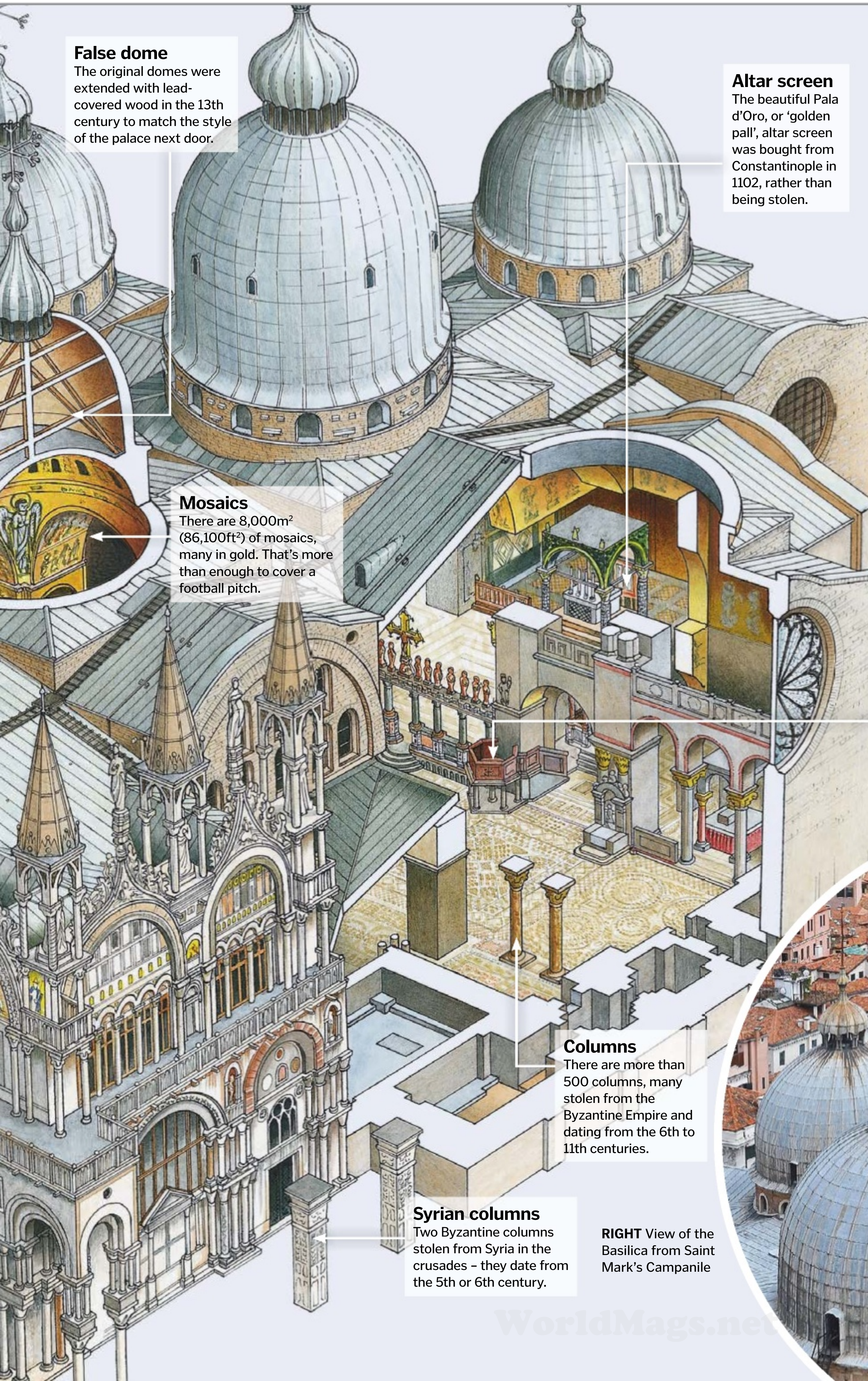
976
The Basilica is damaged by a fire during a revolution against Venice's ruler Pietro IV Candiano.

1094
The new church is consecrated. It will be modified many times over the coming centuries.

1202
Venice leads the Fourth Crusade against Constantinople; Saint Mark's is showered in booty.

1797
Napoleon Bonaparte steals many treasures from Saint Mark's. Most are later returned.

DID YOU KNOW? Saint Mark's Basilica only became Venice's cathedral in 1807 – prior to that it was a chapel



The falling tower

Italian churches often have bell towers, or 'campaniles', separate from the main building and Saint Mark's Campanile, which stands 50m (164ft) high, was built in the 9th century. The tower is so iconic that not only does it adorn postcards, magnets and T-shirts, but replicas – most often used as clock towers – can be found around the world.

But even Saint Mark's Campanile itself is something of a replica. In the early hours of 14 July 1902 a crack appeared in the wall, which continued to grow. Then at 9.45am, the tower completely collapsed. It was rebuilt with stronger foundations and finally opened on 25 April 1912. The reconstruction cost 2.2mn lire (£88,000), a vast amount at the time.

RIGHT View of the Basilica from Saint Mark's Campanile

AGE OF THE DINOSAURS

From birth to extinction, get to know these prehistoric beasts inside and out with our comprehensive A-Z guide

Dinosaurs have long sparked our imagination. From the Ancient Greeks' perception of their remains as evidence of a time when giants ruled Earth, right through to modern man's pursuit of their resurrection – be that in films like *Jurassic Park* or in laboratories via advanced DNA cloning techniques – dinosaurs remain a tantalisingly alien part of our world's history.

They may no longer roam the land like they did millions of years ago, but thanks to their genetic legacy and preserved remains they still remain a very real presence today.

From the fossils lying trapped in the ground through to the descendants flying above our heads, dinosaurs have unique tales to tell.

In this special History feature we take a closer look at this ancient world through an A-Z encyclopedia of all things dinosaur. You'll learn not just about the creatures themselves but the tools and techniques used to study them, and what Earth was like during their reign. This guide truly has it all, so strap yourself in and prepare for one wild, prehistoric ride…

Benton on a fossil dig near Albuquerque, New Mexico

Professor Mike Benton, palaeontologist

Mike Benton is the Professor of Vertebrate Palaeontology at the University of Bristol, UK, and is a world-renowned dinosaur specialist. His areas of expertise include the diversification of life through time, the origin of dinosaurs and the end-Permian mass-extinction event. He can often be found working on digs in Russia and China. He offers some words of wisdom throughout our dino guide, but for a more in-depth interview, head to www.howitworksdaily.com.

252.2mn years ago (Ma)
Triassic starts – The Triassic period begins, marking the beginning of the Mesozoic era. The first dinosaurs emerge at this point.

252.2 Ma
Induan is hot – The first stage of the Early Triassic, known as the Induan, is characterised by a hot and largely deserted world.

250 Ma
Archosauriformes appear – Archosauriformes, a clade of diapsid reptiles, evolve and take over all semi-aquatic environments.

247.2 Ma
Mid Triassic – The Mid Triassic period begins, consisting of the Anisian and Ladinian ages. Ferns and mosses dominate the flora.

A

Amber & dino DNA

Amber is fossilised tree resin that, due to a chemical change after burial in the ground, turns into a solid. Despite its stable state today, when the majority of the Earth's amber formed, it was far more fluid, which means many little organisms unwittingly became stuck within it – including plant matter and insects. Today these appear frozen within the amber and have been perfectly preserved. While one or two studies in the Nineties claimed to extract DNA from these organic inclusions (as portrayed in *Jurassic Park*), more recent research suggests this isn't possible. Scientists at the University of Manchester using advanced DNA sequencing in 2013 were not even able to find traces of DNA in copal (a precursor to amber) only 10,000 years old, so they're very doubtful that dino DNA could have survived from millions of years ago.

C

Communication in focus

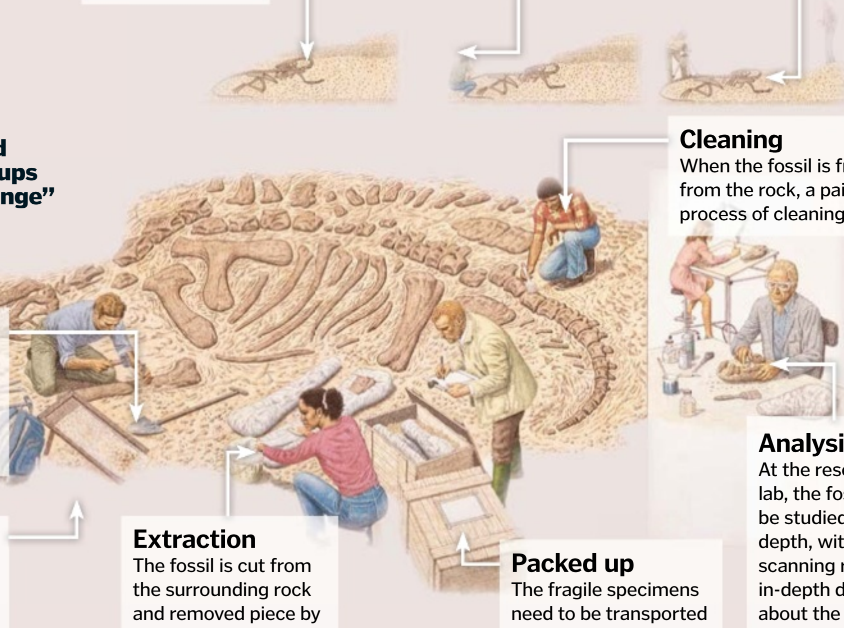
Dinosaurs, much like the many species of animal alive today, communicated in very different ways. From complex dance-like movements to more obvious calls and scent markings, each dino marked their territory, warned of potential predators and relayed information regarding food in its own unique way. One of the most interesting examples comes in the form of the hadrosaurid (above), a duck-billed dinosaur family sporting a distinctive bone crest on their heads. These crests were used as a resonating chamber for projecting their calls. Considering the hadrosaur's modest size and its wide range of predators, the ability to amplify its calls was no doubt a valuable defensive mechanism.

B

Bone secrets

Dinosaur bones are one of a palaeontologist's greatest sources of information, supplying data about their age, anatomy, distribution and much more. The bones of dinosaurs can only be found if they went through the process of fossilisation, where the tissue of the creature dissolves and gets replaced with minerals under pressure beneath the ground. Finding and extracting these fossilised bones is a major challenge for palaeontologists, with a carefully planned out dig site essential.

"Certain kinds of excavation and study out in the field can be for palaeoecology, trying to reconstruct food webs and modes of locomotion, or they can be about looking at patterns over time, going up metre by metre in rock formations and analysing fossil groups to see how they change"



Discovery
Most fossils are discovered at first only in part, with just a small fragment visible above the surface.

Shooting in situ
Photography plays a crucial part of any excavation. The specimen is continuously snapped from its discovery right through to removal.

Clearance
Once the fossilised bone has been photographed, the rock around it is carefully cleared to allow better access to the fossils.

Cleaning
When the fossil is freed from the rock, a painstaking process of cleaning follows.

Tools
Clearance is achieved with chisels, hammers and spades. The closer to the fossil the more delicate the tools.

Boundary
As soon as the fossil has been confirmed, a boundary is staked, protecting the area so palaeontologists can work unhindered.

Extraction
The fossil is cut from the surrounding rock and removed piece by piece, with each one meticulously labelled.

Packed up
The fragile specimens need to be transported with great care, with fossils placed in padded containers.

Analysis
At the research lab, the fossil can be studied in depth, with laser scanning revealing in-depth detail about the dinosaur.

230 Ma
Lagosuchus – The small archosaur Lagosuchus emerges. This creature can run quickly on its hind legs for short periods like later dinosaurs.

225 Ma
Sharovipteryx glides – An early gliding reptile called Sharovipteryx mirabilis evolves, capable of flying between tree habitats.

216 Ma
Coelophysis arrives – The theropod dinosaur Coelophysis flourishes on land. It is a slenderly built carnivore that walks on two legs.

201.3 Ma
Triassic ends – The Triassic-Jurassic extinction event wipes out nearly 30 per cent of marine life.

D

Diplodocus: a dino titan

Of all the dinosaurs that lived on Earth few can truly lay claim to be a terrestrial giant – but the Diplodocus can. Built like a suspension bridge, the Diplodocus measured over 25 metres (82 feet) long – that's longer than five African elephants! It weighed over 12 tons, roughly 170 times more than the average human. It had an incredibly long neck and counterweight tail, the former used to elevate its head into the foliage of trees for food, while the latter was its primary form of defence. With a typical Diplodocus estimated to have lived between 50 and 80 years, it also had one of the longest life spans of any dinosaur from the Jurassic period.

F

Feathered fiends

Since palaeontologists began uncovering dinosaur remains in the 19th century, our depictions of them in the flesh have been largely coloured by a few initial artist impressions, with figures such as Charles Knight often drawing species in inaccurate postures and with factually incorrect sizes, colours and features. Based on current evidence, the lack of feathers on most species is one of the most obvious flaws in these early depictions, with half of all non-avian theropods now thought to have been partly feathered. The main cause for these misassumptions has been the lack of evidence, with feathers and soft tissues rarely preserved like fossilised bone.

"Colour in dinosaur feathers was a topic I think people thought that we would never know the answers to. But we were able to rely on a fair number of fossil feathers that were exceptionally well preserved and deep within their internal structure we could see colour-bearing organelles. So by using some smart observations and techniques we have proved it to be possible"

E

Extinction

Dinosaurs perished some 65 million years ago in what is known as the K-Pg (formerly K-T) extinction event. This cataclysmic event at the Cretaceous-Palaeogene boundary led to 75 per cent of all species on Earth dying off. From the smallest ocean plankton to the largest land beasts, the K-Pg extinction event resulted in devastation at every level of the world's ecosystems, with all non-avian dinosaurs eradicated. The current theory for the catalyst of this global wipeout is an asteroid impact in South America, but the real cause for such widespread carnage was not the impact itself but its knock-on effects. These include plants not being able to photosynthesise due to dust blocking out the Sun plus a series of epic tsunamis and fire storms.

G

Genetic legacy

Today the study of dinosaurs is entering an exciting new age, where we can achieve an unprecedented level of accuracy through cutting-edge analysis. After a T-rex's soft tissue was discovered within a bone sample, we can now study things like proteins, blood vessels and other micro-anatomy to help us determine how individuals lived and died, as well as how dinos evolved.

H

Hunting strategies

Whether dinos hunted and scavenged alone like the T-rex or in large packs like the Deinonychus – the model for the Velociraptor in *Jurassic Park* – carnivorous dinosaurs were no doubt the apex predators on Earth. However, debate rages as to how co-ordinated dinosaur pack hunters were. Since first described in 1969 by palaeontologist John Ostrom, the Deinonychus has been imprinted in the public consciousness as a highly intelligent, synchronised team hunter. However, many modern dino experts disagree with this assumption, believing that while Deinonychus did move and chase prey in groups, they did so with little co-ordination, with each individual simply acting out of self-interest rather than working together like, say, lions.

201.3 Ma
Mid Mesozoic – The middle period of the Mesozoic era begins, with the Jurassic following the Triassic mass-extinction event.

199.6 Ma
Plesiosaurus – The large marine sauropterygian reptile Plesiosaurus evolves and goes on to become an apex predator of the oceans.

196.5 Ma
Sinemurian age – The Early Jurassic sees the Ichthyosaurus genus diversify and mammalian life such as Hadrocodium appear.

183 Ma
Toarcian turnover – The Pliensbachian stage of the Early Jurassic ends with anoxic ocean waters leading to wide-scale marine extinctions.

I

Ichthyosaurus

Although technically not a true 'dinosaur', Ichthyosaurus, or 'fish lizard', filled the same niche in Earth's oceans and was one of the most dominant marine species of the Mesozoic era (252-65.5 Ma) Resembling today's dolphins, Ichthyosaurus measured in at roughly two metres (6.6 feet) in length and was capable of cruising through the water at around 40 kilometres (25 miles) per hour, enabling it to catch fish and squid with ease. The fact that Ichthyosaurus had a very large pair of eyes protected by a pair of bony, structural-supporting rings has led some palaeontologists to believe the species frequently hunted at great depths where pressure was very high.

1 Eyes
Large eyes were protected by rings of bone to keep them intact at great depths.

2 Teeth
The jaws were lined with rows of sharp, conical teeth, primed for shredding soft prey such as squid.

3 Fins
Stunted limb-like fins were used for stability and manoeuvring rather than propulsion.

4 Prey
Fish, squid and marine reptiles were the main food of Ichthyosaurus, but the sharp teeth could crush shellfish as well.

5 Body
Its body was streamlined, with a curved spine and no neck. By undulating its body it could alter its speed and direction.

6 Tail
A top speed of 40km/h (25mph) came courtesy of the bilobed, shark-like tail.

J

Jurassic lark Five factual bloopers from the famous Hollywood films

Timing problems
Jurassic Park portrayed many famous dinosaur species, including T-rex and Triceratops, but most of the animals shown actually lived in the Cretaceous period, not the Jurassic.

Out of proportion
One thing the film's producers definitely need punishing for is the depiction of the park's Velociraptors. Portrayed as being as tall as a man, in reality they barely stood 0.5m (1.6ft) off the ground.

Feather-brained
Another massive omission in *Jurassic Park* was the lack of any feathers. Most dinosaur species, especially sauropods, had some plumage on their bodies.

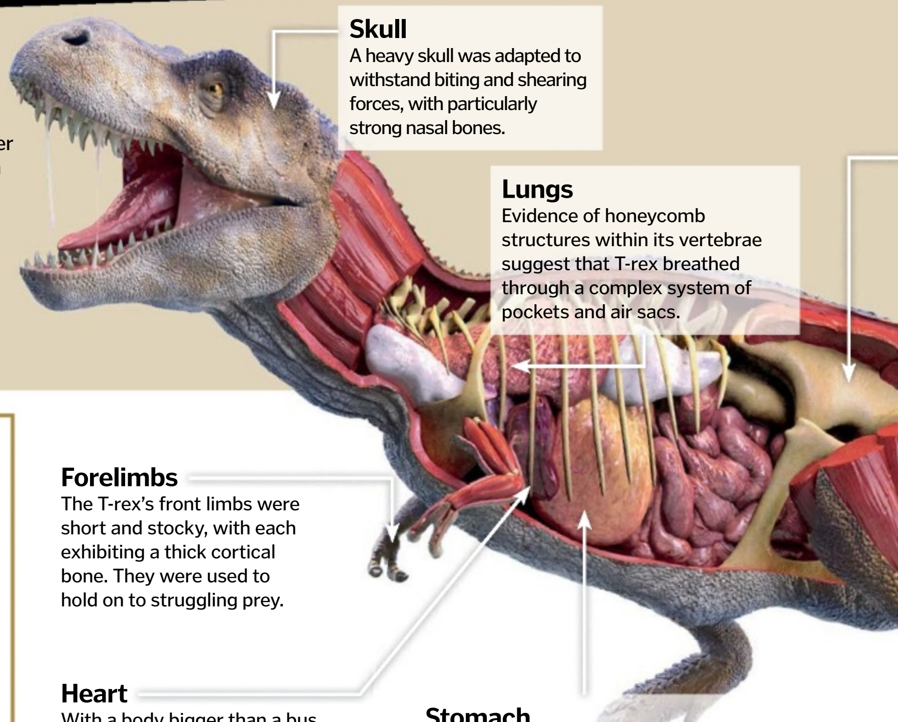
No grudge match
In the third film, the Spinosaurus is shown going toe-to-toe with its supposed arch-nemesis, the T-rex. In reality they never met as they lived on different continents of prehistoric Earth.

Spit on a grave
Another creative addition was Dilophosaurus's ability to spit out poison. However there is no evidence to suggest it could do this; neither did it have a frilled neck.

K

King of the dinosaurs

While not the biggest or smartest, the Tyrannosaurus rex was no doubt the closest to a king the dinosaurs ever had. A colossal bipedal carnivore, the T-rex measured in at over four metres (13 feet) tall and over 12 metres (39 feet) long, weighing over seven tons. It was no slow-poke either, with computer models estimating that the dino was capable of hitting a top speed of around 29 kilometres (18 miles) per hour chasing prey. When it caught up it could quickly dispatch them with a single bite that had a force of three tons – the equivalent weight of a fully grown African elephant. Yikes!



Skull
A heavy skull was adapted to withstand biting and shearing forces, with particularly strong nasal bones.

Lungs
Evidence of honeycomb structures within its vertebrae suggest that T-rex breathed through a complex system of pockets and air sacs.

Forelimbs
The T-rex's front limbs were short and stocky, with each exhibiting a thick cortical bone. They were used to hold on to struggling prey.

Heart
With a body bigger than a bus, the T-rex needed a huge pump to transport blood at adequate pressure. Current estimates suggest its heart was over 100 times bigger than a human's.

Stomach
The T-rex had a hardy stomach due to its high-meat diet and the fact that it scavenged frequently from long-dead carcasses. Analysed T-rex dung has revealed many fragments of bone.

L

Lufeng: a fossil treasure trove

One of the most prolific dinosaur hotspots in the world is Lufeng in Yunnan Province, China. Since 1938, 33 species, each with its own complete fossil, have been found there. Some of the finds have been record-breaking, with many of the vertebrate fossils uncovered the oldest on record – eg, the Lufengosaurus fossil (pictured right) dates from 190 million years ago. Lufengosaurus was a genus of prosauropod that lived during the Early Jurassic period. Tourists can see many excavated dinosaur finds at the nearby Lufeng Dinosaur Museum.

176 Ma
Mid Jurassic – The second epoch of the Jurassic period begins, with marine life flourishing and pliosaurs growing to the size of killer whales.

175 Ma
Pangaea rifts – The first phase of the supercontinent Pangaea's breakup into several continents begins, with the Tethys Sea forming.

154 Ma
Diplodocus – The famous Diplodocus evolves due to the dominance of sauropods in the dino kingdom. It measures 25m (82ft) long.

145 Ma
Jurassic ends – The Tithonian epoch of the Late Jurassic ends, with the Cretaceous period following.

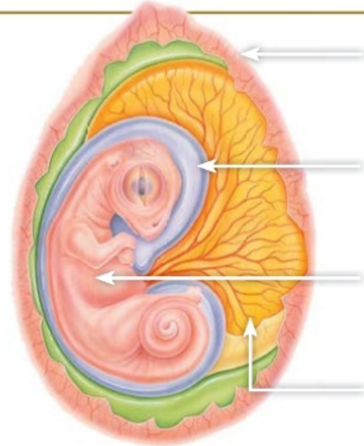
Mesozoic world

Beginning 252.2 million years ago and coming to a close about 65 million years ago, encompassing a colossal stretch of time that includes the Triassic, Jurassic and Cretaceous periods, the Mesozoic era truly defined the age of dinosaurs. All the famous species you can think of lived within it.

The Mesozoic was generally warm with a significantly smaller temperature differential between the equatorial and polar regions – ideal conditions for the emergence and proliferation of flora and fauna. Not only was the Mesozoic famous for its domination by dinosaurs, but also for being the time period where the ancestors of today's major plant and animal groups emerged.

Nesting & dinosaur eggs

Dinos organised their nests, laying their eggs in patterns suggesting complex social behaviours. Palaeontologists have identified two main types of egg-laying strategies – clutches and linear patterns – further divided by the shape of the nest and distribution of eggs. For example, the ornithopod Maiasaura nests generally consisted of bowl-shaped excavations roughly two metres (6.6 feet) wide and 0.8 metres (2.6 feet) deep, the opening covered by loose vegetation. Each nest was spaced roughly seven metres (22 feet) apart and was used by their offspring until they were over a metre (3.3 feet) long.

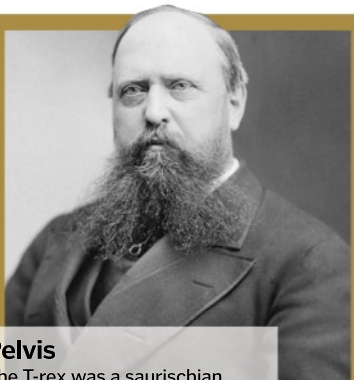


Outer shell
Dinosaur eggs were elongated and had hard, brittle shells. Some of the largest found to date were 0.6m (2ft) long.

Amniotic membrane
Encompassing the dinosaur was a thin membrane, helping keep the embryo hydrated during development.

Embryo
At the centre lay the dinosaur embryo that, depending on the species, could take weeks or months to hatch.

Yolk sac
This contained proteins and fat which served as food for the baby dino.



Palaeontology: key players

Most of our current knowledge of the dinosaur kingdom comes courtesy of palaeontologists, who dedicate their lives to uncovering the secrets of their prehistoric kingdom. From the earliest dinosaur hunters such as Othniel Marsh (pictured left), who discovered and named the Allosaurus, Stegosaurus and Triceratops, to 20th-century scientists who revolutionised our understanding of the dinosaurs' legacy, such as John Ostrom who gained fame for his suggestion that birds were modern-day descendants, palaeontologists have helped provide tantalising glimpses of the prehistoric world.

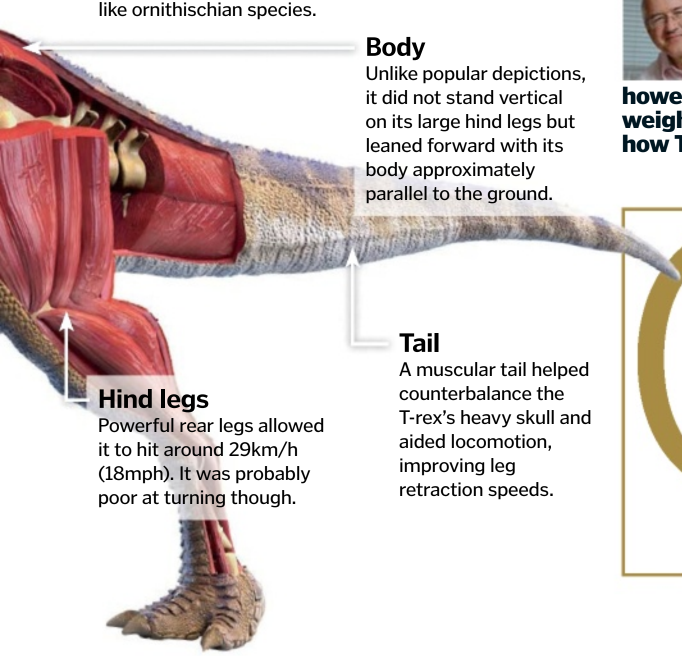
One of the more contemporary palaeontologists who has helped introduce dinosaurs to the general public is Dr Philip J Currie. He is also a museum curator who helped found the prestigious Royal Tyrrell Museum of Palaeontology in Alberta, Canada.

Pelvis
The T-rex was a saurischian dinosaur, meaning it had a lizard hip arrangement. Its pubis bone pointed forward and down rather than backward and down like ornithischian species.

Body
Unlike popular depictions, it did not stand vertical on its large hind legs but leaned forward with its body approximately parallel to the ground.

Tail
A muscular tail helped counterbalance the T-rex's heavy skull and aided locomotion, improving leg retraction speeds.

Hind legs
Powerful rear legs allowed it to hit around 29km/h (18mph). It was probably poor at turning though.



"Weighing something like five tons yet walking bipedally makes the T-rex incredibly interesting, as it pushes the absolute limits of what is possible. I mean, you look at an elephant and think, 'Wow, that's amazing', however, an elephant has to walk on four legs and weighs roughly the same amount, so understanding how T-rex functioned is a fascinating area of research"

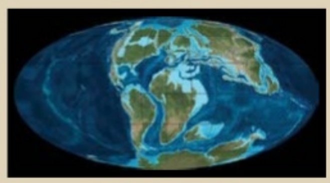
Queensland

If you were to visit Queensland's more remote regions, you may very well find yourself standing face to face with one of many 100-million-year-old beasts. That's because Queensland's outback was once part of the Great Inland Sea, a huge swampy inland ocean that existed in the age of the dinosaurs. As such, hundreds of fossils have been excavated from this region and there is even an established 'Australian Dinosaur Trail' that tourists can follow.

Oceans & continents

1 Triassic
At the beginning of the Mesozoic era in the Early Triassic period, all the land on Earth was joined together into the supercontinent of Pangaea, itself surrounded by the superocean Panthalassa.

2 Jurassic
As the Mesozoic progressed and the Triassic made way for the Jurassic period, plate tectonics split Pangaea into two mega-continents: Gondwana and Laurasia, separated by the Tethys Sea.



3 Cretaceous
As the Mesozoic came to a close, Gondwana and Laurasia had split into many of the continents we know today, including North and South America and Antarctica.

4 Palaeogene
In the Palaeogene period – the era immediately following the K-Pg extinction event – those continents continued to move to their current positions.

145 Ma
Cretaceous starts – The last period of the Mesozoic era, the Cretaceous, begins with all types of dinosaurs dominating on land, sea and air.

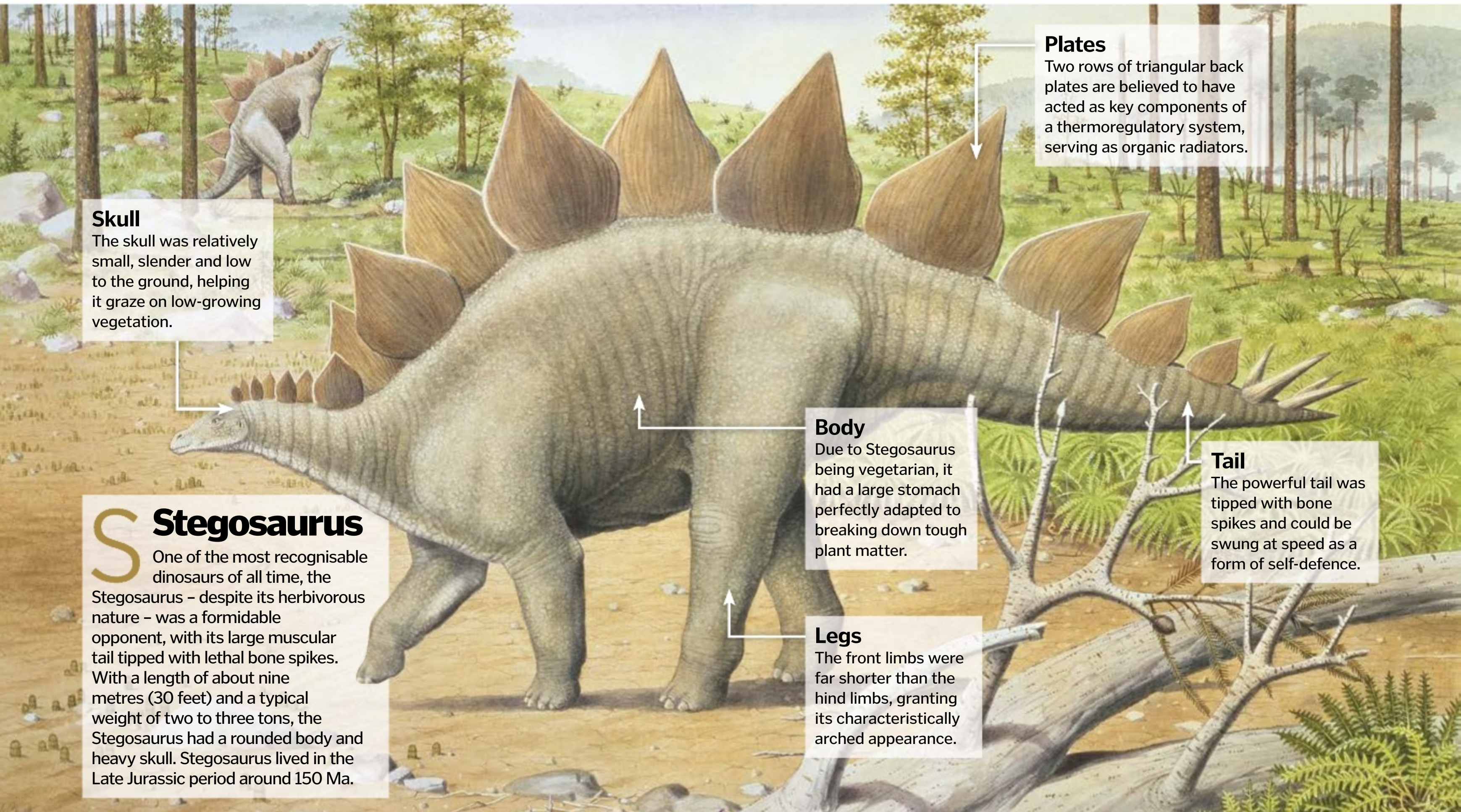
135 Ma
Geosaurus gone – After some 14 million years of swimming the Earth's seas, the crocodyliform Geosaurus goes extinct.

135 Ma
Gallornis spreads – Gallornis, a genus of prehistoric birds, is very successful throughout the humid conditions of the Early Cretaceous.

125 Ma
Leptocleidus passes – After 15 million years of marine dominance, the plesiosaur Leptocleidus dies out once and for all.

Relatives in the modern world

Massive scientific effort has been put into identifying which creatures today can trace their roots back to these prehistoric beasts. One of the best examples of this was the hunt for the nearest living relative of the once-mighty T-rex, undertaken by a research team at the North Carolina State University in 2007. To go about this the researchers sequenced proteins from a 68-million-year-old T-rex tissue sample and, much to their surprise, discovered that the king of the dinosaurs' molecules showed remarkable similarity to the common chicken and that its collagen makeup was almost identical. So, at least for the time being, the humble chicken is the rightful ruler of the Earth…



Plates
Two rows of triangular back plates are believed to have acted as key components of a thermoregulatory system, serving as organic radiators.

Skull
The skull was relatively small, slender and low to the ground, helping it graze on low-growing vegetation.

Body
Due to Stegosaurus being vegetarian, it had a large stomach perfectly adapted to breaking down tough plant matter.

Tail
The powerful tail was tipped with bone spikes and could be swung at speed as a form of self-defence.

Legs
The front limbs were far shorter than the hind limbs, granting its characteristically arched appearance.

Stegosaurus

One of the most recognisable dinosaurs of all time, the Stegosaurus – despite its herbivorous nature – was a formidable opponent, with its large muscular tail tipped with lethal bone spikes. With a length of about nine metres (30 feet) and a typical weight of two to three tons, the Stegosaurus had a rounded body and heavy skull. Stegosaurus lived in the Late Jurassic period around 150 Ma.

Tall tails

You'll struggle to find a dinosaur without a tail. This is because the majority of dinosaurs used their tails for two important roles: the first being balance and the second being self-defence. Large animals like the T-rex and Diplodocus, thanks to their skulls or necks, were very top-heavy. They needed long and heavy tails to counterbalance this, especially when running. Other smaller creatures such as Ankylosaurus (left) used its tail when under attack, evolving a large bony club at the end which could painfully bludgeon assailants.

Unenlagia: half bird, half dinosaur

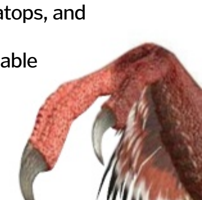
One of the most telling links between dinosaurs and birds is the Unenlagia, a genus of theropod dinosaur from the Late Cretaceous that in almost all aspects, aside from flight, resembles a modern bird. It was discovered in 1997 and to date two species have been confirmed – U comahuensis and U paynemili – both of which share an almost identical pelvic structure to the early bird species Archaeopteryx.

Velociraptors debunked

Due to their appearance in the *Jurassic Park* films, the Velociraptor is easily one of the most recognisable of all species. Importantly though, this image of the Velociraptor is way off the mark in terms of reality.

In contrast to the movie monster, research evidence suggests that the Velociraptor was actually a feathered dinosaur under 0.6 metres (two feet) in length, with colourful plumage used in mating rituals and visual displays. The species also had hollow bones, much like birds, and built large nests to protect their offspring.

The Velociraptor did impress in ground speed – one thing *Jurassic Park* got right – with it capable of hitting 39 kilometres (24 miles) per hour at top speed and boasting amazing agility, being able to change direction incredibly quickly. It used this speed to chase down prey, which largely consisted of small to medium-sized herbivores such as Protoceratops, and then kill them with its nine-centimetre (3.5-inch) retractable claws and sharp teeth.



As mentioned in 'Hunting strategies' new research suggests that, while sociable compared with other carnivorous species, Velociraptors were not apex pack hunters, with co-operative kills possible but infrequent.

99.6 Ma

Albian ends – The Albian age closes and gives way to the Cenomanian, made famous for its dramatic, anoxic end event.

68 Ma

Late to the party – The giant herbivorous Triceratops becomes one of the last non-avian dinosaur genera to appear before the K-Pg extinction event.

67 Ma

King is born – Tyrannosaurus rex takes over as the apex terrestrial predator on Earth. It retains this title until all dinosaurs are wiped out.

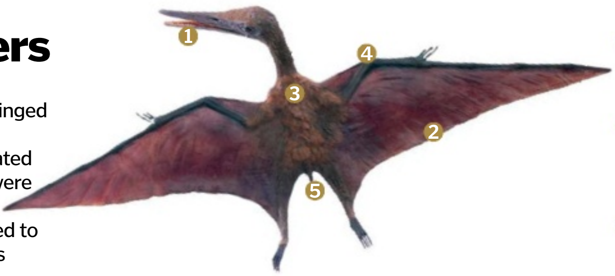
65.5 Ma

Dino death – A massive space rock smashes into Earth, sparking a chain of events that very few creatures survive, resulting in the K-Pg extinction event.

W Winged wonders

While not technically dinosaurs, pterosaurs were very much the winged wonders of the dinosaur era. Flying reptiles that evolved throughout the Late Triassic and dominated the skies until the Late Cretaceous, pterosaurs were the earliest vertebrates currently known to have evolved powered flight. Pterosaurs are not related to modern-day birds or bats, with the many species evolving earlier and separately.

The genus Pterodactylus was one of the most notable, with the species Pterodactylus antiquus one of the most impressive, with a toothed beak, large eyes and clawed wings. In terms of wingspan P antiquus could extend its wings up to a metre (3.3 feet) and had a long, narrow skull packed with dozens of sharp, pointed teeth. It used these to snap up fish and smaller reptiles.



"Microraptor was a small, four-winged dinosaur… very close to the origin of birds. Its remains show it had wings on its arms and legs. It couldn't fly properly, but used its wings to glide. This shows the origin of flight in birds and their ancestors was much more complex than expected"

1 Beak

Up to 90 teeth in the long beak intermeshed when the jaw was closed, and were perfect for grabbing fast prey.

2 Wings

A wingspan of around 1m (3.3ft) was typical for Pterodactylus, with the wings structured in a way that indicates it would have flown like an albatross.

3 Body

Not as large as depicted in fiction, Pterodactylus was very lightly built with hollow bones and a long neck.

4 Limbs

Pterosaurs evolved a unique pteroid bone on the wrists of their forearms, used to support the forward wing membrane located between the wrist and shoulder.

5 Tail

Unlike some other pterosaurs, Pterodactylus had a relatively short, stubby tail.

X X-raying prehistoric remains

X-ray scanners have become incredibly useful and important tools in the world of palaeontology as they can reveal many fossils and features that otherwise would remain hidden. For example, in November 2013, researchers in Germany used an X-ray machine to unveil the detailed structure of a fossil trapped within a plaster cast, all without ever having to break it open and risking damage to the specimen. What's more, the researchers then made use of a 3D printer to re-create the X-ray scans in solid form, allowing palaeontologists to pick up and handle a cast of the fossil as fine and detailed as the real thing. Modern technology is set to further our understanding of dinosaurs by no bounds.

Y Yucatán impact

The colossal Chicxulub crater in the Yucatán Peninsula, Mexico, since its discovery in the Seventies, has heavily hinted as to how 75 per cent of all life on Earth was eradicated around 65.5 million years ago. The crater indicates that a space rock – probably an asteroid – at least ten kilometres (six miles) across impacted Earth. As a result of the extensive damage caused directly by the collision and consequently by tsunamis, dust storms and volcanism, it caused a total collapse in the world's ecosystems, with all non-avian dinosaurs at the top of the death list. Despite being challenged repeatedly, the impact's link to the K-Pg mass extinction has recently been reaffirmed with even more detail, with a research team linking the two events in time to within 11,000 years. That said, the researchers also highlighted that various precursory phenomena, such as dramatic climate swings, also contributed to the end of the dinosaurs post-impact.

Z Zalmoxes sized up

Zalmoxes, a genus of herbivorous dinosaur from the Late Cretaceous period, is believed by some to be one of the earliest examples of insular dwarfism – a condition whereby a species undergoes a continuous reduction in size to better suit its environment, shrinking over several generations. Fossils from at least two species of Zalmoxes have been found in central Europe and one of its closest ancestors is thought to be the much larger Iguanodon.

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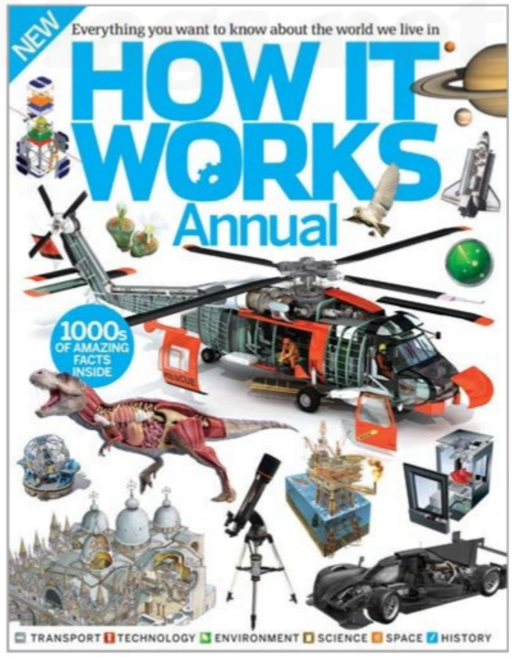

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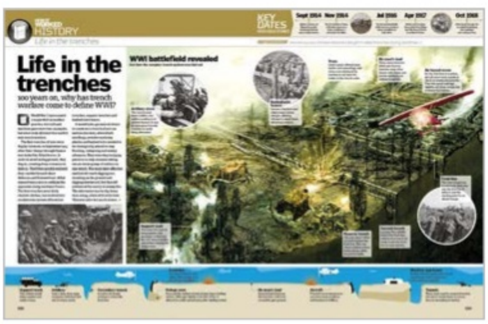

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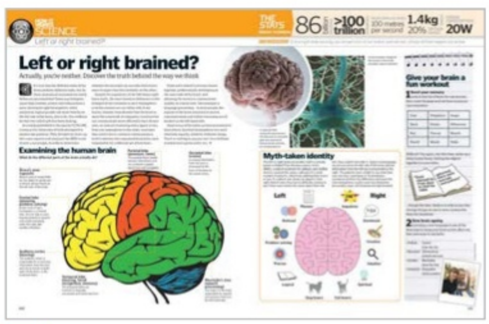

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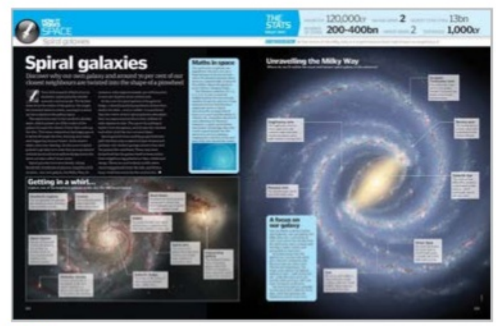

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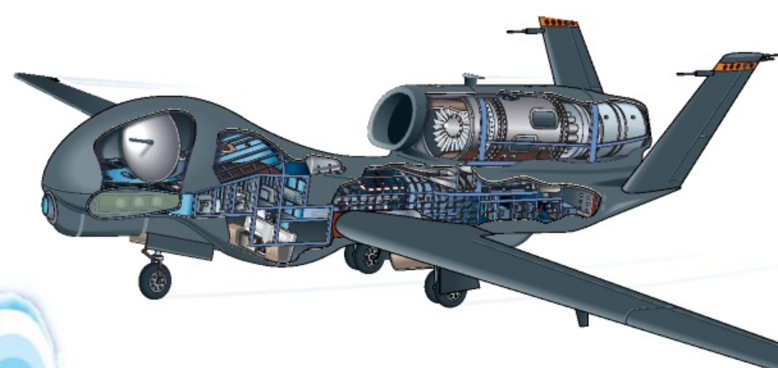

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