THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS™

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

INSIDE

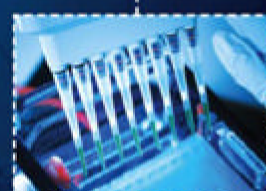
SPACE ROVERS
THE NEXT-GEN VEHICLES EXPLORING NEW WORLDS

SUPER STORMS
Why Earth's tornadoes are more devastating than ever

MEGA CITIES
The engineering behind a super-sized metropolis

WHAT IS THE HUMAN GENOME PROJECT?

CAN SCIENTISTS MANIPULATE OUR GENETIC CODE?



WHY ARE WE LIKE OUR PARENTS?

WHAT CAUSES FAULTY GENES?

THE SCIENCE OF GENETICS

DISCOVER THE INCREDIBLE CHEMISTRY THAT DETERMINES WHO YOU ARE

MUSKETEERS
How did these famous soldiers once fight?

FIGHTER JETS
The tech that trains pilots to fly the most advanced jets

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- RACING YACHTS
- THE STOMACH
- DRAWBRIDGES
- OUYA CONSOLE

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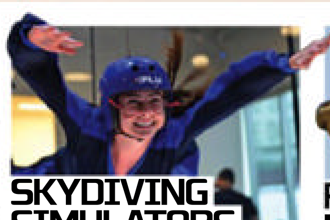

SKYDIVING SIMULATORS
How do we re-create the feeling of freefall indoors?

PEREGRINE FALCONS
Hunting techniques of the planet's fastest animal

5 TOP FACTS: BAe HAWK T MkI

Famous
Introduced in 1976 to RAF service, the Hawk replaced the famous Folland Gnat trainer.

Display Team
Adopted by the Red Arrows in 1979, it has served with the team ever since.

Livery
Today operated by a number of squadrons, the Hawks operate in a stunning gloss black livery.

World-Class
Other versions and updated aircraft have found service with various foreign users, from South Korea to Finland.

Sold
As of July 2012, BAe had sold nearly 1000 Hawk trainers across the world.

AIRFIX®

How it works

The Hawk uses Martin Baker Mk10B Zero-Zero ejector seats, enabling low altitude ejections.

Powered by a Rolls-Royce Turbomeca Adour, the Hawk is capable of over 600mph.

The Hawk has been praised for its manoeuvrability, noticeably its roll and turn handling.

In their function as a weapons trainer the Hawk can carry two Sidewinder missiles, one under each wing.

The Hawk is also able to carry a 30mm ADEN cannon.

Design your own Hawk in the Airfix range!

Design a Royal Air Force Benevolent Fund Hawk scheme and we will turn the best into a 1:48th Scale kit for 2014 to raise more funds for this fantastic charity.

Scan this QR code with your smartphone to find out more!

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BAe HAWK T MkI

Replacing the Gnat in the fast jet training role, the Hawk T MkI has proved to be an excellent trainer with secondary attack and fighter capabilities. The Hawk is a tandem two-seat aircraft which will continue to serve with the RAF for the foreseeable future.

Speed: 638 mph **Range:** 1,565 miles
Length: 40ft 9in (12.43m)
Wingspan 32ft 7in (9.94m)
Armament: 1 x 30 mm ADEN cannon
4 x AIM-9 Sidewinder or ASRAAM

A05121 1:48 Scale BAe Hawk T MkI

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HOW IT WORKS

ISSUE 49

WELCOME

The magazine that feeds minds!

Get in touch

Have YOU got a question you want answered by the How It Works team? Get in touch via:

- HowItWorksMagazine
- howitworks@imagine-publishing.co.uk
- www.howitworksdaily.com
- @HowItWorksmag

Page 64
Ever wondered how pilots are taught to fly fighter jets? We reveal all this issue...

It's amazing to think that almost every cell inside our bodies contains a secret code that dictates who we are and what we're like – including everything from our appearance, personality and even susceptibility to inherited diseases. This issue, How It Works is on hand to help you crack that code and to understand the miracle of your genetic makeup. Armed with what you learn from this feature you'll be able to look smart when a relative says, "You have your mum's hair," because you'll have a ready-made reply: "You mean, I've inherited a gene from my mum that makes a protein that tells the cells in my hair follicles to produce curly hair, like Mum's?" Also learn about the Human Genome Project, which was a groundbreaking venture to map the human genome and pin down a basic recipe for a human being. This is some of the most exciting science in the world right now, so turn to page 12 to get started. Enjoy the issue.

Helen Porter
Editor

What's in store...

The huge amount of information in each issue of How It Works is organised into these key sections:

Science
Uncover the world's most amazing physics, chemistry and biology

Technology
Discover the inner workings of cool gadgets and engineering marvels

Transport
Everything from the fastest cars to the most advanced aircraft

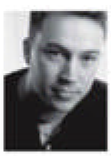
Space
Learn about all things cosmic in the section that's truly out of this world

Environment
Explore the amazing natural wonders to be found on planet Earth

History
Step back in time and find out how things used to work in the past

Meet the team...

Robert
Features Editor
Taking a look inside the first community-funded games console, the OUYA, was fun. Check it out on page 50.



Marcus
Designer
I've enjoyed getting to know Earth's fastest animal, the peregrine falcon – particularly its lethal stoop dive attack.

Jackie
Research Editor
Learning about the mechanics of flight simulators and fighter jet training was fascinating.

Adam
Senior Sub Editor
Allegedly the most exploded building in Hollywood films, the Capitol is an American icon that's well worth a tour.

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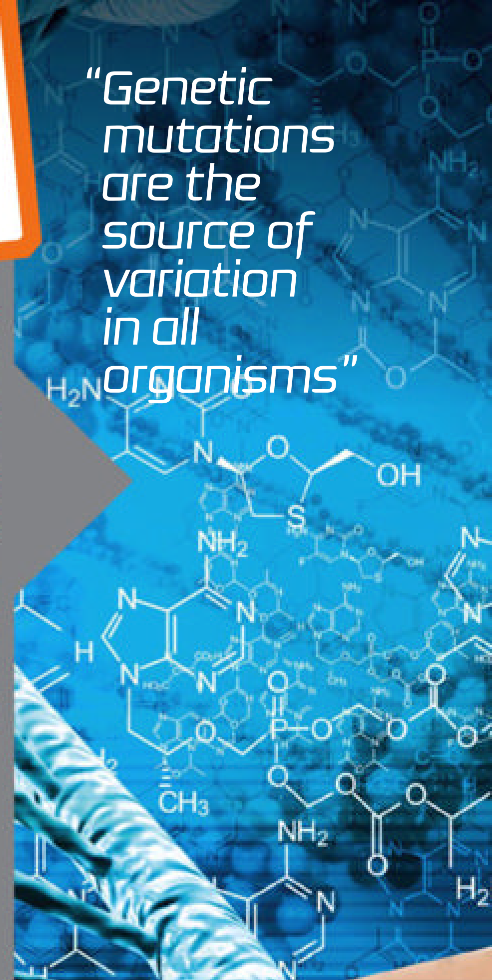


"Genetic mutations are the source of variation in all organisms"

MEET THE EXPERTS

Find out more about the writers in this month's edition of **How It Works…**

Giles Sparrow
Space rovers

Find out how awesome rover vehicles are exploring the surfaces of new worlds, as well as the up-and-coming technology currently in development, in our space expert's fantastic feature.

Tim Hopkinson-Ball
The US Capitol

Architecture aficionado Tim takes us behind the doors of this iconic American landmark and reveals the long history of its design and construction, and how it has been destroyed both in life and film.

Vivienne Raper
Pyrenees formation

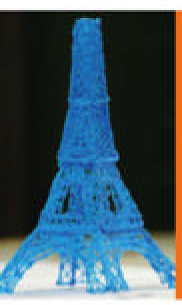
Vivienne delves beneath the surface to look at the geophysics behind the development of the Pyrenees mountains that have formed a barrier between France and Spain for thousands of years.

Luis Villazon
Megacities

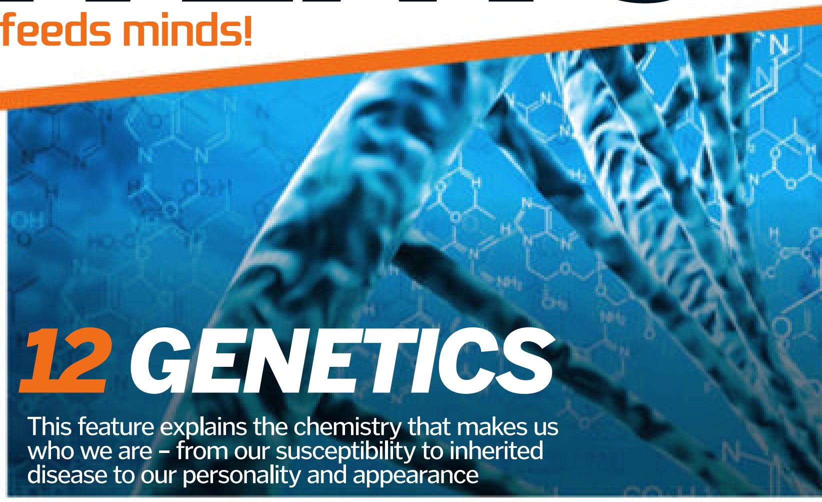
From energy production to coping with disasters, Luis explains the impressive feats of engineering and infrastructure that keep the planet's most populous cities from meltdown.

Michael Scott
Seed dispersal

Botany expert and conservationist Michael is back this month to reveal how plants exploit natural carriers like wind, water and even animals to ensure the next generation.



How can a pen create 3D pictures? Find out now on page 48



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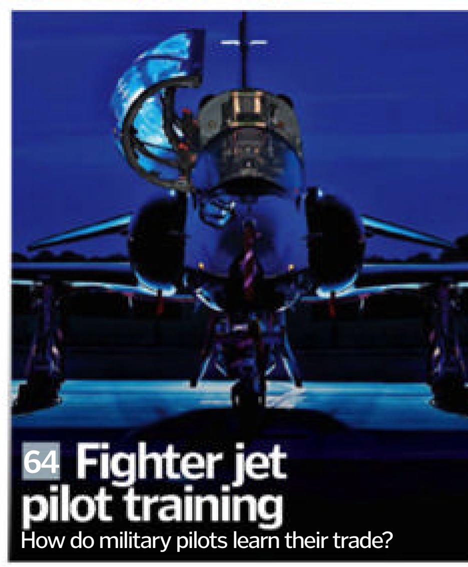

What made these gallant soldiers popular the world over

REGULARS

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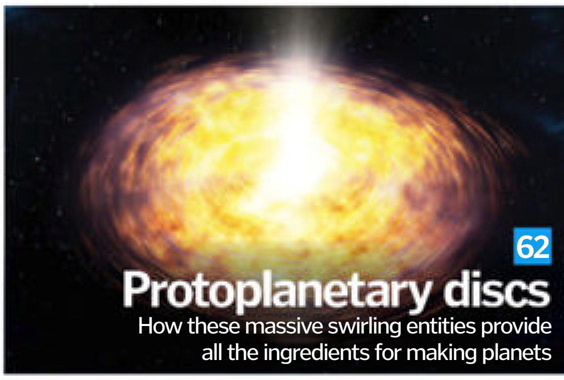
How do these massive metropolises sustain themselves?



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Protoplanetary discs

How these massive swirling entities provide all the ingredients for making planets

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GLOBAL EYE NEWS

Showcasing the incredible world we live in...

The team found a number of engraved monuments at Chactun

Lost Mayan city discovered

Forgotten in the Mexican rainforest for over 1,000 years, an ancient city is unearthed

Archaeologists have uncovered an ancient Mayan city in the rainforests of eastern Mexico. Now named Chactun – meaning Red Rock or Large Rock – it's believed to date from the height of the Mayan civilisation, with the majority of the site's structures built between 600 and 900 CE.

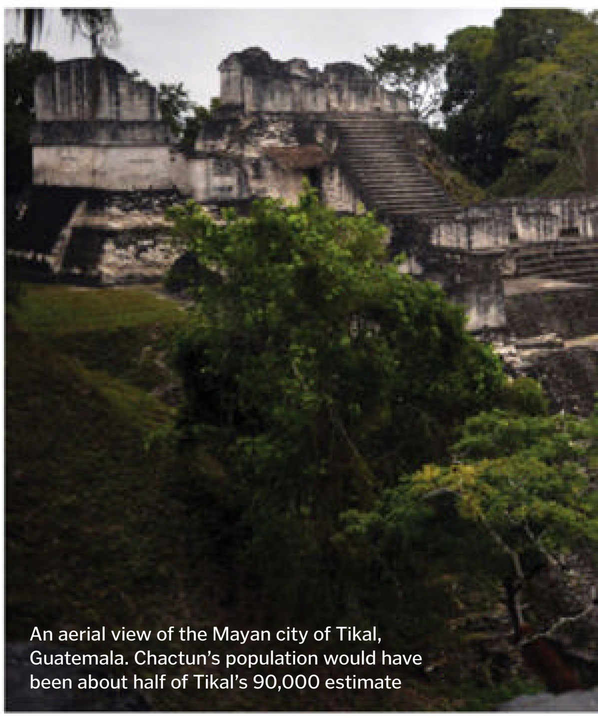
So far the team, which is being managed by associate professor Ivan Sprajc from the Slovenian Academy of Science and Arts, has discovered 15 pyramids, ball courts, a host of plazas and many sculpted stone monuments.

Indeed, initial estimates by the team suggest that, while Chactun was probably not as big as the Mayan city of Tikal in Guatemala, it would still have been home to between 30,000 and 40,000 people in its heyday.

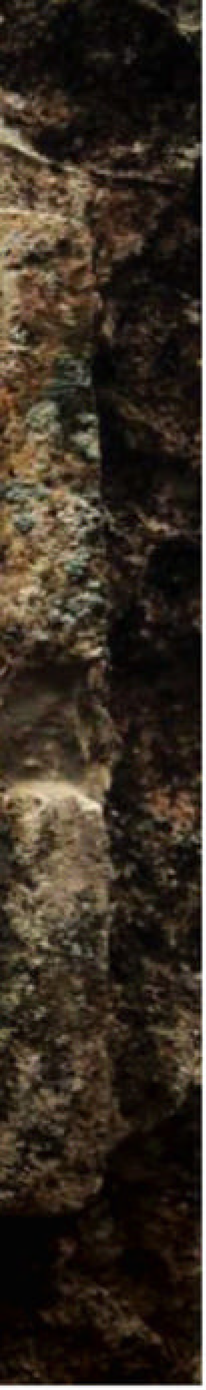
Sprajc's team found the site while reviewing aerial photographs of the region. After noticing hints of ruins, they marked the co-ordinates and set off on a three-week expedition, clearing a 16-kilometre (ten-mile) path through the dense forest. Upon arriving at the co-ordinates, the team's suspicions were proven correct and they spent six weeks exploring the site.

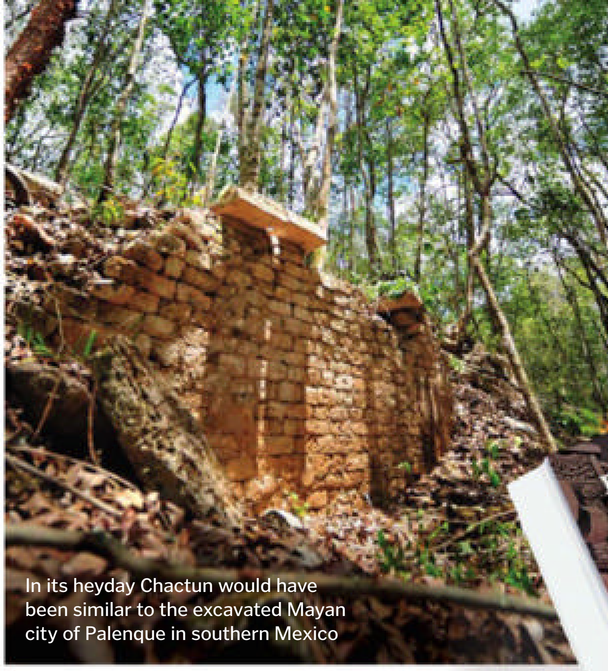
Moving forward, the team are planning to continue excavation of the area, in the hope of unearthing more of the lost city and shedding new light on the Mayan civilisation which once dominated the region.

"Sprajc's team discovered the site while reviewing aerial photographs of the region"



An aerial view of the Mayan city of Tikal, Guatemala. Chactun's population would have been about half of Tikal's 90,000 estimate

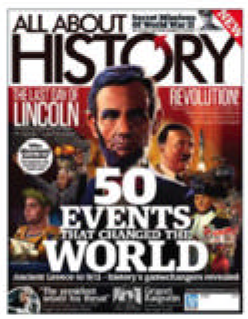




In its heyday Chactun would have been similar to the excavated Mayan city of Palenque in southern Mexico

The city of Chactun covers just 0.2km² (0.08mi²) and is located 120km (75mi) west of the modern city of Chetumal

To read more about the incredible secrets and mysteries of the Mayan civilisation, check out the newly launched *All About History* magazine. Not to be missed.



All About History on sale now!

Make a date with Imagine's amazing new history title

All About History, Imagine Publishing's groundbreaking new history magazine, is now on sale. Priced at just £3.99 ($9.99) and available from Barnes & Noble, supermarkets and all good newsagents, it's an exciting portal into the past. Speaking on the launch, Editor In Chief, Dave Harfield, said: "There's no other magazine that takes such an accessible and entertaining approach to the past than **All About History**. History is rich, diverse and fascinating and that's exactly what we strive to reflect in this new launch: well-crafted stories filled with eye-opening and well-researched facts as well as expert opinions."

Packed with stunning images, authoritative eyewitness accounts and never-before-seen cross-sections, battle maps and step-by-step event diaries, **All About History** turbo-charges the dry and dusty history magazine market and presents bygone days in a fresh way.

To experience history like never before, pick up issue 1 of **All About History** and pay a visit to www.historyanswers.co.uk.

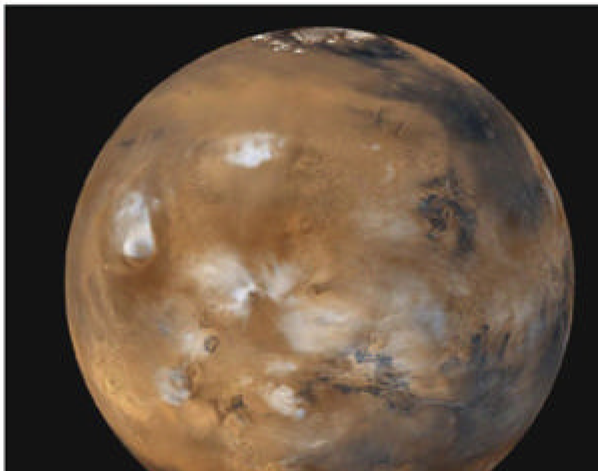
"All About History turbo-charges the dry and dusty history magazine market and presents bygone days in a fresh way"

Mars's atmosphere was 'oxygen rich'

NASA discovers that the Red Planet had oxygen in its atmosphere before Earth

Scientists using NASA's Spirit Rover have found Mars had an oxygen-rich atmosphere 4 billion years ago – about 1,500 million years prior to Earth. The researchers discovered this by comparing samples gathered by Spirit with Martian meteorites that have crashed into Earth, with differences in composition in the former indicating they had been exposed to oxygen. Speaking on the findings, which were reported in the journal *Nature*, lead scientist Bernard Wood of Oxford University commented: "The implication is that Mars had an oxygen-rich atmosphere at a time, about 4,000 million years ago, well before the rise of atmospheric oxygen on Earth around 2,500 million years ago. As oxidation is what gives Mars its distinctive colour, it is likely that the Red Planet was wet, warm and rusty billions of years before Earth's atmosphere became oxygen rich."

"It is likely that the Red Planet was wet, warm and rusty billions of years before Earth…"



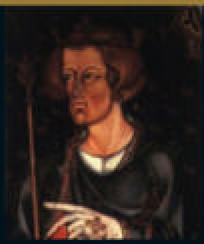
Mars obtained its characteristic colour due to oxidation

This day in history

18 July: How It Works issue 49 goes on sale, but what

390 BCE
Roman defeat
Raiding Gauls beat a Roman army in the Battle of Allia, leading to the eventual sacking of Rome.

1290 CE
Jews ejected
King Edward I of England issues the Edict of Expulsion, banishing all Jews from England.



1389
Peace treaty
The Kingdoms of France and England agree to the Truce of Leulinghem, leading to 13 years of peace.

1555
Up in arms
The College of Arms is reincorporated by Mary I of England and Spain's Philip II.

1862
High climber
The first ascent of Dent Blanche, one of the highest summits in the Alps, is completed.

The long-tailed mayfly can measure up to 12.7cm (5in) long

Epic swarm hits Hungarian river

Mayflies take over the Tisza River in Hungary

The annual swarming of Hungary's long-tailed mayflies has been imaged on the country's Tisza River. The photographs, which were taken during the insects' mating season, show how millions of the flies emerge to reproduce before they die.

The long-tailed mayfly – commonly called the Tisza fly due to their association with the river south-east of Budapest – spend the majority of their lives as larvae, buried deep in the earth. They develop underground for three years before emerging and then have just three hours to mate before they die – hence the swarming frenzy.

Interestingly, the regular location and timing each year of the Tisza mating swarm has led it to become a major tourist attraction, with visitors travelling from far and wide to experience the display, with some even swimming in the river as it takes place.

"The mayflies have just three hours to mate before they die"

Flying car for sale

A car capable of flight that was manufactured back in 1949 is going on sale, allegedly for £600,000 ($925,000). The Aerocar, which was designed by American aeronautical engineer Moulton Taylor to beat congestion, can drive around on the ground like a normal car before attaching a pair of foldable wings to take to the skies, cruising around at up to 177 kilometres (110 miles) per hour.

The 6.4-metre (21-foot)-long Aerocar can carry two people sitting side by side, features four wheels and is powered by a single Lycoming four-cylinder, 112-kilowatt (150-horsepower) engine. The single propeller that generates the car's thrust is mounted at the rear of the vehicle via a long tail cone, with the car capable of reaching a maximum altitude of 3,660 metres (12,000 feet).

Speaking on the sale of the Aerocar, aviation enthusiast Greg Herrick said: "There really was nothing like it around at the time and the design attracted so much attention – it was such an incredibly advanced piece of kit. It was on the front of newspapers, magazines, books and on television shows across the globe – its popularity was unprecedented."

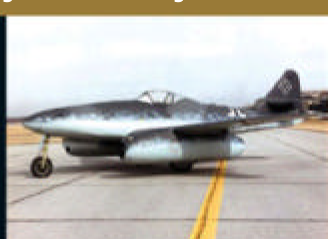
The vehicle's incredibly high price tag stems from the fact that just five Aerocars were ever produced – and only four of those still exist today.

One of the surviving Aerocars is owned by the Smithsonian Institution

else happened on this day in history?

1925
Hitler in print
Adolf Hitler publishes his personal manifesto and autobiography *Mein Kampf*.

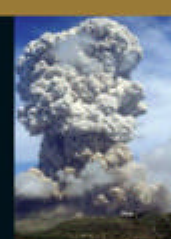
1942
German jet
During World War II Germany first tests the Messerschmitt Me 262 jet aircraft.



1955
Disney lands
The very first Disneyland theme park in Anaheim, California, opens to the public.

1968
New Intel
Integrated Electronics (Intel) is founded in Santa Clara, California.

1995
Tropical eruption
The Soufrière Hills Volcano on the Caribbean island of Montserrat erupts.



10 COOL THINGS WE LEARNED THIS MONTH

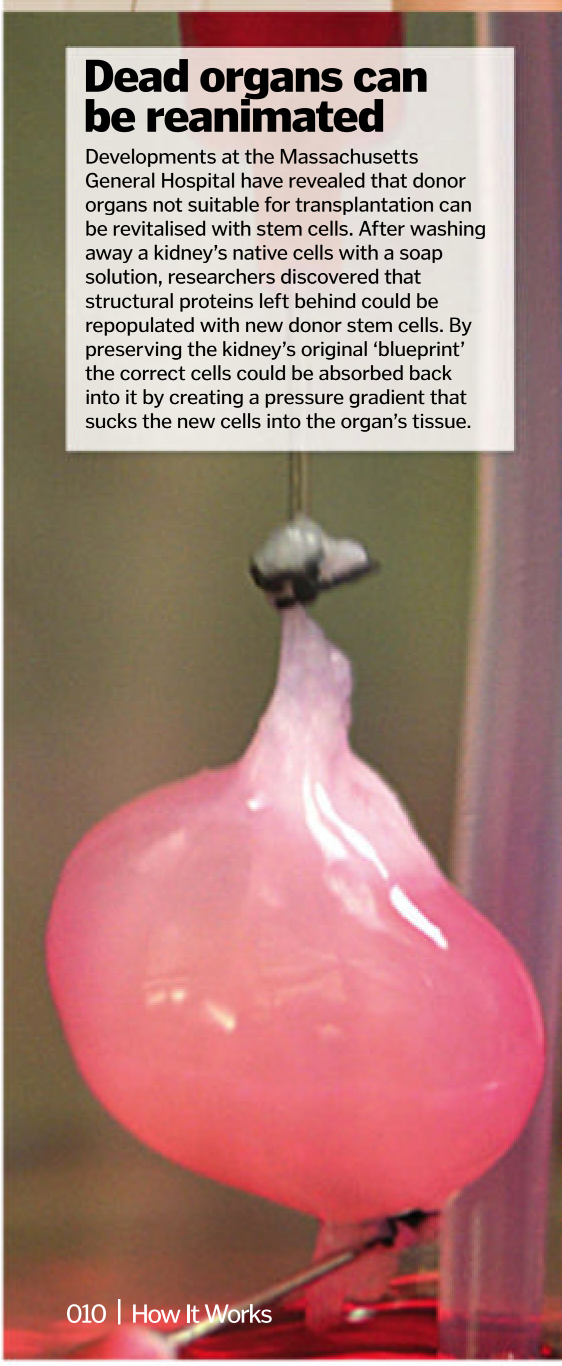
FACTS YOU ALL SHOULD KNOW

Babies predict hugs

Research has revealed infants as young as two months old know when they're about to be picked up, and stiffen their bodies to make it easier to be lifted. A pressure mat detected changes in posture and found the moment a mother approaches her infant with her arms out, the baby guesses what's about to happen and adjusts its posture. A previous study showed autistic babies did not make these adjustments, meaning the research could help diagnose such issues.

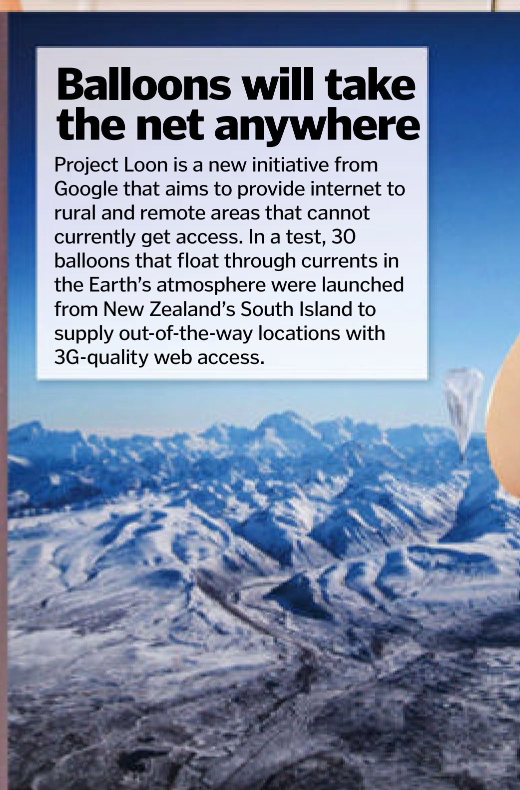
South Korean mobile internet is the best

While many parts of the world are still waiting for 4G networks to roll out in any sort of proper capacity, South Korea's largest mobile operator – SK Telecom – is launching a mobile network that is twice as fast as 4G and a brutal ten times faster than 3G. With a transfer rate of 150 megabits per second, the new network can download an entire 800-megabyte movie in a mere 43 seconds. The fact that over 60 per cent of South Korea's 33 million smartphone users have LTE service also indicates that coverage and takeup will be massive.



Dead organs can be reanimated

Developments at the Massachusetts General Hospital have revealed that donor organs not suitable for transplantation can be revitalised with stem cells. After washing away a kidney's native cells with a soap solution, researchers discovered that structural proteins left behind could be repopulated with new donor stem cells. By preserving the kidney's original 'blueprint' the correct cells could be absorbed back into it by creating a pressure gradient that sucks the new cells into the organ's tissue.



Balloons will take the net anywhere

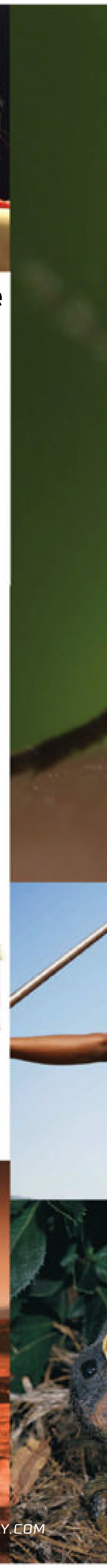
Project Loon is a new initiative from Google that aims to provide internet to rural and remote areas that cannot currently get access. In a test, 30 balloons that float through currents in the Earth's atmosphere were launched from New Zealand's South Island to supply out-of-the-way locations with 3G-quality web access.

Cutlery affects the taste of food

A study into eating behaviours has revealed we make assumptions about the taste/quality of food based on environmental factors. This includes the size, shape, colour and weight of the cutlery. For instance, yoghurt eaten with a lightweight spoon is perceived to be denser and more expensive than that eaten with a heavier spoon.

Super-Earths are closer than thought

A system in the Scorpius constellation contains up to seven planets including three super-Earths. These orbit Gliese 667C, one of three stars held together in a triple system located 22 light years from Earth, and they sit in the system's habitable zone. If liquid water were to exist on any of the super-Earths then conditions would be hypothetically viable for life to have formed.



Asian tiger mosquitoes hitchhike to North America

An invasive species of mosquito is threatening to spread diseases like yellow fever throughout the USA. The Asian tiger mosquito (Aedes albopictus) is an indiscriminate feeder that thrives on the blood of humans, birds, pets and wild animals. Though already native to South America, this tropical pest has managed to migrate to the cooler northern continent because the larvae have hitched a ride on used tyres that are sold all over the world. The global spread of the Asian tiger mosquito could fuel outbreaks of tropical disease in many other temperate regions.

Throwing made humans clever

New research suggests developments in early human shoulders and arms proved key in us rising to the top of the food chain. This ability to hurl objects over large distances proved crucial in later hunting activities and meant we could spend more time evolving greater brains and bodies.

You shouldn't feed the birds

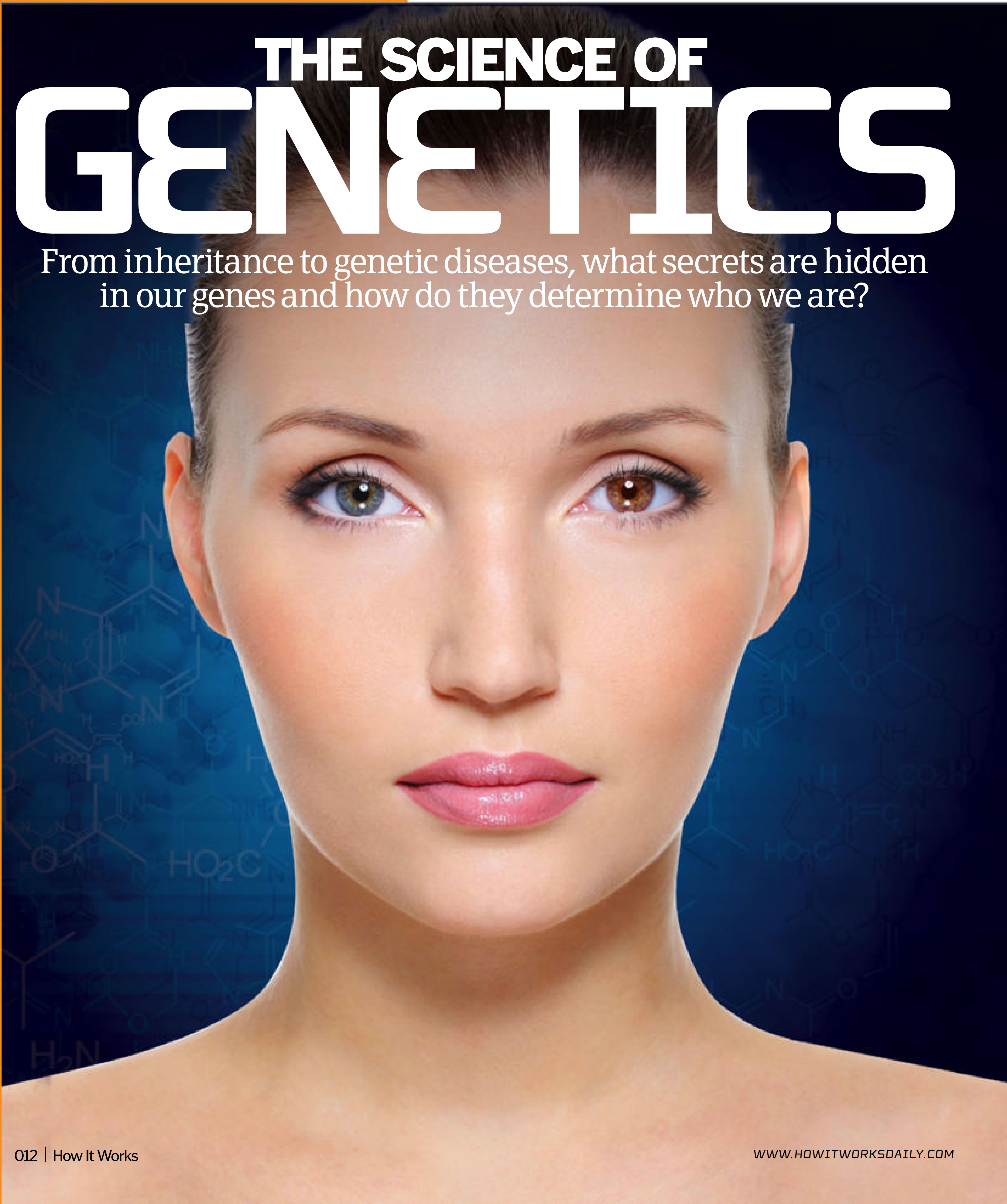
Leaving large amounts of food out for birds during the cold winter months may not actually be good for them. A study has found that leaving out fat balls for blue tits over a long period reduced breeding success in the spring. This is not conclusive though, with other research indicating that birds do benefit.

There's a new EV land speed record

The Lola-Drayson B12 69/EV has smashed the land speed record for an electric vehicle. Driven by the Drayson company's founder, Lord Drayson, the Le Mans prototype achieved a record 328.604 kilometres (204.185 miles) per hour. The figure is calculated by taking the average speed reached by the car over two 1.6-kilometre (one-mile)-long runs completed within the same hour. This blistering new speed surpasses the previous record by 47 kilometres (29.2 miles) per hour.

THE SCIENCE OF GENETICS

From inheritance to genetic diseases, what secrets are hidden in our genes and how do they determine who we are?



150bn

THE LONGEST GENOME

An ordinary-looking white flower, Paris japonica, has the longest known genome with 150 billion base pairs. If stretched out it would measure over 91 metres (300 feet)!

DID YOU KNOW? *If all 46 human chromosomes were stitched together and stretched they would measure nearly 2m (6.6ft)*

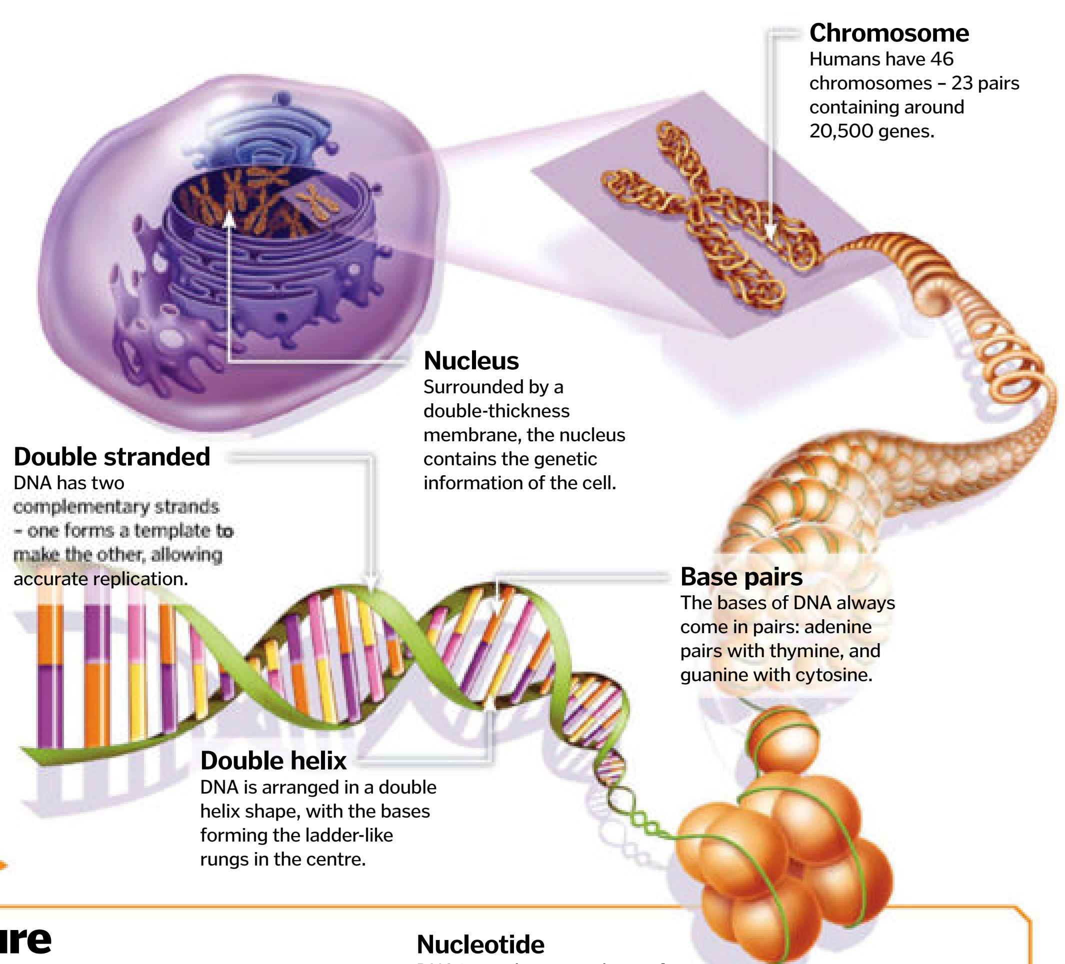
Genes define who we are. They are the basic unit of heredity, each containing a coded set of instructions to make a protein. Humans have an estimated 20,500 genes, varying in length from a few hundred to more than 2 million base pairs. They affect all aspects of our physiology, providing the code that determines our physical appearance, the biochemical reactions that occur inside our cells and even, many argue, our personalities.

Every individual has two copies of every gene – one inherited from each parent. Within the population there are several alleles of each gene – that is, different forms of the same code, with a number of minor alterations in the sequence. These alleles perform the same underlying function, but it is the subtle differences that make each of us unique.

Inside each of our cells (except red blood cells) is a nucleus, the core which contains our genetic information: deoxyribonucleic acid (DNA). DNA is a four-letter code made up of bases: adenine (A), guanine (G), cytosine (C) and thymine (T). As molecular biologist Francis Crick once put it, "DNA makes RNA, RNA makes protein and proteins make us." Our genes are stored in groups of several thousand on 23 pairs of chromosomes in the nucleus, so when a cell needs to use one particular gene, it makes a temporary copy of the sequence in the form of ribonucleic acid (RNA). This copy contains all of ▶

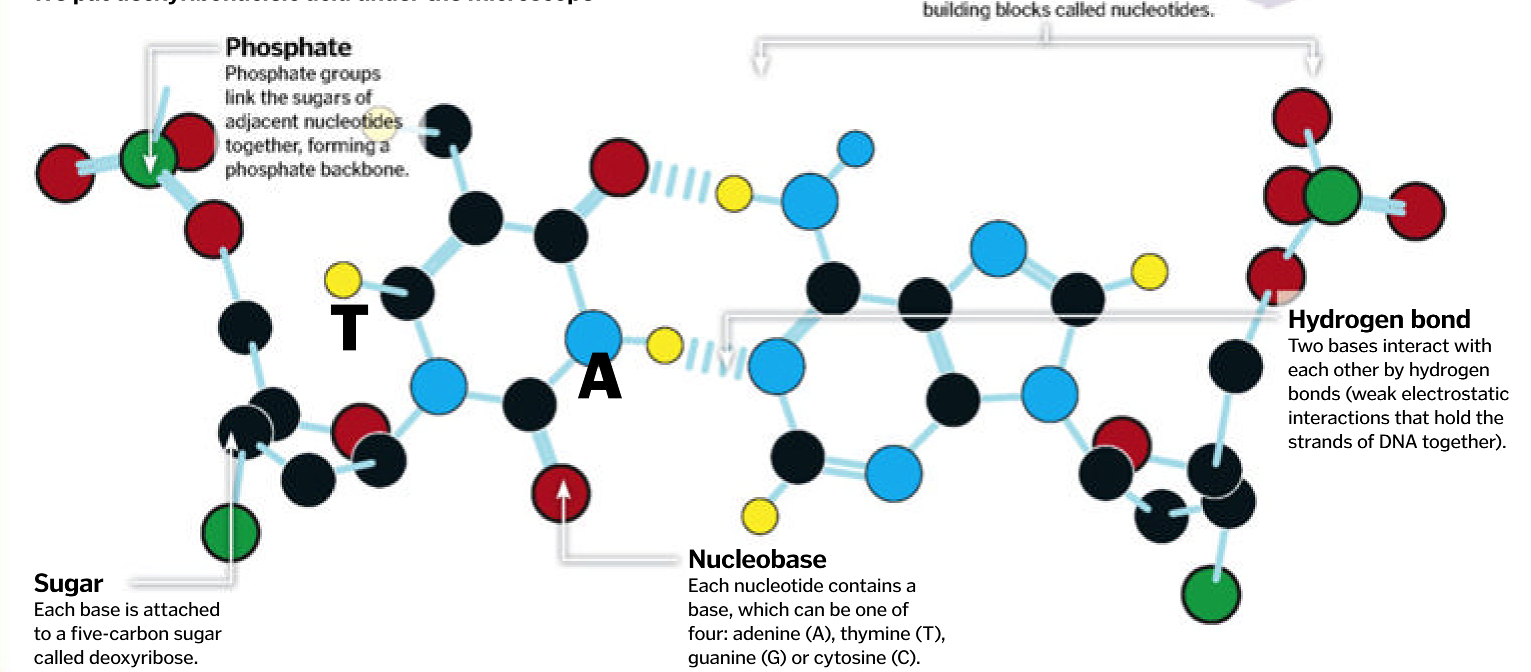
How is our genetic code stored?

Genetic information is coded into DNA using just four nucleobases: A, C, G and T



DNA's chemical structure

We put deoxyribonucleic acid under the microscope



> "Cells have repair machinery to correct errors as they occur, and even to kill the cell if it makes a big mistake"

the information required to make a protein – the building blocks of the human body.

The Human Genome Project aimed to map the entire human genome; this map is effectively a blueprint for making a human. Using the information hidden within our genetic code, scientists have been able to identify genes that contribute to various diseases. By logging common genetic variation in the human population, researchers have been able to identify over 1,800 disease-associated genes, affecting illnesses ranging from breast cancer to Alzheimer's. The underlying genetic influences that affect complex diseases like heart disease are yet fully understood, but having the genome available to study is making the task of identifying genetic risk factors much easier.

Interestingly, the Human Genome Project discovered we have far fewer genes than first predicted; in fact, only two per cent of our genome codes for proteins. The remainder of the DNA is known as 'non-coding' and – instead of containing genes – serves other functions. In many human genes are non-coding regions called introns, and between genes there is intergenic DNA. One proposed function is that these sequences act as a buffer to protect the important genetic information from mutation. Other non-coding DNA acts as switches, helping the cell to turn genes on and off at the right times and regulating gene expression.

Genetic mutations are the source of variation in all organisms. Most genetic mutation occurs as the DNA is being copied, when cells prepare to divide. The molecular machinery responsible for duplicating DNA is prone to errors, and often makes mistakes, resulting in changes to the DNA sequence. These can be as simple as accidentally substituting one base for another (eg A for G), or can be much larger errors, like adding or deleting bases. Cells have repair machinery to correct errors as they occur, and even to kill the cell if it makes a big mistake, but despite this some errors still slip through.

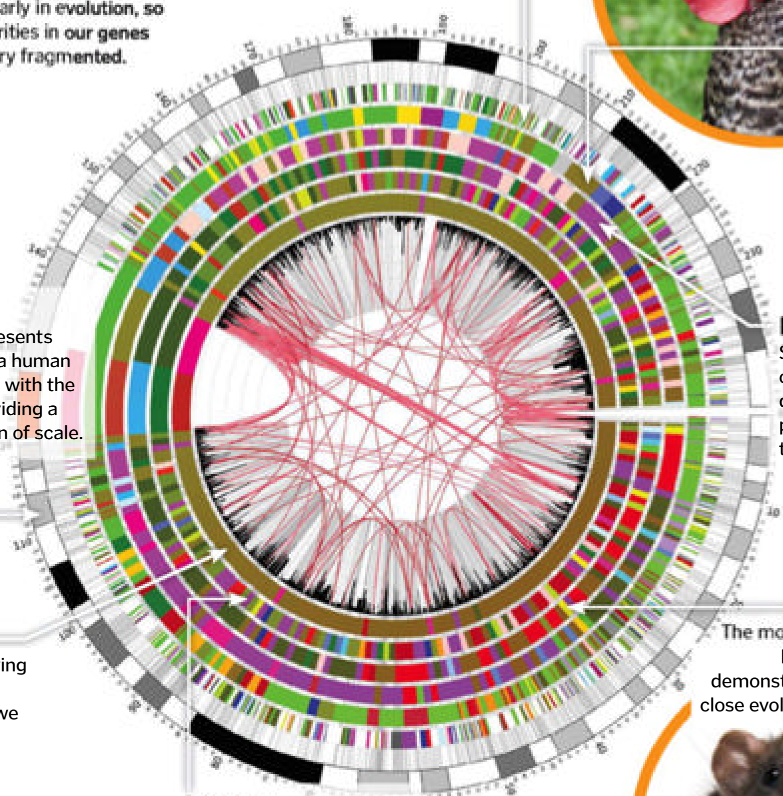
Throughout your life you will acquire many mutations in your cells. Many of these are completely harmless, either occurring in

The Human Genome Project

The Human Genome Project, an initiative to map the sequence of the entire human genetic code, began in 1990 and was completed in 2003. The 3.3-billion base pair sequence was broken into sections of around 150,000 base pairs in length and the sequence for each identified. These were then joined and used to map the information on to chromosomes to determine which genes were found on each – and in what order. The genome map (right) shows a human chromosome compared with other animals; the colours are a 'heat map' demonstrating areas where genetic information has been conserved through evolution (the more fragmented the pattern, the more differences there are in the genetic code).

Mapping the human genome

How does our genetic makeup compare to that of other creatures?



Zebrafish
Divergence between fish and mammals occurred very early in evolution, so similarities in our genes are very fragmented.

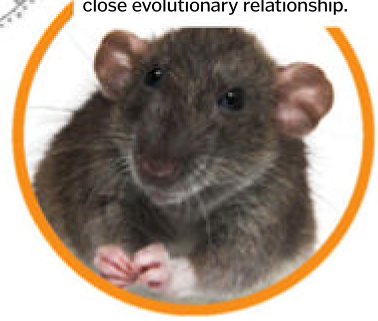
Chicken
Despite the fact that we are not closely related to birds, the chicken still has regions of DNA that are quite similar to ours.

Human
This ring represents the genes on a human chromosome, with the numbers providing a representation of scale.

Dog
Some regions of the canine genome are very different to ours, but the pink bands show an area that has been conserved.

Chimpanzee
One of our closest living relatives – the solid bands demonstrate we share a great deal of genetic information (ie 98 per cent).

Rat
The mouse and rat genomes have similar patterns, demonstrating these rodents' close evolutionary relationship.



Mouse
There is less in common between human and mouse (90 per cent), but we are sufficiently similar that mice make a good scientific model for studying human disease.

non-coding regions of DNA, or changing the gene so nominally that the protein is virtually unaffected. However, some mutations do lead to disease (see 'When genes go wrong' box).

If mutations are introduced into the sperm and egg cells they can be passed on to the next generation. However, not all mutations are bad, and this process of randomly introduced changes in the DNA sequence provides the biological underpinning that supports Darwin's theory of evolution. This is most easily observed in animals. Take, for example, the peppered moth. Before the Industrial Revolution the majority of these moths had white wings, enabling them to hide against light-coloured trees and lichens. However, a minority had a mutant gene, which gave them black wings; this made them an easy target for predators and kept their numbers low. When factories began to cover the trees in soot, however, the light-coloured moths struggled to hide themselves against the newly blackened environment, so black moths flourished. They survived much longer, enabling them to pass on their mutation to their offspring and altering the gene pool.

It is easy to see how a genetic change like the one that occurred in the peppered moth could give an advantage to a species, but what about genetic diseases? Even these can work to our advantage. A good example is sickle cell anaemia – a genetic disorder that's quite common in the African population.

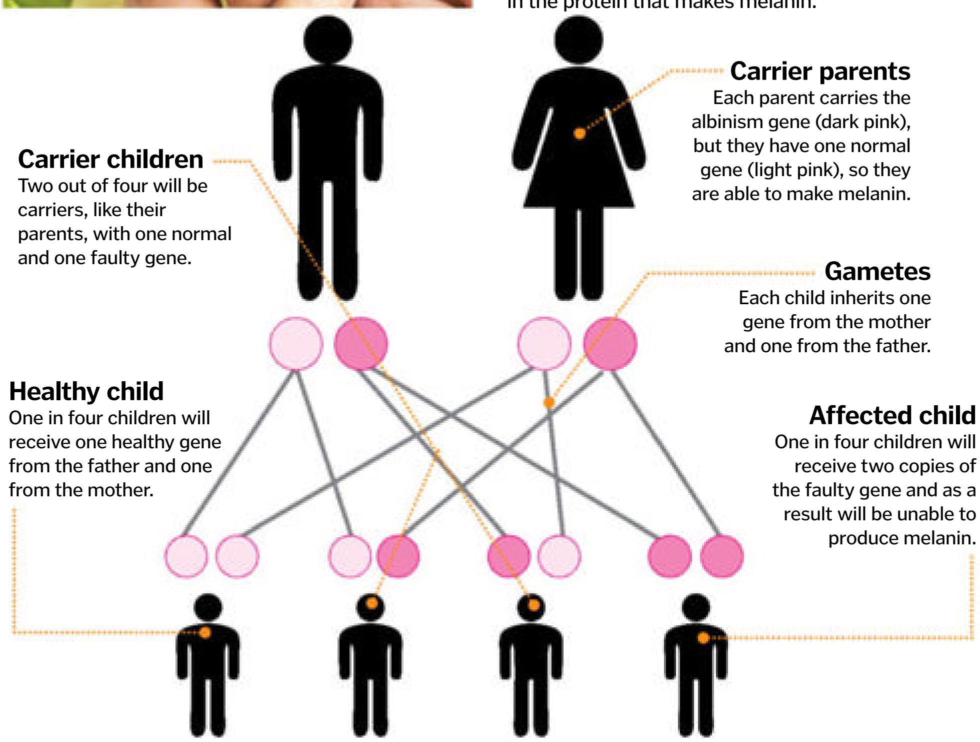
A single nucleotide mutation causes haemoglobin, the protein involved in binding oxygen in red blood cells, to misfold. Instead of forming its proper shape, the haemoglobin clumps together, causing red blood cells to deform. They then have trouble fitting through narrow capillaries and often become damaged or destroyed. However, this genetic mutation persists in the population because it has a protective effect against malaria. The malaria parasite spends part of its life cycle inside red blood cells and, when sickle cells rupture, it prevents the parasite from reproducing. Individuals with one copy of the sickle cell gene and one copy of the healthy haemoglobin gene have few symptoms of sickle cell anaemia,

Using genetics to convict criminals

Forensic scientists can use traces of DNA to identify individuals involved in criminal activity. Only about 0.1 per cent of the genome differs between individuals, so rather than sequencing the entire genome, scientists take 13 DNA regions that are known to vary between different people in order to create a 'DNA fingerprint'. In each of these regions there are two to 13 nucleotides in a repeating pattern hundreds of bases long – the length varies between individuals. Small pieces of DNA – referred to as probes – are used to identify these repeats and the length of each is determined by a technique called polymerase chain reaction (PCR). The odds that two people will have exactly the same 13-region profile is thought to be one in a billion or even less, so if all 13 regions are found to be a match then scientists can be fairly confident that they can tie a person to a crime scene.

Why do we look like our parents?

It's a common misconception that we inherit entire features from our parents – eg "You have your father's eyes." Actually inheritance is much more complicated – several genes work together to create traits in physical appearance; even eye colour isn't just down to one gene that codes for 'blue', 'brown' or 'green', etc. The combinations of genes from both of our parents create a mixture of their traits. However, there are some examples of single genes that do dictate an obvious physical characteristic all on their own. These are known as Mendelian traits, after the scientist Gregor Mendel who studied genetic inheritance in peas in the 1800s. One such trait is albinism – the absence of pigment in the skin, hair and eyes due to a defect in the protein that makes melanin.



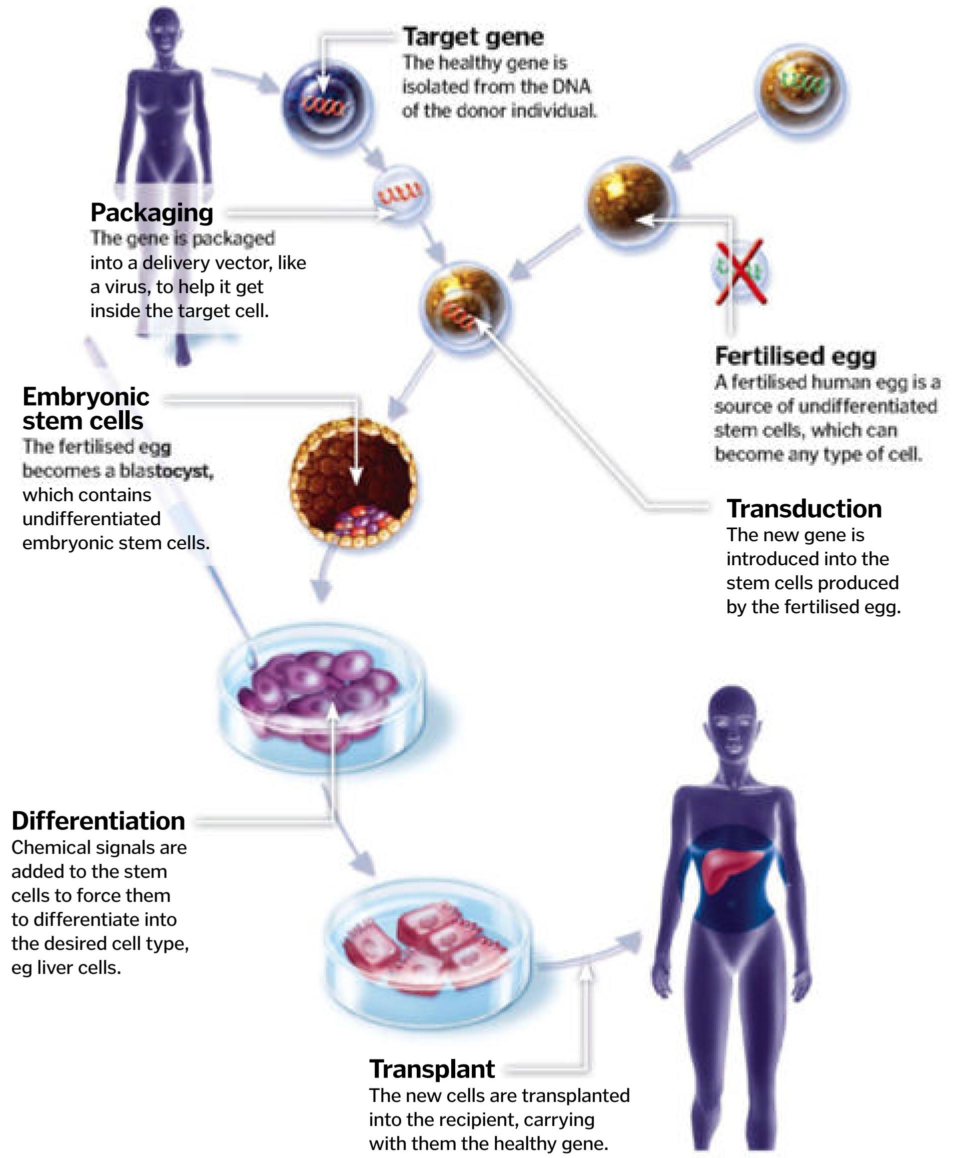
"It is now known that environmental influences can alter the way that DNA is packaged in the cell"

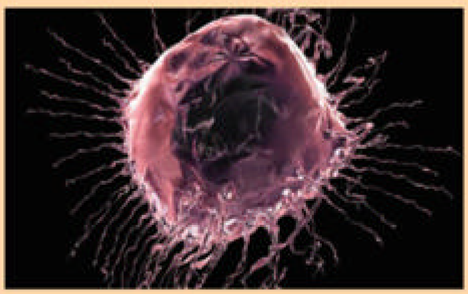
but are protected from malaria too, allowing them to pass the gene on to their children.

Genetics is a rapidly evolving field and more information about the function of DNA is being discovered all the time. It is now known that environmental influences can alter the way that DNA is packaged in the cell, restricting access to some genes and altering protein expression patterns. Known as epigenetics, these modifications do not actually alter the underlying DNA sequence, but regulate how it is accessed and used by the cell. Epigenetic changes can be passed on from one cell to its offspring, and thus provide an additional mechanism by which genetic information can be modified across generations.

Repairing faulty genes

We reveal how donated cells can be used to mend any damaged genes within the human body

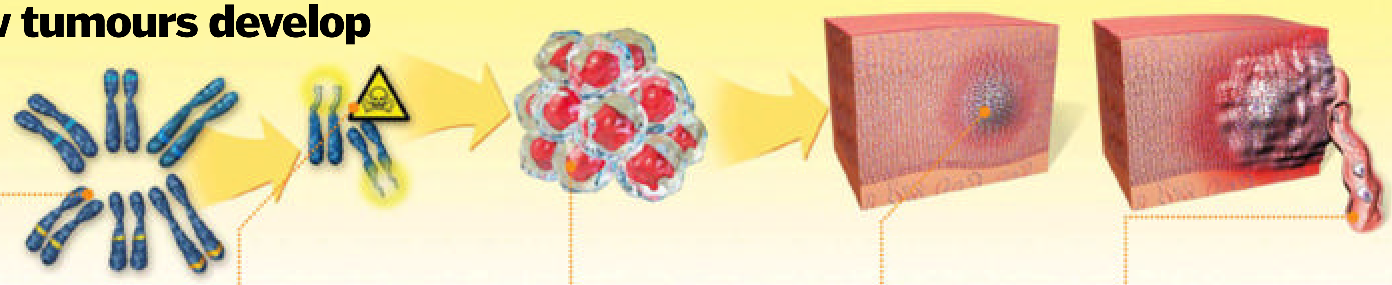




When our genes go wrong...

Cancer is not just the result of one or two genetic mutations – in fact, it takes a whole series of mistakes for a tumour to form. Cells contain oncogenes and tumour suppressor genes, whose healthy function is to tell the cell when it should and should not divide. If these become damaged, the cell cannot switch off its cell division programme and it will keep making copies of itself indefinitely. Each time a cell divides there is a risk that it will make a mistake when copying its DNA, and gradually the cell makes more and more errors, accumulating mutations that allow the tumour to progress into malignant cancer.

How tumours develop



"The stomach can accommodate about a litre (1.8 pints) of food without discomfort"

Inside the human stomach

Discover how this amazing digestive organ stretches, churns and holds corrosive acid to break down our food, all without getting damaged

The stomach's major role is as a reservoir for food; it allows large meals to be consumed in one sitting before being gradually emptied into the small intestine. A combination of acid, protein-digesting enzymes and vigorous churning action breaks the stomach contents down into an easier-to-process liquid form, preparing food for absorption in the bowels.

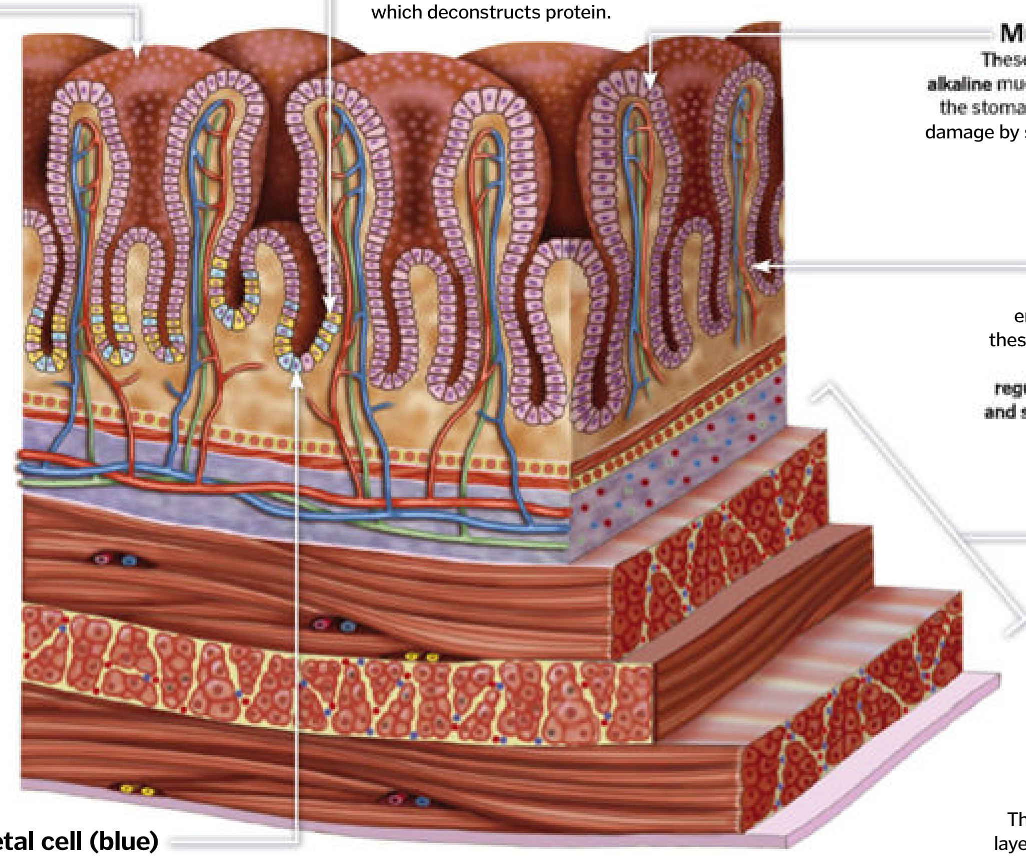
In its resting state, the stomach is contracted and the internal surface of the organ folds into characteristic ridges, or rugae. When we start eating, however, the stomach begins to distend; the rugae flatten, allowing the stomach to expand, and the outer muscles relax. The stomach can accommodate about a litre (1.8 pints) of food without discomfort.

The expansion of the stomach activates stretch receptors, which trigger nerve signalling that results in increased acid production and powerful muscle contractions to mix and churn the contents. Gastric acid causes proteins in the food to unravel, allowing access by the enzyme pepsin, which breaks down protein. The presence of partially digested proteins stimulates enteroendocrine cells (G-cells) to make the hormone gastrin, which encourages even more acid production.

The stomach empties its contents into the small intestine through the pyloric sphincter. Liquids pass through the sphincter easily, but solids must be smaller than one to two millimetres (0.04-0.08 inches) in diameter before they will fit. Anything larger is 'refluxed' backwards into the main chamber for further churning and enzymatic breakdown. It takes about two hours for half a meal to pass into the small intestine and the process is generally complete within four to five hours.

Lining under the microscope

The stomach is much more than just a storage bag. Take a look at its complex microanatomy now...



THE STATS **GASTRIC FIGURES**

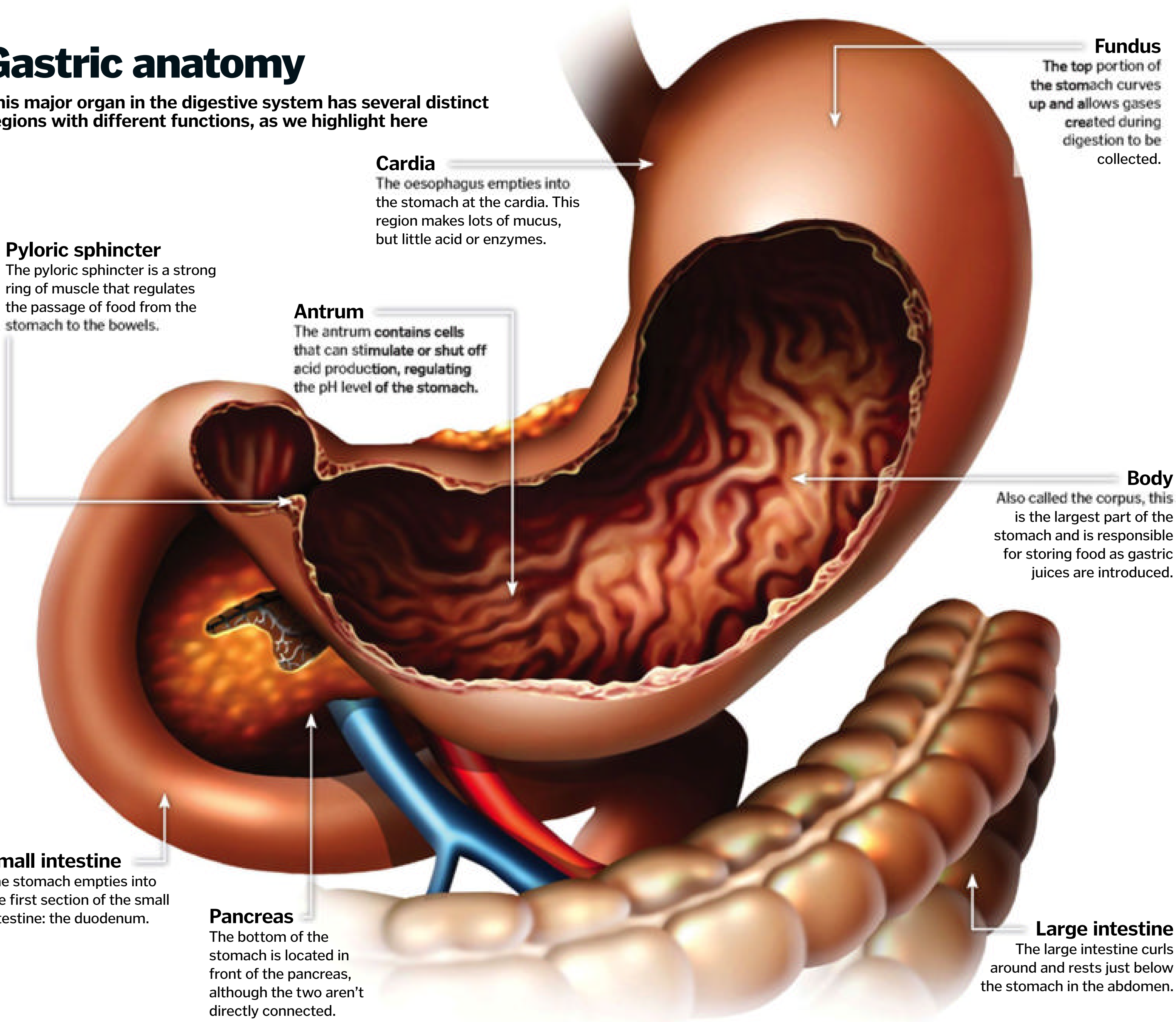
VOLUME WHEN EMPTY **50ml** | GASTRIC ACID PRODUCED **2 litres/day** | AVERAGE pH LEVEL **2.5**

CAPACITY **1-4 litres** | EMPTYING TIME **4-5hrs** | LENGTH **25cm**

DID YOU KNOW? *Stomach rumbling, also known as borborygmus, is actually the noise of air movement in the intestines*

Gastric anatomy

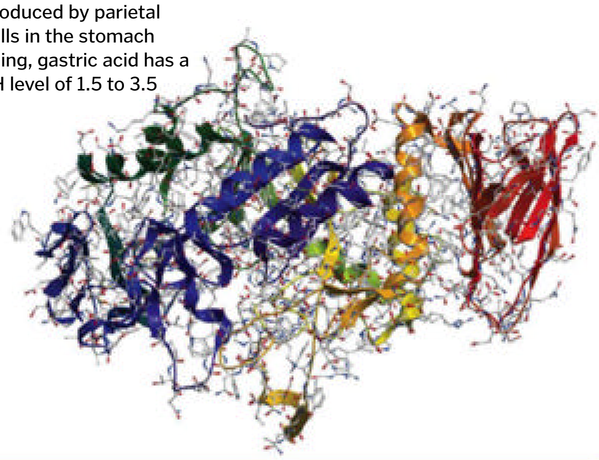
This major organ in the digestive system has several distinct regions with different functions, as we highlight here



Why doesn't it digest itself?

Your stomach is full of corrosive acid and enzymes capable of breaking down protein – if left unprotected the stomach lining would quickly be destroyed. To prevent this from occurring, the cells lining the stomach wall produce carbohydrate-rich mucus, which forms a slippery, gel-like barrier. The mucus contains bicarbonate, which is alkaline and buffers the pH at the surface of the stomach lining, preventing damage by acid. For added protection, the protein-digesting enzyme pepsin is created from a zymogen (the enzyme in its inactive form) – pepsinogen; it only becomes active when it comes into contact with acid, a safe distance away from the cells that manufacture it.

Produced by parietal cells in the stomach lining, gastric acid has a pH level of 1.5 to 3.5



Vomit reflex step-by-step

Vomiting is the forceful expulsion of the stomach contents up the oesophagus and out of the mouth. It's the result of three co-ordinated stages. First, a deep breath is drawn and the body closes the glottis, covering the entrance to the lungs. The diaphragm then contracts, lowering pressure in the thorax to open up the oesophagus. At the same time, the muscles of the abdominal wall contract, which squeezes the stomach. The combined shifts in pressure both inside and outside the stomach forces any contents upwards.

> "The rings are surprisingly stable and persist in the water for a long time"

How vortex rings form

Discover the science behind the shimmering haloes produced by cetaceans

A toroidal, or doughnut-shaped, vortex is formed when fluid flows back on itself, making a spinning ring around an invisible core. The best-known examples of this phenomenon are smoke rings, produced by volcanoes and artillery, but perhaps the most intriguing are the bubble rings generated by marine creatures like whales and dolphins.

These sea mammals,known as cetaceans, generate vortex rings by flicking the tip of their dorsal fin, or quickly moving their head. This causes the rapid acceleration of a small mass of water. Drag at the outer edges of the fast-flowing packet of water slows the flow relative to the centre, causing the edges to wrap back on themselves, which results in a doughnut-shaped vortex of rotating fluid.

These water-based vortices are invisible to the eye, but cetaceans blow air into the vortex, which gets caught up in the core of spinning water as bubbles and forms a visible ring.

The rings are surprisingly stable and persist in the water for a long time. When a fluid flows quickly the pressure drops, so as the vortex spins its pressure relative to the water that surrounds it is lowered. This leads to slight compression, which helps to stabilise the vortex. Additionally, as the ring rises to the surface, the fluid at its edges drags against the water, maintaining its spin, unless disturbed.

Interestingly, dolphins and whales seem to create these bubble rings for fun more than anything else. They move them with their fins, manipulate their shape and can even pull smaller rings out of larger ones. When they have finished playing they often bite the ring, destroying it in a flurry of tiny bubbles.

Toroidal ring physics

How do vortex rings develop and stay intact?

Vortex rings are created by various means, including firing weapons (above) and beluga whales during play

"Moulds are not that dangerous to human health, mainly because large colonies make them easy to spot"

Why food decomposes

Take a closer look at the microscopic world of food spoilage now

Micro-organisms are one of the biggest culprits for the spoilage of food; they feed on the nutrients, breaking them down into small molecules that can be absorbed across their cell walls. This destroys the structure of the food and produces by-products that smell and taste unappetising and – eventually – makes the food unfit for human consumption.

Mould produces the most visible changes to food. The branching filaments of mould are called hyphae, and their growing tips make enzymes, which break down tough molecules like cellulose and starch, converting them to mushier material. This causes the spongy feeling of decaying fruit and vegetables. The spots of mould seen on food represent huge colonies of interconnected hyphae, which advance over the surface seeking nutrients.

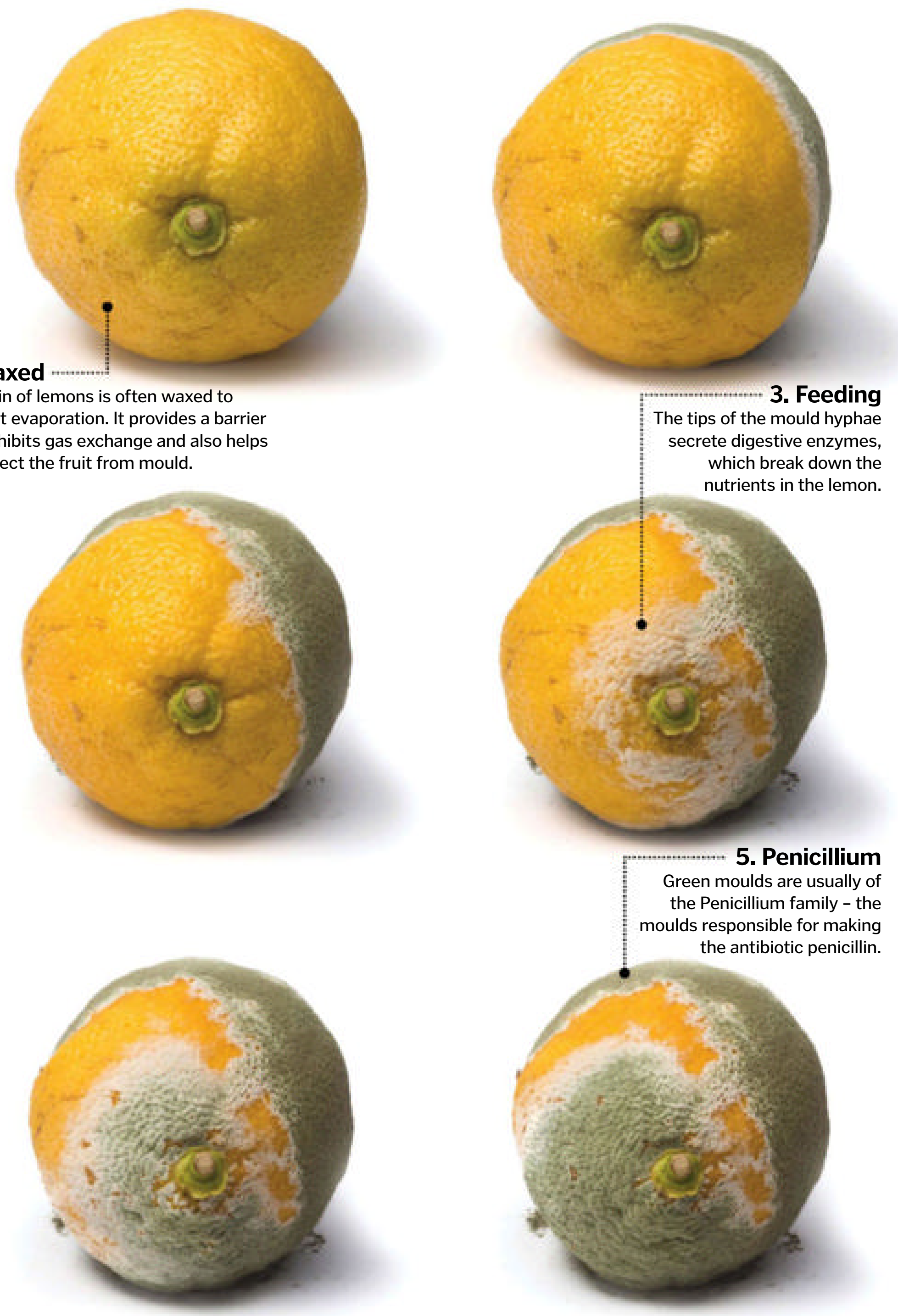
Moulds are actually not that dangerous to human health, mainly because their large colonies make them very easy to spot and avoid. The real danger comes from bacteria, which replicate virtually unseen. Signs of bacterial infection of food include discolouration, odour and a surface slime, but even before these changes are detectable, harmful numbers of bacteria can be present.

Not all decomposition is down to micro-organisms though. Foods contain natural enzymes used during the lifetime of the plant or animal to catalyse reactions. Even after death the enzymes are still functional and contribute to the gradual breakdown of the product. This is particularly obvious in fruit like apples and bananas, which go brown when cut surfaces are exposed to oxygen; this is the result of an enzymatic reaction that produces the brown pigment melanin.

Some foods are so hostile to microbial growth that they do not go off at all. This is often down to water content and osmosis. Microbes require relatively moist environments to thrive, so dried foods, or foods very high in salt or sugar, usually remain good for much longer periods of time. Indeed, honey that's still technically edible has been retrieved from the tombs of Ancient Egyptian pharaohs buried around 5,000 years ago.

When food turns bad...

What happens to a lemon as it goes mouldy?



1. Waxed
The skin of lemons is often waxed to prevent evaporation. It provides a barrier that inhibits gas exchange and also helps to protect the fruit from mould.

3. Feeding
The tips of the mould hyphae secrete digestive enzymes, which break down the nutrients in the lemon.

5. Penicillium
Green moulds are usually of the Penicillium family – the moulds responsible for making the antibiotic penicillin.

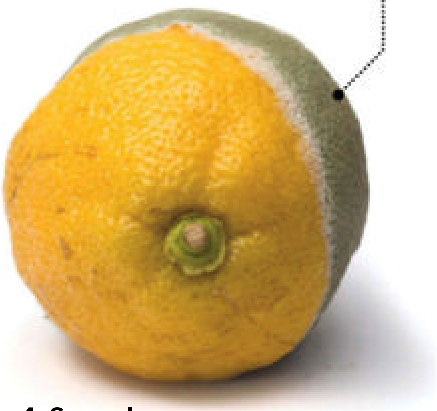
24

WORLD'S OLDEST BURGER

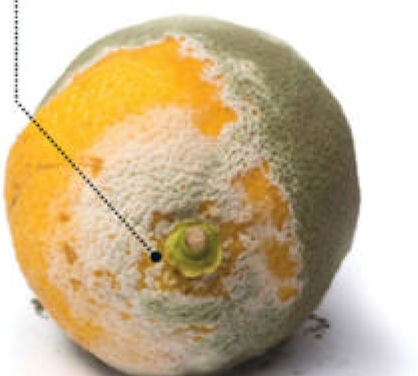
A museum in the USA contains a mummified collection of fast food, dating from 1989. Incredibly the dried-out specimens haven't decomposed after nearly a quarter of a century, prompting debate about the ingredients in processed meat.

DID YOU KNOW? *Infected poultry meat glows under UV light due to the presence of fluorescent Pseudomonas bacteria*

2. Colonisation
Moulds form a colony called a mycelium. The hyphae at the edges of the colony gradually advance across the food source.



4. Spread
Moulds produce spores, which become airborne, enabling them to spread beyond the boundary of the colony.



6. Shrivelling
As lemons start to decompose, water loss causes them to shrink and shrivel, producing a wrinkled, sunken texture.

Meat and maggots

If meat is left exposed for too long it can become infested with maggots; these are most often blowfly larvae. Blowflies are extremely sensitive and can locate meat in minutes. A female will lay 150-200 eggs at a time on any exposed areas and these hatch into maggots within 24 hours. Maggots secrete digestive enzymes onto the flesh to break down complex macromolecules into smaller components. They also have mouth hooks, which they use to grind the tissue and rapidly destroy its structure. If left undisturbed, maggots will live on meat for around four days before they are ready to pupate and become adult blowflies.

How do preservatives work?

Preservatives are added to food to extend its shelf life. There are three main categories, tackling the biggest causes of food spoilage: microbes, oxygen and enzymes.

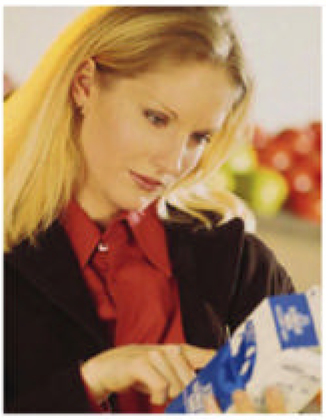
Foods can contain a range of antimicrobials, which interfere with the growth and replication of bacteria, mould and yeast. Salt has been used for centuries as a preservative; it draws water out of micro-organisms by osmosis, creating an incredibly hostile environment and preventing their survival. Oxidation is another big cause of food spoilage; the fatty acids present in butter and oils react with oxygen and then go rancid. As a result, antioxidant molecules are often added to mop up the oxygen radicals responsible for the reaction.

The final class of preservatives interferes with the function of enzymes. Enzymes are very sensitive to changes in pH, and acids like ascorbic acid (a form of vitamin C) and citric acid are often used as additives. Changes in pH alter the shape of enzymes so that they are no longer able to interact with their target molecules, essentially making them impotent.

Best before and beyond

Food packaging often comes littered with dates which indicate the shelf life. This varies from country to country, and by food type, but there are three main categories.

The sell-by date is an instruction to the vendor, provided as guidance for stock control; this actually has very little to do with the quality, or safety, of the food. The best-before date is for the consumer; this is generally used on frozen, dried and tinned goods as an indicator of quality. It is a common misconception that food past its best-before date is unfit to eat; beyond this date the food is unlikely to be harmful, but the flavour and texture may have deteriorated. The use-by date is the most important and is included on fresh foods that go off rapidly, like meat and fish. Past the use-by date, some harmful bacteria may have reached dangerous levels and so the food shouldn't be consumed.



RISE OF THE SUPERSTORM

The science behind tornadoes with the power to devastate cities

Every year around 1,200 tornadoes touch down in the USA. Most occur in a region nicknamed Tornado Alley, with Texas, Oklahoma and Kansas at its core.

The most destructive of 2013 so far has been the Moore Tornado, which touched down at 2.56pm CDT on 20 May, near Newcastle, OK. It was on the ground for 40 minutes and drew a 27-kilometre (17-mile) path through the state, 2.1 kilometres (1.3 miles) across at its widest point. Wind speeds were in excess of 322 kilometres (200 miles) per hour, placing the tornado in the highest category on the Enhanced Fujita (EF) Scale: EF5. Tornadoes of this class cause near-total devastation, levelling multistorey buildings, tearing homes from their very foundations and lifting asphalt from the roads.

North America has unique geography, which provides a deadly spawning ground for storms and tornadoes. The Rocky Mountains extend from north to south along the west side of the continent. As wind travels over the Rockies, it becomes cold and loses moisture via rain and snow, producing cool, dry air at high altitudes. When this air hits warm, humid air from the Gulf of Mexico water vapour condenses and forms storm clouds. This releases huge amounts of energy, causing atmospheric instability.

On 20 May, severe weather warnings were issued for Oklahoma; a polar jet stream came over the Rockies into the southern Great Plains, and simultaneously a low-pressure system moved over the Upper Midwest region. Differences in wind speed at different altitudes – known as wind shear – caused the air to spin, circulating in a horizontal vortex, and in combination with moisture and atmospheric instability. At 2pm CDT, this led to the development of a thunderstorm containing persistent, rotating mesocyclones.

Mesocyclones powerful enough to generate tornadoes often result in hailstorms.

5 TOP FACTS
TORNADO MYTHS

Overpasses are safe

1 It may seem a good shelter, but highway overpasses act like wind tunnels and increase the speed of the air. If you are stuck in your car in a tornado, get out, find a ditch and stay low.

Open windows

2 Despite a myth that opening a building's windows will alleviate wind pressure, it just lets wind and debris in, and chances are, the glass will smash anyway when the storm hits.

Stand in the north

3 Tornadoes often come from the south, but standing in the north of the house won't protect you from debris. Pick a room in the centre on the ground floor, away from any windows.

Outdrive the storm

4 The roads will be congested and covered in debris, and a tornado can quickly change direction without warning. Even weak twisters can lift small cars – so don't drive!

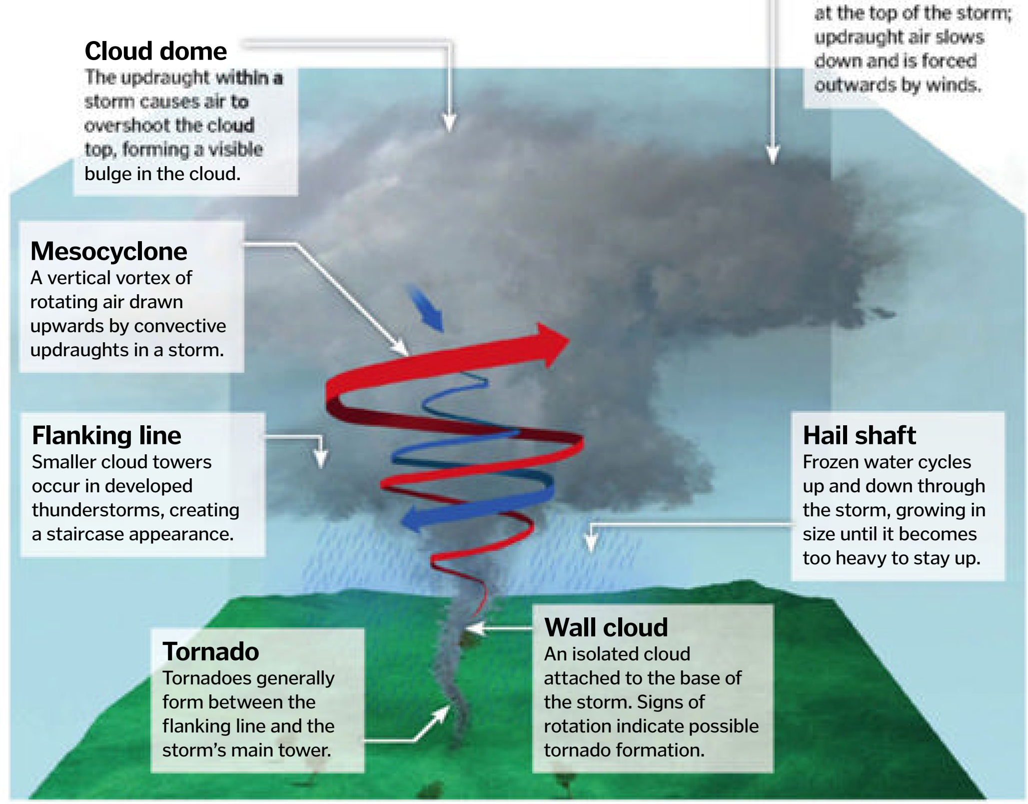
Trailers are targeted

5 Trailer parks are much more likely to be damaged by a tornado, but this is due to differences in the quality of construction rather than any natural bias to these abodes.

DID YOU KNOW? *Most tornadoes travel from south-west to north-east and occur between 3pm and 9pm*

Tornado dynamics

Take a look at the anatomy of a supercell thunderstorm



Updraughts of warm air carry water droplets high into the atmosphere, where they freeze before being carried downwards by cold downdraughts. If they become caught in an updraught again they will refreeze, adding a new layer of ice. This process can repeat several times, generating hailstones that are the size of golf balls or even larger. Oklahoma was pelted with hail as the storm intensified.

If there is sufficient updraught to tighten the central vortex of a mesocyclone it begins to twist, resulting in a powerful vertical column. The inward and outward airflows cause a drop in pressure at the centre, and form what is ▶

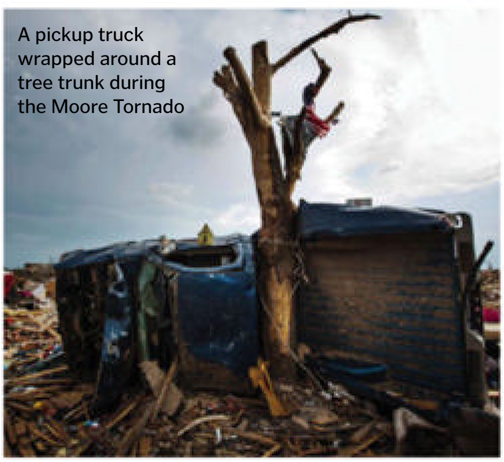
> *"It started out as a weak EF0 twister… but within ten minutes it had intensified to EF4"*

known as a dynamic pipe. At the core of the vortex, the pressure is lowered, which sucks in more air, causing the column to lengthen and extend down towards the ground.

A tornado warning was issued in Oklahoma at 2.40pm, and the tornado that ravaged Moore touched down 16 minutes later. It started out as a weak EF0 twister, capable of only minor damage to roof shingles, trees and guttering, but within ten minutes it had intensified to EF4. EF4 tornadoes have extremely destructive winds of up to 322 kilometres (200 miles) per hour and, on its path to the city of Moore, it severely damaged a bridge and killed nearly 100 horses at the Orr Family Farm.

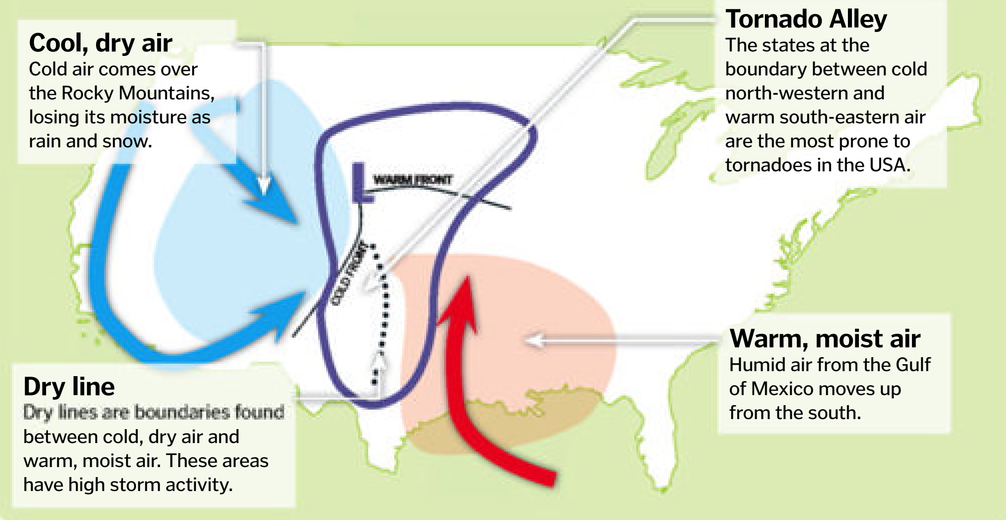
Once in the city, the storm intensified to EF5 – the highest rating for a tornado – and reduced many buildings to rubble. It lost its peak strength and returned to EF4 classification, but the intensity of the storm caused a great deal of damage: 13,500 homes were destroyed, or damaged, affecting 33,000 people, 24 people were killed and hundreds more injured.

The tornado continued to weaken until it eventually dissipated at 3.35pm, about eight kilometres (five miles) east of Moore.


A pickup truck wrapped around a tree trunk during the Moore Tornado

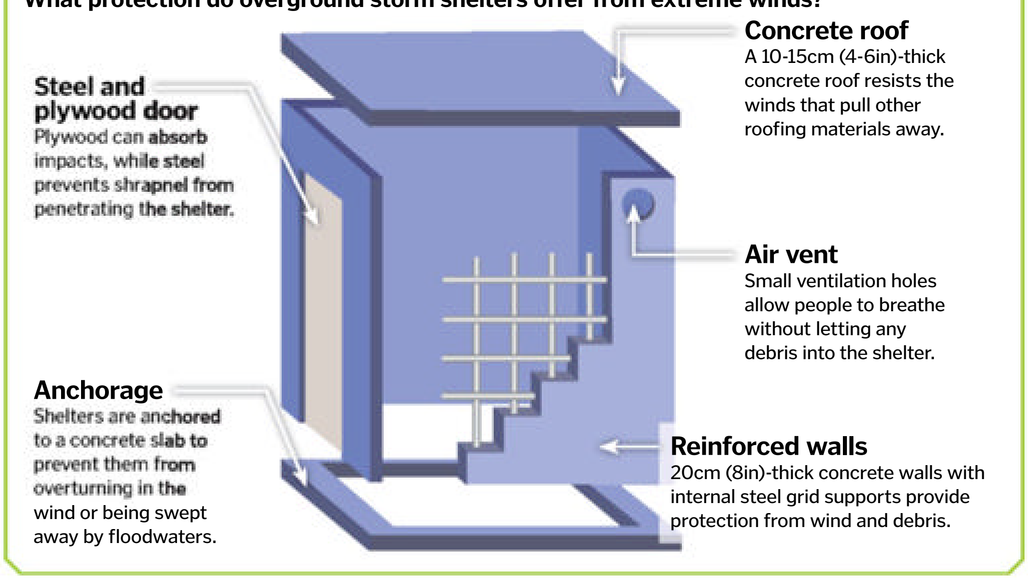
Geography made for disaster

Find out why North America is so prone to twisters

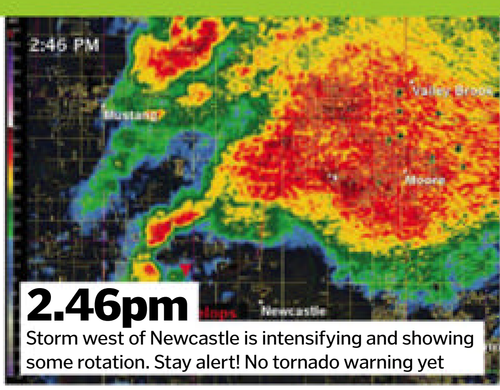


Key features of a storm shelter

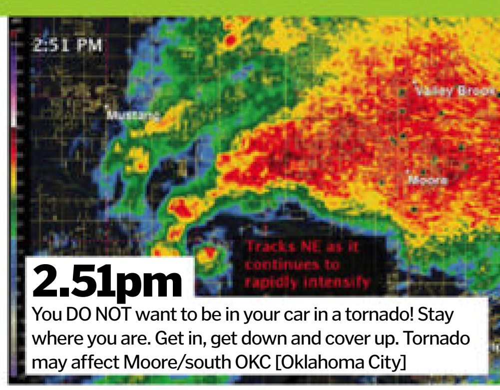
What protection do overground storm shelters offer from extreme winds?



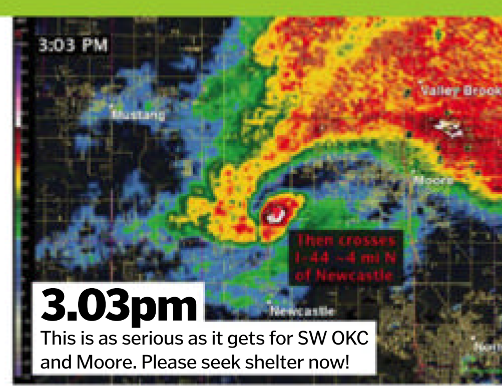
Timeline of the Moore Tornado Live tweets from NWS Norman



2.46pm
Storm west of Newcastle is intensifying and showing some rotation. Stay alert! No tornado warning yet



2.51pm
You DO NOT want to be in your car in a tornado! Stay where you are. Get in, get down and cover up. Tornado may affect Moore/south OKC [Oklahoma City]



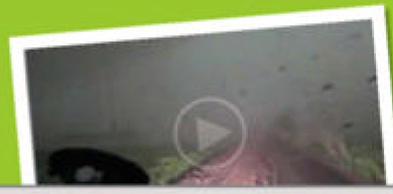
3.03pm
This is as serious as it gets for SW OKC and Moore. Please seek shelter now!

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

Watch the TIV2 get hit by a tornado in Kansas

www.howitworksdaily.com



DID YOU KNOW? *Winds in a tornado have been recorded reaching speeds of 480km/h (300mph)!*

Chasing tornadoes

Discover the technology that allows the Tornado Intercept Vehicle 2 (TIV2) to get to the very heart of violent storms

Turret
Capable of 360-degree rotation, the turret films high-definition IMAX video footage through bullet-resistant tempered glass and polycarbonate.

Mast
Scientific data, including wind speed, barometric pressure and relative humidity, are collected using a retractable mast.

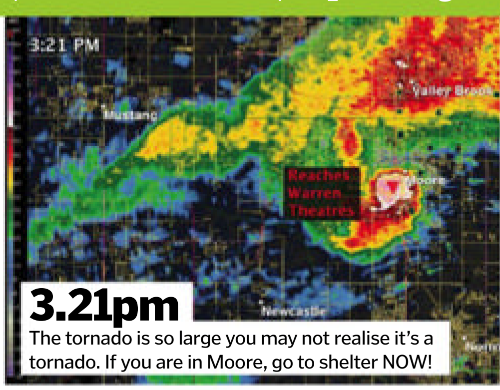
Chassis
Built around a 2008 Dodge Ram 3500 4x4, and covered in 3mm (0.12in)-thick welded plate steel, the TIV2 weighs in at 8,000kg (17,500lb).

Self-levelling suspension
The car has three axles capable of maintaining a fixed height above the road, regardless of changes in load.

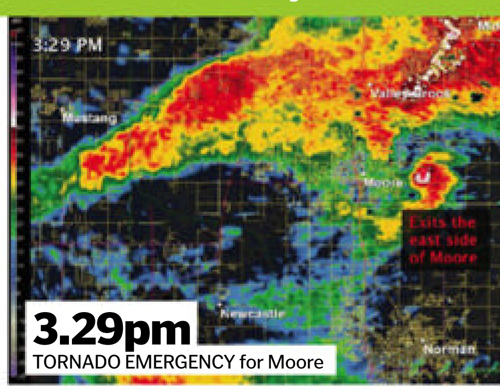
Hydraulic skirt
This can be dropped to divert wind around the base of the truck and to protect the underside from flying debris.

Stabilising spears
A series of 1m (3.2ft)-long hydraulic stakes can penetrate the ground to stabilise the vehicle in the event of particularly violent wind.

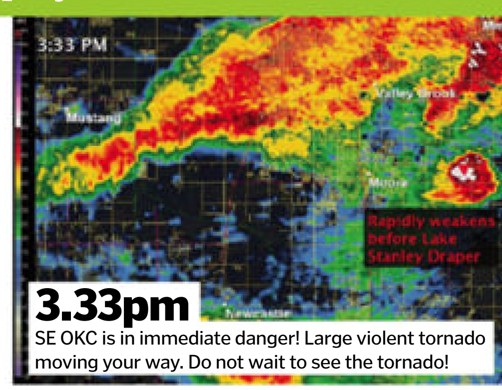
(@NWSNorman) reporting on the Oklahoma City twister as it played out



3.21pm
The tornado is so large you may not realise it's a tornado. If you are in Moore, go to shelter NOW!



3.29pm
TORNADO EMERGENCY for Moore



3.33pm
SE OKC is in immediate danger! Large violent tornado moving your way. Do not wait to see the tornado!

"If a member of the pod appears vulnerable or weak, the rest of the pod will encircle it"

How do sperm whales defend their young?

Discover how these cetaceans form a protective barrier between vulnerable pod members and potential threats like orcas

As well as being the largest toothed whale and one of the deepest diving mammals on the planet, the sperm whale also has the largest brain of any animal known to have lived, which explains their rather intelligent behaviour.

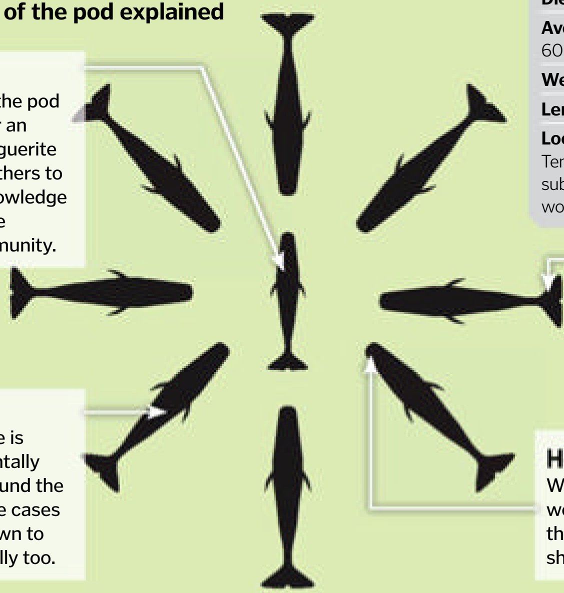
Female sperm whales and their calves live in pods of around 15-20 members, while males tend to roam into cooler waters alone. The pods take good care of their young and are known to defend weaker or younger members from predators such as killer whales on the prowl near the group.

Sperm whales exhibit an unusual form of communal defence – a manoeuvre known as the marguerite formation. If a member of the pod appears vulnerable or weak, the rest of the pod will encircle it. With heads in and flukes (tails) out the group forms a flower-shaped arrangement at the surface in order to shield the weak whale.

Marguerite formation

The defensive manoeuvre that protects weaker members of the pod explained

Weak member
The weak member of the pod may be a young calf or an injured adult. The marguerite formation enables mothers to dive for food in the knowledge that their calves will be protected by the community.

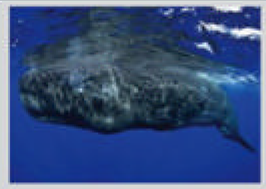


Flukes out
The rear ends point out and can be used to thrash around to deter any potential incoming assailants.

On the surface
While the flower shape is usually formed horizontally across the surface around the weak member, in some cases sperm whales are known to surround them vertically too.

Heads in
With their heads facing the weak whale at the centre, the pod forms a flower shape viewed from above.

The statistics…



Sperm whale

Binomial: Physeter macrocephalus

Type: Mammal

Diet: Carnivore (eg squid)

Average life span in the wild: 60-70 years

Weight: 25-45 tons

Length: 11-20m (36-65ft)

Location: Temperate, tropical and sub-polar deep oceans worldwide (except the Arctic)

How vegetable sheep survive

High in New Zealand's mountains grow remarkable plants whose woolly hummocks resemble flocks of sheep

About 2,000 metres (6,650 feet) up in the mountains of New Zealand's South Island, grey shapes stand like a flock of unmoving sheep. These rounded, ovine cushions are actually Raoulia plants, covered in woolly leaves; they are more commonly known as vegetable sheep because of their appearance.

Plants of the high mountains (called alpines) have to cope with incredibly tough conditions. In winter they are frozen or buried under snow, while in summer, rain soon drains downhill and many hours of sunlight bake the land.

The cushion shape of Raoulia protects it from the weight of snow and it escapes the worst of the winds by hugging the ground. Its woolly leaves form a winter blanket and their grey colour reflects the Sun's rays during summer.

As the cushion grows, its centre rots, forming spongy peat from which the plant's roots draw nutrients

"During such a descent the peregrine falcon reaches speeds three times faster than the fastest land animal"

How to perform a stoop dive

Meet the all-time fastest animal on Earth, the peregrine falcon, and find out how it can grab a meal in midair…

Many birds of prey have special adaptations that help them survive; owls can't move their eyes so they have necks that turn almost 270 degrees, while kestrels eat a diet of small rodents and so have shorter beaks than most other raptors. The peregrine falcon, meanwhile, takes its specialism to the extreme.

Found on all the continents except Antarctica, this bird is a formidable predator. A combination of sharp talons, a hooked beak and lightning-fast reflexes makes the peregrine capable of seizing medium-sized birds in midair. However, that wouldn't be possible were it not for one major attribute: speed. The peregrine falcon is the fastest animal ever to have lived with a maximum velocity of over 320 kilometres (200 miles) per hour.

So how does this bird achieve such great speed and, indeed, use it to its advantage? Well, first it gains a height advantage over its prey and then it uses surprise for a stealthy ambush. To gain sufficient height, the peregrine ascends by flying in tight circles to rise up through warm columns of air known as thermals. Once a good vantage point of over a kilometre (0.6 miles) has been obtained, the falcon trains its eyes on an unsuspecting victim, before using gravity and a technique known as the rapid stoop to swoop silently down.

A stoop is a high-speed dive from high altitude, and during such a descent the peregrine falcon reaches speeds three times faster than the fastest land animal – the cheetah. As well as using gravity to perform these highly controlled dives towards the ground, the peregrine can also boast a number of anatomical attributes that help it achieve such record-breaking aerial acrobatics.

The statistics…

Peregrine falcon

Binomial: Falco peregrinus

Type: Bird

Diet: Carnivore (eg seabirds, pigeons, rats, squirrels)

Average life span in the wild: Up to 17 years

Weight: 530-1,600g (18.8-56.5oz)

Length: 36-49cm (14-19in)

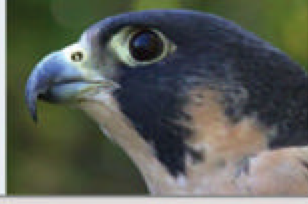
Location: Every continent except Antarctica

STRANGE BUT TRUE

HEADS UP!

Why do peregrine falcons bob their heads when perched?

A To attract a mate **B** To locate prey **C** To keep warm



Answer:
Birds bob their heads up and down and side-to-side in order to better perceive depth. By moving their heads, their eyes can triangulate to determine the exact location of their target in the distance.

DID YOU KNOW? *Peregrines nearly died out due to the use of the now-banned insecticide DDT*

Nictitating membrane
This clear third eyelid moves across the eye from the inner corner to sweep away debris and keep the eye moist without blocking out light.

Nostrils
Due to the pressure of air entering the nostrils when diving at speed, breathing would be impossible if not for bony valves that slow the air as it enters. Similar structures are now used inside jet engines.

Beak
All raptors have strong, sharp beaks, including the peregrine whose short, hooked beak is ideal for puncturing prey and tearing flesh.

Eyes
All birds of prey have very keen eyesight, helping them to locate and train their sights on unsuspecting victims far below. They have a lot more vision cells (cones and rods) than humans.

Toes
The falcon has four toes – three facing forward and one called the hallux, which faces backwards. The middle toe is extra long to help reach through the quarry's feathers and grip the body.

While human skydivers freefall at around 240km/h (150mph), a peregrine can drop into a stoop and achieve freefall speeds in excess of 320km/h (200mph)

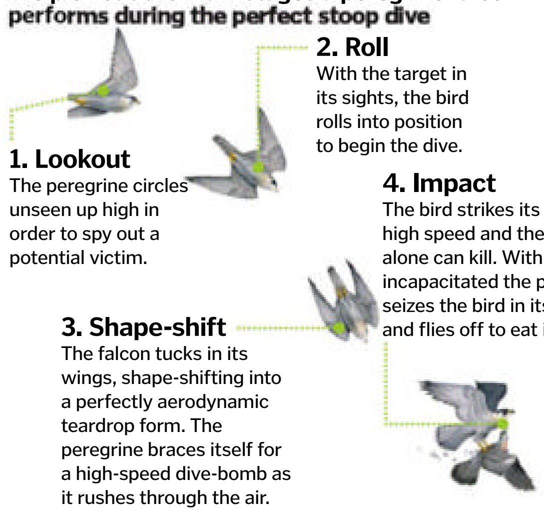
What is terminal velocity?

Freefall occurs when no force other than gravity affects the acceleration of an object in motion. Terminal velocity, meanwhile, is the constant speed of an object (such as a peregrine falcon) as it freefalls through a gas (such as the atmosphere) or a liquid.

A falling skydiver – before they launch their parachute – hits their terminal velocity at around the 240-kilometre (150-mile)-per-hour mark. At this speed they are neither accelerating nor decelerating through the air so the effects of air resistance (ie drag) are equal to the downward force of gravity.

The ultimate flight control

We pick out the main stages a peregrine falcon performs during the perfect stoop dive



1. Lookout
The peregrine circles unseen up high in order to spy out a potential victim.

2. Roll
With the target in its sights, the bird rolls into position to begin the dive.

3. Shape-shift
The falcon tucks in its wings, shape-shifting into a perfectly aerodynamic teardrop form. The peregrine braces itself for a high-speed dive-bomb as it rushes through the air.

4. Impact
The bird strikes its victim at high speed and the impact alone can kill. With the prey incapacitated the peregrine seizes the bird in its talons and flies off to eat it.

HEAD 2 HEAD

SUPER-SEEDS

Coco de mer

The seeds of the coco de mer palm found in the Seychelles are the largest in the plant kingdom, reportedly weighing up to 18 kilograms (40 pounds).

Orchid seed

The tiniest seeds are produced by certain tropical orchids. Dust-like in appearance, a single seed capsule may contain up to 3 million seeds.

Castor bean

The seeds of the castor oil plant are covered with beautiful patterns, but eating just one could kill you as it's packed with the deadly toxin ricin.

DID YOU KNOW? *Much of our daily food, from rice and cereal to pasta and bread, starts out as seeds*

How seeds get around

Plants have developed some ingenious strategies to disperse their seeds and ensure survival of their species…

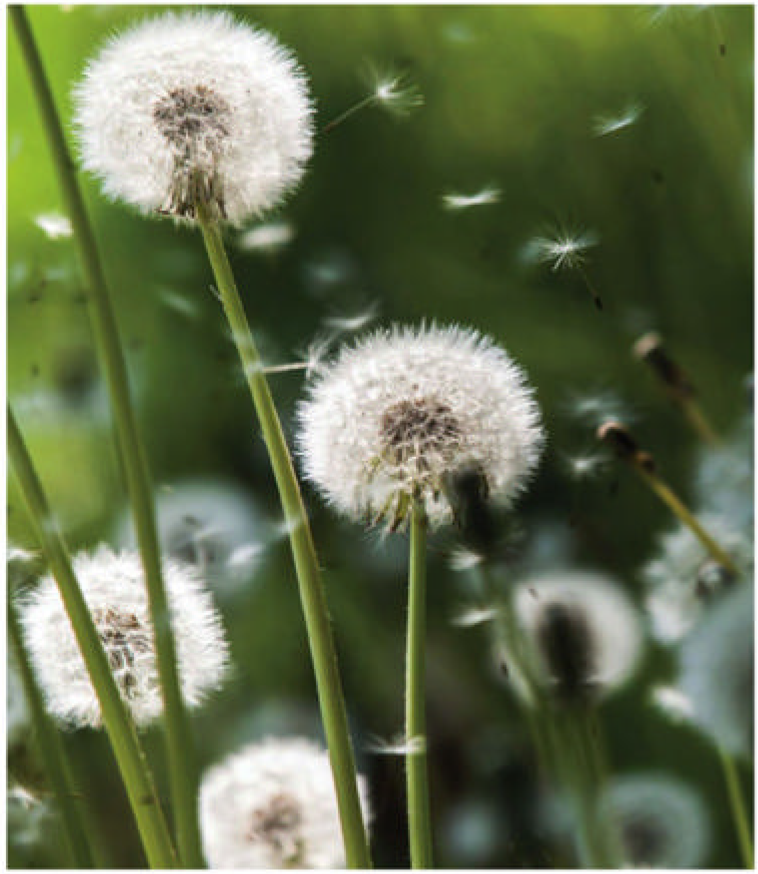
For any species of plant or animal to survive, it must ensure the best possible start in life for its offspring. Some animals nurse their young and move with them to safer 'crèche' areas. Others carefully choose where to lay their eggs to ensure plentiful food when their young hatch.

Plants generally do not have the luxury of being able to move to benefit their young. Simply dropping their seeds beneath them is rarely a good strategy, because the adult plant casts shade that would block the seedlings from the sunlight they need to grow.

Most plants therefore rely on an external mechanism to spread their seeds. Some produce seeds that blow in the wind or float on water. A few use spring-loaded mechanisms to catapult their seeds away. Others offer rewards to encourage hungry critters to spread their seeds on their behalf.

Some plants employ a 'scatter-gun' approach, producing thousands or even millions of seeds to ensure that at least one or two reach a suitable spot to grow. Others invest lots of energy into making just a few, highly developed seeds (eg coconuts) with mechanisms to give them the best possible chance of germination.

Some plants flower in the summer, set seed then die (annuals). That might fail in a bad summer, but their seeds usually last several years to ensure that some germinate eventually. Others take two years before they are ready to flower and seed (biennials). The majority flower and produce seeds for several, or even many, years (perennials), maximising the chances of spreading their kind.



Dispersal techniques

1 Wind

The seeds of many plants have an attached parachute of hairs that carry them off in the wind to new sites where they can germinate. Others have various kinds of wings that keep them aloft as they drift in the breeze.

Examples: Dandelions, rosebay willowherb (fireweed), sycamore and maple trees

2 Sticky

Some seeds have a sticky coat or are covered in hooked bristles. When an animal brushes past the plant, the seeds attach to its fur like Velcro and the creature carries them to a new area. They can also attach to our clothes.

Examples: Bur-reeds, goosegrass (cleavers), African grapple plant

3 Water

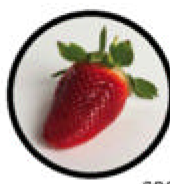
Many riverside plants have floating seeds that are carried downstream, perhaps to an eroded riverbank perfect for colonisation. Seashore plants use the tide and sea currents to spread their seeds. Coconuts can travel great distances this way.

Examples: Coconut palm, sea-bean (samphire), Himalayan balsam

4 Buried food

Some seeds have an oily, edible covering. Ants carry these to their nests and eat the nutritive coat, leaving the seed to germinate. Also squirrels bury acorns as winter food stores, but forget some of their buried treasure.

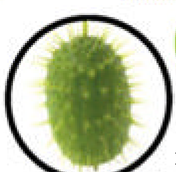
Examples: Castor oil plants, milkworts, oak trees



5 Digested food

Some plants reward seed carriers in a riskier way: they produce an edible, fleshy fruit. Animals eat the fruit, then the seeds pass through their digestive system and are voided in their droppings; this provides a nutrient-rich medium for germination too.

Examples: Apple trees, strawberries, tomatoes



6 Explosion/catapult

As the fruits of some plants dry, their walls stretch. When the ripe fruit splits, tension is released, catapulting the seeds. The squirting cucumber fruit, for instance, swells then explodes, projecting seeds up to 6m (20ft)!

Examples: Broom, cranesbill geraniums, busy-lizzies

"The Spanish and French slopes have different climates and are home to over 3,500 plant and animal species"

How the Pyrenees formed

Discover how an ancient European mountain range came back from the dead to form a high-altitude natural barrier between France and Spain

The Pyrenees stretch from the Mediterranean Sea to the Bay of Biscay in the Atlantic Ocean. This huge mountain chain has acted as a natural barrier throughout human history, separating Spain and Portugal from the rest of Europe. The Spanish and French slopes have different climates and are home to over 3,500 plant and animal species, including brown bears.

The story of the Pyrenees begins more than 500 million years ago when the ancient Hercynian mountains covered much of central Europe. This vast range was comprised of sedimentary rocks folded over granite bedrock.

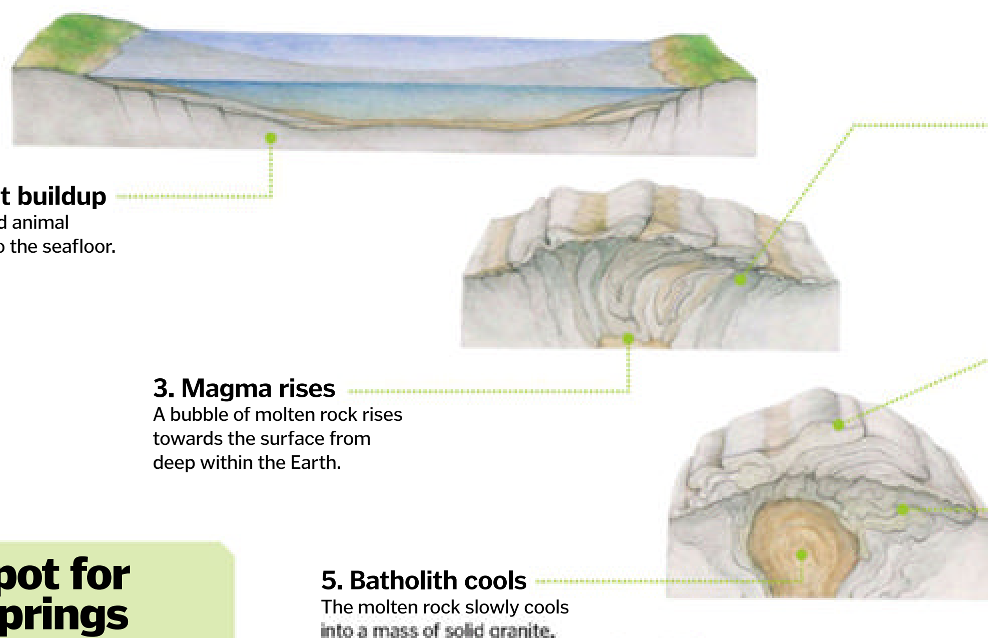
Over millions of years, these mountains were worn down by rivers, wind, frost and ice. At the same time, the jigsaw of tectonic plates that make up the Earth's crust were drifting across our planet's surface. As a result, new oceans opened up. The region containing today's Pyrenees became the Pyrenean basin – a low-lying area between France and Spain often submerged under the sea. Sediment gathered on the seafloor above the old Hercynian range, eventually becoming new sedimentary rock.

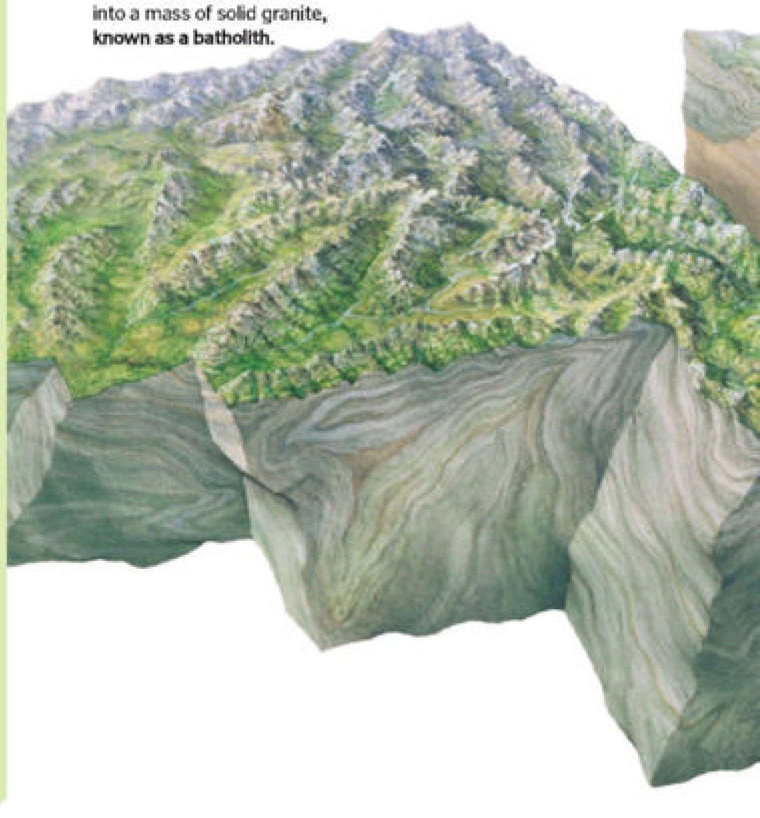
Around 85 million years ago – towards the end of the age of the dinosaurs – the crustal plate that carries Spain moved northwards. This closed the gap between the Mediterranean Sea and the Bay of Biscay, compressed the Pyrenean basin sediments and fractured the Hercynian rocks. The younger sediments folded like modelling clay into new peaks and the Pyrenees emerged.

Since then, the young rocks have worn away in places to reveal the ancient rocks beneath. During the last ice age – approximately 20,000 years ago – rivers of ice flowed down the mountain valleys. These glaciers picked up rocks as they went, grinding and scraping the surface below like sandpaper. Over time, they carved out bowl-shaped hollows called cirques and U-shaped valleys. Today, the Pyrenees continue to be eroded by rivers and frost shatter at higher altitudes.

Pyrenees in the making

See how an ancient mountain range lurks within the foundations of today's Pyrenees





Hotspot for hot springs

In the days before antibiotics, the spa town of Barèges in the French Pyrenees was famous for the curative powers of its sulphurous hot springs. King Louis XIV sent wounded soldiers to the town, many hotels were built and – during its heyday – a fountain was commissioned from Louis Le Vau, the architect of the Palace of Versailles.

There are countless hot springs in the Pyrenees, reaching temperatures of around 37-40 degrees Celsius (99-104 degrees Fahrenheit). Their water comes from rain and snow falling on the mountains. This water migrates down through fractures in the rock over thousands of years. At depth, it's heated by the volcanic rock that once lay beneath the Hercynian mountain range.

The faulted ancient Hercynian rock provides a convenient route for hot water to escape to the surface. It rises so quickly – ie within days or months – that it doesn't have a chance to cool. Minerals dissolved in the warm water lend the springs their sulphurous and/or salty nature.

THE STATS
THE PYRENEES

LOCATION SW Europe | HIGHEST PEAK 3,404m | WIDTH 10-130km
LENGTH 430km | AREA 55,374km^2 | AGE (YEARS) ~25-118mn

DID YOU KNOW? According to legend, the rectangular gap in the Gavarnie Cirque formed when a hero threw his sword at the cliffs

From geology to Jurassic Park

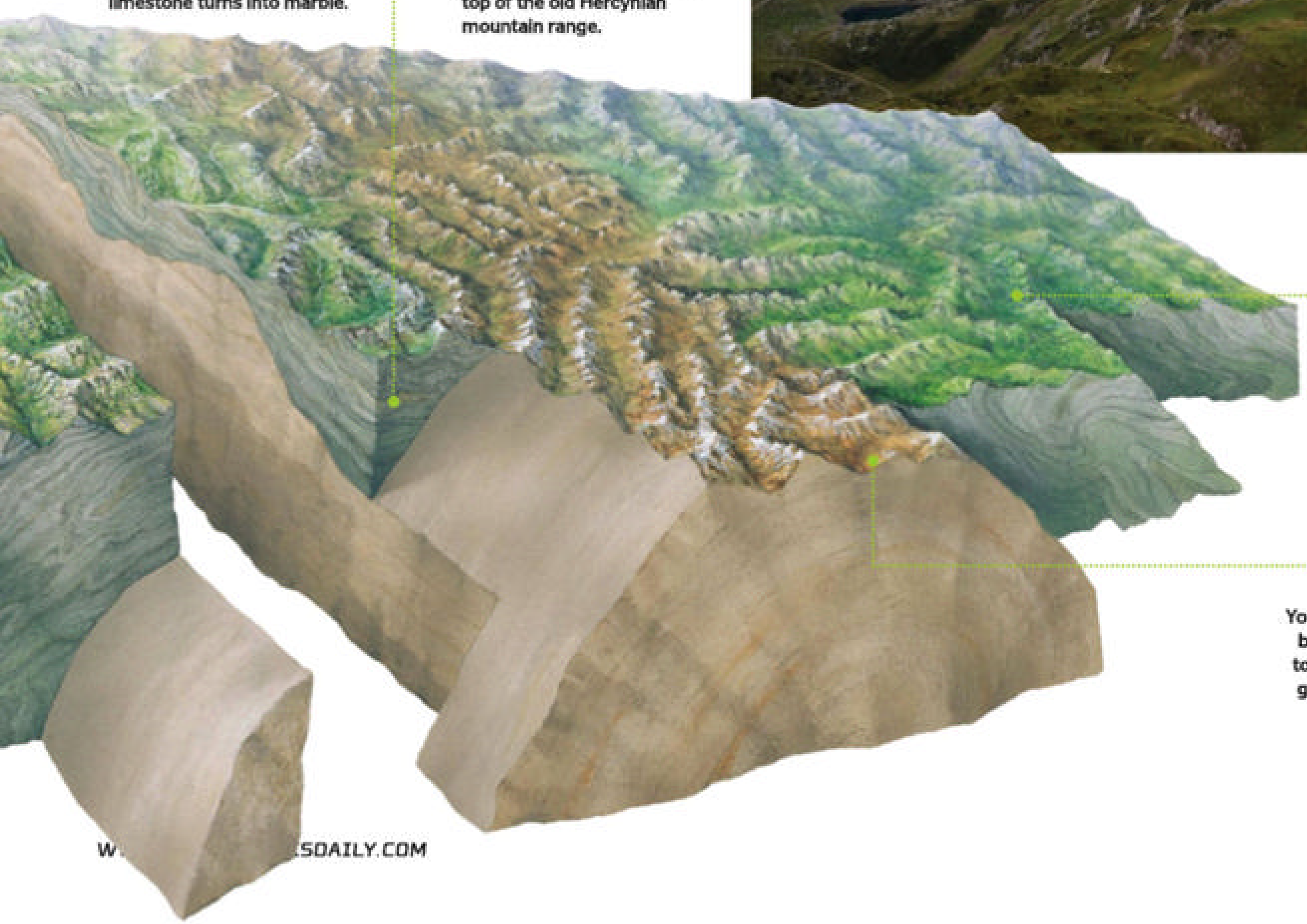
The Cirque de Gavarnie is the Pyrenees' most famous geological feature. This gigantic amphitheatre was carved by rivers of ice tens of thousands of years ago. Its rock walls rise 1,500 metres (5,000 feet) from the valley floor in three terraces; that's about the same as a stack of 350 double-decker buses! One of the world's major waterfalls, the Grande Cascade, plunges 425 metres (1,400 feet) over the cirque's east side and above the cirque are Earth's highest ice caves, hung with frozen stalactites.

Around five per cent of the Pyrenees' species exist nowhere else on Earth. One is the Pyrenean desman (pictured right). This aquatic rodent is hamster-sized and looks a mix between a rat and a platypus.

The Pyrenean ibex – a type of mountain goat with curved horns – turned real-life *Jurassic Park* in 2009 when it became the first extinct species to be resurrected. Scientists used tissues from the last-known animal, which died in 2000, to create a baby ibex; sadly, it only survived a few minutes.

A close relative of moles, desmans live in mountain streams where they eat insect larvae and snails

Large lakes are rare in the Pyrenees, but the mountain group is known for its tall waterfalls and steep valley heads called cirques



2. Sedimentary rocks develop
Over millions of years, the sediments are squashed into sedimentary rock by the weight of debris above.

6. Hercynian mountains
Together the granite and sediments form a huge mountain range called the Hercynian mountains in the location of today's Pyrenees.

4. Metamorphosis
The intense pressure and heat (ie 650°C/1,200°F) of the molten rock transforms the sedimentary rocks, eg limestone turns into marble.

7. Sediment returns
After local tectonic activity causes the land to drop, new sedimentary rocks form on top of the old Hercynian mountain range.

8. Pyrenees rise
A series of mountain-building processes crush and fold the rocks into a chain of new peaks over many millennia.

9. Hercynian rocks revealed
Younger rocks are worn away by wind, frost, rivers and ice to reveal the older Hercynian granite and marble beneath.

Megacities

The immense engineering technologies that can support massive metropolises

In 1976 when the year 2000 seemed impossibly far into the future, the comic book character Judge Dredd presided over an enormous urban sprawl covering the eastern seaboard of the USA, which was called Mega-City One.

Luckily, that particular dystopian vision of lawlessness never materialised, but megacities themselves are very much real and growing all the time. Solving the many problems that they present is an ongoing challenge for the best of 21st-century technology and engineering minds.

A megacity is one with more than 10 million inhabitants. In 1950, there was only one: New York. Today there are 28 and, by 2025, the UN predicts that figure will have risen to 37. This leap isn't just because the population of the world is increasing; it's because that population is becoming increasingly urban. The majority of today's megacities are in developing countries; their growth is fuelled by huge migrations of the rural poor who are attracted to the megacity by its sheer size and the promise of better opportunities.

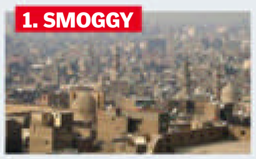
London was the largest city in the world during the 19th and early-20th centuries. It was overtaken by New York in 1925 and then in the 1960s by Tokyo, which has held on to the crown since. But ranking the size of a megacity is hard to do accurately, because it depends on how the boundaries are defined. London, for example, grows or shrinks by 6 million people, according to whether you only count the urban population or include the whole of the Greater London Metropolitan Area; the part referred to as the 'City of London' is actually the *smallest* city in England, with just over 7,000 residents!

Jakarta, the capital of Indonesia, has a population of 10 million, which puts it 13th in the world and roughly level with London. But the Jakarta metropolitan area is a sprawling conurbation that has absorbed the cities of Bogor, Depok, Tangerang and Bekasi. This vast complex is sometimes referred to as Jabodetabek, from the first letters of each of the cities. Its total population is over 28

HEAD 2 HEAD

MEGA POLLUTION

1. SMOGGY



Cairo

A dry climate and unlicensed lead and copper smelting plants have created a thick cloud of smog that appears every autumn.

2. SMOGGIER

New Delhi

A combination of road dust and vehicle fumes, as well as pollution from industry, kill an estimated 10,000 people a year in the Indian capital.

3. SMOGGIEST

Karachi

Pakistan's most populous city, Karachi, is the most polluted megacity, with ten times the air pollution of the world's cleanest megacity, New York.

DID YOU KNOW? *Cities occupy two per cent of the Earth's surface, but consume 75 per cent of its resources*

million – and that's without even including the suburbs – which makes it the second-largest megacity on Earth.

That's still some way behind the 37 million of Tokyo's metropolitan area, but Tokyo's population growth is almost nil today and may even turn negative in the next decade as birth rates in Japan continue to fall. Jakarta, on the other hand, is growing at a rate of more than two per cent per year. Megacities in China and India are growing even faster, and Karachi, Pakistan – which today is fifth in the world – is currently growing faster than any other city has *ever* grown. Indeed, between 1998 and 2011, Karachi more than doubled in size. With growth rates like these, half the world's population could be living in megacities by 2030.

Powering a megacity

London eats 7 million tons of food every year and produces around 20 million tons of rubbish. It uses 28 million tons of concrete, glass and other materials to construct new buildings, and creates 15 million tons of rubble from demolishing old ones. And all of these activities also use electricity and water. The ecological footprint of a megacity extends far beyond the city limits themselves. Tokyo consumes more resources than are produced by all the productive land in the whole of Japan. Indeed, the capital of Japan is only able to function as a megacity because of its ability to plug in to a network that extends overseas and around the globe.

The ability to actively monitor and control that network is crucial to keeping a megacity running smoothly. Mumbai is India's second-largest city, with 19 million inhabitants. Historically it has always had the most reliable power grid in India, thanks to the availability of hydroelectric power. While New Delhi and Calcutta regularly impose rolling power cuts to balance the load on their generating facilities, 95 per cent of Mumbai residents stay plugged in 24 hours a day, 365 days a year. In recent years, however, the megacity has grown to the point where the

> "Mumbai uses a series of sensors that detect when the flow of power into the city changes direction"

2.3 gigawatts that the city power companies can generate isn't enough to meet peak loads of 3.3 gigawatts. To make up the shortfall, power companies buy power in from the surrounding state of Maharashtra, but being connected to the outside grid is risky because sudden spikes in demand around Maharashtra can draw power out of Mumbai and even cause the grid to collapse. In order to prevent this, Mumbai uses a series of sensors that automatically detect when the flow of power into the city changes direction and can trip circuit breakers. These can isolate the city from the state electricity grid and even divide the city itself into 'mini-grids', each served by one of the two main power plants.

Though this may seem selfish, the megacity's isolationist tactic means that the maximum number of customers have their power supply protected and it prevents cascade failures, where excessive demand in one part of the grid causes a domino collapse, as the surplus load is transferred from one network to another.

Rapid growth presents an enormous challenge for megacity engineers. In 2011, Hanoi, Vietnam, didn't have a single sewage treatment plant for a population of 7 million people. The drains were all constructed before 1945 and only covered the central part of the old city – about 35 per cent of the present size of Hanoi. As a result the rivers were silting up with black, toxic sludge. Three new sewage treatment plants are currently under construction in a £20 million ($30.5 million) project that is being partly funded by the Belgian government. Between them the facilities will be able to handle 29 cubic metres (1,025 cubic feet) of sewage per second.

One resource that all megacities are short of is space. Utilities need to be routed underground so that they can cover the whole city without strangling it, but keeping track of all the pipes, cables, tunnels and conduits can be extremely difficult when each network is owned by a different group of companies.

In Japan, Geospatial Information Services (GIS) is a new system that maps and monitors all the overlapping layers of the utility grids to enable companies to compare notes and check what lies beneath, before they break out the pneumatic drills and cause any damage. Ironically, the megacity with the longest established and most complex underground network of pipes is New York, however attempts to create a similar GIS map ▶

Ten megacities by the numbers

Source: UN World Urbanization Prospects report, 2011

1. Mexico City

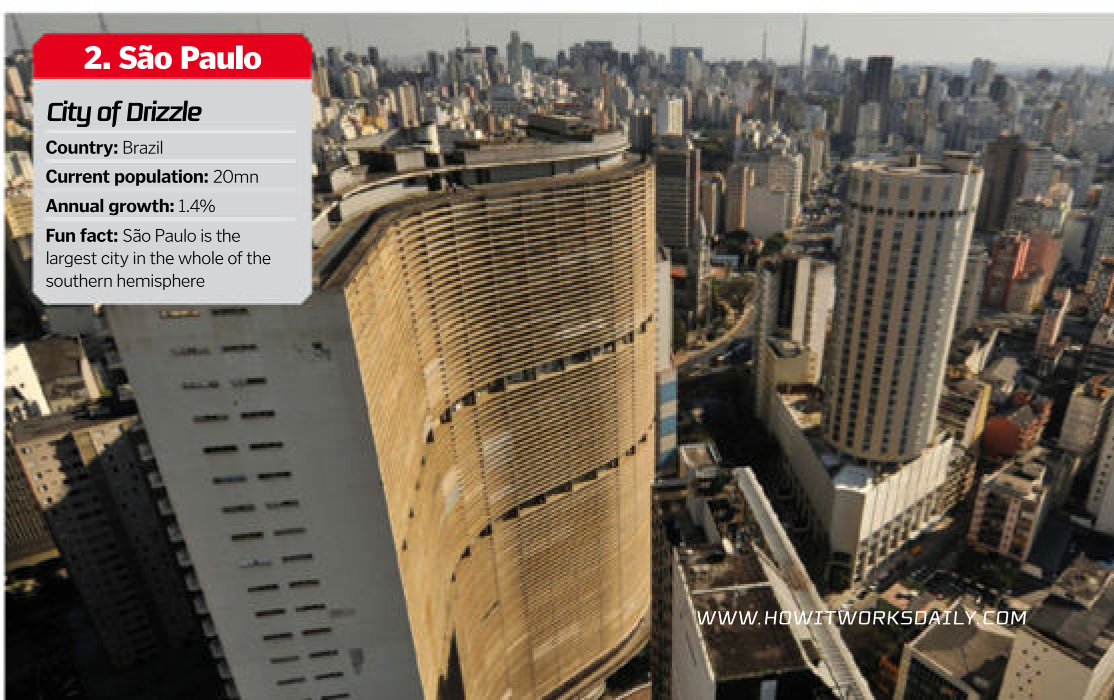
City of Palaces

Country: Mexico

Current population: 20mn

Annual growth: 2.0%

Fun fact: Mexico City will be the world's seventh richest by 2025



2. São Paulo

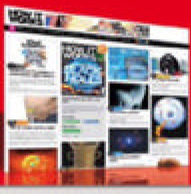
City of Drizzle

Country: Brazil

Current population: 20mn

Annual growth: 1.4%

Fun fact: São Paulo is the largest city in the whole of the southern hemisphere

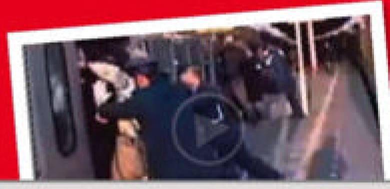


AMAZING VIDEO!

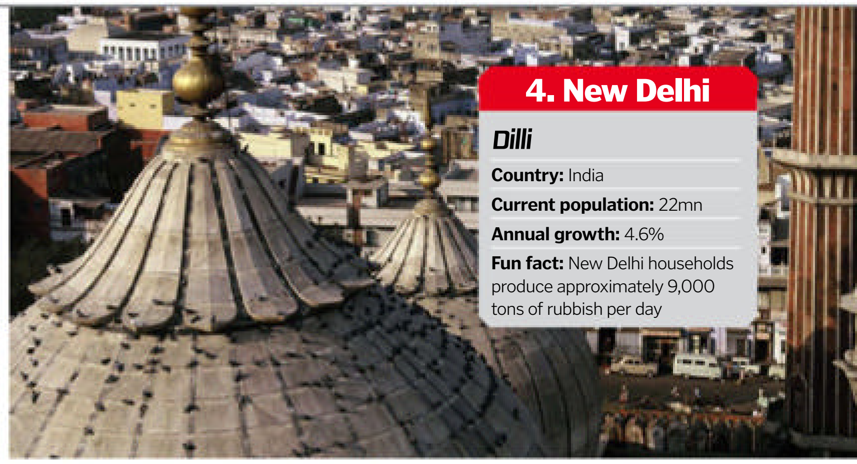
SCAN THE QR CODE FOR A QUICK LINK

How many people can fit on a Tokyo train?

www.howitworksdaily.com



DID YOU KNOW? Jakarta has more Facebook subscribers than any other city: 17 million users and counting



4. New Delhi

Dilli

Country: India

Current population: 22mn

Annual growth: 4.6%

Fun fact: New Delhi households produce approximately 9,000 tons of rubbish per day

3. Karachi

City of Lights

Country: Pakistan

Current population: 14mn

Annual growth: 4.9%

Fun fact: The city of Karachi generates 53 per cent of the taxes for all Pakistan

5. Mumbai

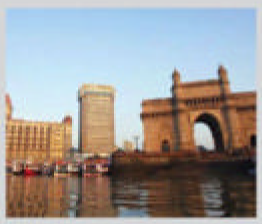
City of Dreams

Country: India

Current population: 19mn

Annual growth: 2.9%

Fun fact: There are 106,000 auto-rickshaws in Mumbai



8. Shanghai

Paris of the East

Country: China

Current population: 20mn

Annual growth: 2.2%

Fun fact: Almost 40 per cent of Shanghai residents are migrants from rural China

7. Manila

The Pearl of the Orient

Country: Philippines

Current population: 12mn

Annual growth: 2.5%

Fun fact: Manila has the most densely populated city centre of any metropolis on the planet

6. Jakarta

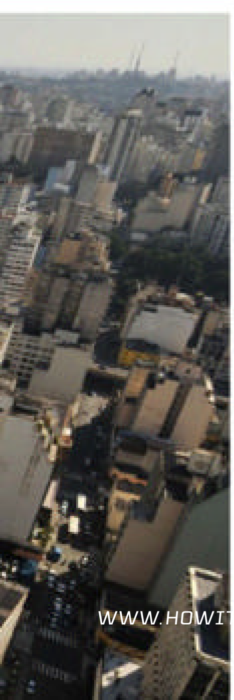
Big Durian

Country: Indonesia

Current population: 10mn

Annual growth: 2.2%

Fun fact: Jakarta is slowly sinking and 40 per cent already lies below sea level



10. Tokyo

The Eastern Capital

Country: Japan

Current population: 37mn

Annual growth: 0.6%

Fun fact: Tokyo has 23 special wards, each with its own mayor

9. Seoul

Special City

Country: South Korea

Current population: 10mn

Annual growth: 1.4%

Fun fact: Seoul boasts the world's largest cinema screen, sized 31 x 13m (101 x 43ft)

> "Traffic congestion in typical megacities costs each driver the equivalent of £700 [$1,070] a year"

have been stalled by fears that such a system could be exploited by terrorists.

Getting around

We all know megacities are dominated by commuter traffic. To function effectively, a workforce of millions must be transported between the suburbs and the business district at the start and end of every day.

In 2000, the 75 largest cities in the US sat through 3.6 billion vehicle-hours of traffic jams. This wasted 21.6 billion litres (5.7 billion gallons) of fuel and £44 billion ($67.5 billion) in lost productivity. Traffic congestion in typical megacities costs each driver the equivalent of £700 ($1,070) a year in unproductive time. In São Paulo, Brazil, the traffic is so bad that the city has 193 helipads and 420 privately owned helicopters, making it the second-largest helicopter fleet in the world. The largest? That other commuter nightmare, New York.

Since chartering a private helicopter isn't within the budget of most Paulistanos, São Paulo also operates the world's most complex bus system. More than 26,300 buses operate over 1,908 routes with almost 160 kilometres (100 miles) of dedicated lanes. Not only was the city one of the first to pioneer microchip-based cashless payment systems much like London's Oyster card, but it has gone much further, with computer-controlled route scheduling packing buses more efficiently into the bus lanes. A typical lane on a motorway or freeway can transport no more than 2,200 car passengers an hour. In contrast, São Paulo's Bus Rapid Transit (BRT) network manages 15,000 an hour. This is on a par with most light rail systems, but without the enormous additional cost and extra space required for building tracks.

Even more efficient, however, are subway systems. Underground train lines can connect stations in straight lines without routing around buildings or following historical road layouts – and multiple train lines can be dug at different levels, so that they overlap without the need for signalling. Underground trains can be stacked much closer together than surface trains and they don't suffer from leaves on the line or the 'wrong type of snow'.

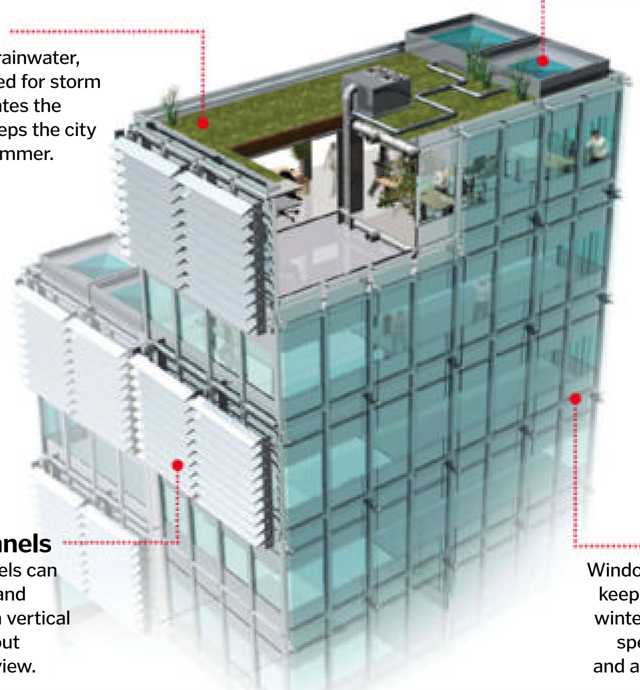
Though London has the oldest subterranean train network in the world – and one of the largest in terms of track miles and stations – it is completely dwarfed by Tokyo's Metro. Trains are the primary mode of transport in Tokyo and it has 882 separate

Sustainable office space

In an effort not to strangle a city under the weight of its own infrastructure, urban planners around the world are exploring ways to make buildings self-sustaining. The Hearst Tower in New York, for instance, was built using a diagonal grid ('diagrid') that uses fewer steel beams than a traditional cuboid shape and 80 per cent of that steel is recycled. In Chicago, the 340 On The Park development uses a rainwater-capture system to irrigate a multistorey winter garden on the 25th floor. While in Rotterdam, Holland, Urban Cactus takes this a step further with a staggered system of curved balconies, giving each apartment a private garden that receives lots of sunlight. Helical wind turbines can also be mounted on the top of a skyscraper or run down the sides. Indeed, the Waugh Thistleton tower in London will generate up to 15 per cent of the building's power needs this way.

Learn more

To find out more about the future of sustainability we recommend you pay a visit to this year's British Science Festival. The event is taking place in Newcastle from 7-12 September where – as usual – you'll be treated to a packed programme of events. This includes sustainability-themed shows, talks and street science on everything from the history of fossil fuels to how we will feed the world in 2050. For details head to **www.britishsciencefestival.org**.

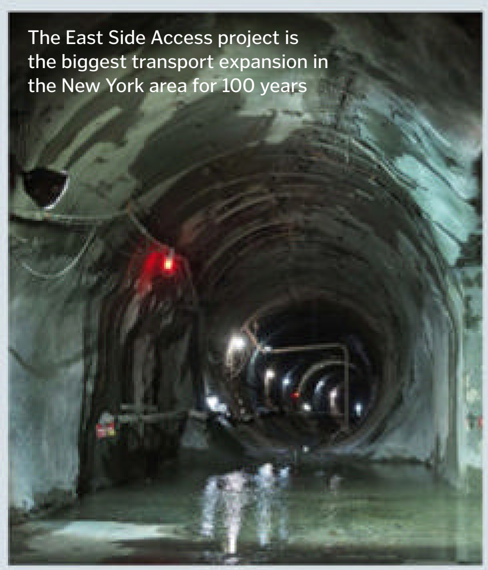


Getting into New York

The Long Island Rail Road (LIRR) carries 81 million commuters a year between Long Island and Manhattan. It is the second-busiest commuter line in North America and the only one to run 24/7. The East Side Access project is designed to extend the rail line farther into the centre of Manhattan, so that it connects directly to Grand Central Station.

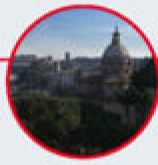
The $8.8 billion (£5.8 billion) scheme is being built entirely underground, with a terminal at Grand Central, a whole new station in Queens and eight new station tunnels. These were excavated by two 580-ton tunnel-boring machines, digging 43 metres (120 feet) below street level.

This mammoth project was originally due to be finished by 2013, but this has now been pushed to August 2019. When it does open, the extra 162,000 commuter journeys made each weekday will also increase pressure on connecting train and bus links. Other schemes, such as the $17 billion (£11 billion) Second Avenue Subway project – also long overdue – will be needed to cope with the load.


The East Side Access project is the biggest transport expansion in the New York area for 100 years

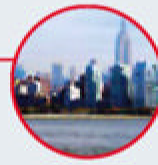
KEY DATES
URBAN SPRAWL

150 CE At the height of its empire, the city of Ancient Rome has a population of 1 million.



1800 Just three per cent of the world's population – around 30 million people – live in cities.

1962 Tokyo overtakes NYC as the largest city in the world. It has remained at the top ever since.



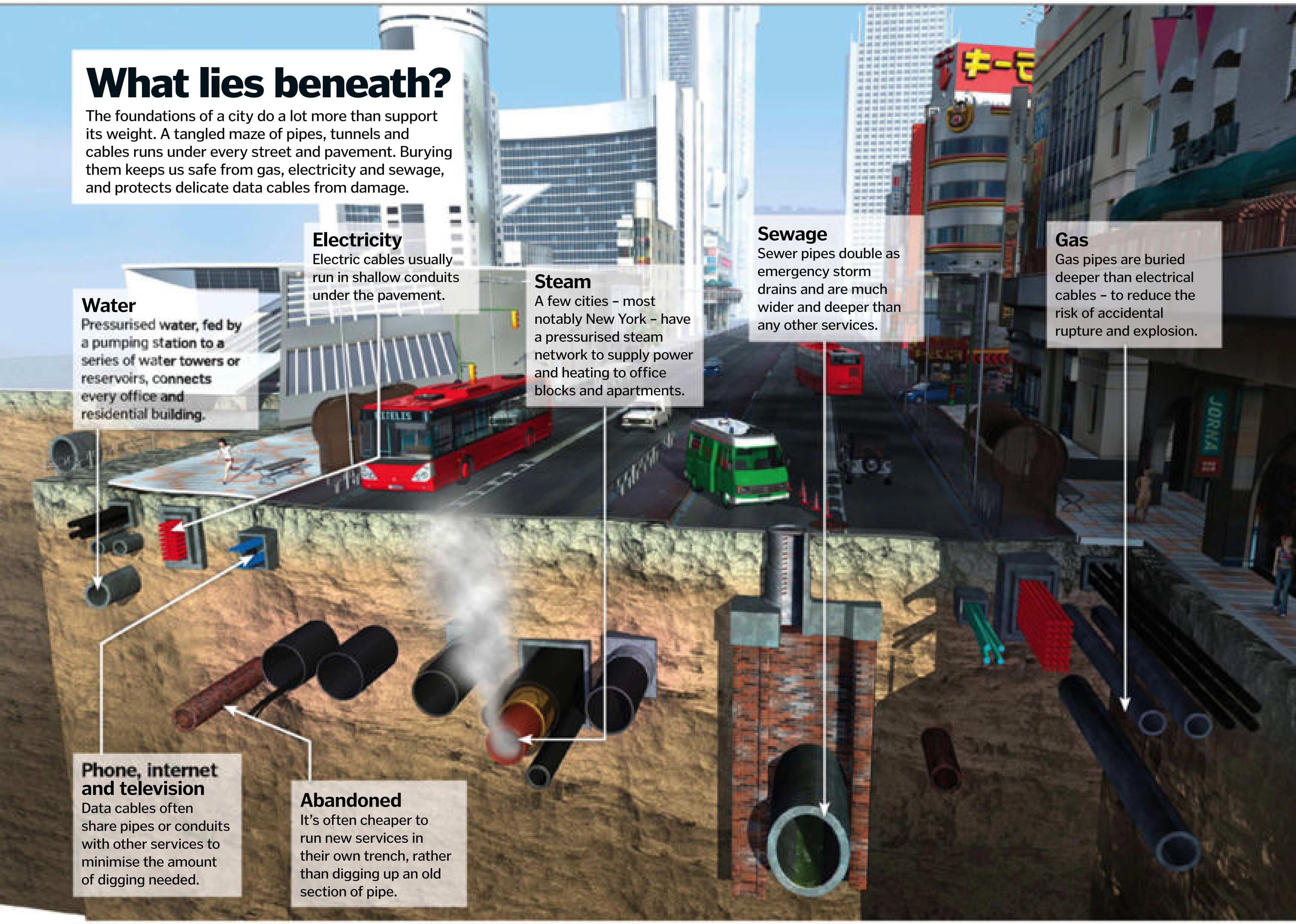
2013 There are now 28 megacities in the world; 18 are in Asia and just four in Europe.

2025 Kinshasa, Shenzhen, Guangzhou, Bogotá, Lima and Lahore are all expected to reach megacity status.

DID YOU KNOW? *City residents in the USA use 450l (119ga) of water a day each; African megacities use 100l (26ga) per person*

What lies beneath?

The foundations of a city do a lot more than support its weight. A tangled maze of pipes, tunnels and cables runs under every street and pavement. Burying them keeps us safe from gas, electricity and sewage, and protects delicate data cables from damage.

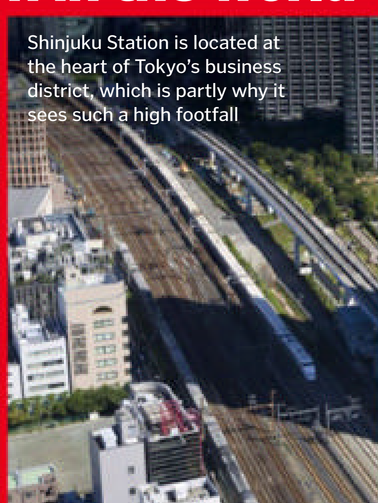


The busiest train station in the world

Tokyo's Shinjuku Station isn't just the busiest rail station in the world – it's the busiest transport hub of any kind. Over 1.2 billion people pass through it every year: the equivalent of the population of Japan ten times over. London's busiest station, Waterloo, handles less than one-13th as much traffic.

Shinjuku has 36 separate platforms serving ten different train operators running on six train lines that converge on the station. It actually functions as a cluster of five different stations, each managed by a different company. This includes two separate subway systems – one of which, Tokyo Metro, is also the busiest subway on the planet.

To keep over 3.5 million passengers a day flowing smoothly through the Shinjuku Station complex, the overground trains have platforms on both sides of the track, with one for passengers getting on and one for those disembarking the train. Platforms are connected by a series of concourses on several different levels. The Odakyu Station section of Shinjuku, for example, covers ten platforms across two levels beneath the Odakyu department store. Six of these are at ground level and four are underground. Altogether, Shinjuku Station has 200 exits to street level.



Shinjuku Station is located at the heart of Tokyo's business district, which is partly why it sees such a high footfall

Dealing with disasters

The streets and subways of any megacity can only just cope with the normal levels of traffic in rush hour. A natural disaster or terrorist attack can instantly overwhelm available escape routes and crash mobile phone networks.

But the more notice residents have of a disaster, the less chaos ensues. In Japan a network of 1,000 monitoring stations can detect earthquakes and signal major cities a few tens of seconds before they hit. That's enough for sensors fitted in every single lift to automatically stop them at the nearest floor, and slow down all trains to a safer speed. Some Tokyo apartments even have special alarms that count down to a quake. Phone networks often crash or slow down after a terrorist attack due to the sudden spike in calls. The rise of Twitter has provided a useful way to reassure family and Google has also begun trialling its Person Finder (**www.google.org/personfinder**) service to help reconnect people after disasters.

> "A key advantage of underground trains is they can run on electricity, which reduces air pollution"

stations with 30 train operators running on 121 train lines; that's one station for every 4.1 square kilometres (1.6 square miles). Every day 40 million passengers board Tokyo's trains and, at rush hour, the trains are so crowded that railway staff called oshiya (which translates as 'pushers') physically shove commuters on to the trains so that the doors are able to close. Though it looks pretty brutal to outsiders, this allows trains to leave much more punctually; the Tokaido Shinkansen 'bullet train' arrives at JR Central Station in Tokyo within six seconds of its scheduled time, on average.

Another key advantage of underground trains is that they can run on electricity, which reduces the amount of air pollution. New York is the megacity with the cleanest air, in part because of its subway, while Karachi in Pakistan, which is the most polluted megacity, has no mass transit system at all.

Traffic pollution isn't just about fumes and smog though. Noise pollution is a significant problem in many megacities. Electric vehicles do a lot to reduce this, but interestingly there is a psychological element as well. Research in Munich in 2005 showed that, for exactly the same decibel level of noise, we perceive a red train to be louder than a green one. Trains in Germany are often red or have a red stripe, whereas Japanese train companies favour white trains with a green or blue stripe.

Technology boom

Global population is expected to stabilise at 10 billion, but *urban* populations could keep rising. As countries become more developed, their cities swell. Boundaries burst and conurbations merge to form megacities. In southern China, for example, nine cities in the Pearl River Delta are being joined up to create a single metropolis of 42 million people that will be 26 times larger than Greater London and twice the size of Wales! Stitching these cities together involves 150 infrastructure projects to link energy, telecommunications, water and transport networks. Together they will cost £190 billion ($289 billion), but the resulting megacity is expected to account for more than ten per cent of China's GDP.

Megacities can provide the reactor core for a nation's economy, but scaling them up isn't just a case of building more skyscrapers. Once it reaches critical mass, a megacity can go into meltdown without the technology to support its population, as we explore on this page.

Technology to the rescue!

Ten technologies that megacities will take advantage of in the future

Commuter power

A rushing commuter gives off about 100 watts of heat. That energy is normally just wasted, but with heat exchanger technology it can be channelled to a nearby building. Rambuteau Metro Station in Paris channels the hot air from the morning rush hour through pipes to heat 17 apartments in the building next door. Stockholm Central Station in Sweden uses the same technique to heat a nearby office block.

Driverless cars

Free Ranging On Grid (FROG) technology uses vehicles with a built-in map of a defined area. Passengers call a FROG car from a pickup point, just like calling a lift, and select their destination from a touchscreen map. FROG vehicles are already used for cargo loading in some ports. By combining this technology with GPS navigation from Google, driverless cars could offer much tighter traffic spacing and better use of the road network.

Biogas buses

Biogas can be produced by using bacteria to digest almost any organic matter. This includes waste food from restaurants and sewage. Even a megacity doesn't generate enough waste to power all of the cars on the road, but it could run the public transport system. Linköping has a fleet of biogas buses and the world's first biogas commuter train too.

Gigabit internet

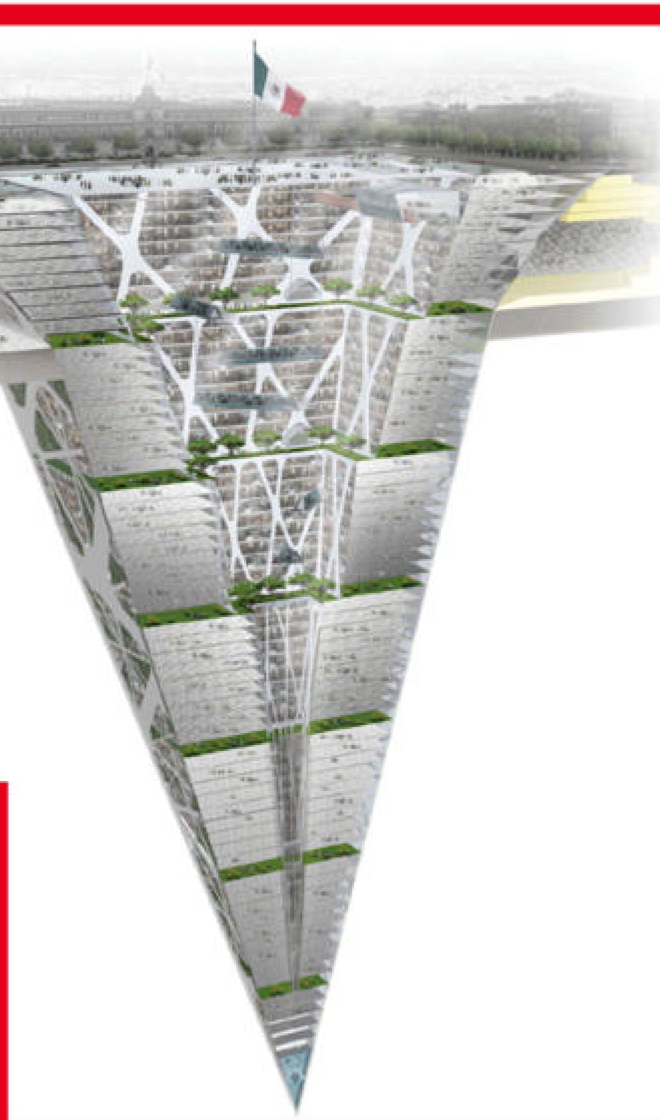
Last year Google began trialling its Google Fiber service. This offers 1,000 megabits per second for both upload and download of data – roughly 100 times faster than most broadband speeds. More bandwidth makes working from home easier using cloud computing, and this reduces the transport demands on the inner city. Austin, TX, and Provo, UT, also signed up to the Fiber service this year.

293km

WORST-EVER TRAFFIC

São Paulo in Brazil broke the record for the worst rush-hour jams in 2009. On 10 June, 293 kilometres (182 miles) out of the city's 888 kilometres (552 miles) of road were gridlocked.

DID YOU KNOW? New York City has 34,000 police officers, costing $4.6bn [£3bn] each year



Underground buildings

Where do you build in a crowded city where every building has historical significance and can't be demolished? You build downwards, of course! The 'Earthscraper' (right) is an inverted pyramid that will be built under Mexico City's Zócalo Square. The first ten storeys beneath ground level will be a museum dedicated to Mexico before Columbus. After that will be ten floors of shops and apartments and then 35 storeys of office space.

Mega-skyscrapers

US architect Frank Lloyd Wright first proposed a mile-high skyscraper in 1956. The compressive strength of the best concrete then would only allow for a 20-storey building, but new concrete formulations with carbon nanotube fibres could be ten times stronger. Saudi Prince Al-Waleed bin Talal has spoken of plans for a mile-high skyscraper. Currently, the Kingdom Tower in Jeddah, designed by Adrian Smith and Gordon Gill, will be Earth's tallest building come 2017 at 1km (0.6mi) high.

Artificial trees

Parkland is an important part of any city, but the amount of carbon dioxide the trees planted there can remove from the air is fairly small. Artificial 'trees' that are specifically designed for the task can remove CO_2 approximately 1,000 times faster than a similar-sized tree. Plus algae-filled, photosynthetic pipes can be run down the sides of skyscrapers to suck carbon from the city pollution.

Next-gen bullet trains

Japan's bullet trains already manage an average speed of 240km/h (150mph), but the new-and-improved L01 uses superconductive magnetic levitation (maglev) technology to float above the tracks and electromagnetic propulsion systems to rocket along at almost 500km/h (310mph). This will cut the commute times between Tokyo and the city of Nagoya in the neighbouring Chubu prefecture from 90 minutes to just 40. The ultra-streamlined train is scheduled for track tests in September 2013 and will begin operation in 2027.

Pay-as-you-throw refuse

Instead of charging a fixed price for rubbish collection as part of local rates, pay-as-you-throw (PAYT) automatically 'meters' the service using different-sized bins. Radio-frequency (RFID) tags on certain recyclable containers charge residents more if they throw away materials that could have been recycled. This reduces the total amount of rubbish chucked away and also creates consumer pressure to do away with unnecessary packaging.

Civic responsibility apps

Code for America has been described as 'a Peace Corps for geeks'. It is a non-profit organisation that uses smartphones and social media to encourage civic engagement. In Boston, MA, for example, users can sign up to 'adopt' a fire hydrant near their home and commit to keep it clear after heavy snowfalls.

"Your activity on Google-owned sites like YouTube is also fed back to advertisers for use in targeting"

Electronic cigarettes

How do eCigarettes create vapour that mimics tobacco smoke and are they harmful?

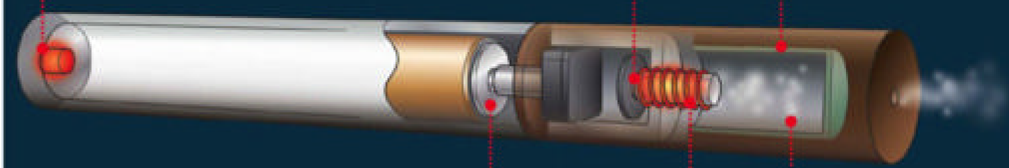
Battery-powered cigarettes convert dissolved nicotine concentrate into vapour, which can then be inhaled without many of the toxic by-products associated with burning tobacco.

The electronic cigarette has three basic components: a chamber, an atomiser and a battery. The chamber contains nicotine and flavourings in a carrier liquid, such as propylene glycol. A wick, made from metal mesh or silica, draws the liquid into the atomiser, where it is heated by a battery-powered coil until it vaporises. The vapour is then inhaled and exhaled like tobacco smoke.

Electronic cigarettes are designed to simulate the feel, taste and nicotine hit of cigarettes, but their safety is debated. In many countries their manufacture and sale is unregulated, resulting in variation in their chemical contents. Their usefulness as nicotine replacement therapy is also largely unknown and the World Health Organization does not condone their use.

No smoke, no mirrors

The technology that powers smoke-free eCigarettes is surprisingly simple



How targeted advertising works

How is the internet uncannily accurate at knowing what kind of things we like?

Advertisers use a range of information about you, like your age, gender and location, to flag up relevant ads

If you look at a product on the web you may find that it follows you around, popping up in adverts on seemingly unrelated websites. This is one of the simplest forms of targeted advertising. When you visit a website, third-party advertisers leave tracking cookies in your browser, enabling them to monitor your online activity and remind you later of items or services you looked at earlier.

Search engines like Google collect data about the searches performed from a particular IP address, taking into account search terms, but also the user's location. They even target advertising based on keywords collected from the messages in your email inbox. Your activity on Google-owned sites like YouTube is also fed back to advertisers for use in targeting.

Social networks sell data to advertisers too. Facebook uses the personal information that you provide about your life and interests, along with your 'Likes' and friendships, to help advertisers pitch to a suitable audience.

RECORD BREAKERS
CHIP CHAMP

83HRS

FRENCH FRY COOKATHON
Belgian chef Chris Verschueren cooked and served a staggering 15,000 portions of french fries in just 83 hours, taking only a 100-minute break for a shower during the shift.

DID YOU KNOW? Don't feel guilty about using your fryer; some oven chips actually have more fat than deep-fried chips!

Deep fryer technology

Cooking the perfect chips requires oil at scorching temperatures, but how do deep fat fryers get so hot and yet remain safe to use?

Deep fat fryers operate at an average temperature of 185 degrees Celsius (365 degrees Fahrenheit), and have a reputation as dangerous kitchen appliances that start fires, but modern equipment has sophisticated technology to both keep the oil hot and protect the cook from potential risks.

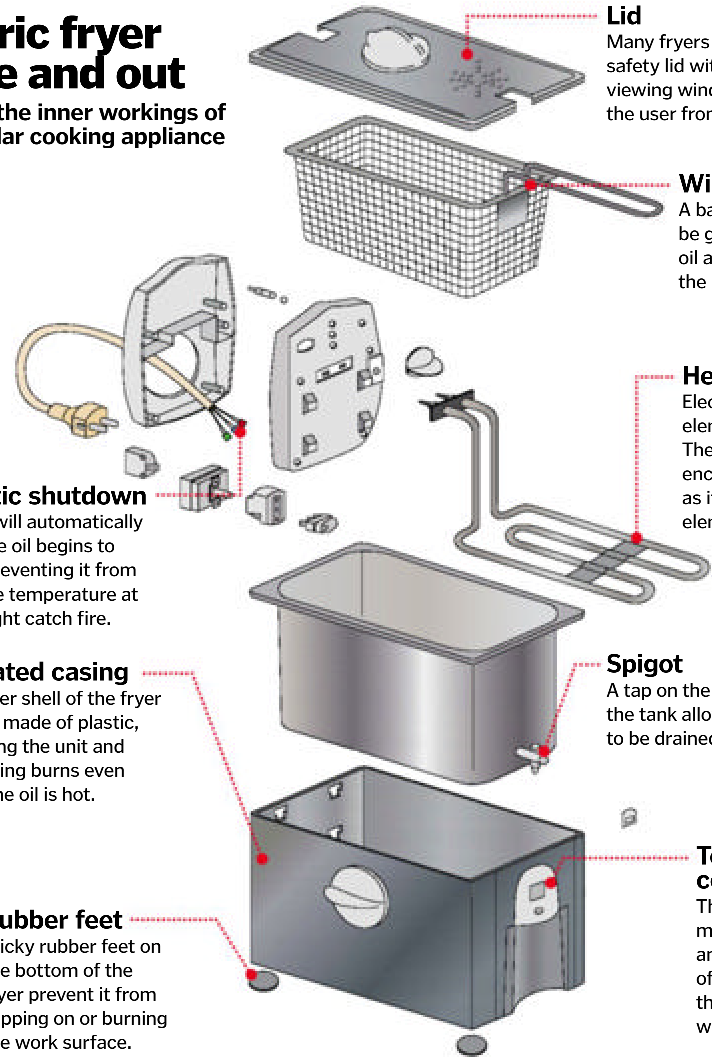
The most important component of the fryer is the mechanism by which the oil is heated: this can either be gas or electric. An electric fryer works almost like an electric kettle; a heating element is immersed in the oil, and as an electric current passes through it, resistance generates heat, which is transferred to the oil.

In contrast, gas fryers use gas burners underneath the vat of oil to generate heat. These warm up much more rapidly, which can be an advantage, but any food particles that sink to the bottom are easily burned, tainting the taste of the oil. Gas fryers therefore often feature a 'cool zone' – a dip in the base of the fryer that extends below the gas burners; this area is cooler than the rest of the oil. As food particles sink, they drop into this recess and are shielded from the most intense heat.

Many oils will ignite at 260 degrees Celsius (500 degrees Fahrenheit), so modern fryers often incorporate a microchip which shuts off the power should the oil begin to overheat. Many new fryers also have a sophisticated thermostat that continually senses and adjusts the oil temperature, keeping it close to the optimum heat level at all times.

Electric fryer inside and out

A look at the inner workings of this popular cooking appliance



Lid
Many fryers have a locking safety lid with a clear viewing window to protect the user from spitting oil.

Wire basket
A basket allows food to be gently lowered into the oil and removed without the need for utensils.

Heating element
Electric fryers use an element to heat the oil. The electric current encounters resistance as it moves through the element, generating heat.

Automatic shutdown
The power will automatically cut out if the oil begins to overheat, preventing it from reaching the temperature at which it might catch fire.

Insulated casing
The outer shell of the fryer is often made of plastic, insulating the unit and preventing burns even when the oil is hot.

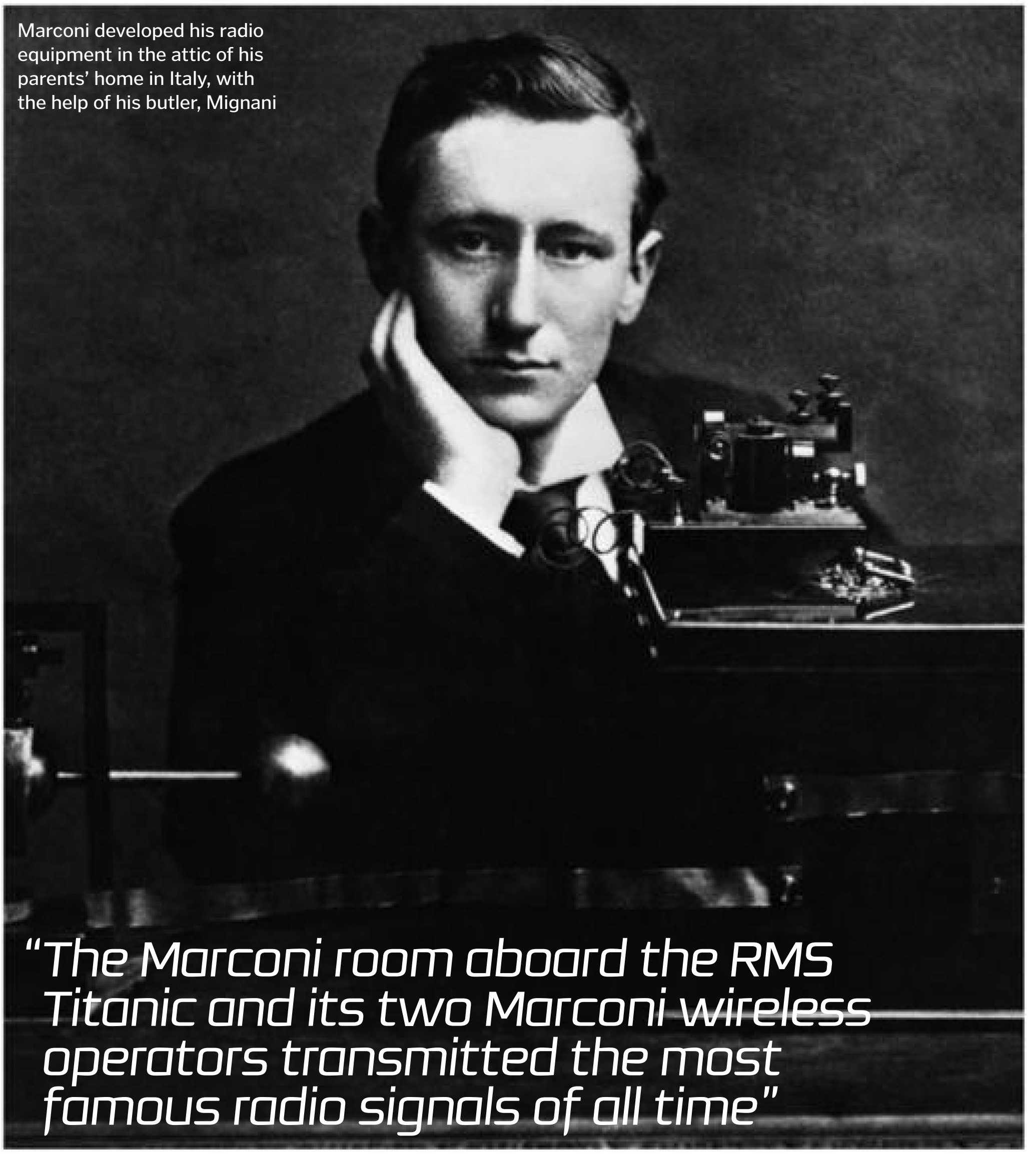
Spigot
A tap on the bottom of the tank allows used oil to be drained easily.

Rubber feet
Sticky rubber feet on the bottom of the fryer prevent it from slipping on or burning the work surface.

Temperature control
The temperature can be manually adjusted, but an internal thermostat is often also used to keep the oil temperature within the ideal range.

Guglielmo Marconi

Sometimes called the father of radio, this resourceful inventor's practical telegraphy system led to the widespread use of wireless communications



Marconi developed his radio equipment in the attic of his parents' home in Italy, with the help of his butler, Mignani

"The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted the most famous radio signals of all time"

Guglielmo Giovanni Maria Marconi was a widely respected Italian inventor who pioneered the development of wireless communication and long-distance radio transmission.

Often credited as the inventor of radio, Marconi was actually an astute businessman who combined, and built upon, the work of other scientists to develop a commercially viable method of long-distance communication.

His interest in electricity and physics began at an early age, and he was inspired by the work of scientists like James Clerk Maxwell, Heinrich Hertz and Nikola Tesla, among others.

In 1894, Marconi read the work of German physicist Hertz, who had developed equipment to send and detect electromagnetic waves over short distances. Marconi saw the potential for transmitting information using radio waves and set about developing a longer-range system to replace wire-based telegraphy.

Marconi began his experiments at his father's estate and with the help of his butler, Mignani, built equipment in the attic. Soon he could transmit radio waves over short distances, so he moved his experiments outdoors to develop the technology further. He found that increasing the length of the antennas – and arranging them vertically – increased the range of transmission so much that he was able to send and receive signals over distances of around 2.4 kilometres (1.5 miles).

It was at this point that Marconi began to see the potential commercial applications of his experiments. Italy already had a well-established telegraph system though, with

A life's work

Tune in to some of the major events from the lifetime of this astute Italian radio pioneer

1874
Guglielmo Marconi is born in Bologna, Italy, to landowner Giuseppe Marconi and his Scots-Irish wife Annie Jameson.

1894
Begins to develop a method of transmitting telegraph messages without wires, using radio waves.

1896
Travels to London, where he gains the support of engineer-in-chief of the Post Office, William Preece.

1899
Sets up the first wireless link between Britain and France from Wimereux, France, to a lighthouse in Dover, England.

1900
Takes out his No 7777 'Improvements in Apparatus for Wireless Telegraphy' patent to protect his technological developments.

Post Office engineers inspect Marconi's radio equipment before the first-ever transmission of radio signals over the open sea

In their footsteps…

Edwin Armstrong

Captivated by Marconi's radio technology, Armstrong was a prolific inventor and made the regenerative circuit – the first radio amplifier; it used a positive feedback loop to greatly amplify incoming radio signals. He also invented modern frequency modulation (FM) radio transmission, which enabled much clearer communication.

John Logie Baird

Baird was a pioneer in the development of publicly available television broadcasting, who compiled, tested and modified the work of others to produce a live, moving TV image. He once said of Marconi: "It was he who ventured forth like Columbus and forced upon the attention of the world the existence of a new means of communication."

The big idea

Marconi combined and modified the inventions of other scientists to develop equipment that could transmit radio waves over great distances. He used a spark-gap transmitter to generate radio frequency electromagnetic waves and a coherer receiver to detect them. A telegraph key enabled him to send radio waves in bursts, generating Morse code. Marconi discovered that the maximum distance of radio wave transmission varied directly according to the square of the height of the transmitting antenna, so tall, vertical antennas were the key.

networks of wires extending across the country, and his applications for funding were dismissed. Undeterred, Marconi travelled to the UK. Britain had a powerful Royal Navy and was the world's greatest trading empire, and his thinking was that they might have use for his work in maritime communication.

Marconi gained the support of the engineer-in-chief of the British Post Office and, with his help, demonstrated his technology to the British government. During his first few years in England he gradually improved the distance of radio transmission – first on land and then over sea. His work excited the international community and stations were set up in France for the first radio crossing of the Channel.

As his technology continued to evolve, 'Marconi rooms' were installed in ships, containing a suite of wireless telegraphy equipment which enabled communication with land as well as other vessels. The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted perhaps the most famous radio signals of all time: 'CQD CQD SOS Titanic position 41.44 N 50.24 W. Require immediate assistance. Come at once. We struck an iceberg. Sinking'.

Marconi died in Rome in 1937 at the age of 63. He was given a state funeral and – as a tribute to his massive contribution to wireless communication – every radio station in the world fell silent for two minutes.

Top 5 facts: Guglielmo Marconi

1 Royal connections

Marconi installed radio equipment on Queen Victoria's royal yacht so that she could communicate with the Prince of Wales (Edward VII).

2 Educated but unqualified

Marconi had no formal qualifications, but had a keen interest in physics. At the request of his mother, he was mentored by physicist Professor Augusto Righi, who introduced him to radio waves.

3 Are you ready?

The first radio transmission across the open sea was sent over the Bristol Channel and travelled a distance of 6.4 kilometres (four miles). It read 'Are you ready'.

4 High-speed Morse

To be employed as a wireless operator by Marconi's Wireless Telegraph Company you had to be able to send and receive Morse code at a speed of 25 words per minute.

5 Lucky escape

Marconi was offered free passage on the RMS Titanic, but decided to travel to America three days earlier on the RMS Lusitania because he had paperwork to do.

1901
Successfully transmits the letter 'S' in Morse code 3,380km (2,100mi) across the Atlantic Ocean to Newfoundland.

1909
Receives the Nobel Prize in Physics – along with Karl Ferdinand Braun – for their contribution to wireless telegraphy.

1912
Marconi radio is used to save victims of the Titanic, and passes distress signals from the sinking ship to the RMS Carpathia.

1914
Joins the Italian war effort during World War I, where he takes charge of the military's radio service.

1937
Marconi dies aged 63. He receives a state funeral in Italy and all radio stations hold a two-minute silence in his honour.

"It solidifies so quickly that the pen can be used to draw vertically in the air, creating instant 3D models"

3D drawing

The world's first 3D printing pen allows you to draw freehand plastic sculptures

The 3Doodler pen, which is manufactured by WobbleWorks, is a handheld 3D printer that functions in a similar way to a hot glue gun. The pen uses melted, extruded plastic to build three-dimensional images.

The 3Doodler started life as a cannibalised 3D printer. The developers removed one of the plastic-extruding heads and added a handle to make a prototype that they called 'the Teacup'. Further revisions of the new technology added a small fan at the tip, which blows cold air onto the plastic as it exits the device, cooling it down and enabling it to harden much more rapidly. Indeed, it solidifies so quickly that the pen can be used to draw vertically in the air, creating instant 3D models.

The 3Doodler uses standard three-millimetre (0.12-inch)-thick strands of plastic specifically designed for 3D printing applications. They are fed into the nib, which can reach temperatures of up to 270 degrees Celsius (518 degrees Fahrenheit).

Artists have a choice of acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA). ABS plastic is one of the most commonly used in this field to make everything from toys to car parts; it sets rapidly, comes in many vibrant colours and can be laid down on paper templates before being peeled off to assemble more complicated structures.

PLA, on the other hand, is biodegradable, has a lower melting point and is made from cornstarch. Although it doesn't solidify as quickly as ABS, it is much stickier, enabling sculptures to firmly attach to a variety of surfaces for stability.

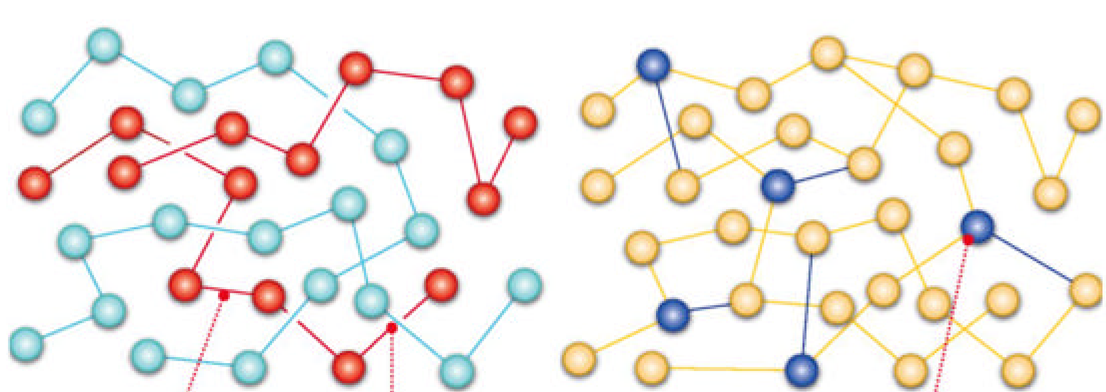
All manner of things can be made with the 3Doodler from basic ornaments and decorations to more complex objects like this model of the Eiffel Tower

Plastic at a molecular level

3D printers use thermoplastics (aka thermosoftening plastics), which soften when heated and then solidify when cooled. In their solid state, the molecular chains that make up thermoplastics are held together by weak links. These are based primarily on differences in the charge of the atoms that make up the molecules, providing small-scale electrostatic attraction between adjacent chains. When heated, the increase in energy in the molecules means that they vibrate free of these weak interactions, melting the plastic. As it cools, the links can re-establish, producing a solid structure again. This is in contrast to thermosetting plastics, which form cross-links when they're heated, permanently joining chains together to produce stronger 3D structures.

Thermoplastic elastomer

Thermoset elastomer



Chains Plastics are made up of long chains, or polymers, with several thousand repeating units.

No bonds There are no chemical bonds between chains in thermoplastics; instead they are held together by weak electrostatic interactions.

Cross-links In thermosetting plastics, chemical bonds develop between chains when the plastic is heated, forming permanent links and preventing re-melting.

© 3Doodler

"As the system has no physical media, all titles are installed on the console's storage drive"

Inside the OUYA

Meet the open-platform console which lets you play your videogames on a system that was designed to evolve

The OUYA is a videogame console that runs on a custom version of the Android 4.1 Jelly Bean operating system. Unlike many existing games consoles, however, the development of this machine was achieved through crowd-sourced funding, with the maker – OUYA, Inc – raising a whopping $8.5 million (£5.6 million) in 2012. Breaking from the norm, the OUYA has been designed as an open platform, with the device capable of being modified easily by owners.

As can be seen in greater detail in the teardown, the OUYA runs off an NVIDIA Tegra 3 system on a chip, which combines the console's CPU, GPU and memory. This, in partnership with a selection of mainboard ports and connectivity chips – including Wi-Fi and Bluetooth – allows the OUYA to be connected to a television or computer and run its own custom user interface (UI) off the Jelly Bean OS.

Key to the OUYA's UI is the OUYA store, which is the main conduit to the console's selection of games. Indeed, as the system has no physical media, all titles are installed on the console's storage drive (eight gigabits internal; expandable via USB or digital download). The majority of games currently available or confirmed are ports of titles already existing on the Android marketplace. Games are played via the OUYA's own Bluetooth-linked control pad.

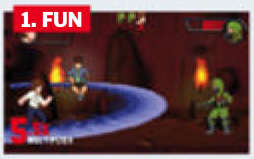
The gaming side of things is combined with a host of media-related applications, including the open-source XBMC media player, TwitchTV live videogame stream broadcaster and iHeartRadio internet radio platform. Along with a selection of videogame emulators this completes the OUYA's stock package, but due to the system's open hardware and software architecture, many other applications and services are in the pipeline.

The next-gen gamer

Take a look at the major components inside this cutting-edge gaming system

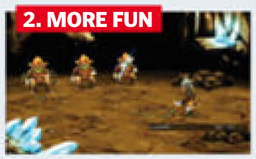
HEAD 2 HEAD OUYA GAMES

1. FUN



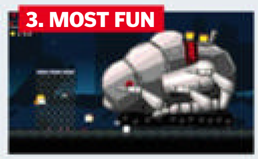
Saturday Morning RPG
An old-school RPG with an Eighties cartoon look, *Saturday Morning RPG* is an episodic title that was community funded too.

2. MORE FUN



Final Fantasy III
The Nineties classic, remade in full 3D in 2006, gets a fantastic port on OUYA, with new story sequences and improved visuals across the board.

3. MOST FUN



Gunslugs
A hectic 8-bit-style, side-scrolling shooter, *Gunslugs* is a pleasure to play and captures the Eighties arcade gaming scene with aplomb.

DID YOU KNOW? *The OUYA's development was funded by the public in just eight hours*

Ports
The OUYA has five ports: a DC-in power, microUSB, HDMI, Ethernet and USB 2.0. These feed the system power or are used to connect to the web, TVs and computers as needed.

Heatsink
The system-on-a-chip is covered with a small heatsink. Soldered to the processor, this grants greater stability and some damage resistance should the device be dropped.

System-on-a-chip
The OUYA's heart is an NVIDIA Tegra 3 system-on-a-chip (SOC). This primarily combines the CPU and GPU onto a single chipset, improving efficiency and also saving on space.

Touchpad
A 22.9 x 38.1mm (0.9 x 1.5in) touchpad is powered by a MA32P03 controller – this provides 2D mouse tracking for the OUYA system.

Mainboard
The mainboard holds the SDRAM modules, USB 2.0 and Ethernet controller, Wi-Fi and Bluetooth 4.0 module, NVIDIA Tegra 3 multicore CPU and Kingston 8GB flash memory.

Transceiver
A Broadcom Bluetooth 3.0 transceiver features an integrated ARM Cortex M3 processor. This receives all inputs from the controller and transmits them to the OUYA.

The statistics…
OUYA console

CPU: 1.7GHz quad-core ARM Cortex-A9

RAM: 1GB

Storage: 8GB internal flash memory

GPU: NVIDIA ULP GeForce

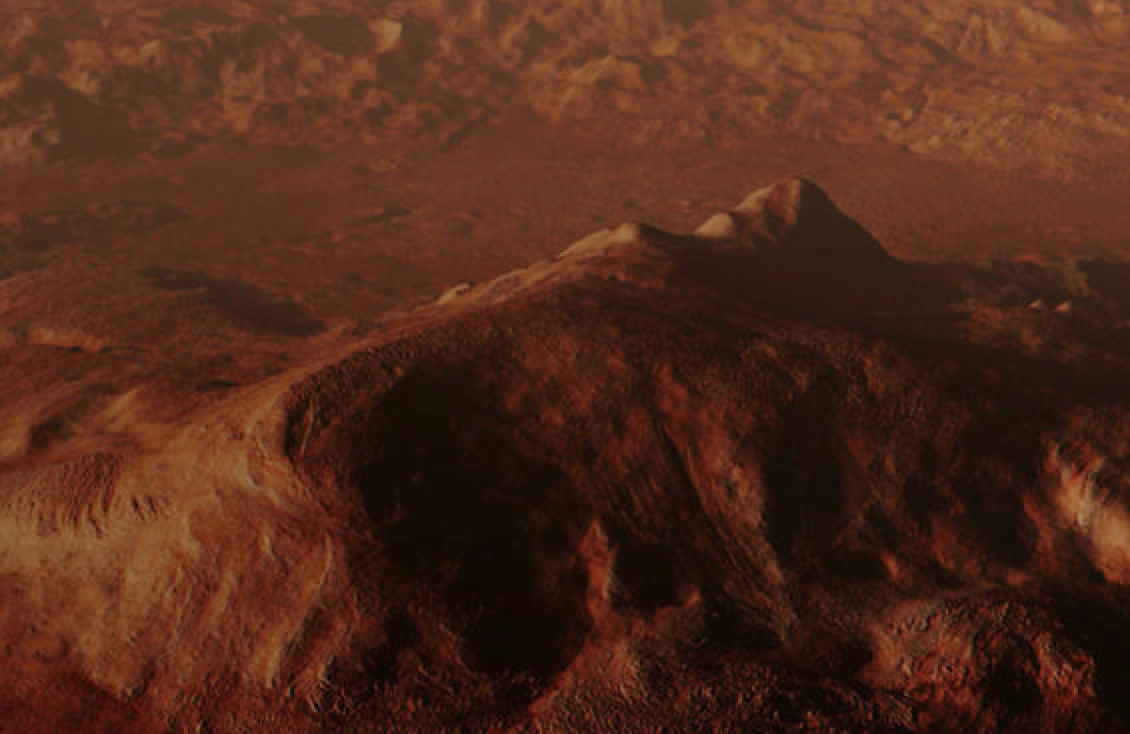
Dimensions: 75mm (3in) a side

OS: Android 4.1 Jelly Bean

Cost: $99 (£99)

EXPLORING NEW WORLDS

Going where no one has gone before, these robotic rovers are our eyes and hands which we can use to investigate alien planets



Crawling, trundling and perhaps one day walking across the surface of other worlds, roving vehicles are designed to cope with the roughest terrain and most hostile conditions the Solar System has to offer. The famous Lunar Roving Vehicle (LRV) driven by NASA astronauts on the later Apollo missions is a distant cousin of the robot explorers that have been revealing the secrets of Mars since the late-Nineties, and may one day venture to even more distant planets and their satellites. Equipped with ever-more sophisticated instruments, they offer a cheaper and safer – if less versatile – alternative to human exploration of other worlds.

While the LRV is probably the most famous wheeled vehicle to have travelled on another body, the true ancestors of modern robot missions were the Soviet Lunokhod rovers. Resembling a bathtub on wheels with a tilting 'lid' of solar panels, two Lunokhods operated for several months on the Moon in the early-Seventies. Despite this success, however, it was 1997 before another rover – NASA's small but robust Sojourner, landed on the surface of Mars. Sojourner's success paved the way for the larger and more ambitious Mars Exploration Rovers, Spirit and Opportunity, then even more successful Curiosity, and planned missions such as the ESA's ExoMars rover, due in 2018.

Robotic rovers have to cope with a huge range of challenges; millions of miles from any human assistance, they need to tackle the roughest terrain without breaking down or tipping over. Designs such as the car-sized Curiosity run on a set of robust wheels, each with an independent drive motor and suspension so that if one does become stuck their designs will manage in alien conditions, engineers first test them in hostile Earth environments such as California's Mojave Desert near Death Valley. Engineering teams on Earth even maintain a 'clone' of their Martian rovers so they can test difficult manoeuvres in safe conditions on Earth prior to the real thing.

These robot explorers carry a variety of equipment, often including weather stations, an array of cameras, robotic arms, sampling tools and equipment for chemical analysis. Science teams on Earth study images of the rover's surroundings and decide on specific targets for study, but the rover often conducts many of its basic operations autonomously.

What rovers lack in flexibility compared to human astronauts, they make up for in endurance. Drawing power from solar panels or the heat from radioactive isotopes, they can operate for months or even years (indeed, NASA's Opportunity rover landed in the Meridiani Planum region in January 2004 and is still running more than nine years later).

Properly designed, they can resist the dangers of high-energy radiation and extreme temperature changes and, of course, they don't need food, drink or air to breathe. In the future, designs for multi-legged 'walking' rovers may make our mechanical stand-ins even more flexible, helping to further bridge the gap between robotic and human explorers.

37KM

LONGEST DRIVE OFF EARTH

During four months of operation in early-1973, the Soviet Lunokhod 2 rover crossed an impressive 37 kilometres (23 miles) of treacherous lunar terrain – a record that still hasn't been beaten to date.

DID YOU KNOW? *Spirit and Opportunity owe their long lives to Martian winds blowing away dust from their solar panels*

Keeping in touch with Earth

Sending commands to a rover in space is a unique challenge. While radio signals take little more than a second to reach the Moon, signals can take anything from four to 21 minutes to reach a robot on the Red Planet.

So while the first Soviet Moon rovers could be 'remote controlled' with just a little delay, it's impossible to do the same with Martian rovers; it would simply take too long to send each command and assess its results.

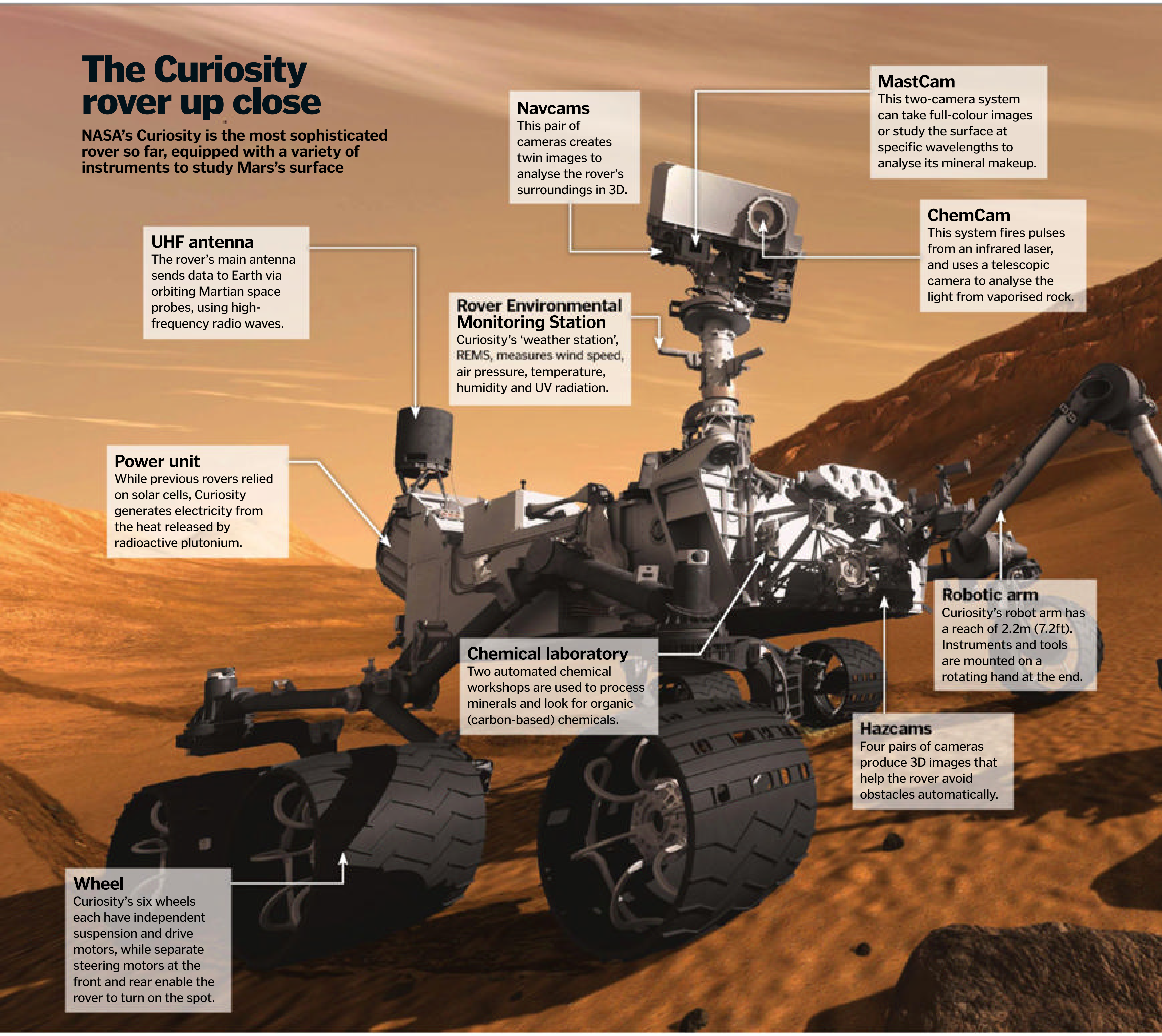
Instead, rovers from Sojourner through to Curiosity and beyond are pre-programmed with a range of functions that allow them to work more or less independently; their operators back on Earth select directions of travel and rocks for inspection, and the rover can then do many of the tasks for itself.

The huge distance to Mars also causes problems for the strength of radio signals, since it's impractical for a rover to carry a directional high-gain antenna dish and keep it locked on to Earth. Instead, rovers use broadcast radio antennas to send their signals to a relay station (usually a Mars-orbiting satellite), which then uses its dish antenna to relay them to Earth. In case of emergencies, however, modern rovers are also usually capable of slow communications directly with Earth.

"As rovers have become more sophisticated, they have also improved their sampling abilities"

The Curiosity rover up close

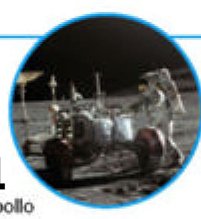
NASA's Curiosity is the most sophisticated rover so far, equipped with a variety of instruments to study Mars's surface



Roving through history

We pick out some of the major milestones in the development of rovers

1970
The Soviet Union's Lunokhod 1 lands on the Moon. The first-ever off-Earth rover operates for ten months.

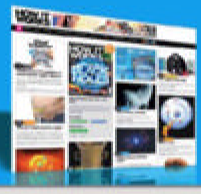


1971
NASA's Apollo 15 mission lands the first of three Lunar Roving Vehicles on the surface of the Moon.

1973
Lunokhod 2 lands on the Moon, operating for four months but failing when it overheated, presumably due to soil contamination.

1997
NASA's Mars Pathfinder mission carries the Sojourner, a small robot that becomes the first rover on another planet.

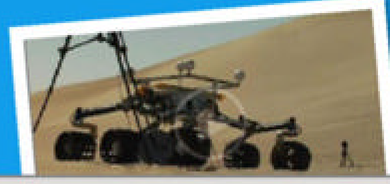
2004
NASA's Mars Exploration Rovers, Spirit and Opportunity, land on opposite sides of the planet in the Gusev Crater and Meridiani Planum, respectively.



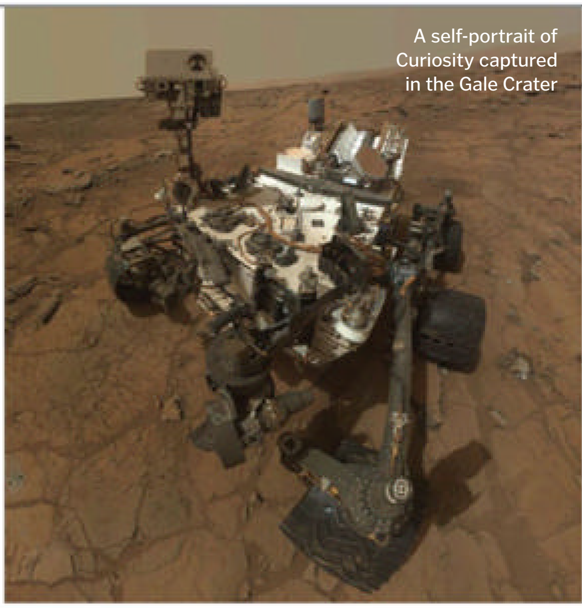
AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK

Curiosity's twin is tested in Death Valley, CA

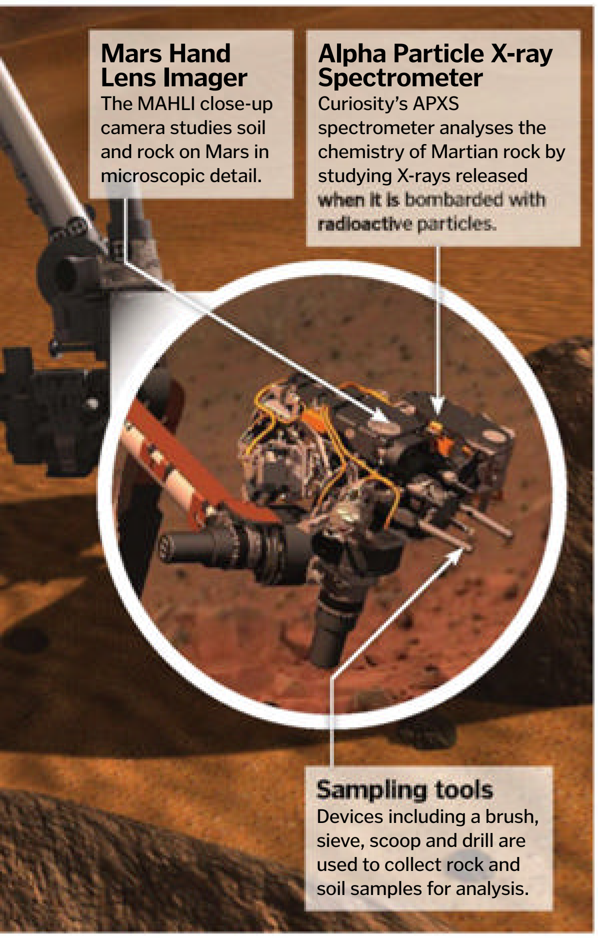
www.howitworksdaily.com



DID YOU KNOW? *Scientists have adapted Curiosity's X-ray analysis tools to study Roman manuscripts from Herculaneum*



A self-portrait of Curiosity captured in the Gale Crater



Mars Hand Lens Imager
The MAHLI close-up camera studies soil and rock on Mars in microscopic detail.

Alpha Particle X-ray Spectrometer
Curiosity's APXS spectrometer analyses the chemistry of Martian rock by studying X-rays released when it is bombarded with radioactive particles.

Sampling tools
Devices including a brush, sieve, scoop and drill are used to collect rock and soil samples for analysis.

On-board technology

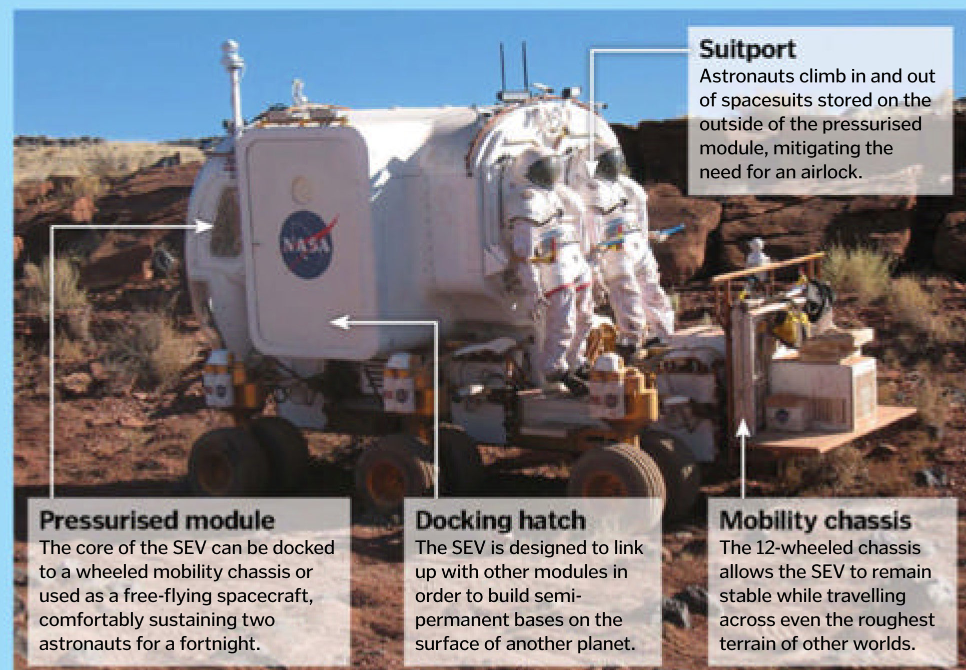
Rovers can carry a variety of different equipment for studying the soil of other worlds. Multispectral cameras (capable of photographing objects through a variety of colour filters) can reveal a surprising amount about the mineral properties of the rocks around them, while spectrometers – which study the light emitted when a target object is bombarded with radiation – can serve as chemical 'sniffers' to identify the signatures of specific elements and molecules.

As rovers have become more sophisticated, they have also improved their sampling abilities. The compact mini-rover Sojourner could only investigate rocks that were exposed at the surface, while Spirit and Opportunity were both equipped with a rock abrasion tool (RAT) that allowed them to expose fresh rock for study with the instruments on their robotic arms. Curiosity and the planned ExoMars rover, meanwhile, are both equipped with special drills that enable them to collect subsurface rock samples and pass them to built-in chemical laboratories for analysis.

This sample of Martian rock drilled by Curiosity indicated the Red Planet could have once supported life

The SEV: rover of the future?

NASA's concept Space Exploration Vehicle is designed for space and surface missions



Suitport
Astronauts climb in and out of spacesuits stored on the outside of the pressurised module, mitigating the need for an airlock.

Pressurised module
The core of the SEV can be docked to a wheeled mobility chassis or used as a free-flying spacecraft, comfortably sustaining two astronauts for a fortnight.

Docking hatch
The SEV is designed to link up with other modules in order to build semi-permanent bases on the surface of another planet.

Mobility chassis
The 12-wheeled chassis allows the SEV to remain stable while travelling across even the roughest terrain of other worlds.

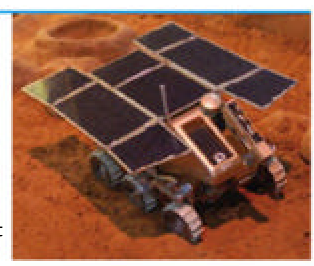
2010
After becoming stuck in 2009, the Spirit rover finally loses contact with Earth.

2011
Opportunity finds evidence for ancient water flowing through underground springs in Mars's Endeavour Crater.

2012
NASA's car-sized Curiosity rover touches down in the Gale Crater near the Martian equator.

2013
Curiosity uses its drill to sample rocks from beneath the Martian surface for the first time, discovering evidence for clays formed in hospitable Martian water.

2018
Currently scheduled landing of the European-built ExoMars rover, the first robot explorer specifically designed to search for signs of ancient life on the Red Planet.



THE STATS
GOES-15 SATELLITE

LENGTH 8.2m | ORBIT TIME 1,436 mins | WEIGHT 3,238kg
WIDTH 2.3m | ORBITAL ALTITUDE 35,780km | YEAR OF LAUNCH 2010

DID YOU KNOW? Comet tails face away from the Sun because they are blown outwards by solar wind

Secrets of solar wind

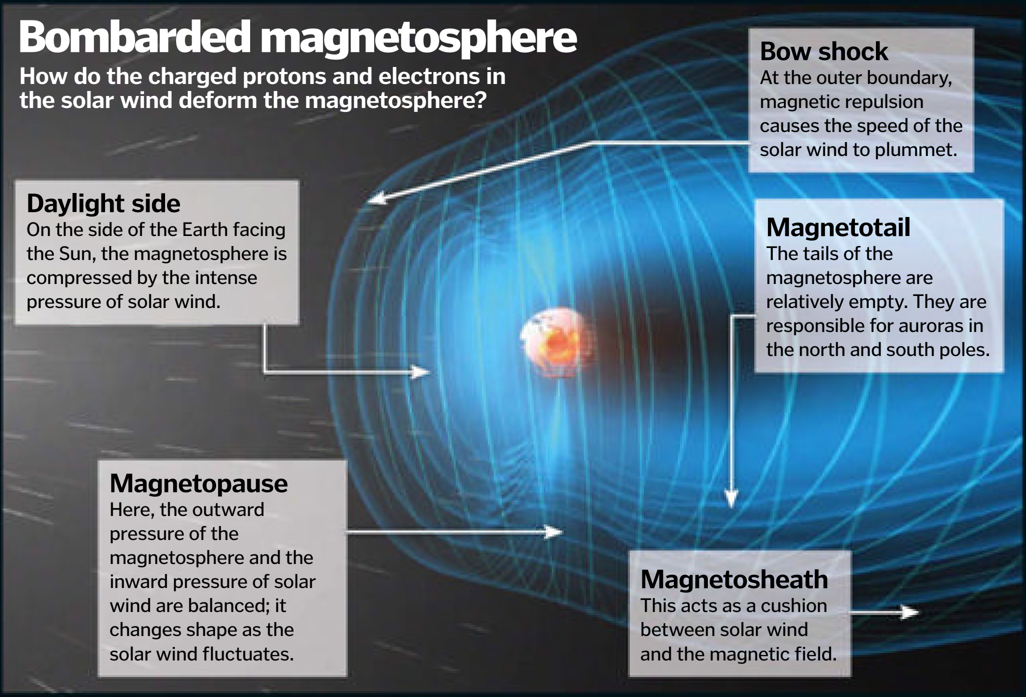
How do charged particles ejected from the Sun affect Earth's magnetic field?

Solar wind streams from the Sun at a blistering 400 kilometres (250 miles) per second. The intense heat of the corona – the outermost portion of the Sun's atmosphere – energises particles to such a level that the Sun's gravitational field can no longer hold on to them and they escape into space. Solar wind strength varies, creating space weather capable of disrupting technology, like global positioning system (GPS) satellites.

The movement of solar wind has a characteristic pattern that resembles a rope wobbling up and down – technically known as an Alfvén wave (after Hannes Alfvén). These magnetic strings can be observed as the greenish light that appears during the polar auroras. Until recently scientists have struggled to understand this unusual wave behaviour, but a new set of models – based on similar waves generated by polarised light – might enable us to understand, and even predict, future fluctuations in solar wind.

Bombarded magnetosphere

How do the charged protons and electrons in the solar wind deform the magnetosphere?



Bow shock
At the outer boundary, magnetic repulsion causes the speed of the solar wind to plummet.

Daylight side
On the side of the Earth facing the Sun, the magnetosphere is compressed by the intense pressure of solar wind.

Magnetotail
The tails of the magnetosphere are relatively empty. They are responsible for auroras in the north and south poles.

Magnetopause
Here, the outward pressure of the magnetosphere and the inward pressure of solar wind are balanced; it changes shape as the solar wind fluctuates.

Magnetosheath
This acts as a cushion between solar wind and the magnetic field.

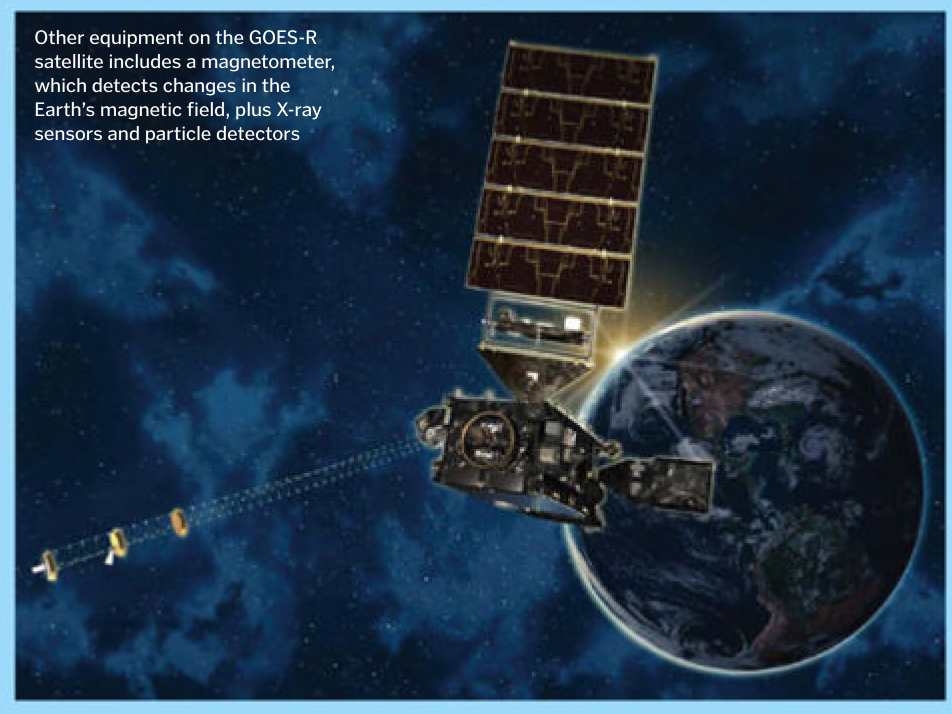
On board a weather satellite

Discover the technology that allows us to keep track of our planet's climate

Two types of satellite system are used to monitor weather around the globe: geostationary and polar orbiting. Geostationary satellites orbit near the equator, offering a distant overview of Earth, while polar orbiting satellites give close-up, high-res images.

The on-board imager senses visible and near-infrared light, enabling the satellites to monitor cloud cover during the day, while infrared sensors provide thermal imaging and information about levels of water vapour in the atmosphere.

The new generation of weather satellites are equipped with technology that even lets them see through clouds. The GOES-R Geostationary Lightning Mapper (GLM) will be able to measure lightning between and inside clouds – day and night – allowing more accurate forecasting of dangerous thunderstorm activity that could lead to tornadoes. This satellite will also house an Advanced Baseline Imager (ABI), which looks for overshooting clouds – an indicator of cyclone activity within developing storms.



Other equipment on the GOES-R satellite includes a magnetometer, which detects changes in the Earth's magnetic field, plus X-ray sensors and particle detectors

"The Soyuz system is now so slick that on 29 May 2013, Expedition 36 reached the ISS in five hours and 39 minutes"

Inside Soyuz

Responsible for carrying astronauts to the ISS, the Soyuz launch system is one of the most efficient in the world – and off it

The Soyuz launch system – which consists of a Soyuz Launch Complex, a launch vehicle and, when astronauts are involved, a Soyuz TMA spacecraft – is the main means crew and equipment have been taken to and from the International Space Station (ISS) for the last decade. To date the system has made over 40 launches and 100 per cent have been successful, with a mix of astronaut-ferrying spacecraft, cargo and satellites transported into low Earth orbit.

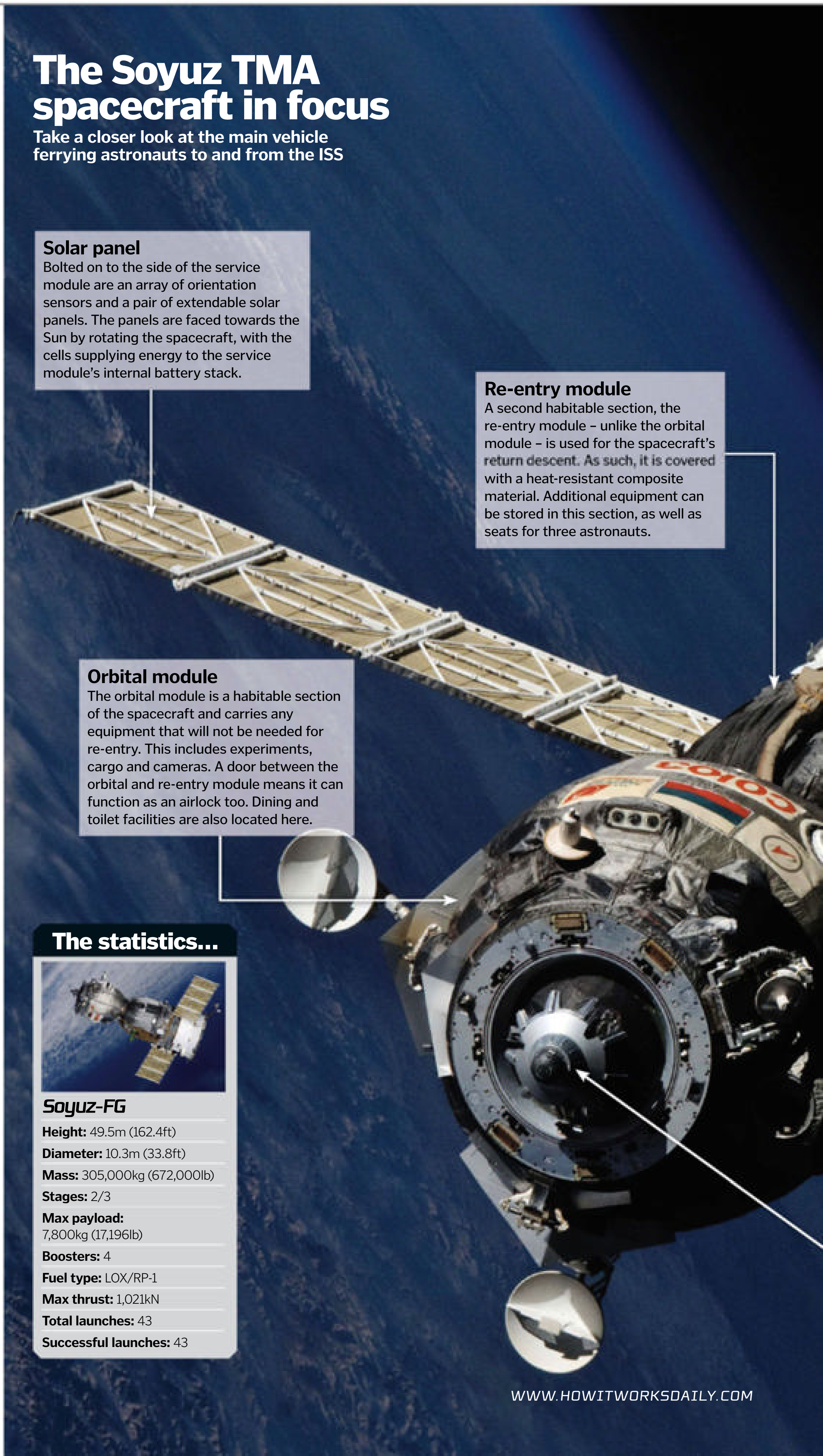
The two primary Soyuz launch system facilities are located at the Baikonur Cosmodrome in Kazakhstan and the Guiana Space Centre in French Guiana. Both sites can be used to transport astronauts, cargo and satellites off Earth, however Baikonur has been the principal launch site for TMA spacecraft and Guiana for satellites. Each site utilises Soyuz-family launch vehicles – ie the Soyuz-FG and Soyuz-2 – as well as a Soyuz Launch Complex (see boxout over the page for a detailed breakdown of the latter).

What is arguably key to the Soyuz's overall popularity is the Soyuz-FG launch vehicle. All three stages of this rocket use the same type of fuel, which is a highly efficient mix of liquid oxygen and kerosene. In partnership with four strap-on boosters that can be jettisoned once spent, as well as a protective launch abort system designed to rescue the crew in an emergency, the launcher carries multimillion-pound equipment and highly trained astronauts safely to and from space.

Indeed, the Soyuz system is now so slick that on 29 May 2013, Expedition 36 reached the ISS in a world record-breaking time of only five hours and 39 minutes. To put that in context, that's an hour faster than the average car drive between London and Edinburgh!

The Soyuz TMA spacecraft in focus

Take a closer look at the main vehicle ferrying astronauts to and from the ISS



The statistics...

Soyuz-FG

Height: 49.5m (162.4ft)

Diameter: 10.3m (33.8ft)

Mass: 305,000kg (672,000lb)

Stages: 2/3

Max payload: 7,800kg (17,196lb)

Boosters: 4

Fuel type: LOX/RP-1

Max thrust: 1,021kN

Total launches: 43

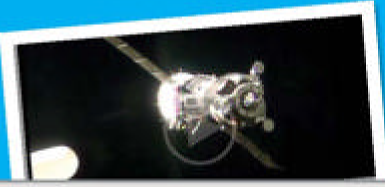
Successful launches: 43

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

Watch a Soyuz TMA-09M dock with the ISS now

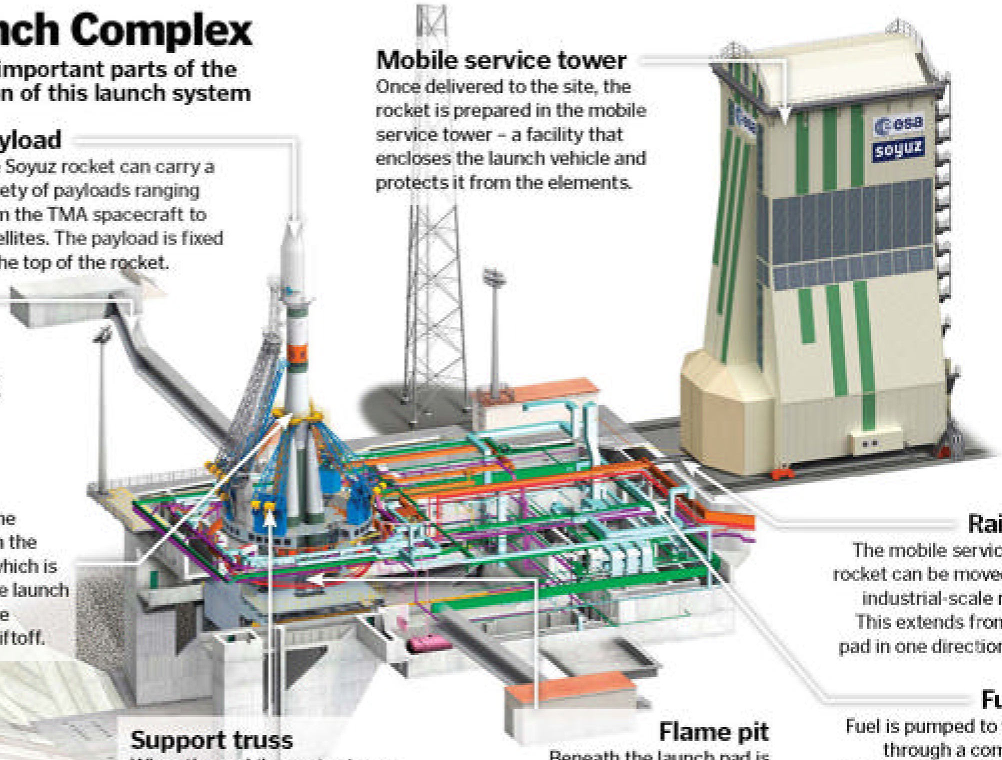
www.howitworksdaily.com



DID YOU KNOW? *The Soyuz-FG is scheduled to be replaced in 2014 by the Soyuz-2*

Soyuz Launch Complex

Check out the most important parts of the ground-based section of this launch system



Payload
The Soyuz rocket can carry a variety of payloads ranging from the TMA spacecraft to satellites. The payload is fixed to the top of the rocket.

Mobile service tower
Once delivered to the site, the rocket is prepared in the mobile service tower – a facility that encloses the launch vehicle and protects it from the elements.

Tunnel
Engineers and technicians approach the site via two entrance tunnels positioned either side of the launch pad.

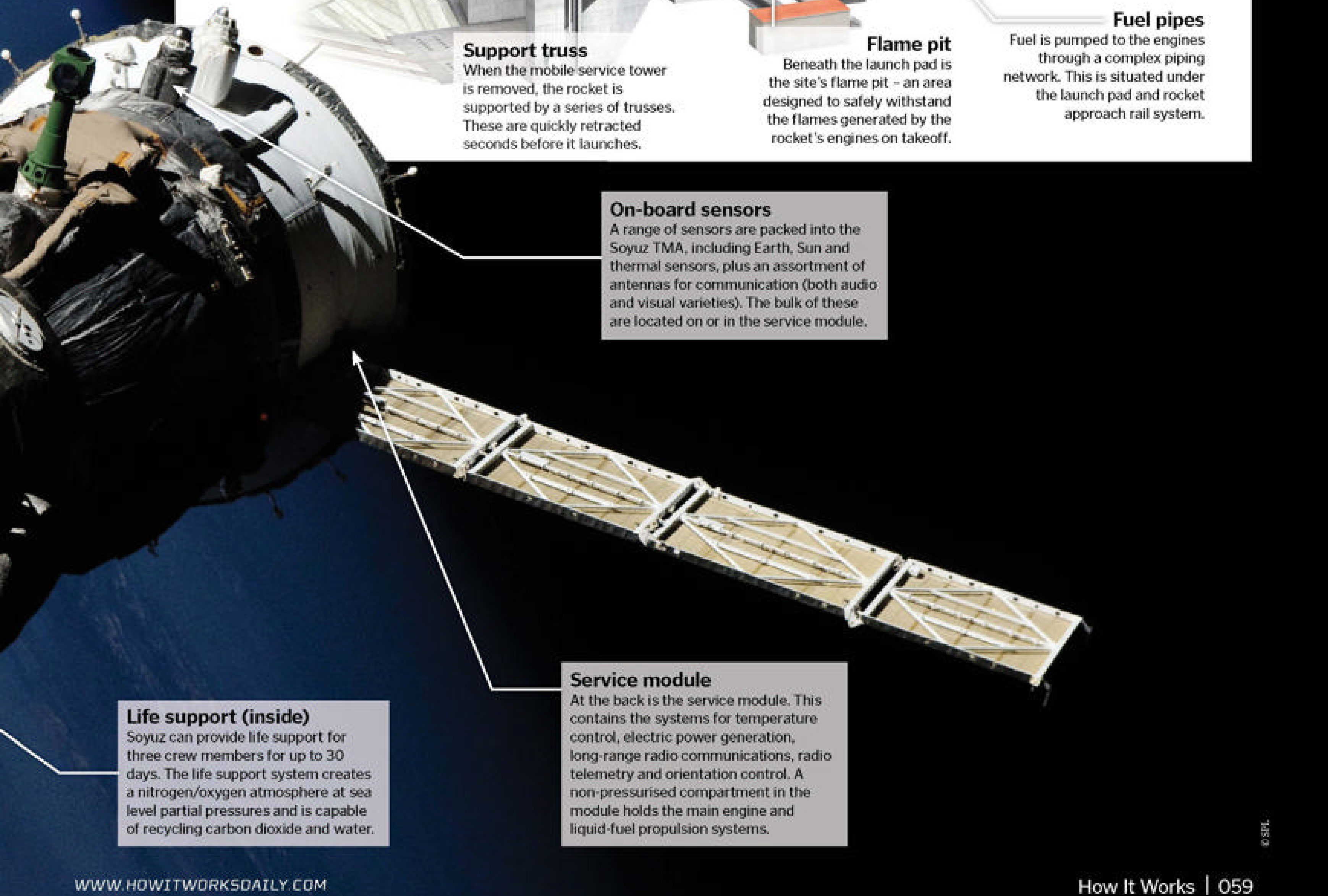
Soyuz rocket
The various stages of the rocket are assembled in the mobile service tower, which is then positioned over the launch pad (the entire structure moves on rails) before liftoff.

Rail system
The mobile service tower and rocket can be moved on a large, industrial-scale rail network. This extends from the launch pad in one direction to the rear.

Fuel pipes
Fuel is pumped to the engines through a complex piping network. This is situated under the launch pad and rocket approach rail system.

Support truss
When the mobile service tower is removed, the rocket is supported by a series of trusses. These are quickly retracted seconds before it launches.

Flame pit
Beneath the launch pad is the site's flame pit – an area designed to safely withstand the flames generated by the rocket's engines on takeoff.



On-board sensors
A range of sensors are packed into the Soyuz TMA, including Earth, Sun and thermal sensors, plus an assortment of antennas for communication (both audio and visual varieties). The bulk of these are located on or in the service module.

Service module
At the back is the service module. This contains the systems for temperature control, electric power generation, long-range radio communications, radio telemetry and orientation control. A non-pressurised compartment in the module holds the main engine and liquid-fuel propulsion systems.

Life support (inside)
Soyuz can provide life support for three crew members for up to 30 days. The life support system creates a nitrogen/oxygen atmosphere at sea level partial pressures and is capable of recycling carbon dioxide and water.

© SPL

THE STATS
EROS FIGURES

YEAR DISCOVERED	1898	DAYTIME TEMPERATURE	100°C	ORBITAL SPEED	24.4km/s
ORBITAL PERIOD	1.76 years	NIGHT-TIME TEMPERATURE	-150°C	MASS (TONS)	6.7tn

DID YOU KNOW? *The gravity on Eros is so weak that if you threw a stone from its surface it would escape into space*

What's inside Eros?

This near-Earth asteroid is packed with precious metals like gold and could be worth trillions of dollars, but how did it form?

It is predicted that within 50-60 years the Earth's crust will have been emptied of all its precious metals like gold, zinc and tin. However, nearby asteroids carry billions of tons of metal and more.

Asteroid 433 Eros is the second-largest near-Earth asteroid, measuring 33 x 13 x 13 kilometres (20.5 x 8 x 8 miles). NASA's Near-Earth Asteroid Rendezvous (NEAR) spacecraft passed close to Eros, enabling estimates to be made of its metal content. It is a typical stony asteroid and is projected to be at least three per cent metal; this equates to 20,000 million tons each of metals like aluminium and gold.

But why is there so much metal on this small rock, when the Earth has barely any at all? When Earth formed, molten iron sank to the core, carrying with it 'iron-loving' precious metals. In fact, the Earth's core contains so much molten precious metal that if it were brought to the surface and spread out it would form a layer about four metres (13 feet) thick.

The fact that we have any precious metals on the surface at all is actually all down to a lucky series of collisions with asteroids like Eros, which bombarded the Earth and left their metallic contents scattered over the ground. It is estimated that it took 20 billion billion tons of asteroids to supply the Earth's crust with the metals that we find today.

There are hundreds of these asteroids still floating in the Solar System – a huge untapped resource of metal waiting to be harvested.

Asteroid showdown

We compare Eros with two of the biggest asteroids in the Solar System

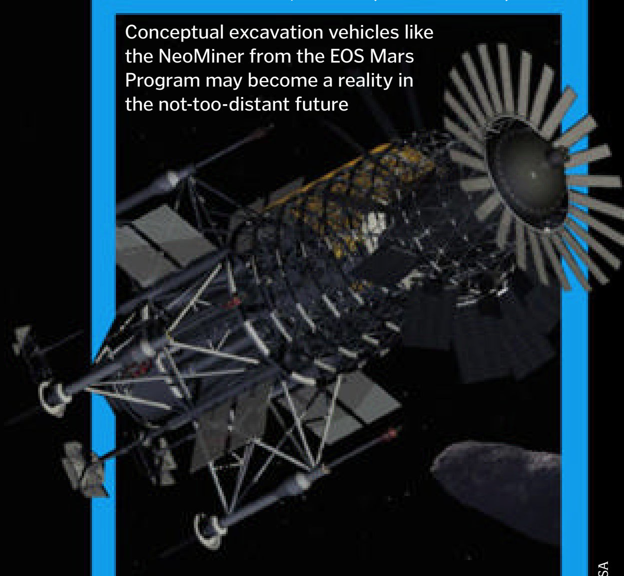
Eros 33km (length)

Vesta 530km (diameter)

Ceres 960km (diameter)

Mining in space

Asteroid mining could provide millions of tons of raw materials for a variety of applications, both on Earth and in space. Not only is there an abundant untapped supply of metal in the Solar System, but ice on extinct comets could provide a source of water for space travellers. Using native materials to build equipment and produce fuel could dramatically reduce the cost of space travel and allow humans to explore farther and for longer. NASA, and several private companies – eg Planetary Resources and Deep Space Industries – have set up projects to mine asteroids. They also plan to make a fuel station using water ice from comets. Prospecting for potential mining sites is due to begin in the next decade, but the cost of space travel is currently much too high to sustain such ventures. NASA's 2016 OSIRIS-REx mission, which will return just 60 grams (two ounces) of asteroid material, is set to cost around $1 billion (£635.5 million).



Conceptual excavation vehicles like the NeoMiner from the EOS Mars Program may become a reality in the not-too-distant future

"Discs have a bulging shape – thinnest at their outer edges and close to the star, and thickest in the middle"

Protoplanetary discs

Vast rotating regions of gas and dust around newborn stars supply the raw materials from which planets emerge

In the past few decades, astronomers have discovered that many young stars in our cosmic neighbourhood are surrounded by flattened discs of warm, dark material. These are protoplanetary discs – leftovers of starbirth that are in the process of coalescing to form planetary systems.

Stars are born from dense knots in broader glowing regions known as emission nebulas. As the knots collapse under their own gravity, the centres eventually become hot and dense enough to ignite in nuclear fusion, transforming into an unstable young star, surrounded by a flattened disc of gas and dust. The disc owes its shape to random collisions of material in the cloud, which tend to cancel out other movements, as they do in Saturn's rings.

Because the disc is not solid, different parts orbit the star at different speeds, with the innermost regions spinning fastest. Discs also have a distinctive bulging shape – thinnest at their outer edges and close to the star, and thickest in the middle. This is due in large part to heat from the star itself; close in, chemicals with low melting points (such as water ice, ammonia and methane) evaporate and are blown away by the force of its fierce radiation, leaving behind only dusty material. Farther out, meanwhile – beyond the 'ice line' – these chemicals can persist and form a greater component of the disc. This is thought to explain the distribution of small rocky planets and larger gas/ice giants in our Solar System.

Most astronomers agree that planets form from the disc by a process called collisional accretion, in which particles stick together and amass to create planetesimals around a kilometre (0.6 miles) across, whose gravity is then strong enough to pull in more material from their surroundings and undergo runaway growth. Many protoplanetary discs show telltale signs of this process underway.

Beta Pictoris up close

63 light years from Earth, Beta Pictoris is surrounded by a protoplanetary disc in the process of forming planets

5 TOP FACTS
PLANET FACTORIES

Early starters
1 The majority of protoplanetary discs surround stars that are less than 10 million years old. Older stars, on the other hand, tend to have fully grown planets as in our Solar System.

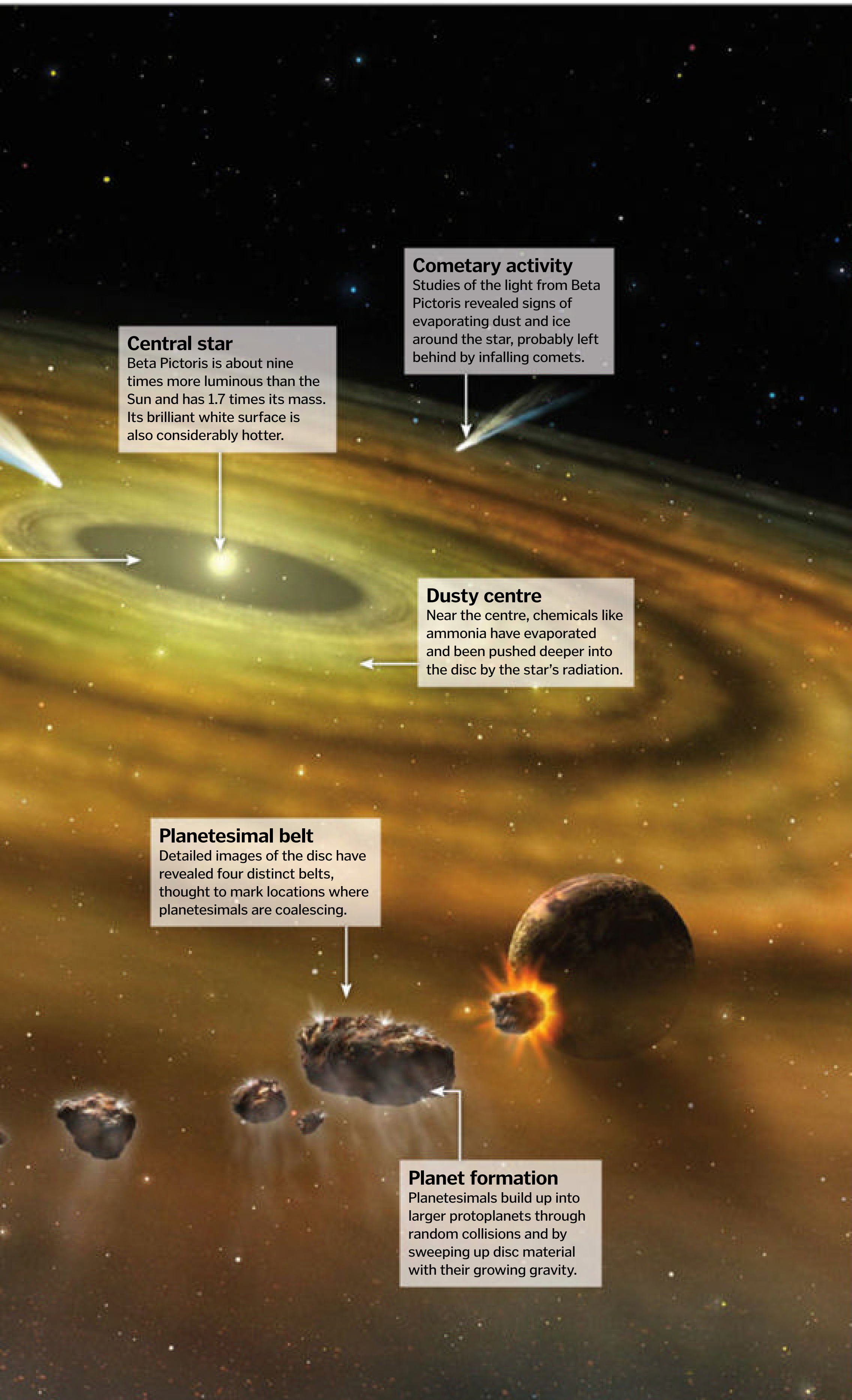
First discovery
2 The first circumstellar disc to be discovered was around the star Beta Pictoris in the Pictor constellation. It was found by the Infrared Astronomical Satellite (IRAS) in 1983.

Jet powered
3 Material that's floating close to the centre of the disc often spirals down onto the star's surface, only to be thrown off in powerful jets along its axis of rotation.

Dust to dust
4 Drag on the dust in a disc should cause it all to spiral onto the star over time. Dust around older stars may be regenerated by protoplanets and planetesimals colliding.

Glow in the dark
5 Most discs are generally dark, but occasionally the light of a nearby star makes them fluoresce. These glowing discs are known as proplyds (short for protoplanetary discs).

DID YOU KNOW? *A recent study of meteoroids (shooting stars) showed that many of them come from Beta Pictoris*



Nurseries for life?

The raw materials that make up protoplanetary discs have already been recycled and enriched with elements such as carbon, nitrogen and oxygen by previous generations of stars. Such elements can naturally combine with abundant hydrogen gas to form relatively simple compounds such as water, ammonia and alcohol, but it now seems that discs could provide an ideal environment for the creation of much more complex 'organic' molecules – perhaps even the building blocks of life itself. Computer models have shown how fierce ultraviolet light from a newborn star could break down chemicals within the dust particles, allowing them to recombine in larger chemical compounds. And in 2012, astronomers discovered the sugar molecule glycolaldehyde – an important component of the complex RNA molecule – around a binary star 400 light years from Earth: IRAS 16293-2422.

Big disc-overy

The first protoplanetary discs were discovered in the Eighties by the earliest infrared space telescopes. With their ability to observe 'heat radiation' from objects too cool to glow in visible light, they uncovered a number of stars emitting more infrared than was expected – an 'infrared excess' that turned out to be generated not from the stars themselves, but from dusty discs surrounding them. The same technique is still used to find circumstellar discs today, but far more powerful telescopes are now available to study the features of the discs themselves. Getting to grips with the processes by which planetary systems form helps astronomers understand the history of our own Solar System and the evolution of other extrasolar planets.

Fighter pilot training

When new pilots need to get to grips with flying advanced jet planes, only one vehicle is adequate for the job: the Hawk AJT

Training to become a fighter pilot today is harder than it has ever been. The pace of combat has increased massively over the last 50 years, with supersonic jets becoming faster and more agile with every generation. Not only that, but these predators of the sky have become increasingly complex too, with ever-more advanced electronic systems packed into their fuselages. Far from the days of simple visual dogfights, now conflicts can be won or lost without even seeing the enemy, with radars, sensors, guided missiles and the tactics to use them all fundamental to the outcome of a fight.

Due to these escalating demands on the current generation of pilots a number of advanced training aids are being devised, ranging from flight simulators to full-blown training jets – intelligent machines built to teach students the art of flying fast, while also acclimatising them quickly to a career of flying more complex, frontline fighters.

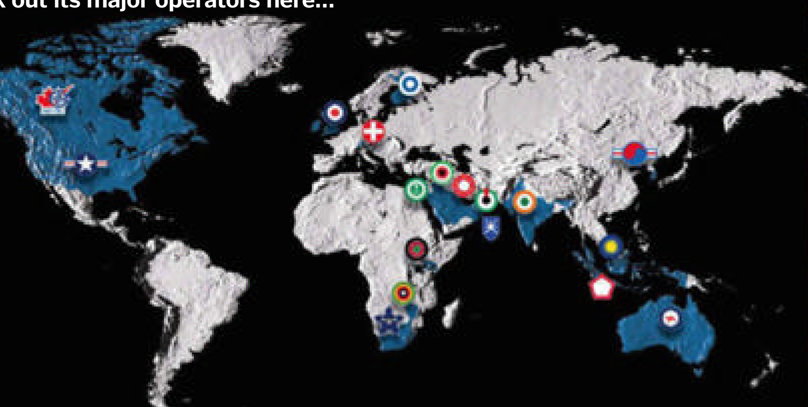
Foremost of these training craft is BAE Systems' Hawk Advanced Jet Trainer (AJT), a plane that has been purposely designed to replicate the feel and precision of the world's most deadly multi-role jet fighters: the F-35 Lightning II and the Eurofighter Typhoon.

In this feature **How It Works** takes a closer look at the Hawk, as well as the advanced hardware that, together, are revolutionising the way military pilots learn their trade.

Who flies the Hawk?

The Hawk AJT is part of national air forces right around the world. Check out its major operators here...

1 Saudi Arabia
2 Australia
3 Oman
4 Kuwait
5 Kenya
6 Indonesia
7 India
8 Finland
9 Canada
10 Zimbabwe
11 USA
12 Malaysia
13 UK
14 UAE
15 Switzerland
16 South Korea
17 South Africa
18 Bahrain



THE STATS
HAWK T2 AJT

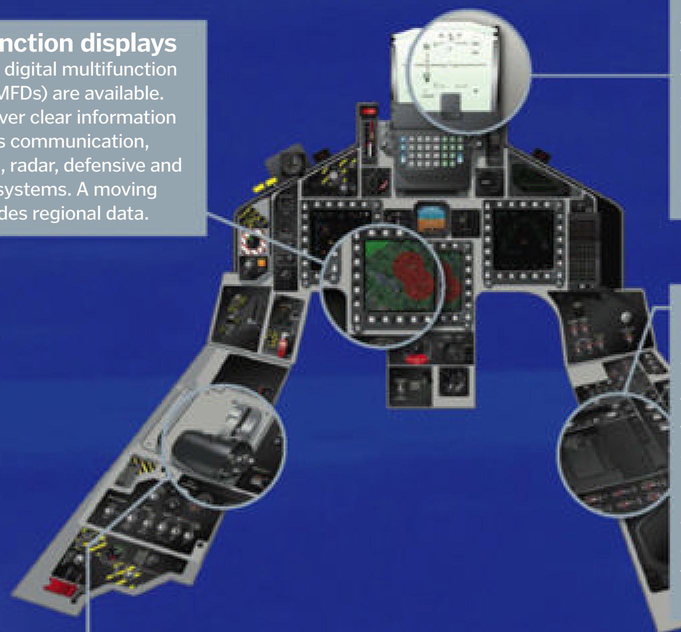
WEIGHT 4,480kg | MAX RANGE 2,520km | THRUST-TO-WEIGHT RATIO 0.65

MAX SPEED 1,028km/h | SERVICE CEILING 13,565m | RATE OF CLIMB 47m/s

DID YOU KNOW? *Although not ordinarily armed, the Hawk can be fitted with weapons to fulfil a combat role, if needed*

A guide to the cockpit

The Hawk AJT delivers a suite of tech that's always close to hand



Multifunction displays
A range of digital multifunction displays (MFDs) are available. These deliver clear information on the jet's communication, navigation, radar, defensive and offensive systems. A moving map provides regional data.

Heads-up display
The heads-up display (HUD) in the Hawk provides the pilot with flight, navigation, sensor and weapon-aiming data. A camera on the HUD records the view seen by the trainee and feeds it to the instructor behind; this allows for a finer level of tuition.

Mission data system
One of the cleverest parts of the AJT's cockpit is the mission data loading and recording system. This allows mission planning data to be transferred to the plane via a cartridge, continuous in-air recording of data while the pilot is training, and extraction of data for replay once back on land. This enables learner pilots to study their performance and practise hypothetical scenarios.

Hands-on throttle
Critical flight and weapon system controls are embedded into the cockpit in an intuitive and real-world position. These let the pilot interact with the controls – and displays – just as they would when operating a frontline combat aircraft such as the F-35 Lightning II.

Tools of the trade
The Hawk AJT also supplies the novice pilot with the ability to initiate simulated weapon releases. This level of real-world simulation helps pilots to become fully versed in all aspects of flying a military fighter jet. The commitment to realism is further enhanced with each Hawk coming with its own pair of night-vision goggles.

Simulating flight

Flying jet aircraft is an expensive business, with large quantities of fuel needed for each outing. As such, during pilot training a lot of time is spent in flight simulators, which enable pilots to experience a variety of virtual scenarios without ever leaving the ground.

Military flight simulators include: a replica of a jet's cockpit controlled via electronic motors or hydraulics – these tilt the cockpit to replicate in-flight manoeuvres; a bank of screens covering the pilot's field of view – typically in a concave arc layout; and a selection of force-feedback motors to represent real-world forces. These systems work with the simulator's software to react realistically to pilot inputs.

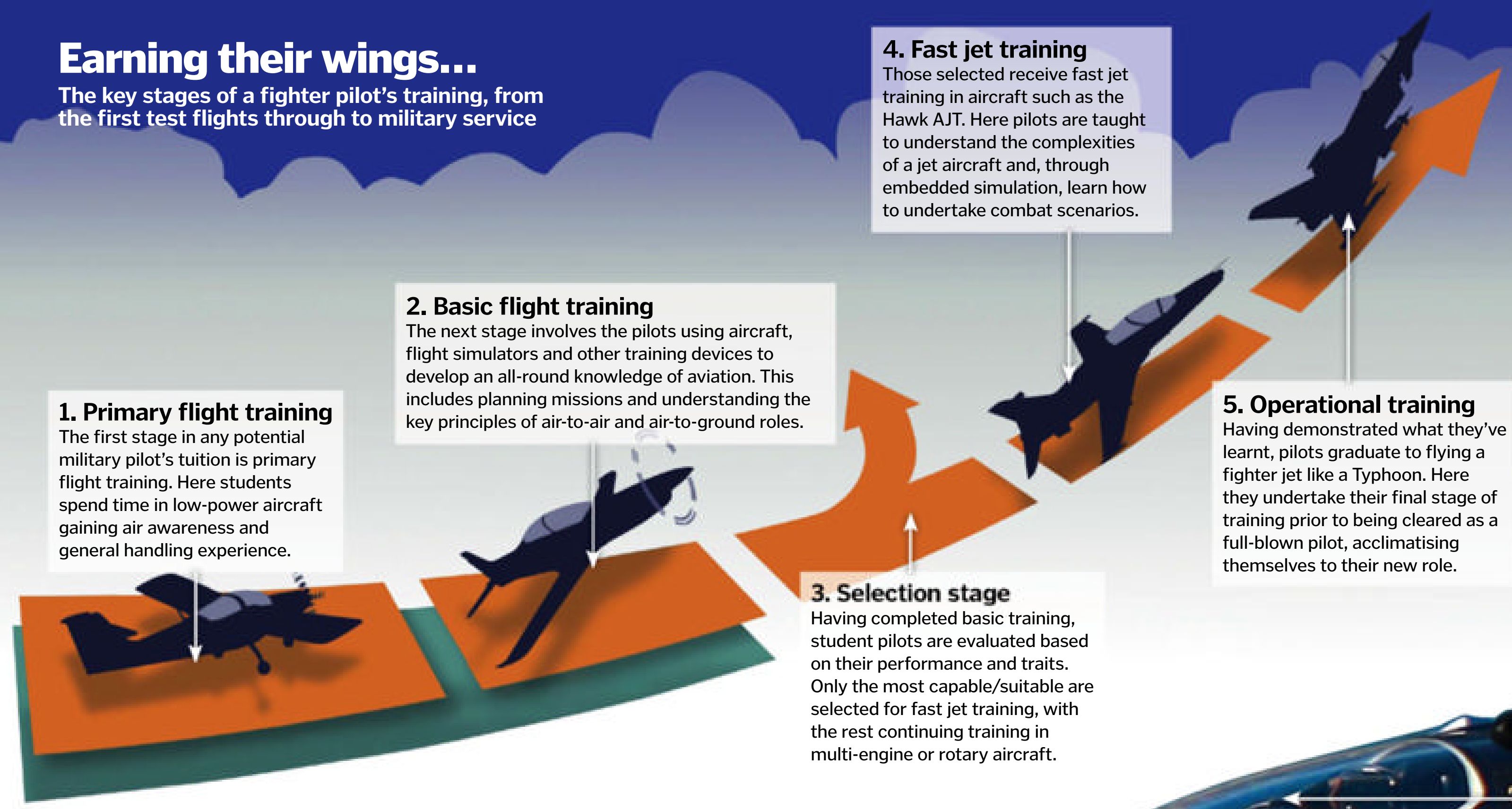
The software that runs each simulation is derived from real flights and this – partnered with an accurate rendering of the virtual environment – grants a highly accurate replication. Of course, even the most advanced simulators can't be relied on for complete pilot training though.

A flight simulator used for training pilots to fly the Eurofighter Typhoon

"Pilots are taught to understand the complexities of a jet aircraft and how to undertake combat scenarios"

Earning their wings...

The key stages of a fighter pilot's training, from the first test flights through to military service



1. Primary flight training
The first stage in any potential military pilot's tuition is primary flight training. Here students spend time in low-power aircraft gaining air awareness and general handling experience.

2. Basic flight training
The next stage involves the pilots using aircraft, flight simulators and other training devices to develop an all-round knowledge of aviation. This includes planning missions and understanding the key principles of air-to-air and air-to-ground roles.

3. Selection stage
Having completed basic training, student pilots are evaluated based on their performance and traits. Only the most capable/suitable are selected for fast jet training, with the rest continuing training in multi-engine or rotary aircraft.

4. Fast jet training
Those selected receive fast jet training in aircraft such as the Hawk AJT. Here pilots are taught to understand the complexities of a jet aircraft and, through embedded simulation, learn how to undertake combat scenarios.

5. Operational training
Having demonstrated what they've learnt, pilots graduate to flying a fighter jet like a Typhoon. Here they undertake their final stage of training prior to being cleared as a full-blown pilot, acclimatising themselves to their new role.

4-year period

On board a Hawk AJT

We take a look at some of the advanced hardware packed into this exceptional training aircraft

Electronics
A suite of advanced electronic systems are included in the AJT, including multifunction digital displays (MFDs), a heads-up display (HUD), mission data system and hands-on throttle and stick (HOTAS) array.

Cockpit
The Hawk's cockpit has been designed to represent a real frontline military fighter jet. With this in mind, instruments, controls, displays and tools are all found in intuitive and realistic positions. This speeds up the transition process.

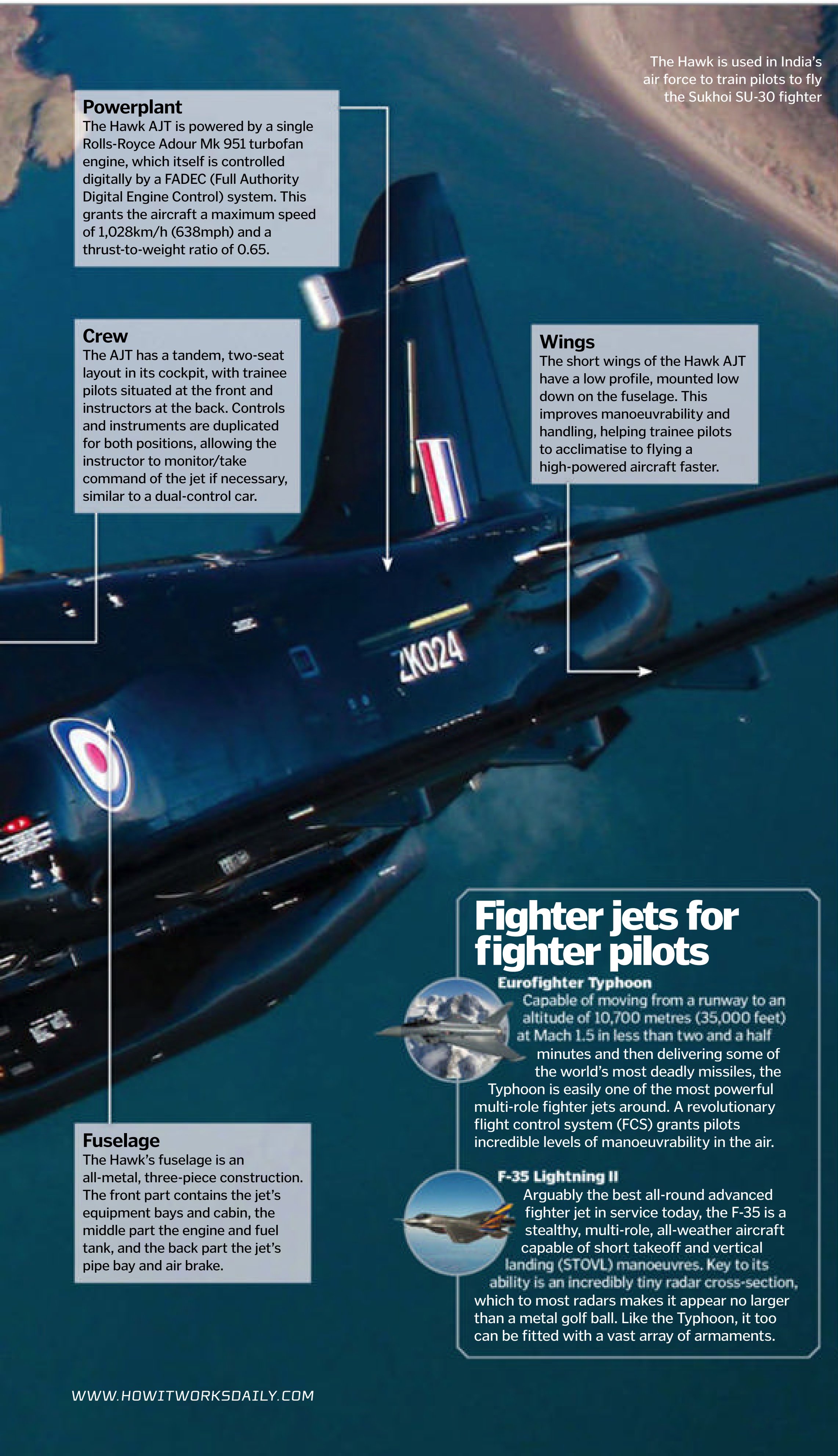
AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

Take a backseat tour in a Hawk T2 now!

www.howitworksdaily.com

DID YOU KNOW? *18 different countries use the Hawk to train their military pilots all over the world*



The Hawk is used in India's air force to train pilots to fly the Sukhoi SU-30 fighter

Powerplant

The Hawk AJT is powered by a single Rolls-Royce Adour Mk 951 turbofan engine, which itself is controlled digitally by a FADEC (Full Authority Digital Engine Control) system. This grants the aircraft a maximum speed of 1,028km/h (638mph) and a thrust-to-weight ratio of 0.65.

Crew

The AJT has a tandem, two-seat layout in its cockpit, with trainee pilots situated at the front and instructors at the back. Controls and instruments are duplicated for both positions, allowing the instructor to monitor/take command of the jet if necessary, similar to a dual-control car.

Wings

The short wings of the Hawk AJT have a low profile, mounted low down on the fuselage. This improves manoeuvrability and handling, helping trainee pilots to acclimatise to flying a high-powered aircraft faster.

Fuselage

The Hawk's fuselage is an all-metal, three-piece construction. The front part contains the jet's equipment bays and cabin, the middle part the engine and fuel tank, and the back part the jet's pipe bay and air brake.

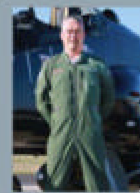
Fighter jets for fighter pilots

Eurofighter Typhoon

Capable of moving from a runway to an altitude of 10,700 metres (35,000 feet) at Mach 1.5 in less than two and a half minutes and then delivering some of the world's most deadly missiles, the Typhoon is easily one of the most powerful multi-role fighter jets around. A revolutionary flight control system (FCS) grants pilots incredible levels of manoeuvrability in the air.

F-35 Lightning II

Arguably the best all-round advanced fighter jet in service today, the F-35 is a stealthy, multi-role, all-weather aircraft capable of short takeoff and vertical landing (STOVL) manoeuvres. Key to its ability is an incredibly tiny radar cross-section, which to most radars makes it appear no larger than a metal golf ball. Like the Typhoon, it too can be fitted with a vast array of armaments.



A Hawk-eye view

We talk to BAE test pilot Andy Blythe about working with the Hawk

What does your current role entail at BAE?
I fly Tornadoes, Typhoons and Hawks for the company and perform two primary roles. These are developing the product – as there is constant development going on with the software and adjusting it to meet all of our customers' needs – and the other role is purely as a test pilot, checking that all aircraft are safe to fly for BAE's end-users.

How close an experience is flying a Hawk compared to a frontline military jet?
In some respects it is very similar and in others there is a difference. Compare the Hawk to a Typhoon in terms of physical performance and there is a difference, but then again there is a difference in price too. It's like comparing an F1 car to a Golf GTI. There is performance there, and it has some of the traits of a sports car, but it's not a high-end F1 car.

The most important part of what we've done with the Hawk is sensor simulation. All combat aircraft will have a mixture of sensors – be it radar, an infrared search and track or a military data link. All these systems are very expensive and they require a lot of development, so what we have done in the Hawk – rather than integrate very expensive pieces of equipment – [is essentially make] it a 'flying PlayStation'.

Can you describe how the Hawk AJT's sensor simulation works in more detail?
All the Hawk T2 aircraft we produce have their own data link on. It's not a military data link, but it is like having your own Wi-Fi network protected by an encryption key. It's a wireless data network just for the Hawk to transmit information on – things like height, speed, switch selection, weapon selection and trigger selection, etc. So all that information is spread between all of the Hawks so each one has a constant feed of information about any other. This allows sensors such as radar to be simulated with real data.

All flight data can be recorded on the Hawk – how is this later used on the ground?
It's absolutely amazing. When I was learning all we had on the ground was wet film, 30-second tapes that you had to be really careful with. Today, it's all solid state – just like in your mobile phone – with everything recorded in 1s and 0s on a 32GB hard drive. This hard drive holds the pilot's mission planning data and, as soon as it is inserted into the Hawk, it records everything in the data bus. So every bit of equipment, every switch selection is recorded during the pilot's flight. On landing we plug the hard drive into a computer and the information is extracted. Then you can see absolutely everything the student has done and the instructor can advise them on best practice. You can even merge aircraft data together and then replay it on a big screen so you can see what everyone was doing [at once].

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“If pure hydrogen and oxygen from the air are combusted in an engine, only water forms as an emission”

The statistics...

Hybrid Hydrogen Rapide S

Manufacturer: Aston Martin/Alset Global

Dimensions: Length: 5,020mm (197.6in); width: 2,140mm (84.3in); height: 1,350mm (53.2in)

Weight: 1,990kg (4,387lb)

Top speed: 306km/h (190mph) on petrol

Power: 560bhp (418kW)

Engine: V12, alloy, 48 valve, 5,935cc

Price: Not available to buy

Status: Research showcase project

Inside a hydrogen hybrid supercar

You may not think eco-friendly and speed go together, but Aston Martin’s Rapide S hybrid proves otherwise

The new 2013 Hybrid Hydrogen Rapide S made history at the Nürburgring 24-hour race in May. It was the first hydrogen hybrid supercar to compete, and the first to run a zero carbon dioxide emissions lap.

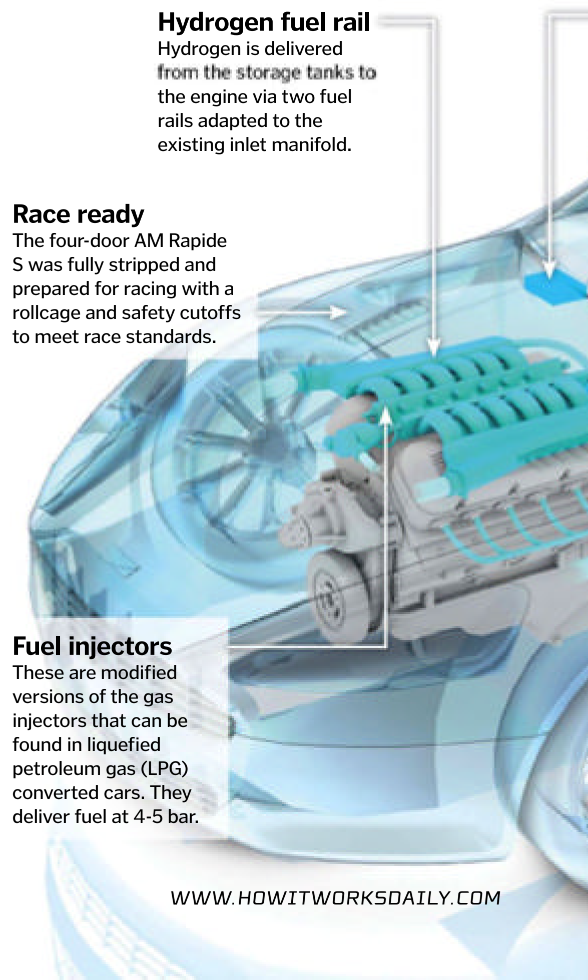
You may have heard of hydrogen technology in cars before, such as the Honda FCX Clarity, however there is no fuel cell involved here. Instead, the hydrogen is burned in the conventional Aston Martin (AM) six-litre V12 engine to produce its power. So what are the differences between burning hydrogen and petrol in an internal combustion engine (ICE)?

In a conventional ICE, petrol – or more specifically octane – is burned in air to produce the engine’s power via this simplified equation: $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$.

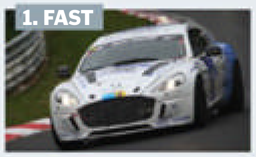
The products of the reaction are a bunch of carbon dioxide molecules and water vapour. This carbon dioxide is a significant contributor to global warming, and increasing efforts to reduce these emissions are underway. But if you use hydrogen as the fuel in an ICE, you get a very different outcome: $2H_2 + O_2 \rightarrow 2H_2O$.

If pure hydrogen and oxygen from the air are combusted in an engine, only water forms as an emission. Therefore using hydrogen as a fuel can remove the carbon aspect of conventional ICEs altogether, leading to dramatically reduced carbon dioxide output worldwide.

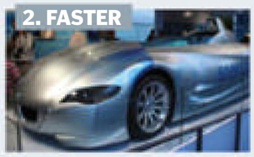
Aston Martin and Alset Global teamed up to adapt a 2013 Rapide S to run on either petrol, hydrogen or a blend of the two. The car was recently tested on the renowned ‘Green Hell’ of Nürburgring by Aston Martin’s CEO, Ulrich Bez, in preparation for its appearance at the Nürburgring 24-hour race in May. During the race it successfully completed a full lap on pure hydrogen, becoming the first ever car to do so. It finished the race with no issues to report.



HEAD 2 HEAD
HYDRO-POWER



AM Rapide S
While racing around the Nürburgring, the AM Rapide S hybrid clocked a top speed of over 257 kilometres (160 miles) per hour running on hydrogen.



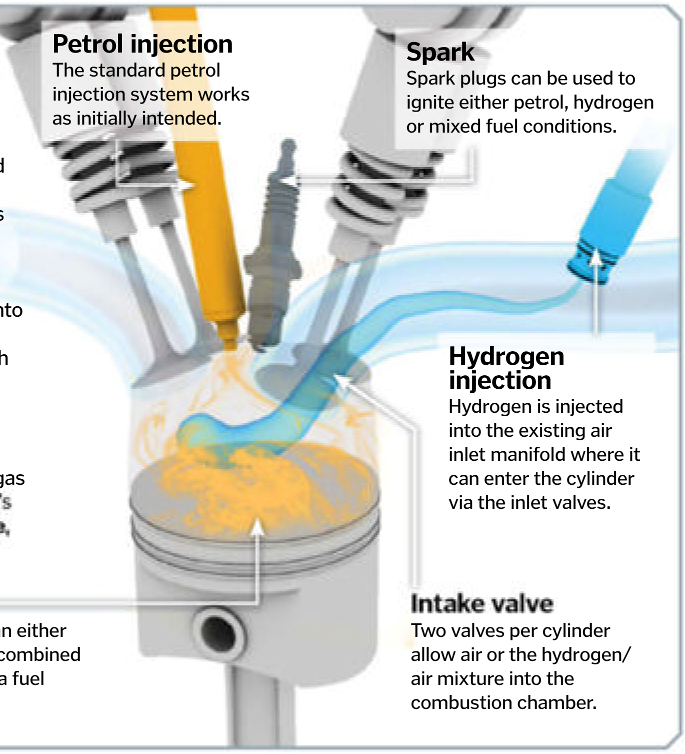
BMW H2R
This hydrogen vehicle made by BMW uses liquid hydrogen as a fuel and has a top speed of around 300 kilometres (187 miles) per hour.

Buckeye Bullet
The Buckeye Bullet hydrogen fuel cell-powered vehicle reached 488 kilometres (303 miles) per hour on the Bonneville Salt Flats.

DID YOU KNOW? *Hydrogen gas can be harvested from water then used in vehicles to reproduce water, making it sustainable*

Hydrogen injection

The injection system was designed to require as little remodelling and new parts to the existing engine as possible. It is inherently simple: compressed gaseous hydrogen is released from the storage tanks at around four to five bar and is fed into the inlet manifold of the existing six-litre V12. This is usually the path that air takes to get to the engine where it is mixed with petrol. This adaptation allows hydrogen to be injected with the air to reach the combustion chamber. The rate of gas flow is determined by Alset Global's own engine management software, also controlling the fuel mix ratio.



Petrol injection
The standard petrol injection system works as initially intended.

Spark
Spark plugs can be used to ignite either petrol, hydrogen or mixed fuel conditions.

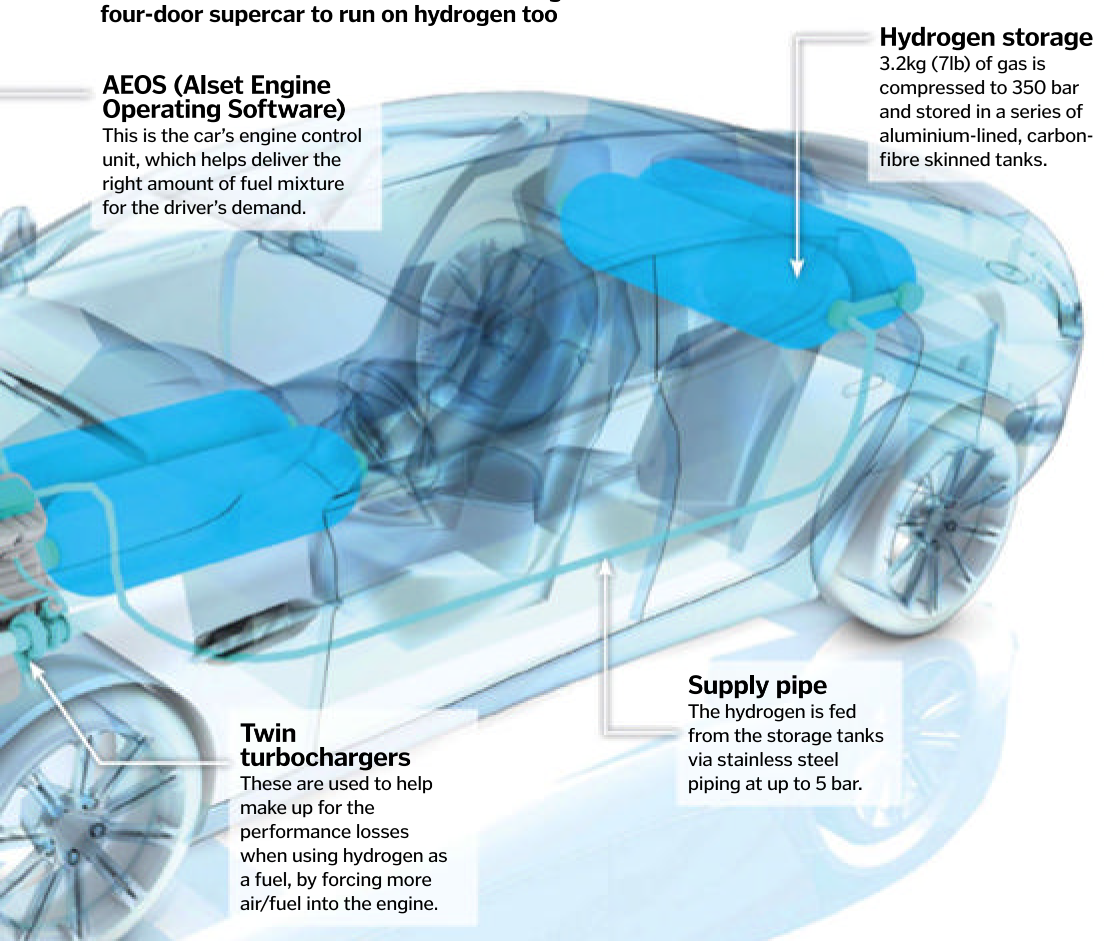
Hydrogen injection
Hydrogen is injected into the existing air inlet manifold where it can enter the cylinder via the inlet valves.

Fuel mix
Petrol and hydrogen can either be used separately, or combined in the cylinder to form a fuel blend for combustion.

Intake valve
Two valves per cylinder allow air or the hydrogen/air mixture into the combustion chamber.

Rapide S hybrid under the hood

See how Alset Global modified the existing four-door supercar to run on hydrogen too



AEOS (Alset Engine Operating Software)
This is the car's engine control unit, which helps deliver the right amount of fuel mixture for the driver's demand.

Hydrogen storage
3.2kg (7lb) of gas is compressed to 350 bar and stored in a series of aluminium-lined, carbon-fibre skinned tanks.

Twin turbochargers
These are used to help make up for the performance losses when using hydrogen as a fuel, by forcing more air/fuel into the engine.

Supply pipe
The hydrogen is fed from the storage tanks via stainless steel piping at up to 5 bar.

Behind the Hybrid Hydrogen project

Meet the VP of product management and technology, Thomas Korn

Can you tell us about the main difficulties you faced when using this system?
The main challenges were combustion control and power loss mitigation. Our focus in the past has been to improve the two, and develop technologies for that. A very challenging aspect was that because it was a new engine, implementing the hydrogen technologies into it in a tight timeframe was also a [big hurdle].

Was there a significant drop in power output when using hydrogen?
Usually if you use hydrogen as a fuel with a lower volumetric energy density, you always lose power. So we used two different technological processes that enabled us to reach 90 per cent of the performance an engine would normally have using gasoline; one of which was using two turbochargers to increase the mixture value in the combustion chamber. Secondly we used a blend of fuels which allows us to control combustion and gain more power.

How long before this technology is commercially available in your opinion?
We think that we have shown with the Nürburgring race that, even in such demanding and harsh conditions, the technology is very reliable. So if we can convince the car manufacturers today to go into development, then I think in under two to three years we can see the first vehicles on the road. The technology can be implemented relatively quickly in a commercial context.

Finally, what is the top speed of the Hybrid Hydrogen Rapide S?
For the race, we were limited to a certain power output by the race organisations. Using gasoline we reached 560 horsepower [418 kilowatts], and with pure hydrogen we were just below that. We had to use an air restrictor in gasoline mode to bring the engine power down. So for the maximum speed, the weight, aerodynamics and the track layout dictate this. We achieved 280 kilometres [174 miles] per hour on the course in gasoline mode and we were not much lower than that [in hydrogen mode].

"Coaster launch mechanisms share much technology with aircraft carrier launch systems for fighter jets"

Rollercoaster launchers

Learn about the engineering that propels thrill-seekers to 240km/h in mere seconds

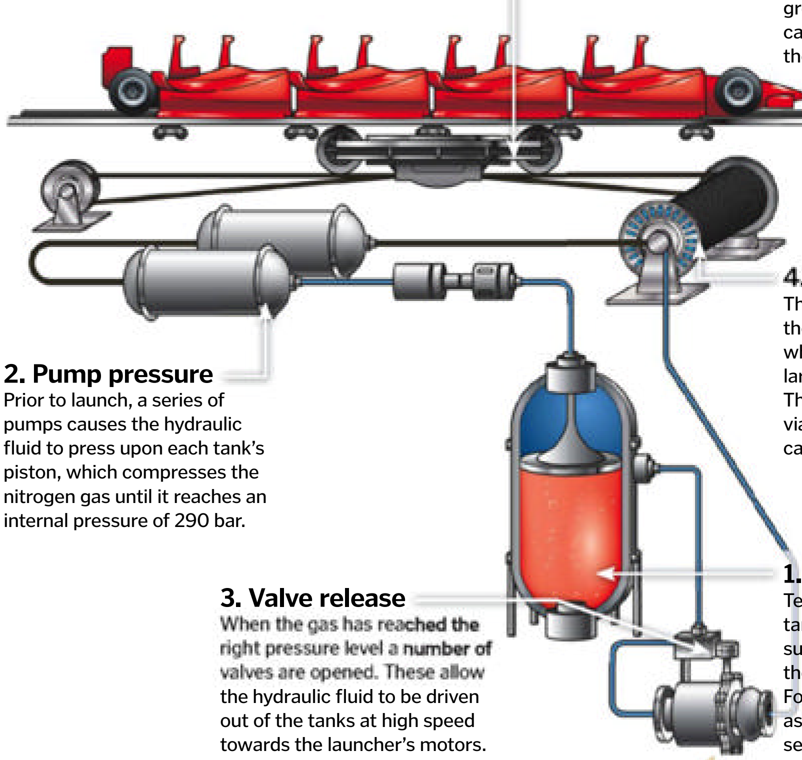
Many of today's superfast rollercoaster rides wouldn't get anywhere without special launching mechanisms. These mechanisms are typically powered by hydraulics and grant incredible speeds to the coaster's train; indeed, the fastest in the world can achieve 240 kilometres (150 miles) per hour, which it reaches in under five seconds.

Key to a hydraulic launch system is its 'catch car', which runs underneath the coaster's train and track. The car is responsible for receiving the energy generated by the launcher's hydraulic motors and mechanisms and converting it into linear motion. The catch car does this by effectively towing the train down a portion of the track at high speed, with it then detaching at the last moment, leaving the train and its passengers free to zoom away.

These hydraulic coaster launch mechanisms share much technology with aircraft carrier launch systems for fighter jets, with both situations requiring the vehicle to be propelled to high velocity within a short distance and timeframe. Both the fastest and tallest rollercoasters in the world – the Ferrari-built Formula Rossa in Abu Dhabi, UAE, and the Kingda Ka in the USA, respectively – use hydraulic launch systems for propulsion.

Anatomy of a launcher

See how hydraulics power the Formula Rossa, the planet's fastest rollercoaster



5. Catch car
The catch car is pulled along under the train's launch track, propelling the train forward at great speed. The system can then be reset for the next launch.

4. Winch
The hydraulic fluid enters the launcher's 48 motors, which in turn power a large drum and winch. The winch is connected via steel cables to the catch car on the train.

2. Pump pressure
Prior to launch, a series of pumps causes the hydraulic fluid to press upon each tank's piston, which compresses the nitrogen gas until it reaches an internal pressure of 290 bar.

3. Valve release
When the gas has reached the right pressure level a number of valves are opened. These allow the hydraulic fluid to be driven out of the tanks at high speed towards the launcher's motors.

1. Accumulator
Ten cylindrical storage tanks contain a large supply of nitrogen gas – the energy source for the Formula Rossa – as well as hydraulic fluid, each separated by a piston.

How pogo sticks bounce

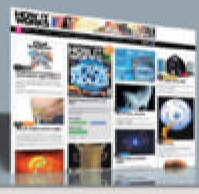
What makes these popular toys so adept at jumping?

Many of us will have played with a pogo stick when we were younger, but what unique technology lends this toy its impressive bounce? The device consists of a cylindrical tube with footpads mounted on the bottom and handlebars on the top, with the tube containing a second cylinder attached to a large internal spring. Lastly, fixed to the bottom of the stick is a tough, rubberised foot contact.

When the user climbs onto the pogo stick – with their feet positioned on the pads and hands on the bars – a jumping motion causes the internal spring to become compressed, storing the generated kinetic energy. As such, rather than the energy dissipating into the ground – as would happen if the person was jumping without a stick – what follows is the decompression of the spring, which propels the device up in a sudden release of energy.

As a portion of this energy remains within the spring after the first decompression, upon making contact with the ground again this energy is added to the second jump. As a result the bouncer gets higher each time until a plateau is reached where forces balance out.

Traditionally pogo sticks were created as children's toys, with low-power springs offering only modest jumps. Today, however, there are also high-power versions that allow a variety of tricks and stunts to be performed by extreme sports enthusiasts.



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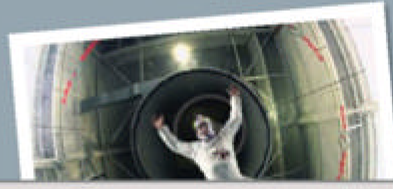


DID YOU KNOW? Felix Baumgartner holds the current record for the highest freefall jump in history from 39km (24mi) up!

Skydiving wind tunnels

Vertical 'bodyflight' simulators allow indoor training for skydiving without the big drop, but how do they work?

Vertical wind tunnels aim to re-create the physics of freefall. Air in the tunnel travels at a speed that matches the terminal velocity of a skydiver (about 200 kilometres/120 miles per hour), and produces a column of air up to five metres (16 feet) wide.

A skydive typically lasts no longer than seven minutes, so the goal of a wind tunnel is to create a smooth, laminar flow of air which enables skydivers to practise for several hours at a time.

There are two main designs currently in use. Open-circuit wind tunnels use a continuous stream of new air, drawn in at the bottom and expelled at the top. Powerful fans direct the air upwards, producing a jet upon which people can float. These tunnels can be made in portable form and used outdoors too for a more natural skydiving experience.

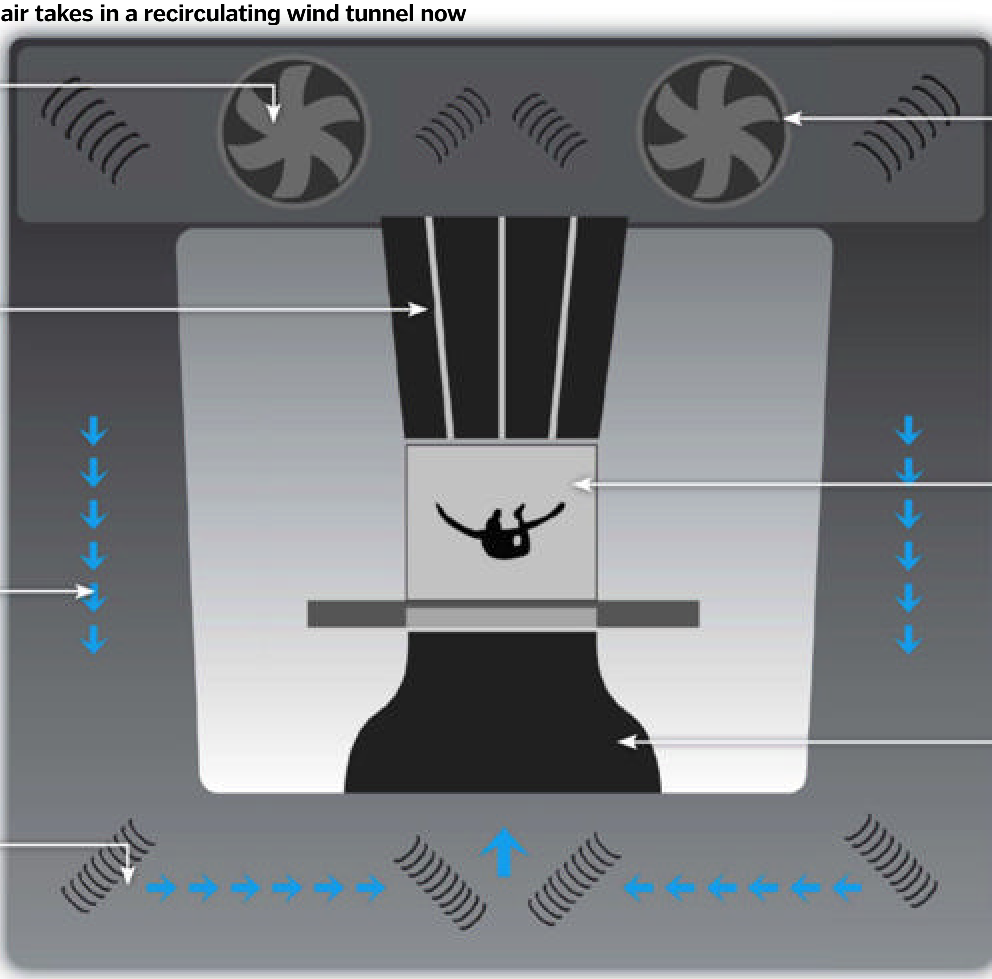
In contrast, recirculating wind tunnels reuse air in a loop to conserve energy and provide more uniform airflow. Typically, four fans positioned above the tunnel circulate air around a series of tubes in an aerodynamic loop. The air is 'turned' through the tubes using vanes, moves up through the flight chamber and is then recirculated to the bottom again. Friction in the mechanism causes the air to become very warm, so often cool fresh air is incorporated in order to make the experience more comfortable for the flyer.

Tackling turbulence

Proper simulation of skydiving requires even, laminar airflow to provide uniform upthrust across the body of the diver. Fluctuations in airflow and turbulence create pockets of differential pressure in the column and cause the diver to dip and bump. Fan blades generate turbulence as they chop through the air, so mesh panels – or vanes – are used to smooth and channel the air. The walls of vertical wind tunnels are also made incredibly smooth to cut down on friction. A curved design, as opposed to sharp-edged chambers, also aids in maintaining laminar flow by preventing air constriction in any corners.

Going with the flow...

Follow the cyclic journey air takes in a recirculating wind tunnel now



Fans
Four powerful fans (placed in pairs) are used to generate air circulation around the tunnel.

Downstream
The fans are placed downstream of the chamber so that the air is pulled through instead of pushed, providing smoother airflow.

Diffuser
The diffuser gradually gets wider to gently slow the airflow without causing turbulence in the flight chamber.

Flight chamber
Air flows through the central chamber at 198km/h (120mph).

Return air tower
Air is recirculated around the system through air towers that run parallel to the main chamber.

Inlet contractor
As the air enters the cone-shaped contractor it is compressed, which increases its velocity.

Turning vanes
Panels with honeycomb-shaped holes are used to direct and smooth the airflow around the tunnel.

“The mast and sails use aircraft tech to create an efficient aerofoil shape”

Able to hit speeds in excess of 20 knots (37km/h; 23mph) the Oracle AC45 was used in both 2011 and 2012’s America’s Cup

Next-gen racing yachts

Manufactured using aircraft technology, today’s racing yachts have the ability to sail faster than the wind thanks to a unique balancing act

Modern racing yachts take the latest aircraft technology to build the lightest and fastest sailboats. Weight is critical to performance, but just like a plane, the stresses are also very high so designers have to find the critical balance between the lightest weight and the maximum strength. Advanced composites combining carbon fibre, Kevlar and epoxy resins are blended and then cooked in a vast ‘oven’ for the optimum shell.

The top racing catamarans are the ultimate sailboats for performance because their slim hulls are the most efficient in terms of resistance. Their stability comes from the wide beam and they need no ballast keel to balance the boat against wind pressure. To reduce resistance further they have foils on fins below the hull that generate lift to bring the hull clear of the water so they glide across the waves.

The mast and sails also use aircraft tech to create an efficient aerofoil shape. Sails are made from exotic fibres such as a polyester film laminated over a carbon-fibre base for high strength and a smooth surface. On racing catamarans the sails are matched to a wing mast that is part of the required aerofoil shape which allows the yacht to sail upwind at speed.

Actually sailing these yachts is also a great balancing act. The hull on the windward side comes completely clear of the water and the helmsman has to balance the stability against the wind pressure to power the yacht forward. On the most advanced racing catamarans speeds of 40 knots (74 kilometres/46 miles per hour) are possible, making for both very exciting and very demanding racing.

87HRS

FASTEST TRANSATLANTIC CROSSING

The sailing record for the Atlantic is now faster than the Atlantic liners. A 40-metre (131-foot) French trimaran averaged 33 knots on its crossing in 2009, which took three days, 15 hours and 26 minutes.

DID YOU KNOW? *Some boats can sail faster than the wind as the sails accelerate the wind as it passes over their curved surfaces*

Sailing lingo

Tacking
Sailing in a series of dog-legs to make progress into the wind.

Close-hauled
This means sailing as close to the wind as possible. Racing yachts can normally sail at about 40 degrees off the wind.

Spinnaker
A big balloon sail designed to catch as much wind as possible when sailing downwind.

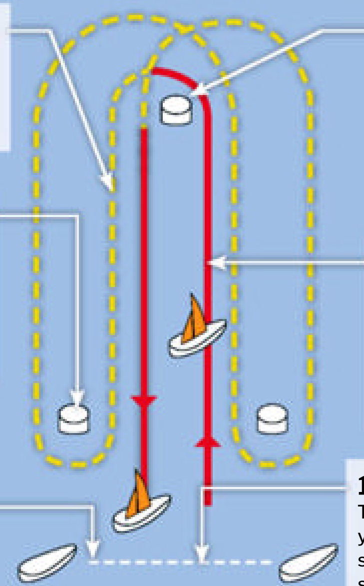
Downwind sailing
Sailing with the wind behind when the maximum sail area is exposed to the wind.

Reaching
Sailing with the wind on the beam, which is often the fastest type of sailing.

Foils
Small aerofoil-shaped winglets attached to the rudder and a fin that generate lift from the water flowing past to decrease resistance.

A sailing race step-by-step

The main stages in a windward-leeward buoy course explained



1. Start
The start is always upwind so you need to find a place on the start line at one end if possible so you cross the line first.

2. Upwind leg
Here the yachts are tacking, sailing close to the wind and heading in a series of tacks to the top mark. You have the advantage when the wind is on your starboard (right) side.

3. Rounding the top mark
Here you aim to round the mark (a buoy) as close as possible without touching it, but competitors may impede you as the inside yacht always has priority.

4. Downwind leg
Here you fly the spinnaker sail to catch as much wind as possible. A competitor close behind can blanket your wind and catch up.

5. Rounding the bottom mark
Here the crew need skilful sail handling to bring the spinnaker in without allowing it in the water and to set the sails ready for tacking on the upwind leg.

6. Finish
There may be several circuits before the finish, which is always at the end of the downwind leg.

Racing yacht anatomy

We highlight the major components of a cutting-edge sailing boat and explain the role they play

Wing mast
The rigid fin that supports the sails and also acts as an aerofoil.

Mainsail
The sail that extends aft from the mast to complete the aerofoil.

Supporting structure
These wires and struts help to reinforce the hull so it can absorb high stresses.

Steering station
The helmsman controls the boat from here where they can see everything clearly.

Rudder with foil
There is a rudder on each hull for steering and the fins on the bottom generate lift.

Fin with foil
This fin helps to prevent the boat drifting sideways and the foil generates lift.

Foresail
The front sail on the yacht that curves into an aerofoil shape to generate thrust.

Crossbeam
Two crossbeams link the two hulls to create a rigid structure.

Slim hull
The most efficient and lightest shape for performance.

Bowsprit
This boom extends forward from the crossbeams to support the foresail.

Competing in the Extreme Sailing Series requires a combination of great skill and engineering

Inside the US Capitol

Explore the building that is a symbol of the American people

The meeting place of the United States legislature, the Capitol is one of America's most recognised buildings. Construction began on 18 September 1793 when George Washington laid the cornerstone. Building was swift and, in November 1800, the US Congress met in the first completed portion: the north wing. By the 1850s, major extensions to the north and south ends of the Capitol were authorised because of America's westward expansion and the resultant growth of Congress. In 1855, the old dome was considered too small and so the iconic dome which tops the building today was designed and installed, drawing inspiration from St Paul's Cathedral in London and St Peter's Basilica in Rome.

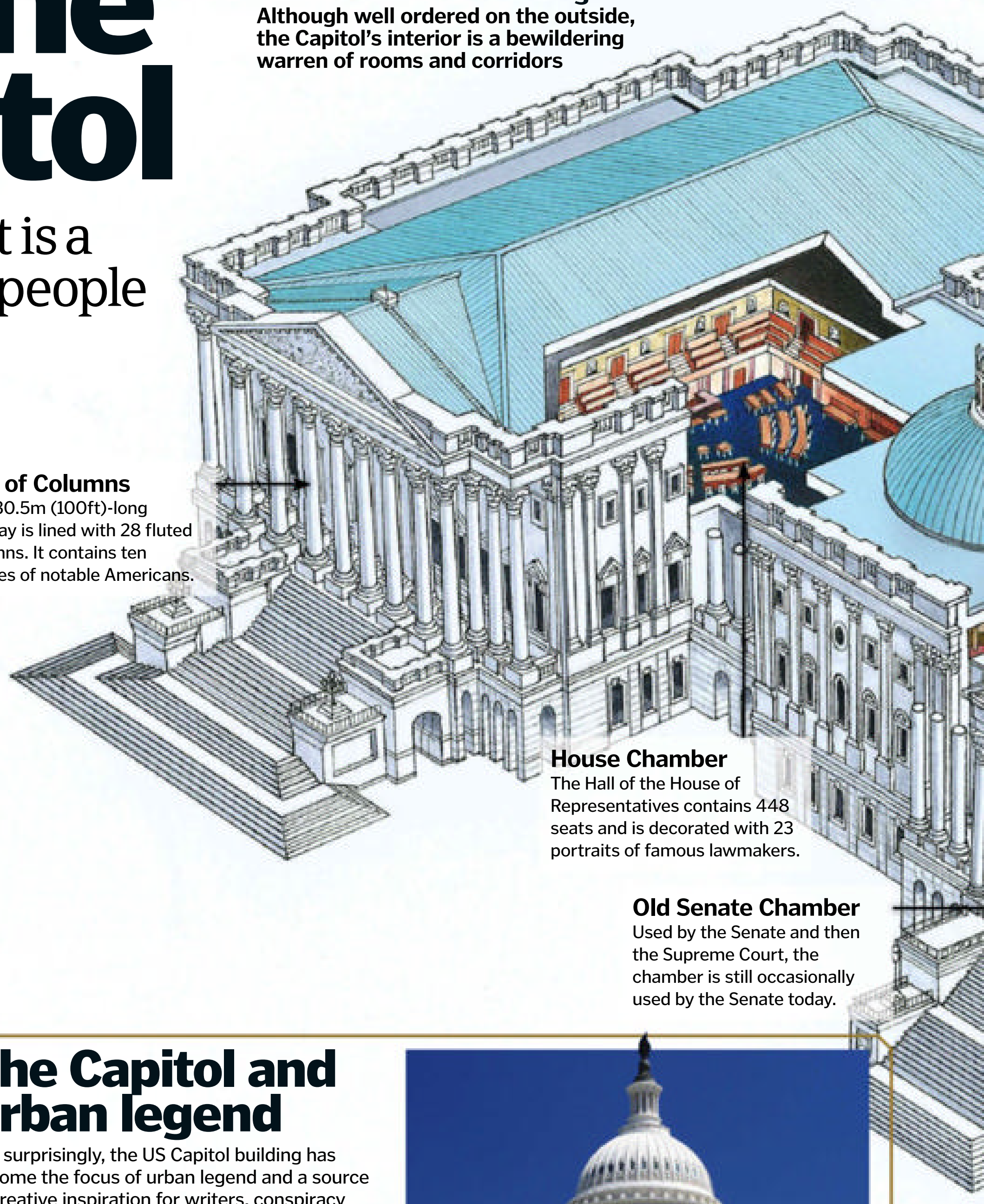
From its conception to completion, a number of materials have been used in the Capitol's construction. Built in the neoclassical style, the Capitol was first made of brick and sandstone. Only later did it take on its gleaming white appearance – the whole of the exterior and much of the interior being faced with white marble. The dome it's crowned with, however, is supported by cast iron and most of the more recent building projects have been constructed from more reasonable reinforced concrete.

The Visitor Center is the newest and possibly final addition to the US Capitol building. Covering an area of nearly 53,885 square metres (580,000 square feet), the Visitor Center is the largest building project in the Capitol's more than two-century history and is approximately three-quarters the size of the Capitol itself.

Due to its size, the entire facility was built underground so as not to detract from the appearance of the original building and the grounds designed by Frederick Law Olmsted in 1874. As well as a tourist attraction visited by millions every year, the US Capitol – like the Palace of Westminster in London – is a working office building and the centre of the world's largest democratic government.

Behind the façade

Although well ordered on the outside, the Capitol's interior is a bewildering warren of rooms and corridors



Hall of Columns
This 30.5m (100ft)-long hallway is lined with 28 fluted columns. It contains ten statues of notable Americans.

House Chamber
The Hall of the House of Representatives contains 448 seats and is decorated with 23 portraits of famous lawmakers.

Old Senate Chamber
Used by the Senate and then the Supreme Court, the chamber is still occasionally used by the Senate today.

The Capitol and urban legend

Not surprisingly, the US Capitol building has become the focus of urban legend and a source of creative inspiration for writers, conspiracy theorists and film directors alike. Not only has it been claimed that the number of columns and steps in various locations in the Capitol have symbolic meanings, but it is believed by some that the building conceals hidden passages and chambers. It is also widely thought that the Capitol served as a prison during the American Civil War, although this is not the case.

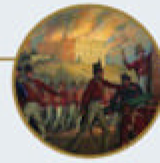
The Capitol has frequently appeared in works of fiction too. For example, in Dan Brown's book *The Lost Symbol*, the idea that the Capitol's crypt originally featured an eternal flame tended by its own 'keeper' is introduced – a delightful conceit which many now cite as historical fact. It's also said to be the American landmark which has been most frequently blown up in Hollywood films, including 2013 movie *White House Down*.

KEY DATES
CAPITOL IN PROGRESS

1793
The construction of the US Capitol commences to the designs of William Thornton (right).

1800
At the start of the 19th century, Congress first meets in the Capitol which is still under construction.

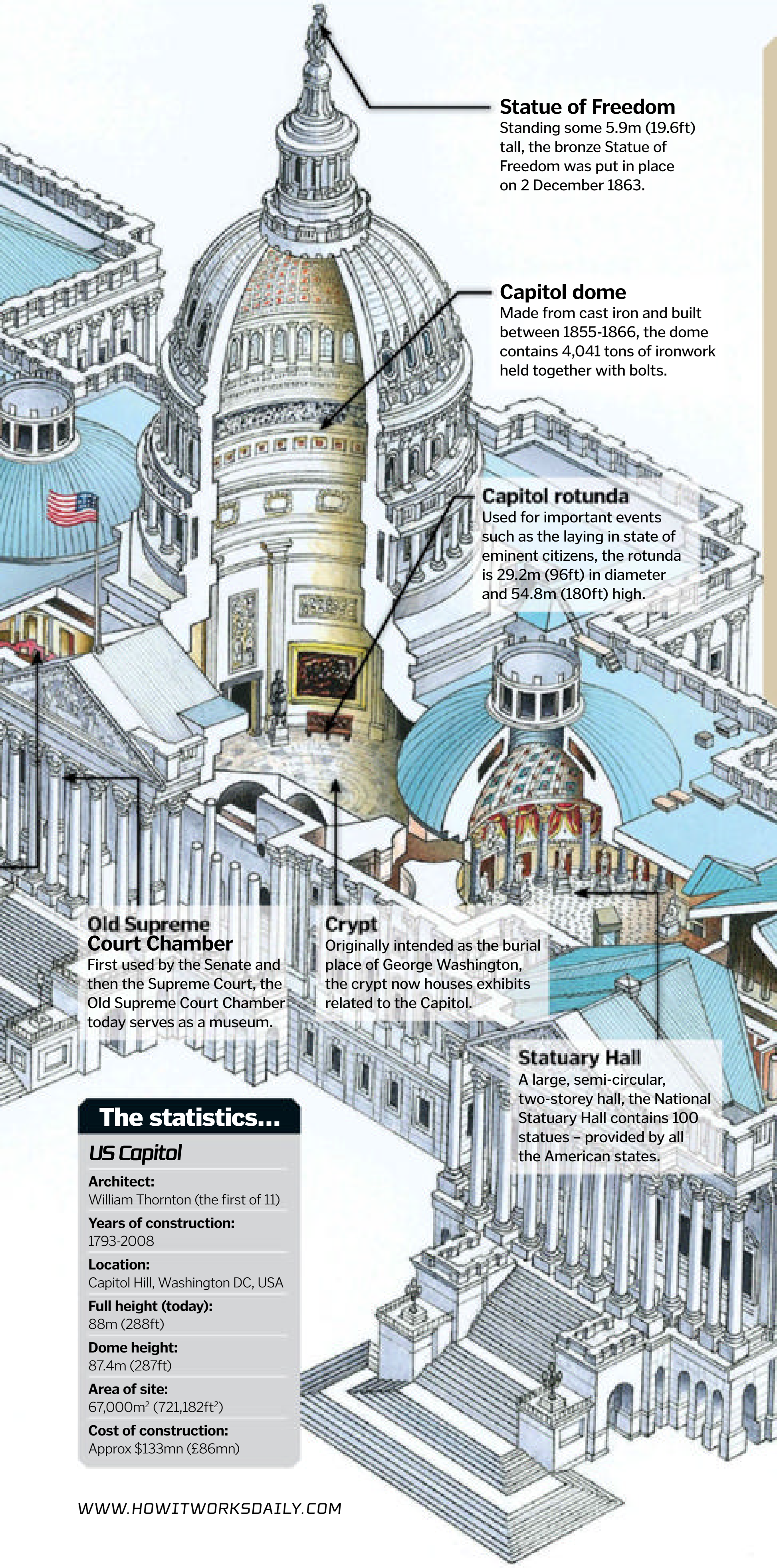
1814
The first US Capitol is burned down by British soldiers on 24 August (pictured right).



1962
The extension of the east front of the Capitol is completed.

2008
The last major addition to the Capitol – the Visitor Center – opens to the public.

DID YOU KNOW? *The US Capitol used to have its own subway that once brought politicians from their offices in Washington*



Statue of Freedom
Standing some 5.9m (19.6ft) tall, the bronze Statue of Freedom was put in place on 2 December 1863.

Capitol dome
Made from cast iron and built between 1855-1866, the dome contains 4,041 tons of ironwork held together with bolts.

Capitol rotunda
Used for important events such as the laying in state of eminent citizens, the rotunda is 29.2m (96ft) in diameter and 54.8m (180ft) high.

Old Supreme Court Chamber
First used by the Senate and then the Supreme Court, the Old Supreme Court Chamber today serves as a museum.

Crypt
Originally intended as the burial place of George Washington, the crypt now houses exhibits related to the Capitol.

Statuary Hall
A large, semi-circular, two-storey hall, the National Statuary Hall contains 100 statues – provided by all the American states.

Senate Chamber
Opened in 1859, this chamber is adorned with white marble busts of former presidents of the Senate (vice-presidents of the United States).

A focus on the frescoes

The Capitol contains a number of frescoes, the most famous of which – *The Apotheosis Of Washington* – covers some 433 square metres (4,664 square feet) on the main dome's ceiling.

Fresco is an ancient art form in which paint is applied to freshly laid lime plaster on a wall or ceiling. Water is used as the vehicle for the pigment which is absorbed into the surface as the plaster sets. The painting thus becomes an integral part of the surface to which it has been applied. Fresco is often used for large-scale artistic compositions in buildings as small sections of plaster can be applied and painted at a time, enabling the artist to slowly build up the composition. This means that mistakes or changes can be easily implemented too.

Although fresco is very durable, grime accumulates on its surface over time and the plaster can darken. Modern cleaning techniques, however, can rectify this problem.

The statistics…

US Capitol

Architect:
William Thornton (the first of 11)

Years of construction:
1793-2008

Location:
Capitol Hill, Washington DC, USA

Full height (today):
88m (288ft)

Dome height:
87.4m (287ft)

Area of site:
67,000m² (721,182ft²)

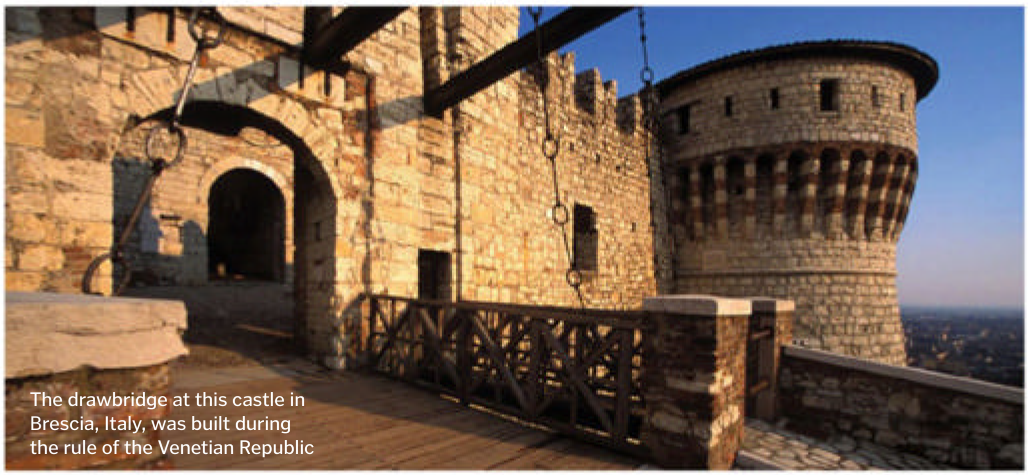
Cost of construction:
Approx $133mn (£86mn)

"By employing counterweights, incredibly heavy bridges could be operated by just a few people"

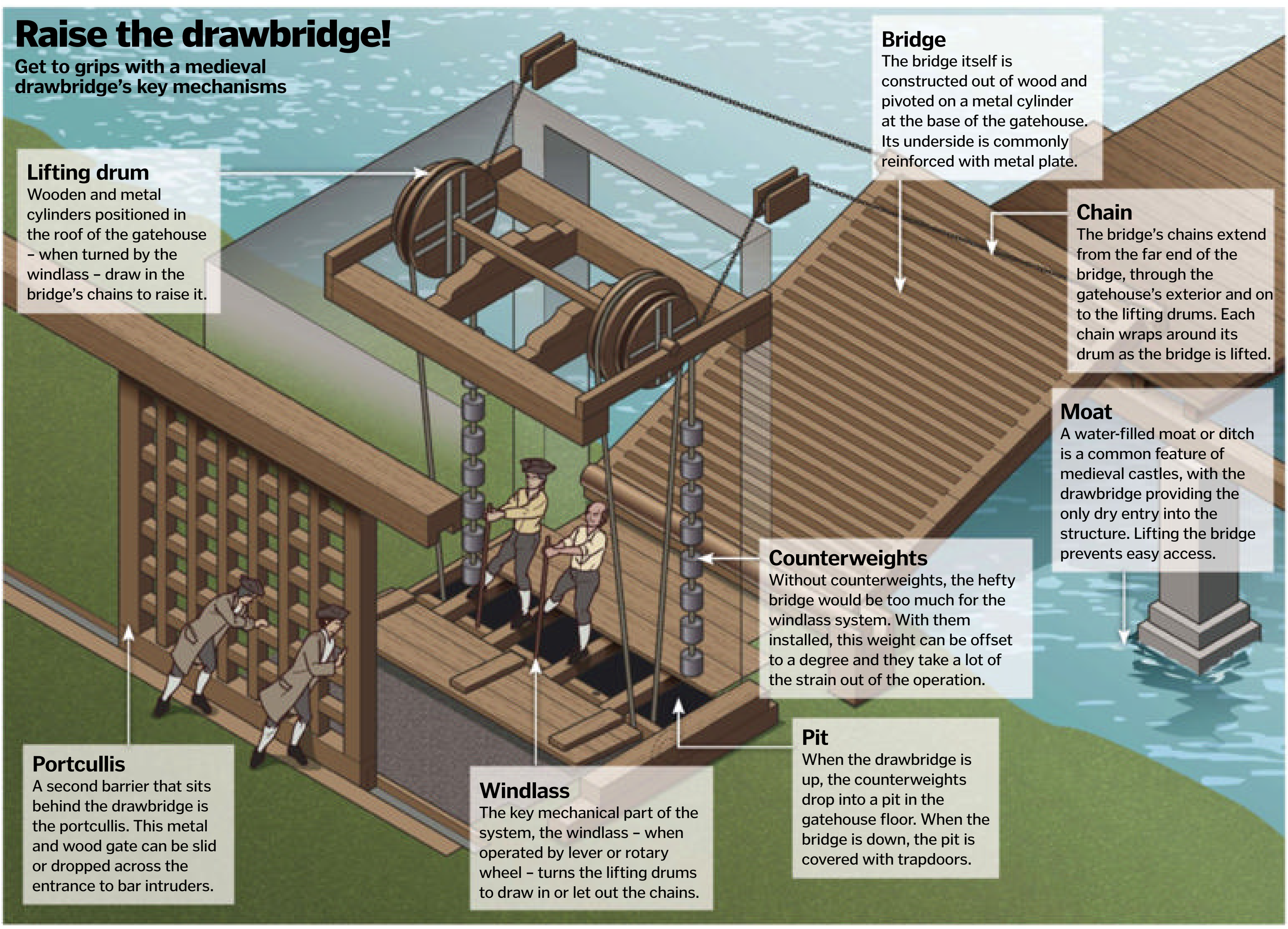
How drawbridges worked

Used to defend castles for centuries, these fold-up entrances were simple yet effective

Classical, medieval drawbridges worked via the simple principle of counterweight, with large wood and metal bridges pivoted via a series of balancing weights in a castle's gatehouse. The weights, which were attached to the bridge's lifting chains, enabled the platform to be raised via a windlass, which in turn rotated a pair of lifting drums that gathered in the chains. By employing counterweights, incredibly heavy bridges could be operated by just a few people – useful when under attack. Along with a moat, a reinforced drawbridge served as a two-fold barrier, making it much more difficult for any enemies to invade a fortification or city.



The drawbridge at this castle in Brescia, Italy, was built during the rule of the Venetian Republic

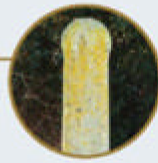


KEY DATES
PILTDOWN HOAX

1912 Scientist Charles Dawson unearths skull and jaw fragments from the Piltdown gravel pit, UK.

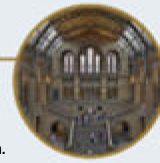
1915 Dawson claims to find fragments of a second skull – Piltdown II – near the original site.

1938 A memorial is unveiled celebrating Dawson, despite opposition in the scientific field.



1953 *Time* magazine publishes evidence that proves the Piltdown Man is a forgery.

1970 Martin Hinton, a hoax associate, is found to have left a bone-filled suitcase in the Natural History Museum.



DID YOU KNOW? Piltdown Man's Latin name was Eoanthropus dawsoni, after Charles Dawson who 'discovered' it

The first electric submarine

Learn about the Goubet I – the earliest underwater vessel to be electrically powered

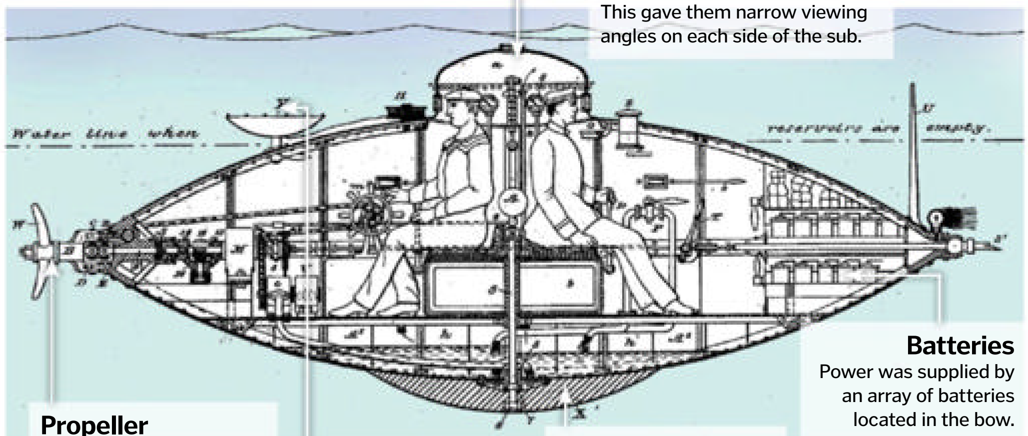
The Goubet I submarine was a two-person, electric submarine built by French inventor Claude Goubet in 1885. Manufactured in Paris, the sub has gone down in history as the first to be electrically powered, with a brace of cutting-edge tech advancing more primitive models.

The Goubet I was battery powered, utilised a Siemens electric motor to drive its propeller and power a navigation light, and measured five metres (16.4 feet) long. The craft weighed in at just over six tons. It was controlled from a central position, with its two crew positioned back to back, seeing out of the vessel via small glass windows; they could see up, down and to the sides to some extent thanks to prisms.

After testing in the River Seine in Paris, however, the Goubet I was ultimately deemed a failure, because the submersible wasn't able to maintain a stable course or depth while moving forward. As a result, while some of its innovative technology lived on in later designs, the Goubet I itself was quickly scrapped.

Tour of the Goubet I

Take a peek inside the first sub that ran on electricity and learn why it failed



Tower
The crew saw out of the Goubet I via a series of windows and prisms in the conning tower. This gave them narrow viewing angles on each side of the sub.

Batteries
Power was supplied by an array of batteries located in the bow. These sent electricity to the pumps and lights.

Propeller
The sub did not have a rudder or dive planes, instead being fitted with a 'Goubet joint' – a mechanism that allowed the propeller to be redirected for steering.

Mine
Quickly commandeered for military ends, the Goubet I could carry a single mine which was released via a wire.

Ballast tanks
Stability was supposed to be ensured by a ballast system that filtered a small quantity of water between the front and back of the vessel, but it didn't work.

Who was the Piltdown Man?

How did these fake 'missing link' bones fool scientists for decades?

Piltdown Man was a famous hoax in which a species of extinct hominin was supposedly dug up at the Piltdown gravel pit in East Sussex, England, in 1912. The excavation, led by scientist Charles Dawson, appeared to unearth the fossilised fragments of a cranium and jawbone that, on analysis by Dawson and some of his contemporaries, was confirmed as a new species: a missing link between apes and early humans.

For the next 40 years other scientists voiced serious doubts over Piltdown Man's authenticity – especially as later, genuine discoveries left the species isolated in the evolutionary sequence.

These misgivings were eventually proven justified in 1953 after an intensive re-examination of the bone fragments with modern scientific techniques revealed they were in fact from three different species. The cranium was from a modern human, the jawbone from an orangutan and the teeth from a chimpanzee.

Today the word 'Piltdown' is used to describe any fake or poorly executed research in the scientific world

"Spain, Britain, Russia, Sweden, Poland and India each developed their own musketeer units"

Meet the musketeers

One of the most popular military units for centuries, musketeers fought in battles and protected esteemed rulers all the way from France to India

Musketeers were an early form of soldier who were armed with muskets. They acted as a bridge unit between traditional infantry – which fought on foot and typically hand-to-hand with swords – and dragoons, a type of light cavalry armed with long-ranged weapons. This granted them a level of versatility and flexibility most prized on the battlefield, with musketeer units typically reserved for the protection of nobility or, in many Western nations, royalty.

While musketeers as a unit are older (see 'Musketeer origins' boxout for details), they didn't emerge in Europe until the 16th century, with the concept only really taking off on a large scale in the early-17th century. While this particular era was dominated by the French musketeers of the Maison du Roi (the Royal Household) – upon which the fictional musketeers of Dumas's *The Three Musketeers* are based – Spain, Britain, Russia, Sweden, Poland and even India each developed their own musketeer units in this period and used them on the battlefield frequently.

Musketeers as a common military unit were largely phased out by the middle of the 19th century, with developments in firearms rendering the musket obsolete. With the introduction of the rifle – which could shoot both farther and much faster than the musket – the rifleman unit could emerge, negating the need for the greater speed of the mounted musketeer. This, combined with the decline of many dynasties throughout Europe – like the Ancien Régime of France – saw all musketeer units permanently disbanded.

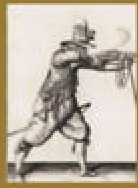
A Prussian engraving of a French musketeer (right) from the reign of Louis XIV (1643-1715)

How to fire a musket step-by-step

1 Carry While marching to position the musket should be carried over the shoulder, with the firing rest secured in your off-hand.

2 Firing prep When firing is ordered, the musket is filled with priming powder, charge and ball, with the weapon held in a diagonal orientation.

3 Insert fuse The match fuse should then be cocked in the matchlock and blown on, ensuring at all times that the match doesn't extinguish.



4 Shoot Draw up the musket while simultaneously securing the firing rest. Slot the musket in the rest's support brace, aim and fire.

5 Withdraw Bring the musket off its rest, draw it down to your side, then take the fuse off the musket and await further instructions.

5 TOP FACTS
MUSKETEER MYTHS

Comte d'Artag-non
1 The real Comte d'Artagnan was nothing like the fictional hero portrayed in Alexandre Dumas's famous novel *The Three Musketeers*, which itself was based on a semi-fiction.

For richer, not poorer
2 In fact, far from emerging from poor and humble origins, the real-life D'Artagnan was the son of a nobleman who lived in a large chateau in south-west France.

More than three
3 Despite the Dumas novel being called *The 'Three' Musketeers*, halfway through D'Artagnan officially joins their ranks, taking the number of musketeers in the tale to four.

Behind the times
4 Despite Dumas's novel stating that D'Artagnan left his home to become a musketeer in 1625, in fact the real man did not do so until later – during the 1630s.

Mort realistic
5 Indeed one of the only things in Dumas's fictionalised account of D'Artagnan that is 100 per cent accurate is the date of the soldier's death – he died in Maastricht in 1673.

DID YOU KNOW? Musketeers of the Guard fought both on foot and on horseback

Uniform of a musketeer

Check out the essential kit worn by famed musketeer captain, Comte d'Artagnan

Hat
Musketeers started off in the West wearing simply ornate hats, but by the early-19th century these evolved into metal helmets. They did remain decorative though, often with large feathered plumes attached.

Bandolier
Bandoliers (a pocketed belt) and ammunition pouches/bags were a common accessory for musketeers, so they were always well supplied on the battlefield. These belts were strapped around the waist or chest.

Tunic
Considerably more elaborate than standard infantry, musketeer tunics and – in later periods – cuirasses, favoured manoeuvrability over armoured protection.

Musket
The musketeer's primary weapon, the musket was deadly albeit cumbersome to use. Its slow reload rate restricted use to four shots per minute at best.

Holdall
As musketeers were on the road during much of their military service, each carried their own holdall to store food and personal belongings.

Cape
A feature associated more with earlier iterations of musketeers, the cape offered some protection from the elements while travelling.

Sword
As musketeers were trained to fight both on horseback like dragoons and on foot like infantry, they were also equipped with a sword for hand-to-hand engagements.

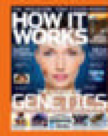
Boots
Boots were an important part of the musketeer's uniform, both communicating their prestigious position and providing good support on the ground and on horseback (some had spurs attached).

Musketeer origins

Unlike the musketeers of the Maison du Roi – the Royal Household of France – who were founded in 1622 during the reign of Louis XIII, musketeers had already been operating across the other side of the world in China since the 14th century. Indeed, through the Ming Dynasty (1368-1644) no national army was complete without multiple musketeer divisions, with soldiers armed with matchlock muskets. Surviving texts indicate that these musketeers fired in lines and typically from a kneeling position. This development of the concept of musketeers in China stemmed from their invention and mastery of gunpowder, with the musket revolutionising traditional forms of combat.

BRAIN DUMP

Because enquiring minds want to know...



Ask your questions

Send us your queries using one of the methods opposite and we'll get them answered

MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon

Luis has a degree in Zoology from Oxford University and another in Real-time Computing. He's been writing about science and tech since before the web. His science-fiction novel *A Jar Of Wasps* is published by Anarchy Books.

Giles Sparrow

Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in publishing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Alexandra Cheung

With degrees from the University of Nottingham and Imperial College, Alex has worked for several scientific organisations including London's Science Museum, CERN and the Institute of Physics. She lives in Ho Chi Minh City, Vietnam.

Rik Sargent

Rik is an outreach officer at the Institute of Physics in London, where he works on a variety of projects aimed at bringing physics into the public domain. By far his favourite part of the job is travelling to outdoor events and demonstrating 'physics busking'.

Dave Roos

A freelance writer based in the USA, Dave has researched and written about every conceivable topic, from the history of baseball to the expansion of the universe. Among his many qualities are an insatiable curiosity and a passion for science.

Some chameleons can shoot their tongue as far as 70cm (28in)!

Which animal has the longest tongue relative to its total size?

Relative to body length, it's the chameleon. Chameleons catch insects by firing their sticky tongues at them, and range is extremely important, because even a stealthy chameleon can only get so close to a fly without startling it. Some species have tongues that are 70 centimetres (28 inches) long; that can be twice the length of their body, and as long as the tongue of a giant anteater. But chameleons also have very long tails and, if you include this in the measure of body size, then the tongue drops to 'only' the same as the total body length. In that case, the record would have to go to the tube-lipped nectar bat. This is just 5.5 centimetres (2.2 inches) long, but its tongue measures in at 8.5 centimetres (3.3 inches) – one and a half times its total body length. **LV**

Is there an optimal position at which to shoot a basketball at the hoop?

Ben

There is no 'sweet spot' for shooting a basketball at the hoop that works for everyone. The chance of success depends on skill, but there are optimal angles at which to shoot a ball that increase your chances. Professional players tend to shoot the basketball up at an angle of around 35-45 degrees, allowing the ball to fall towards the basket at a steep angle, making a larger area of the hoop accessible. Throwing a basketball with the correct spin can also increase the chance of success. Spin will not affect a ball's motion through the air, but it will change the way it bounces off the rim or the backboard. This subtle change in velocity that spin adds to the rebound can make or break a shot. **RS**

Is it true that closing down iPhone apps saves the battery?

Sam Nair

In almost all cases it makes no difference to battery life. When you press the Home button, iOS moves the running app to 'Background' mode. As soon as this happens, most apps have five seconds to save any important information before they are switched to 'Suspended' mode. While they are paused, they are still loaded into memory, so they can resume quickly but they aren't running and they consume no power.

Some apps are allowed to remain in Background mode for longer – for example, to finish downloading a podcast. And a very small number are allowed to run in Background mode indefinitely; these include GPS navigation apps, music players and apps that listen for incoming internet calls, such as Skype. Quitting these apps does save power. Press the Home button twice, tap and hold the app icon on the Recent Apps list then hit the red no-entry sign. **LV**

When cooking with wine does all the alcohol evaporate?

Clara

Cooking with wine or any other alcoholic beverages will always leave some alcohol in the finished meal. The amount of remaining alcohol depends on both the cooking time and method. The longer the cooking time, the more alcohol will evaporate. Water and alcohol molecules have an affinity for one another and form an azeotrope – a mixture with similar characteristics to a compound. Water normally boils at 100 degrees Celsius (212 degrees Fahrenheit) where as alcohol boils at 78.4 degrees Celsius (173 degrees Fahrenheit). As an azeotropic mix, they boil together somewhere between these points; the exact temperature depends on the ratio of water to alcohol. Wine (and food) contains water and will behave in this way – all the liquid in the food would need to evaporate to remove all traces of alcohol. **RS**

Does evolution always improve a species? Find out on page 82

BRAIN DUMP

Because enquiring minds want to know...

Is centrifugal force real?
Find out on page 83

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

Does evolution always make a species better?

Rob

Evolution does not make a species 'better', but natural selection – the mechanism that drives evolution – selects for traits that improve an organism's chance of survival and reproduction. The trouble is that 'better' and 'worse' are subjective judgements that don't really apply to the blind process of evolution. During reproduction, every organism is subject to an infinite number of random genetic mutations, not all of which are positive. One mutation might kill an organism in its infancy, while another will help the creature become a more successful hunter. It makes sense that the successful hunter has a greater chance of mating and passing on its DNA than the animal that dies young. Over thousands and thousands of years, as more and more organisms with the successful hunter mutation survive and reproduce, that trait becomes embedded in the collective DNA of the species. The result is a species that is not necessarily better than its ancestors, but better suited for reproductive success. **DR**

What would happen if you tried to freeze water in a container filled to the brim?

Claire Cherrett

As water freezes, it expands by nine per cent and will force its way out of almost any container. But if you trap it in an ultra-strong canister, a denser type of ice forms. Under normal pressure conditions, water molecules below 0 degrees Celsius (32 degrees Fahrenheit) hold each other at arm's length to form hexagonal crystals just like snowflakes. This is ice I_h (pronounced 'one h'), which makes up virtually all the ice on Earth. If there's no space to expand into, the pressure inside the container will soar to up to 2,000 times normal atmospheric pressure, smashing glass bottles, tin cans and pretty much anything else. Find a container that can withstand the pressure, though, and the water will eventually crystallise into a tighter arrangement, forming pyramid-shaped crystals; this is called ice VI (ice six). By freezing water in a variety of extreme pressure and temperature conditions, researchers have created 16 different types of ice so far. **AC**

What advantages will the new NASA Z-1 spacesuits have?

Gary Peake

The Z-1 spacesuit being developed by NASA and ILC Dover is intended to be a far safer, more convenient and more capable suit for exploring space. It features radiation-proof materials that should protect astronauts during long spacewalks beyond the protection of Earth's magnetic field, and has flexible joints to allow easier movement. What's more, it is capable of operating at roughly double the internal atmospheric pressure of previous suits, allowing astronauts to go straight from spacecraft to suit without a long 'prebreathing' adaptation process to prepare for the sudden drop in pressure. This allows for the suit's most unusual feature: an entry system known as a suitport. Like the widely used Russian Orlan suit, it is a single-piece design with a hatch at the back for the astronaut to climb in and out. But unlike Orlan, the Z-1 can simply be attached to a hatch on the side of a spacecraft or ground exploration vehicle, so users can just climb in and unhook themselves without the need for an airlock. **GS**

The Z-1 suit has been designed to assist astronauts with tricky manoeuvres in space

Which bird migrates the farthest in winter?

Jessica Miles

The Arctic tern holds the record, making a round trip of 70,800 kilometres (44,000 miles) a year. It spends summer in the Arctic and then flies halfway around the world for a second summer in Antarctica. Being seabirds, Arctic terns can feed on fish and krill along the way, but the bar-tailed godwit is a wader and flies an incredible 11,430 kilometres (7,100 miles) from Alaska to New Zealand in just nine days, without once stopping to eat, drink or rest. The lifetime achievement record, however, must go to the Manx shearwater. This species migrates between Norway and the Falkland Islands each year and, since they can live for up to 50 years, some individuals are estimated to have flown 8 million kilometres (5 million miles) – that's more than ten round-trips to the Moon! **LV**

What is the benefit of rotating crops?

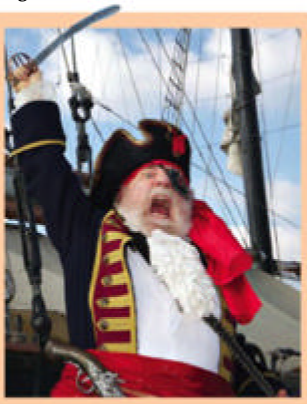
Emma Squire

Crop rotation reduces the transmission of certain plant diseases and pests, and improves overall soil fertility. As a rule, farmers and gardeners try not to plant crops from the same plant family in the same location for at least three years. Tomatoes, potatoes and peppers, for example, are all members of the Solanaceae, or nightshade, family. There are several diseases (eg fungi, viruses and blights) and pests (eg beetles and larvae) that target the nightshade family and can survive in the soil over the winter. That's why farmers don't plant nightshades in the same location year after year. Different crops also require different soil nutrients to thrive. Farmers usually plant a grain crop, eg wheat, after a legume, like soy, because legumes raise nitrogen levels in the earth. **DR**

Why did pirates used to wear eye patches?

Mike Ballard

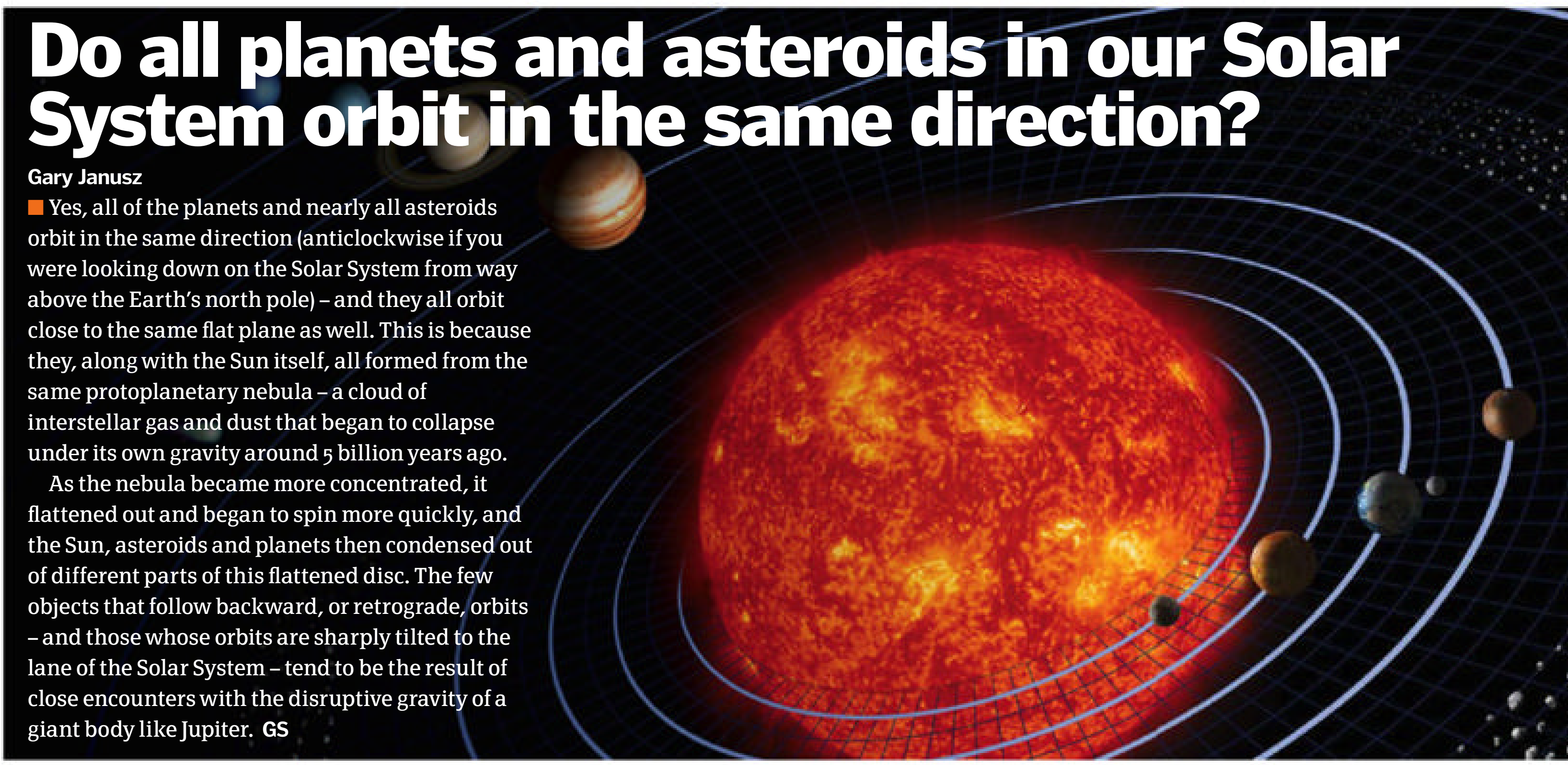
The clichéd image of a pirate with an eye patch seems to owe more to popular fiction than to historical records. However, there is a popular theory that wearing an eye patch was common among seafarers, as it allowed one eye to constantly be accustomed to the dark – useful if someone needed to go below deck and see quickly without waiting for their eyes to adjust. This is plausible since it can take up to 25 minutes for eyes to completely adjust to the dark – not very useful in a battle! **RS**



What is centrifugal force?

Alex Holt

Centrifugal force describes the sensation one has of being pushed outward when moving on a circular path, but it's not really a force. The feeling of being pushed outwards when speeding round a bend in a car, or on a merry-go-round, comes from your preference to move in a straight line. Isaac Newton showed that all objects have inertia and will either stay at rest, or move in a straight line, unless a force acts on them. When you move in a circle there is a force pulling on you, constantly changing your direction from that of a straight line. This is centripetal force and pulls inwards. The feeling of the 'outward pull' of centrifugal force is just your natural resistance to this change in direction. **RS**



Do all planets and asteroids in our Solar System orbit in the same direction?

Gary Janusz

Yes, all of the planets and nearly all asteroids orbit in the same direction (anticlockwise if you were looking down on the Solar System from way above the Earth's north pole) – and they all orbit close to the same flat plane as well. This is because they, along with the Sun itself, all formed from the same protoplanetary nebula – a cloud of interstellar gas and dust that began to collapse under its own gravity around 5 billion years ago.

As the nebula became more concentrated, it flattened out and began to spin more quickly, and the Sun, asteroids and planets then condensed out of different parts of this flattened disc. The few objects that follow backward, or retrograde, orbits – and those whose orbits are sharply tilted to the lane of the Solar System – tend to be the result of close encounters with the disruptive gravity of a giant body like Jupiter. **GS**

Why do some whistles have little balls inside? Find out on page 84

Do man-made magnets exist?

Find out on page 85

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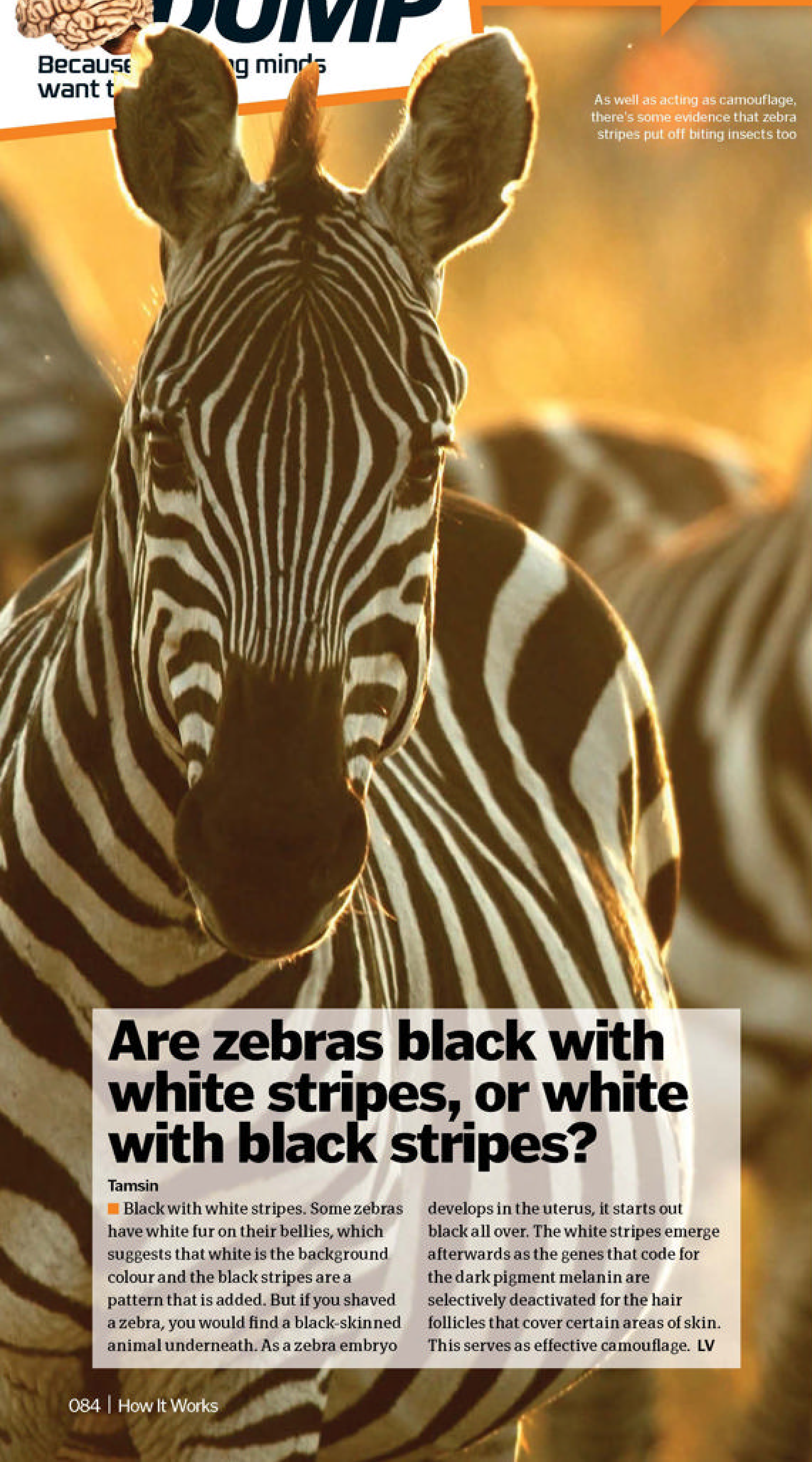


As well as acting as camouflage, there's some evidence that zebra stripes put off biting insects too

Are zebras black with white stripes, or white with black stripes?

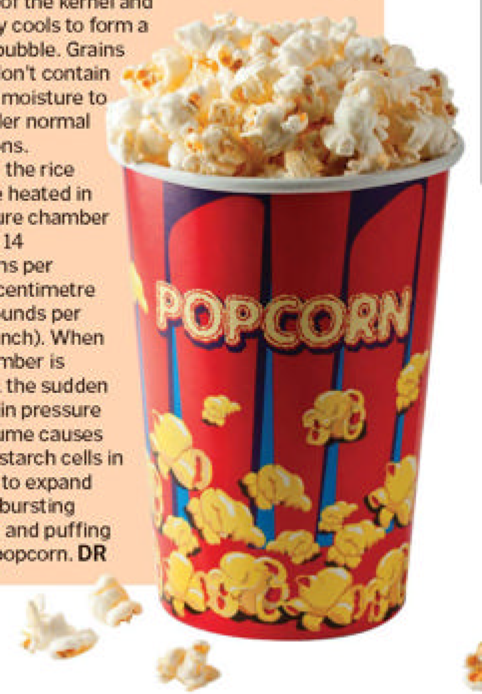
Tamsin

Black with white stripes. Some zebras have white fur on their bellies, which suggests that white is the background colour and the black stripes are a pattern that is added. But if you shaved a zebra, you would find a black-skinned animal underneath. As a zebra embryo develops in the uterus, it starts out black all over. The white stripes emerge afterwards as the genes that code for the dark pigment melanin are selectively deactivated for the hair follicles that cover certain areas of skin. This serves as effective camouflage. **LV**

What's the difference between popcorn and puffing rice?

Sally Evans

You can pop corn with any heat source, but to puff rice you also need a pressure chamber. Popcorn is the only grain that can be 'puffed' at home, because it has the right moisture content (14 per cent) and a fragile hull. When the temperature of the kernel reaches 100 degrees Celsius (212 degrees Fahrenheit), water starts to boil inside the starchy cells of the endosperm, causing them to expand. At 175 degrees Celsius (347 degrees Fahrenheit), the superheated starchy material explodes through the hull of the kernel and instantly cools to form a chewy bubble. Grains of rice don't contain enough moisture to pop under normal conditions. Instead, the rice must be heated in a pressure chamber at up to 14 kilograms per square centimetre (200 pounds per square inch). When the chamber is opened, the sudden change in pressure and volume causes the hot starch cells in the rice to expand rapidly, bursting through and puffing up like popcorn. **DR**



Why do some whistles have balls inside?

John P

The ball, called a pea, creates the whistle's distinctive trilling sound. Whistles come in all shapes and sizes, from a rounded coach's whistle to the long metal tubes of a pipe organ. They all work in essentially the same way. Air is blown or forced into a narrow tube, creating pressure. As the air escapes through a small slit or opening, it vibrates at a certain frequency, or pitch. The lightweight pea inside a coach's whistle gets tossed around by the column of swirling, fast-moving air. The movements of the pea create turbulence in the air stream that oscillates the frequency of the whistle's pitch, resulting in a loud, trilling tone. **DR**

Winds on Uranus are estimated to reach up to 900km/h (560mph)

Why are winds on Neptune and Uranus so fierce?

Adam Pritchard

Part of the driving force is probably their fast rotation. Both planets are about four times the diameter of Earth, but spin on their axis in 16 (Neptune) to 17 (Uranus) hours, which generates huge Coriolis forces along bands parallel to their equators. The winds on Neptune are the strongest in the Solar System, reaching up to 2,100 kilometres (1,305 miles) per hour, and those on Uranus are similarly fierce, but these are the two farthest planets from the Sun, and so receive the least heat to drive weather. In addition, Neptune seems to have some powerful internal energy source that helps power its winds – one idea is that this may come from liquid methane condensing to form diamonds around the planet's core. **GS**

How do viruses and bacteria differ?

Lucas Matthews

Viruses and bacteria can both cause disease, but they are radically different when it comes to their structure, reproduction and just about anything else. Bacteria are made up of just one basic cell possessing DNA, cell walls, ribosomes and cytoplasm. Viruses are tiny in comparison, simply consisting of a strand of genetic information (as DNA or RNA) encased in protein. In this sense, viruses are not considered to be living things. Bacteria reproduce asexually, dividing into two identical cells. Viruses, meanwhile, multiply by infiltrating their host's cells and tricking them into producing copies of the virus. Viral infections are harder to cure since the virus is taken up inside the patient's cells, while bacterial infections can usually be treated with antibiotics. **AC**

Can we create magnetic material artificially?

Pete

There are two easy ways to create a magnet. Firstly, you can make a permanent magnet like the ones you get on your refrigerator by exposing a ferromagnetic material such as iron to an external magnetic field. Inside ferromagnetic materials, atoms stick together in groups called domains. Within each domain, atoms are aligned in the same way, making the domain act just like a tiny bar magnet. In an ordinary chunk of iron, these domains point in different directions, essentially cancelling out each other's effects. But under the influence of a magnetic field, they line up together, forming a permanent magnet. Alternatively, you can make an electromagnet by winding a coil of wire around a core (usually made of iron). When an electric current runs through this wire, it creates a magnetic field around the core, turning it into a magnet. **AC**

Next-gen gaming PC

Raptor GeForce GTX 770

Price: £1,249/$N/A
Get it from: www.dinopc.com

The Raptor GeForce GTX 770 is the latest gaming system from DinoPC. The computer, which comes stacked with high-end hardware as well as Windows 8, is also one of the builder's first to use the cool Fractal Design Node 304 case, which ensures the profile of the system remains compact and stylish despite the many components.

And speaking of components, boy, have the guys at DinoPC managed to fit some serious hardware into the Raptor. An Intel Core i5 4670K CPU comes overclocked to 4.2 gigahertz and liquid cooled. Pixel-pushing duties come courtesy of a monstrous NVIDIA GeForce GTX 770 two-gigabyte GPU, with two eight-gigabyte sticks of Corsair 1,600-megahertz Vengeance RAM. While power is handled by the super-efficient 650-Watt Corsair VS PSU and storage by a 128-gigabyte solid-state disk and a whopping two-terabyte hard disk drive.

The result of all this silicon? Excellent performance across every game we threw at the Raptor and, aside from extreme resolutions above 1080p, every other resolution is stunning. From *Crysis 3*, through to *Defense Of The Ancients* (*DotA*) and *BioShock Infinite*, the Raptor continuously delivered rates above 30 frames per second (the benchmark for smooth gameplay). Indeed, when compared to cross-platform titles on consoles, the Raptor absolutely blew them away in terms of fidelity and smoothness of action.

Of course, all this tech and gaming performance doesn't come cheap, with the Raptor ringing in at just under £1,250. That said, it's hard to criticise DinoPC, with the Raptor's equivalent parts pricing in at not much cheaper individually and the pre-built system coming with a three-year warranty which brings some peace of mind. The fact that its specification smashes the recently announced, much-hyped next generation of consoles also means it's pretty future-proof too.

Verdict:

Cooling
Not only does the Raptor come with the Node 304 case's excellent ventilation, but its overclocked CPU is kept cool by a self-contained, state-of-the-art Corsair water cooler.

Ports galore

There is a serious bonanza of ports on the back of the Raptor, including a brace of HDMIs, multiple DVIs and a selection of USB 3.0 slots – not to forget all the usual candidates as well.

Raw power

The Raptor's videogame-playing power largely comes courtesy of the monstrous NVIDIA GeForce GTX 770 2GB. Simply put, this takes everything – including even *Crysis 3* – in its stride.

Maximum storage

The primary data bank in the Raptor is the ridiculously huge 2TB S-ATAIII hard drive. This drive is great for handling media, leaving the SSD free for the OS and games.

Sleek chassis

It's quite amazing how much powerful hardware is packed into such a small case, but regardless, the Fractal Design Node 304 is clean, well laid out and sits well either on or under a desk.

The statistics...

CPU:
Intel Core i5 4670K (4.2GHz)

GPU:
NVIDIA GeForce GTX 770 2GB

RAM:
16GB Corsair 1,600MHz Vengeance (2 x 8GB)

SSD:
Plextor 128GB M5S SSD S-ATAIII 6.0Gb/s

HDD:
2TB S-ATAIII 6.0Gb/s

Motherboard:
Gigabyte GA-Z87N-WIFI

PSU:
650W Corsair VS

Cooling system:
Corsair H60 2013 water cooler

Case:
Fractal Design Node 304

Operating system:
Windows 8 (64-bit)

BITE-SIZE REVIEWS

Your essential guide to the other awesome stuff we like this month

Razer Atrox

Price: £179.99/$199.99
Get it from: www.razerzone.com

Do you own an Xbox 360? Do you like to play fighting games? And do you have a soft spot for the old-school arcade experience? If you answered yes to all three questions, then you're the perfect person for the Razer Atrox controller. It's expensive, for sure, but the build quality and performance are basically unparalleled, as this is arguably the best fight stick on the market. Both joystick and buttons are sourced from Japanese arcade machine specialist Sanwa Denshi, the system's case is easily accessible – via just one button – and the entire layout of the top panel is 100 per cent customisable, with simple screw mountings for each component.

Verdict:

PURE Jongo A2

Price: £99.99/$149
Get it from: www.pure.com

This is one for any music lovers. Simply plug the Jongo A2 into a speaker/hi-fi system, sync it with any other nearby Wi-Fi or Bluetooth-enabled device – whether it's your mobile phone, tablet or PC – and, hey presto, you can stream and play your music from anywhere around your house. Admittedly, it's a simple concept, yet – despite the average person's music collection today being split over many devices – this hasn't been addressed in such a simple and stylish way as the Jongo. Small, sleek and reliable, this device is a fantastic gift for those who love their tunes.

Verdict:

GROUP TEST

PUTTING PRODUCTS THROUGH THEIR PACES

Multi-tools

As the summer DIY and camping season gets in full swing, HIW puts three multi-tools to the test

Leatherman Style CS

Price: £29.95/$27.60

Get it from: www.leatherman.com

Leatherman is probably the most famous multi-tool maker in the world, so we were looking forward to getting our hands on it. However, it fell a little short of our expectations. On a positive note, the CS is by far the lightest tool on test, at just 43 grams (1.5 ounces). Further, the CS is constructed out of stainless steel and glass-filled nylon, with an open, skeleton frame that made it the narrowest multi-tool we trialled. Of the six tools it offers, the knife is very sharp and the central scissor mechanism fluid too. A simple clip attachment makes snapping it into belt loops or key chains easy.

So what's not to like? Well, secondary tools were too small and insubstantial for our liking, while the frame made holding and using the tool uncomfortable. What's more, with an RRP just shy of £30 you could argue a basic six tools is not good enough – especially when compared with the rivals' offerings.

Verdict:

Gerber Bear Grylls Compact Multi-tool

Price: £29.99/$47.76

Get it from: www.gerber-store.co.uk

Next up is the Gerber Compact Multi-tool, which is part of adventurer Bear Grylls' collection of survival kit. Gerber is not as well known, arguably, as Stanley or Leatherman, but that hasn't stopped it producing a very stylish and well-conceived product.

Offering an impressive ten tools within a gun metal grey, butterfly casing, the Grylls Compact almost doubles the functionality of the Leatherman option for virtually the same price. Key tools in this device include needle nose pliers, a fine-edged knife, a serrated knife, wire cutters, tweezers, a bottle opener along with a good range of screwdrivers.

Unlike the other candidates in this group test, the Gerber is not a skeleton frame; although this makes it heavier than the Style CS, it is far more comfortable to use. Indeed, both ergonomically and aesthetically the Bear Grylls Compact is the clear winner out of this trio.

Verdict:

Stanley 12 Piece Multi-tool

Price: £14.52/$19.60

Get it from: www.amazon.com

Stanley has a good heritage in tool construction and that is evident from the off, with the chunky metal frame encasing a variety of well-made tools. Highlights include long nose pliers at the centre, a robust saw and a good selection of screwdrivers in the internal compartments.

Larger tools are miniaturised, as you'd expect, including a bottle opener, wire cutter and file. Despite their smaller size however, each tool remains well built and performs well, with the Stanley's large gripping handles making operation easy. The open, skeleton-frame styling did mean it was not the most comfortable object to hold over a prolonged period.

For your money Stanley also throws in a nylon, belt-strap holster. For the price this is a decent addition, but its quality overall is fairly average. Combined, the Stanley 12 Piece is a good all-round package, although it fails to excel in any department in our opinion.

Verdict:


DinoPC.com
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■ Gigabyte G1 Assassin 2 Motherboard
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■ Corsair 16GB Vengeance 1866Mhz RAM
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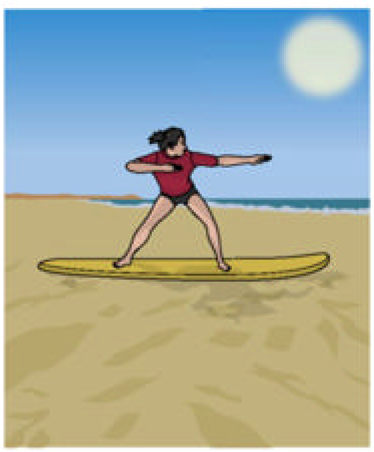
Surf like a pro

If you've always secretly wanted to ride the waves here's a step-by-step guide to finding your feet with a surfboard

1 Learn to stand

It might sound odd, but this is actually best practised on dry land. First, identify which foot you feel most comfortable leading with. Close your eyes and ask a friend to gently push you forward; whichever foot naturally goes out first to steady you is likely to be the best choice. Lie face down on your board and push your body up with your arms, then bring the knee of your leading foot in towards your chest and hop up on your feet.

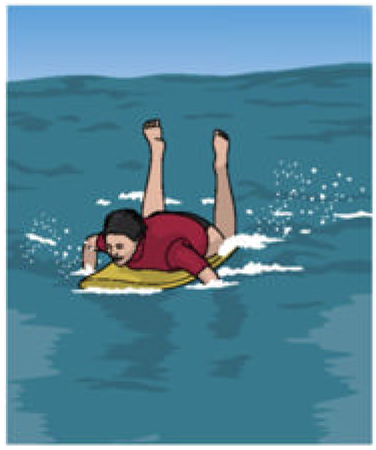


2 Staying upright

As you stand up on the surfboard, the trick is to keep your weight centred and ever so slightly forward. One foot should be positioned near the tail of the surfboard and the other just in front of the midpoint. Stay low by bending your knees and slightly crouched, with your weight focused on the middle of the board, and keep your arms out, using them as a counterweight to provide a bit of balance.

3 Practise paddling

Start off waist deep in small, gentle waves and lie on your stomach on the board. The aim here is to find the best position to minimise resistance, so keep your weight centred at the middle of the board. Using cupped hands and a front-crawl stroke with your arms, pull yourself and your surfboard through the water. If the waves bump you upwards, lift your chest a little to prevent the nose of the board from going under.



4 Catch a wave

Wait with your board pointed out to sea until you spot a good unbroken wave, then turn towards the shore and begin paddling. As the wave hits the board you should feel it lift you up; this is the cue to paddle faster, leaning your weight forward and raising your chest to increase speed. For the first few attempts, remain lying down to get a feel for the waves and how they affect your balance as well as the motion of the surfboard.

5 Standing in the water

Now it's time to bring all the techniques we've looked at together. To start out it's best to pick waves that have just broken in the white water of the sea. Begin paddling until you feel the wave catch the board and then, as the wave begins to move you faster than you can paddle, quickly extend your arms and jump up. Look towards the shore and focus on using your legs, arms and torso together to stay balanced.

In summary…

Surfing is fantastic fun once you have mastered how to stand up on the board. Practise on dry land until you can quickly and comfortably transition from lying on your front to standing. Start out with small, white-water waves and then, as you become more confident, move farther out to larger, unbroken swells.

Learn more

For more on the basics of surfing, including reviews of equipment, the best locations and advice for improving your skills, visit **www.surfscience.com**.

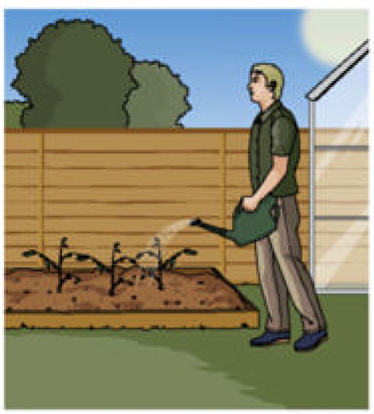
NEXT ISSUE
- Run a marathon
- Make perfect smoothies

Grow tomatoes

Any fruit tastes so much better when picked fresh – read our top tips for tasty tomatoes

1 Choose your plants
For first-time growers it's best to start with small tomato plants; cherry tomatoes are the easiest to grow. Tomatoes need seven hours or more of sunshine a day, so choose a light spot and check the recommended dates for planting in your climate zone. Tomatoes like soil rich in organic matter and are extremely hungry for fertiliser, so enrich the earth with well-rotted compost or use growbags.

2 Get digging
Bury the tomato plants quite deep in the ground, so that between 50 and 75 per cent of the green part is covered, as this will encourage root production. Space them about 45-90 centimetres (18-36 inches) apart, and water them in well. Irrigate daily for the first ten days, keeping the ground moist but not soggy. After this, water two to three times a week – more often if it's particularly dry.



3 Feeding and staking
After about 14 days the plants will benefit from being tied to a support, like a cane, to keep the fruit away from the soil and improve access to sunlight. Place the stake in the ground about five centimetres (two inches) from the plant and loosely tie the stem to it with twine. Plants generally fruit after 60 or so days and the tomatoes will gradually turn from green to red in the Sun.

In summary...
Tomatoes are easy to grow if you have a sunny area and good soil. Keep them well watered and use vegetable fertiliser and well-rotted manure or compost to improve fruiting; steer clear of lawn fertilisers, however, as these encourage leafy growth. If you have trouble with birds eating your crops, pick them early and ripen them on windowsills indoors.

TEST YOUR KNOWLEDGE

ENJOYED THIS ISSUE? WELL, WHY NOT TEST YOUR WELL-FED MIND WITH THIS QUICK QUIZ BASED ON THIS MONTH'S CONTENT?

1 In how many hours was the OUYA games console funded by the public?

2 Which deadly toxin does the castor bean contain?

3 At what speed does solar wind leave the Sun?

4 Which is the fastest rollercoaster in the world?

5 When frozen, by what percentage does water typically expand?

6 Which bird migrates the farthest during winter?

7 In what year were the French musketeers of the Maison du Roi founded?

8 What is the top speed of the Hawk T2 training aircraft?

9 How many tons of gold are estimated to exist on near-Earth asteroid Eros?

10 How fast can the winds on Neptune reach?

ENTER ONLINE

at **www.howitworksdaily.com** and one lucky reader will win a model of the Mikoyan MiG-29A fighter jet, also known as the Fulcrum – good luck!

ISSUE 48 ANSWERS
1. 2016 **2.** Tree resin **3.** 1859 **4.** Water **5.** Men **6.** 2 **7.** B-cell **8.** Limestone **9.** Helicobacter pylori **10.** Megaplankton

INBOX

Feed your mind. Speak your mind

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Get in touch!

We enjoy reading your letters every month. So keep us entertained by sending in your questions and views on what you like or don't like about the mag.

EXCLUSIVE ONE-OFF PRIZE FOR ISSUE 50'S LETTER OF THE MONTH!

WIN TICKETS FOR BRAINIAC LIVE IN LONDON!

Next issue's Letter of the Month will win tickets for you and up to six friends to attend Brainiac Live. Visit www.howitworksdaily.com for the details.

This project by Ben and friends Alex and Schan was presented for 2013's European Schools Science Symposium (ESSS)

Letter of the Month

Ferrofluid fanatics

Dear HIW,
I was delighted to read your section on ferrofluids in issue 45. What a coincidence, it was only a few weeks ago that my friends and I completed a months-long lab project on these fluids at school! We worked in the lab to synthesise our own. We tried varying many factors such as the suspension (various hydrocarbons), basis for the iron particles (redox reactions) and surfactant (oleic acid was the only one non-toxic enough for our mentor to let us work with), and then worked to analyse and measure how each factor affected various properties of spike formation and arrangement. We concluded, in the end, that amateur synthesis of a ferrofluid isn't the way to go, but commercially ordered fluid does make a fantastic desk ornament!

Thanks for an awesome magazine.

Ben Mortishire-Smith

Thanks for the inside information about your findings, Ben – it's brilliant to hear about readers enjoying hands-on science. Whatever way you look at it the sight of ferrofluid is always slightly brain-bending. For your great efforts in the lab, you've won the How It Works Book Of The Human Body as advertised last issue.

While wasps might not be the most popular bugs, they are very impressive animals

Wasps: what's the point?

Hi HIW,
For a few years, since discovering How It Works, my husband and I have been subscribers and read every issue cover-to-cover. Thank you for the variety of topics, great photos and illustrations! When we've read an issue we pass it along to family or friends. Maybe if this topic has been covered in a past issue you can direct me where to look. Otherwise, my question is: what good are wasps? I have a butterfly garden where fritillaries, monarchs, sulphurs, swallowtails and a few other varieties of butterflies benefit by the host and larval plants offered in my yard. Wasps prey on the caterpillars. Sometimes all they do is stun and kill them, leaving the caterpillars to die in agony. Most often, however, they feed on them immediately or fly off with the caterpillars. I might feel comforted by the loss of caterpillar lives if I could believe wasps serve any good. They certainly don't seem to want to eat the pesky mosquitoes abundantly available!

Trying to kill a wasp has its own challenges. They seem to be insects of steel – almost indestructible. We can stomp them underfoot, swat them, grind on them with a stone, but they keep on coming back. It's kind of creepy.

Holly LiBaire (Palm Harbor, FL)

Great letter, Holly, we've not done a huge amount on wasps in the past so we'll put this down as one to research for a future issue. While wasps are clearly a pest from the point of view of a butterfly enthusiast, there are many who believe they are a valuable and necessary part of the garden ecosystem, in terms of pollination and pest control. Interestingly they also mean that we can have figs as wasps are the only insects capable of pollinating this fruit, which is essentially an inside-out flower. Fig wasps burrow inside the fruit where they get covered in pollen to distribute outside the flower/fruit.

Grapes on the brain...

Hi HIW,
In answer to Abraham's point in issue 48, I would say – according to science – that the idea of a universe being created in the space at the centre of another universe is

If there was a contest, we'd vote Earth as the best planet every time!

impossible, as the universe (as far as we know it) is infinite in extent. Therefore, there would be no more room for another infinite space within another infinite space. However, I believe that the idea of an infinite universe is rubbish; you can't have four grapes in a bowl and take out five grapes from that bowl without adding more grapes. (Sorry, for some reason, I had grapes on the brain…). This is the universe if it is infinite.
Jordan Godley, 13

Anyone else have an opinion on this one? Get in touch and share your thoughts with Jordan and Abraham.

Worth the wait

Hi HIW,
When I purchased How It Works issue 45 it stated at the back that issue 46 would be all about the 'Incredible Story of Earth' looking back over 4.6 billion years of natural history, but when I went to purchase it this article was nowhere to be seen. As I'm a keen fossil hunter and enjoy studying and reading about Earth sciences I was really disappointed that the article didn't feature. Then when I picked up issue 47 I saw that the article was there. I purchased the new issue and really enjoyed reading the Earth feature. The article at the end about how fossils are formed was really interesting too, so it's been well worth waiting for. Also I was wondering if there's any chance on having a piece about the Jurassic Coast.
Richard Tuson

Hi Richard. We're sorry for the delay in printing the Earth feature, but we're delighted to hear you enjoyed reading it and that it was worth waiting for. We put a great deal of care and thought into planning, writing and designing it to excite people about the true wonder of our planet's amazing natural history. While every effort is made to ensure features detailed on the Next Month page do appear in the following issue, now and then circumstances outside our control mean the articles we hope to print get pushed back or cancelled. Keep enjoying the magazine!

"You can't have four grapes in a bowl and take out five grapes without adding more grapes"

What's happening on… Twitter?

We love to hear from **How It Works'** dedicated readers and followers, with all of your queries about the magazine and the world of science, plus any topics you would like to see explained. Here we select a few of the tweets that caught our eye over the last month.

Matt Strudwick @Matt_Str27
There's nothing like ending my day with a cup of tea whilst reading **@HowItWorksmag**. I will never look at a hippo the same way again

Myers Heir @Beeza68
@HowItWorksmag has arrived. "Brain. Prepare for education!" #simplybrilliant

just a kid @cloud_iaaa
I'm a bit too addicted to **@HowItWorksmag**. Whenever my dad buys it, I will not put it down until I read it all. Twice

Lee @Lee_1609
@HowItWorksmag thoroughly enjoyed reading about the forces acting on a plane in the Annual 3. Would really appreciate a digital copy of the page?

Wadih Merhy @wadihmerhy
@StBonifaces @geographybeales Pick up a copy of **@HowItWorksmag** would be great for geography project ideas!

Sabeen Yameen @xApriLis_AnGeLx
@HowItWorksmag
This looks great fun :-)

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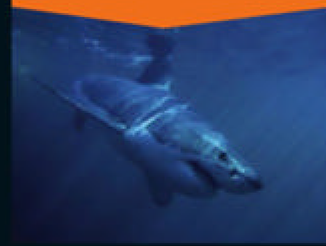
ANSWERED NEXT ISSUE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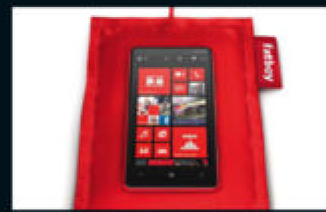
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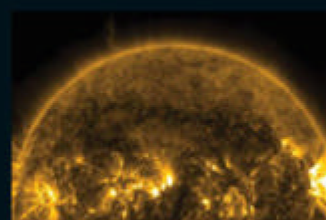
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