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# MAN IN SPACE


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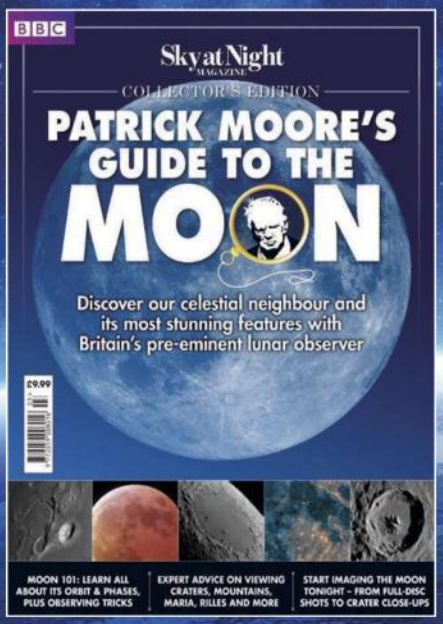


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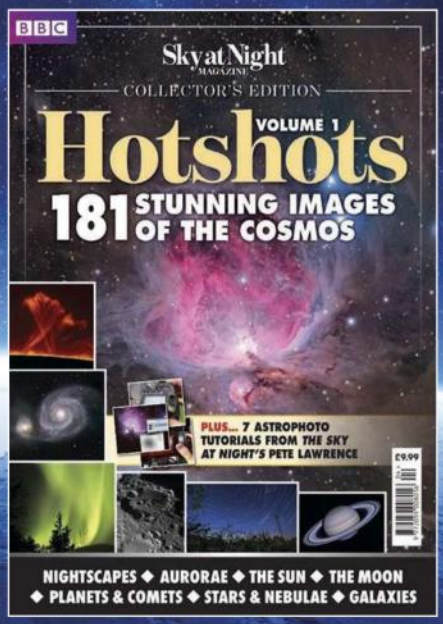


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NASA astronaut Tracy Caldwell Dyson admires Earth from the 360° window of the ISS's Cupola – the ultimate room with a view

# INTRODUCTION

**NOT LONG AGO** I attended a talk by Chris Hadfield, the first Canadian spacewalker, commander of ISS expedition 35 and bona-fide social media sensation – the man who conquered the internet from space by tweeting about it on a near daily basis.

Hadfield's story is of ambition and success, but not one, he explained, that was born on a whim. There were two experiences that led him to pursue this career. One was a childhood spent watching Captain Kirk's escapades in *Star Trek*, which availed him of the belief that space is cool. The other, the moment he watched Neil Armstrong and Buzz Aldrin set foot on the Moon in July 1969, when he realised that space exploration was not confined to the imaginings of science-fiction writers. It was a real endeavour, and real people were doing it. 'Why couldn't I be one of them?' he asked himself.

Like all modern-day astronauts, Hadfield owes a lot to the men and women who came before, and it's their stories that launch this *BBC Sky at Night Magazine* special edition celebrating humankind's journey into orbit and beyond, from the pioneering rocket engineers who made it possible for us to escape Earth's gravity to the men and women who boldly went into the unknown – some time and time again, some never to return.

Yuri Gagarin became the first man in space on 12 April 1961. His flight was brief, a single orbit of Earth lasting 108 minutes from launch to landing. No-one really knew how the trip would affect Gagarin physically, whether he had anything to fear from cosmic rays, or even if the Vostok 1 spacecraft would withstand the journey. It was, of course, a complete success, and a new era was born.

The early post-Gagarin years were experimental, but then came the Space Race, the product of the great rivalry between the US and the Soviet Union, each bitterly determined to be first to land a man on the Moon. Apollo 11 won the race for the US, and Russia turned its attention to unmanned probes. Next came the space labs, Salyut and Skylab, followed by the first space station, Mir, all of which paved the way for our present orbital outpost, the International Space Station. Now we're on the cusp of an exciting future, one in which more nations are planning manned missions and the private sector is developing bold new ideas.

We're still waiting for some of the dreams of the 1960s to materialise; there's still work to be done before Moon colonies, trips to Mars, widespread space tourism are considered the norm. What *Man in Space* avails to you, I hope, is that our progress so far really is a magnificent achievement in itself.

**Kev Lochun**
Managing Editor

NASA

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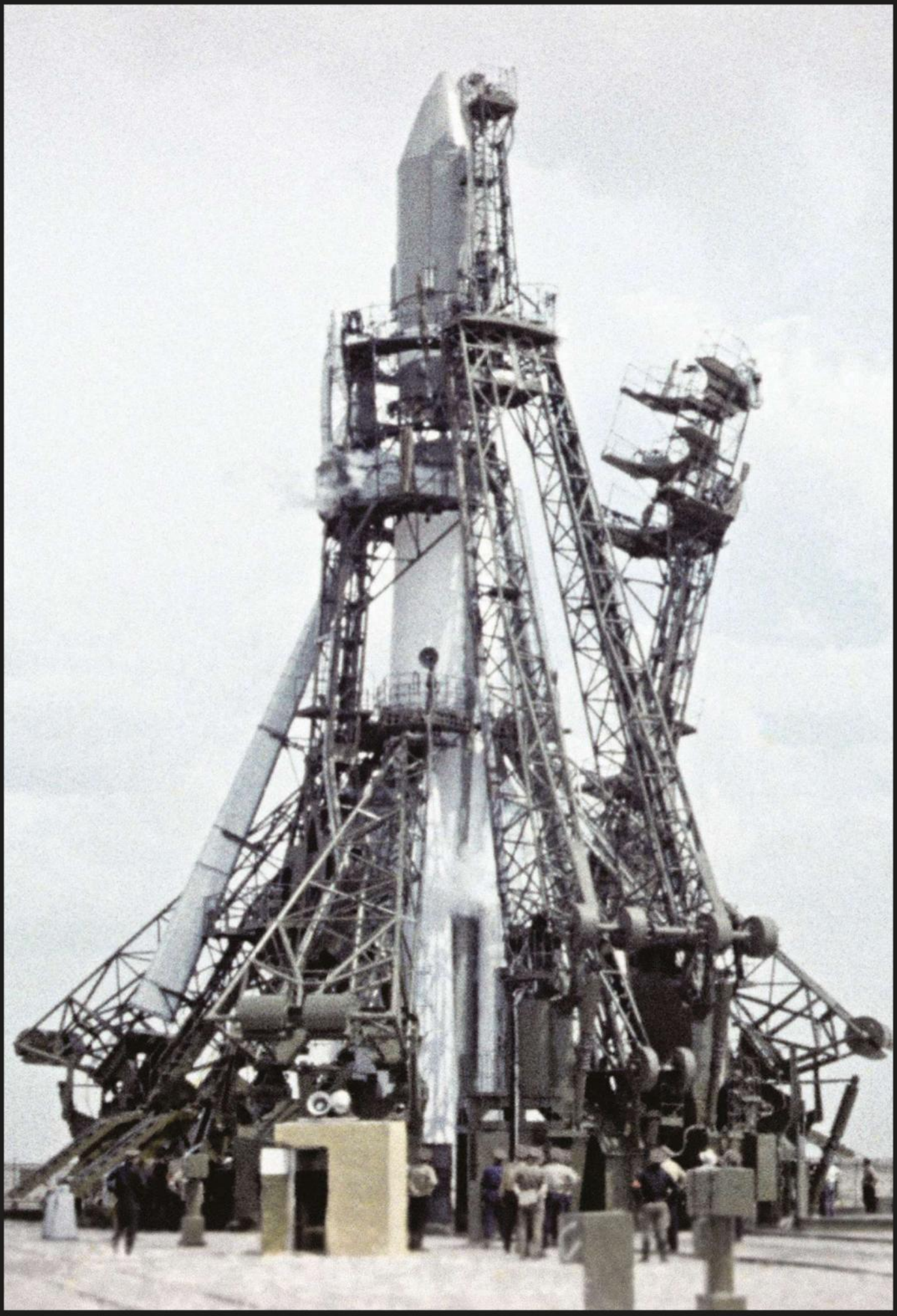
On his Shuttle mission in 1984, Bruce McCandless II ventured further from his spacecraft than any astronaut before him, thanks to a 'jetpack' called the Manned Manoeuvring Unit



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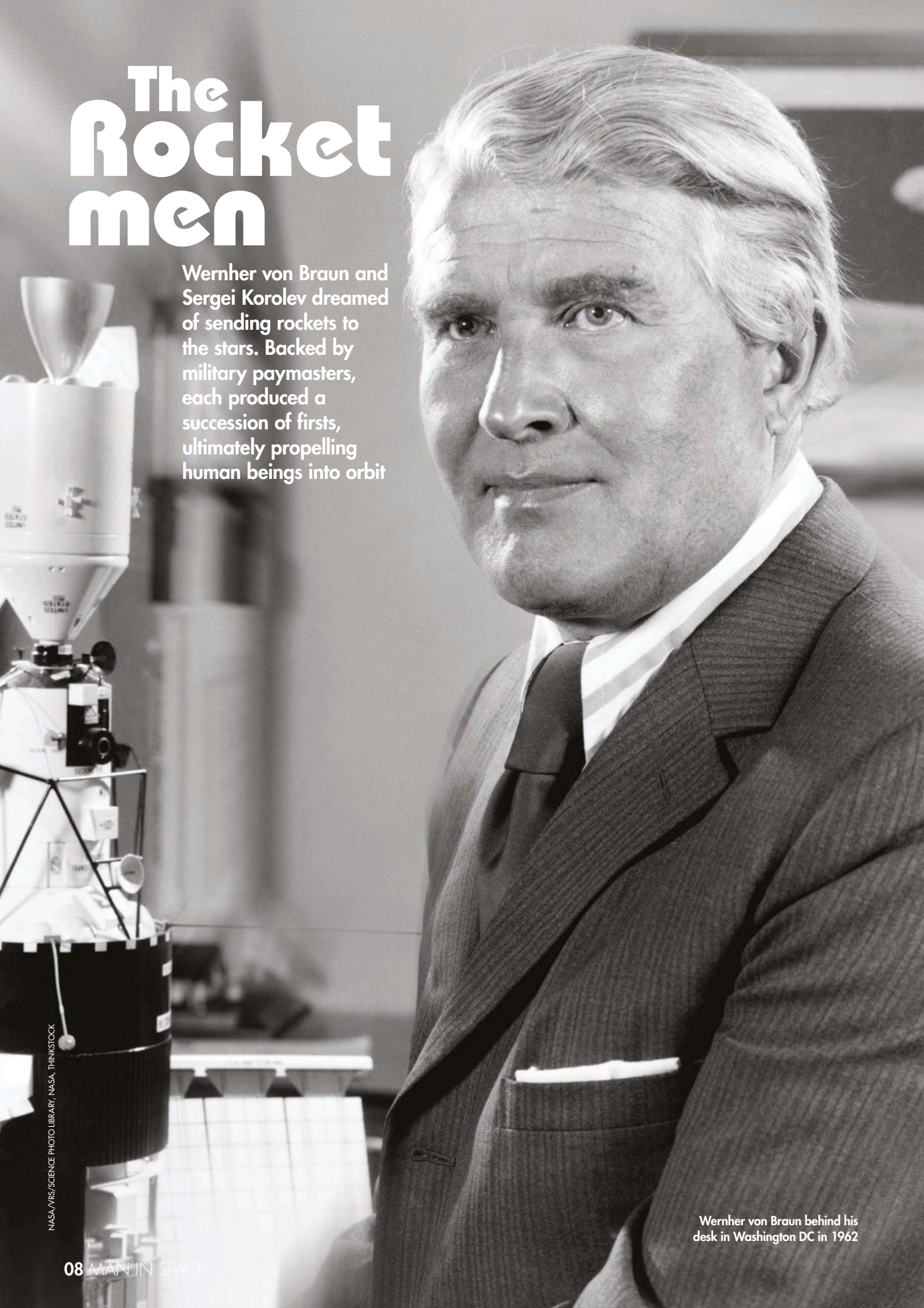
◀ Engineers at the Baikonur launch site in Kazakhstan prepare the Vostok 1 spacecraft for launch

# FIRST STEPS

**THE LAUNCH OF** Hitler's devastating V-2 missiles in World War II and Yuri Gagarin's spaceflight were separated by just 17 years. In the intervening period, both the US and Soviet Union raced to adapt German technology to produce ballistic missiles capable of striking the other's shores. But these missiles were also proved powerful enough to carry satellites, and men, into space

# The Rocket men

**Wernher von Braun and Sergei Korolev dreamed of sending rockets to the stars. Backed by military paymasters, each produced a succession of firsts, ultimately propelling human beings into orbit**



Wernher von Braun behind his desk in Washington DC in 1962

NASA/VRS/SCIENCE PHOTO LIBRARY, NASA, THINKSTOCK

# Wernher von Braun

## The German rocket scientist developed the V-2 missile in World War II before spearheading the US Moon shot

**WERNHER VON BRAUN** was a pivotal, if controversial, figure in the Space Race. Born to an aristocratic family in the Prussian town of Wirsitz (now in Poland) in 1912, he was inspired in his teens by the work of German physicist Hermann Oberth, and became a rocket scientist.

Earning his doctorate in rocket combustion in 1934, the year after Hitler came to power in his homeland he joined the Nazi party and became technical director of the German rocket programme, based in the Baltic village of Peenemünde. By 1942 he had successfully developed the infamous V-2 rocket that was to wreak such havoc on London during the Blitz. Equally notorious was the programme's extensive use of slave labour – an uncomfortable legacy that would stay with von Braun for the rest of his life.

Far from being tried as war criminals, however, von Braun and his team were secretly whisked away to the US after the war, as part of Project Paperclip to recruit German scientists for the American rocket programme. Their arrival was kept secret for over a year from the public – newsreel footage of the Holocaust was still fresh in the minds of Americans.

The scientists saw defecting to the US as their best option for continuing their work. Germany was in ruins, the UK's rocket programme was in its infancy and the whole team feared its fate at the hands of the Russians. After demonstrating the V-2 rocket to the US army, von Braun became technical director of the Guided Missile Development Group at Redstone Arsenal, Alabama, in 1950.

The public perception of von Braun was to change with a somewhat surreal offer from Walt Disney in 1954. Keen to promote his new Disneyland theme park to the parents of America's baby boomer generation, Walt turned to the charming, photogenic von Braun to host *Man in Space* – TV infomercials to promote the park's fantasy theme. He became a space evangelist, preaching to an awestruck audience of 42 million viewers.

Von Braun and Walt Disney (left) teamed up for shows on US TV

In 1960, von Braun became the first director of NASA's Marshall Space Center and found himself centre stage in the Space Race. He never met his rival in this Cold War face-off, Sergei Korolev, and it was no coincidence that with Korolev's death in 1966, the Soviet challenge effectively evaporated. Von Braun's rockets were at the heart of the Mercury, Gemini and Apollo space programmes, not least the Saturn boosters that propelled man to a first Moon landing in 1969. Indeed, had von Braun not insisted on additional tests for safety, Alan Shepard's Freedom 7 would have beaten Yuri Gagarin's Vostok 1 into space by three weeks in 1961.

America's enthusiasm for the space programme cooled after the Moon landing, and von Braun died a frustrated man in 1977, still dreaming of missions to Mars. Had he lived, worse would have followed, as documents about his Nazi past were declassified in 1984. His life remains highly controversial but his mind was unquestionably brilliant.

**OVER THE PAGE: SERGEI KOROLEV ▶**

## TIMELINE Wernher von Braun 1912-1977

**1912** Born 23 March in Wirsitz, Prussia (now Poland)

**1925** Inspired by Hermann Oberth to pursue rocketry and spaceflight

**1930** Attends Berlin Technical University

**1934** Graduates from University

**1937** Becomes technical director of rocket research facility at Peenemünde; develops liquid-fuelled rockets for military

**1937** Joins the Nazi party

**1940** Joins the SS

**1943** Slave labour introduced at Peenemünde to produce V-2

**1944** Arrested by Gestapo as a 'communist sympathiser'; released on Hitler's orders

**1945** Surrendered to American forces and secreted to the US to develop US rocket

**1947** Returns briefly to Germany to marry his cousin, Maria Luise von Quistorp

**1950** Begins developing Redstone rocket, later used in manned Mercury spaceflights

**1955** Becomes a US citizen

**1955** Presents *Man in Space* on US television to promote new Disneyland

**1958** Launches the West's first satellite, Explorer 1, with modified Redstone rocket

**1960** Becomes director of the Marshall Space Flight Center

**1960-69** Develops Saturn rocket for Apollo programme

**1969** Expresses optimism that Saturn V could be developed for a Mars mission

**1970** Appointed NASA's Deputy Associate Administrator for Planning

**1972** Retires as funding cuts bite

**1973** Diagnosed with kidney cancer

**1975** Sets up and becomes president of National Space Institute

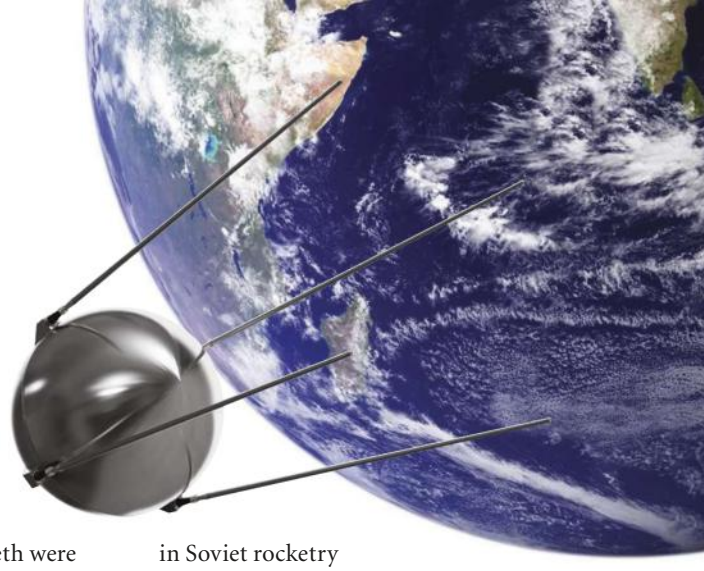
**1977** Dies 16 June of pancreatic cancer, aged 65

Sergei Korolev with one of the many dogs used to test whether animals could survive in space

R.I.A. NOVOSTI/SCIENCE PHOTO LIBRARY, THINKSTOCK, NASA

# Sergei Korolev

## A victim of Stalinist terror, Korolev recovered to win the race into space for the Soviet Union



**SERGEI KOROLEV (OR KOROLYOV)** had a chequered career by any standards. He was both persecuted and highly prized by his own government but, despite his achievements, couldn't enjoy wider acclaim in his lifetime due to the USSR's secretive nature.

He was born in a village in Imperial Russia, the child of an unhappy marriage; his parents soon separated, and the boy was told that his father, Pavel Korolev, had died – actually he lived until 1929, but had no further contact with his son.

His mother Maria married again, much more happily, and the family moved to Odessa, where Sergei studied carpentry at the Building Trades School. His imagination soared higher, though. He joined the Society of Aviation and Aerial Navigation of Ukraine and the Crimea, where he obtained his pilot's licence. His passion well and truly ignited by flying, he founded GIRD with Friedrikh Tsander and others. GIRD was the first serious society to investigate jet propulsion in what had become the USSR. He became the group's chief designer, but the worst period of his life lay ahead.

Without warning he was arrested by the secret police, accused of subversion and thrown into one of Stalin's gulags, or forced labour camps, in Siberia. He was beaten and tortured, all his teeth were knocked out, his knee was badly damaged and his heart was affected. Somehow he survived, and when he was moved to a less brutal camp in Russia proper he was even allowed to carry out research. He was eventually released in 1944. His conviction was overturned, though he did not receive a full pardon until years later.

Once free, his career advanced rapidly. He became the chief figure in Soviet rocketry and he masterminded the first Earth satellite (Sputnik 1), whose radio transmissions from orbit shocked America. He masterminded successful unmanned lunar probes and demonstrated that animals could survive the rigours of spaceflight by sending dogs into suborbital space and then into orbit around Earth.

Rocket testing by Korolev (left) and members of GIRD

After the triumphant spaceflights of Yuri Gagarin and other early cosmonauts, he switched focus to the Moon but his life was cut short. From 1961 his health deteriorated quickly, his body battered from his time in Stalin's death camps and his heavy workload.

In the first days of 1966 he died in hospital in Moscow – either from cancer or a bungled operation. Without him, the Russian space programme floundered, and all immediate plans for reaching the Moon had to be given up. Had Korolev lived longer, the story might have been very different.

He was twice married, and was survived by his daughter Natasha and second wife, Nina. During his lifetime he was not widely known outside his own country but received many honours, including the Order of Lenin from the Russian Academy of Sciences. His name lives on – it's been given to a crater on Mars, a crater on the far side of the Moon, and an asteroid.

## TIMELINE Sergei Korolev 1907-1966

**1907** Born 12 January in Zhytomyr, Ukraine

**1917** Moves to Odessa and begins study at Building Trades School

**1923** Joins Society of Aviation in Odessa and starts flying

**1924** Designs his first glider

**1930** Obtains his pilot's licence

**1931** With F Tsander and others, he forms the Jet Propulsion Research Group (GIRD)

**1933** GIRD merges with another lab to become the Jet Propulsion Research Institute (RNII)

**1934** Publishes his book *Rocket Flight in the Stratosphere*

**1935** Appointed chief of the RNII

**1938** Arrested by the Soviet police, and sent to a gulag (prison camp)

**1942** Moved to a 'sharashka' (prison camp for intellectuals)

**1944** Released from prison; previous convictions dismissed

**1945** Awarded the Badge of Honour, and sent to Germany to study rocketry

**1947** Appointed Chief Designer of the Soviet rocket programme

**1952** Joins the Communist Party

**1953** Proposes a plan for launching an Earth satellite

**1957** First flight test of new R-7 rocket on 15 May – it crashes but flies successfully later that year

**1957** Organises the launch of the first satellite Sputnik 1 on 4 October

**1957** Sends the first animal (the dog Laika) into space on 3 November

**1959** Organises the unmanned Luna 1 probe to the Moon

**1959** Begins the development of N1, an ill-fated rocket designed to fly men to the Moon

**1961** Yuri Gagarin makes the first orbital flight on 12 April

**1965** The first spacewalk, by Alexei Leonov, on 18 March

**1966** Dies on 14 January in Moscow

# Early days

## The Soviet rocket programme flourished in the late 1950s, setting the stage for Gagarin's epic flight

WORDS: PIERS BIZONY

**SERGEI KOROLEV'S GREATEST** creation was the dual-purpose R-7 missile, or Semyorka ('Little Seven') as it was affectionately known by the men who built it. Fuelled with liquid oxygen and kerosene, and incorporating four drop-away boosters parallel to a central core, it was the world's first intercontinental ballistic missile. The development of rockets for space was, at that time, a by-product of creating the instruments of warfare.

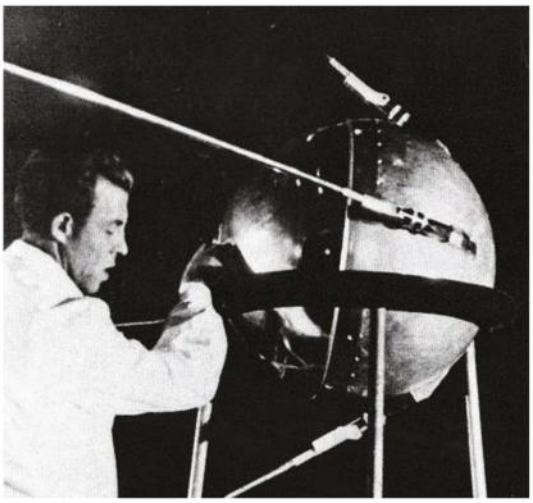
The lower stages, or 'blocks', of the vehicle were fitted with engines designed by Valentin Glushko. His compact turbine fuel pumps and clever pipework serviced four combustion chambers simultaneously. The apparent thrust of 20 separate engines on the R-7 was, in fact, delivered by just five, each of which had four nozzles. This rugged and reliable rocket was the basis for the Soyuz boosters that still carry modern Russian capsules to the International Space Station today.

The first two launches of the R-7 failed, but in August 1957 it flew a simulated nuclear strike mission over Soviet territory and, just weeks later, began its career as a space rocket. On 4 October that year it launched Sputnik, the world's first artificial satellite. Sputnik II went up on 3 November carrying the dog Laika – a living, breathing creature. From that day forwards, the launch of humans into space became much more plausible, at least in principle.

These early successes were the result of Korolev's cunning, explains space historian Andy Aldrin, the son of Apollo 11 astronaut Buzz. "The people who were running the missile programmes owed their careers to him, so they were reluctant to take him on. Many of them didn't really understand rocket technology, and they had to trust him."

Despite Korolev's sheer power of personality, there were dangerous rivals for the top slot in the Soviet space industry. Valentin Glushko, Russia's best designer of rocket engines, operated out of his own specialist bureau. As long as his power

▲ **On board Sputnik 2, the dog Laika waits obediently shortly before becoming the first living being to reach orbit**



◀ **A technician puts the finishing touches to Sputnik 1 – the world's first satellite and a wake-up call to the United States**

NASA/PETER GORIN, NASA X 3, NASA/ASIF SIDDIQI, RIA NOVOSTI/SCIENCE PHOTO LIBRARY


◀ A Mercury-Redstone rocket launches from Florida carrying a chimpanzee called Ham on 31 January 1961

plants were fitted into Korolev's boosters, the two men avoided confrontation, though in private they loathed each other. Mikhail Yangel was another rival, developing alternative missile systems from his bureau in the Ukraine, while the fourth major figure in Soviet rocketry, Vladimir Chelomei, was responsible for the Proton – an even larger and more powerful rocket than the R-7.

Yangel's R-16 missile did eventually go into service, but not before causing Russia's greatest rocket disaster. On 24 October 1960, as the R-16 was being prepared for its first flight, a premature signal caused the upper stage to fire, burning a hole in the top of the lower stage. A gigantic explosion killed everyone on the gantry instantly, while staff on the ground were swamped with viscous burning fuel, their feet stuck in melted tar as they tried to escape.

More than 100 people were killed, including Marshal Mitrofan Nedelin, the man in charge, perched on his chair near the gantry as a surge of blazing chemicals swept towards him. Although it had little immediate impact on Korolev's own team, many of those killed were young technicians, depleting design bureaus involved in the space effort.

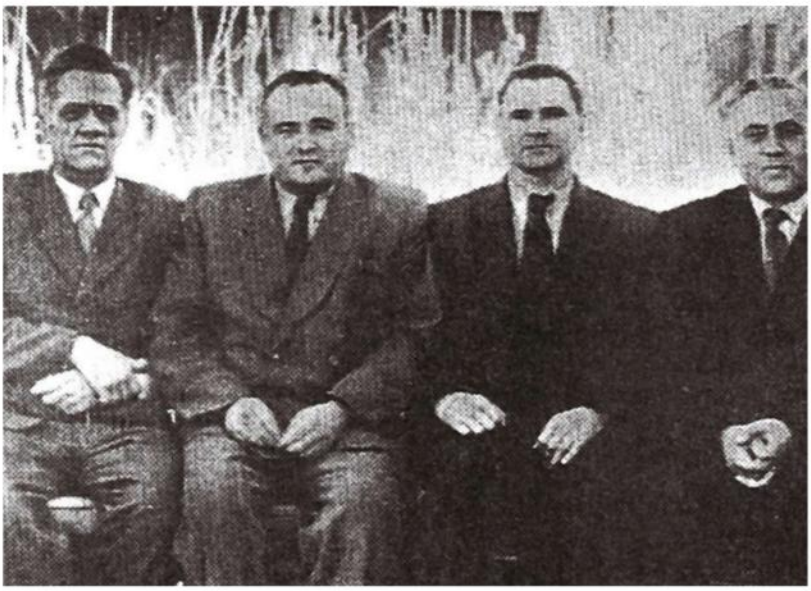
## Eyes down

Sergei Korolev's power, meanwhile, had been consolidated by the triumph of Sputnik in 1957, and he was urged by the Kremlin to create yet more space spectaculars with the R-7. He had to avoid clashes with military chiefs who insisted that the R-7 should be devoted to defence. Korolev tempted them with the idea of spy satellites that could reveal America's secrets from orbit. But first, he said, Russia should launch human pilots with excellent eyesight, to report on what spy cameras might see.

The Kremlin swallowed Korolev's trick but its support for his orbital adventures came at a price, putting great strain on his health. He was pushed to work faster and come up with new triumphs.

America, though, had been spurred into action by Sputnik. NASA was formally created in 1958 and inherited ideas for human spaceflight from its smaller, precursor organisations. The most fully realised project was Mercury. It comprised a tiny, cone-shaped capsule that would ride on the top of Redstone – a small battlefield missile. Redstone was closely based on Wernher von Braun's notorious V-2 rocket from the Second World War.

Many in America doubted the usefulness of adventure for adventure's sake, but in April 1959, NASA announced the selection of seven Mercury astronauts. Unfortunately for them, Korolev was ready with his Vostok spacecraft, and Yuri Gagarin beat Alan Shepard into space by just three weeks.



▼ Korolev (second left) and Glushko (third left) were uneasy partners in the Soviet space effort

## Animal pioneers

A dog called Laika became the first living creature launched into orbit on 3 November 1957, but she wasn't the first canine to be launched on a rocket. Throughout the early 1950s, the Soviet Union had launched pairs of dogs on suborbital flights to see if they could survive the trip – most did.

Laika died in space but two other dogs, Belka and Strelka, later survived. The pair returned to Earth on 19 August 1960, along with assorted rats, mice and other animals in the same capsule.

In America, NASA was testing its Mercury capsule with chimpanzees that were trained to perform tasks in space. The first simian explorer, Ham, was launched 31 January 1961. The rocket used too much fuel, sending the capsule too high and subjecting him to enormous g-forces. The problems persuaded Wernher von Braun to launch more test flights, in the process losing the US the race to space. Ham lived to the ripe old age of 26.

▲ Laika is prepared for her flight in November 1957; she died after just a few hours in orbit

▲ Ham takes his place in the Mercury biopack couch in readiness for his suborbital test flight

▲ Yuri Gagarin and Gherman Titov, in their flight suits and helmets, heading by bus to the Vostok 1 launch site on 12 April 1961

# First man in space

## The life and times of Yuri Gagarin – the first human being ever to travel beyond Earth's atmosphere

WORDS: PIERS BIZONY

RIA NOVOSTI/SCIENCE PHOTO LIBRARY, GETTY X 2

**YURI ALEKSEYEVICH GAGARIN** was born on 9 March 1934 in the village of Klushino, 160km to the west of Moscow. His father, Alexei Ivanovich, and his mother, Anna Timofeyevna, lived and worked on a collective farm – he as a storesman, she with the dairy herd. Two of his siblings were older: brother Valentin by 10 years and sister Zoya by seven. A younger brother, Boris, was born in 1936. The family seems to have been a happy one, despite the harsh conditions of Stalin's regime and the occasional, frightening disappearances of friends and neighbours.

▲ **Gagarin (far right) pictured with his parents, brothers Valentin and Boris and sister Zoya in a family snapshot**

The Soviet description of the Gagarins as 'peasants', however, was a Kremlin propaganda myth. Anna Timofeyevna's father was a senior oil-drilling manager and she was well educated, while Alexei was a skilled craftsman. At his side, little Yuri learned many practical skills. But everything changed in the summer of 1941, when German troops invaded Russia. A brief summer of Nazi success was followed by a long, miserable period of occupation, with appalling casualties on both sides.

German columns eventually arrived in Klushino, with Russian troops counter-attacking. Yuri and his brothers witnessed horrifying events as grim battles unfolded. The Germans dug down in Klushino for the winter, forcing the Gagarins into a crude shelter while their home was overrun. At one stage, Yuri tried to exact retribution – he sabotaged the batteries in German tanks by pouring mud into their water-filler pipes. In 1943, Valentin and Zoya were abducted by SS guards and herded onto a 'children's train' for deportation to Germany as slave labourers. Yuri wouldn't see them again until after the War.

▼ **Yuri, wife Valya and elder daughter Lena enjoy the beach in June 1960**

One wartime memory was more pleasant: the sight of aircraft flying overhead, or landing in nearby fields for repairs. As normality returned, the Gagarins moved to nearby Gzhatsk, where Yuri went to school. One of the schoolteachers, Lev Bespavlov, had been a gunner in the Red Army Air Force, and Yuri found him an inspirational figure.

In 1950, Yuri became an apprentice at the Lyubertsy Steel Plant in Moscow and was soon transferred to a technical college in Saratov, a port on the Volga river. At weekends, he volunteered for part-time training as the Soviet equivalent of an air cadet. His first flight, in an old stringed biplane, changed his life. By late 1955, he was making solo trips in a slightly more modern Yak-18. At this point, he was recommended to the Military Pilot's School at Orenburg, on the Ural river.

## Going solo

He made his first solo jet sortie in a MiG-15 on 26 March 1957. The only other thing on his mind was Valentina 'Valya' Goryacheva, a pretty, shy medical technician. In October that year, Yuri and Valya were planning their marriage and so paid little attention to the big national news: Russia's launch of Sputnik, the first artificial satellite. ►

▲ **Gagarin was always drawn to aircraft – here he is in the cockpit at a training school, circa 1955**

► Lieutenant Gagarin graduated from Orenburg on 6 November 1957. He was posted, with Valya, to the Luostari airbase on the northern tip of Murmansk, 300km above the Arctic Circle, from where he flew a MiG-15 on reconnaissance. Flying conditions at Luostari were dreadful, and Gagarin's friend Yuri Dergunov was killed in his first month. Valya found it a terrible hinterland of sub-zero temperatures, biting winds and long dark nights. It was here, on 10 April 1959, that she gave birth to the couple's first daughter, Lena.

In October 1959, mysterious recruiting teams arrived without warning at all major airbases in the Soviet Union, including Luostari. They didn't say exactly what they wanted, but Gagarin was glad of the distraction. He signed up for a trip to Moscow, where he would be assessed to fly a secret new craft. He and Valya decided that whatever was on offer had to be better than Luostari.

The mystery assignment turned out to be the first cosmonaut squad. By the end of 1960, Gagarin was one of two top contenders to make the first flight into space, aboard a craft called Vostok ('East'). His competitor was Gherman Titov, but the Kremlin decided that they liked Gagarin's 'peasant' origins better than Titov's more obviously middle class background, so Gagarin was given the mission. On 12 April 1961, he rocketed into history as the first man in space (see 'First flight', opposite).

## Later career

On returning to Earth, Gagarin toured the world relentlessly, as Russia made the most of the propaganda coup. Valya found these trips difficult, especially when drink and women claimed her husband's frustrated energies. He was desperate to fly again, but was considered too valuable an asset to risk on any more missions. But when Soviet premier Khrushchev was deposed from power in 1964, Leonid Brezhnev took over at the Kremlin and Gagarin was allowed to go back to work.

In January 1966, Gagarin and his close friend, fellow cosmonaut Alexei Leonov, visited their boss, Sergei Korolev, at his home. The 'Chief Designer' was clearly tired and ill. After downing a few vodkas, the young cosmonauts listened as Korolev told them about his early career, his wrongful arrest and the appalling time he'd spent in the gulag. Gagarin came away from that evening deeply

▼ **Gagarin toured the world after his spaceflight. A former foundry worker, he gave a speech to workers at the Leningrad Steel Plant on 6 September 1962**

RIA NOVOSTI/SCIENCE PHOTO LIBRARY X 2, GETTY, WWW.VIDEOCOSMOS.COM, THINKSTOCK

▲ Later in his career, Gagarin helped out on the new Soyuz spacecraft, seen here at Baikonur Cosmodrome in the 1960s

thoughtful and angry. Korolev passed away in hospital a few days later.

Gagarin was then assigned to lead a team of engineers troubleshooting the new Soyuz spacecraft, which had been designed by Korolev but was now being completed by engineers with lesser skills. He found the craft was riddled with manufacturing errors, but the KGB prevented news of these problems from reaching Brezhnev in the Kremlin. Brezhnev expected Soyuz to make its debut flight in time for May Day 1967, the 50th Anniversary of the 1917 Bolshevik Revolution, and no-one dared disappoint him.

The Soyuz-1 launch went ahead on 23 April with Vladimir Komarov aboard. Multiple systems failures occurred, and when Komarov re-entered Earth's atmosphere the next day, the parachute system failed. He was killed instantly when his craft hit the ground like a meteorite.

## Final days

Infuriated, but still desperate to get back into space, Gagarin decided to freshen up his piloting reflexes. On 27 March 1968, he took off from the Chkalovsky airbase in a two-seater MiG-15UTI jet, with training supervisor Vladimir Serugin occupying the other seat. In poor weather and low visibility, their jet crashed into woodland about 100km northeast of Moscow. Both men were killed. Alexei Leonov spent months afterwards trying to piece together the facts. Inattentive ground controllers had apparently allowed another jet to fly too close, probably a powerful new twin-engined Sukhoi fighter. Caught in its slipstream, Gagarin's MiG went out of control.

Gagarin died young, but he will never be forgotten. No-one can take away from him his charm as an international ambassador, his loyalty to his friends and his love of his wife and family, despite the temptations of superstardom. Above all, he was, and forever will be, the first man in space.

▼ Immortalised on this Russian two ruble coin, Gagarin remains a global icon


# First flight

Vostok consisted of a ball-shaped crew module and a rear equipment module with life support tanks, batteries, radiators and braking rockets. The launch vehicle was Sergei Korolev's R-7 rocket. Two hours before take-off, Gagarin ascended to the top of the gantry at Baikonur and climbed into Vostok through a round hatchway. Technicians then sealed the hatch with explosive bolts; if anything went wrong, these could be blown, allowing a rocket-propelled ejection seat to blast Gagarin to safety.

The rocket was ignited at 9.07am Moscow time. Gagarin shouted, "Poyekhali!" ["Let's go!"], and nine minutes later, he was in orbit. "Weightlessness has begun. It's not at all unpleasant, and I'm feeling fine. I'm carrying out observations of the Earth… I can almost see everything. It's beautiful!"

After orbiting Earth once, small rockets on the equipment module braked Vostok for re-entry. Then, four metal straps were blown by explosive charges, releasing the ball. An ocean splashdown was avoided in case US ships might be nearby. The ball came down within Soviet territory. However, the shock of its heavy landing would be too severe for Gagarin to withstand, so he ejected at a safe altitude and came down under his own parachute.

Most accounts state that Gagarin's descent to Earth went smoothly, but his subsequent report hints at difficulties. "The braking rockets functioned automatically. The turning I was worried about soon stopped." An umbilical cable with a dense bundle of wires had failed to release. For several minutes, ball and equipment module hurtled towards the Earth like a pair of boots with tangled laces. In secret evidence to space officials, Gagarin said, "The craft began to spin rapidly. I waited for the separation but something was wrong."

Friction from Earth's atmosphere eventually burned through the umbilical, but the effect was to sling the ball away with an additional, sickening spin. Gagarin nearly fainted, but the ball settled down when its parachute opened. Gagarin ejected safely and landed near a village called Smelkovka, just a short distance across the Volga river from where he'd first flown a Yak-18 aircraft at Saratov.

Gagarin recalled encountering, on landing, a Russian farm worker and her daughter, who asked him, "Have you come from outer space?"

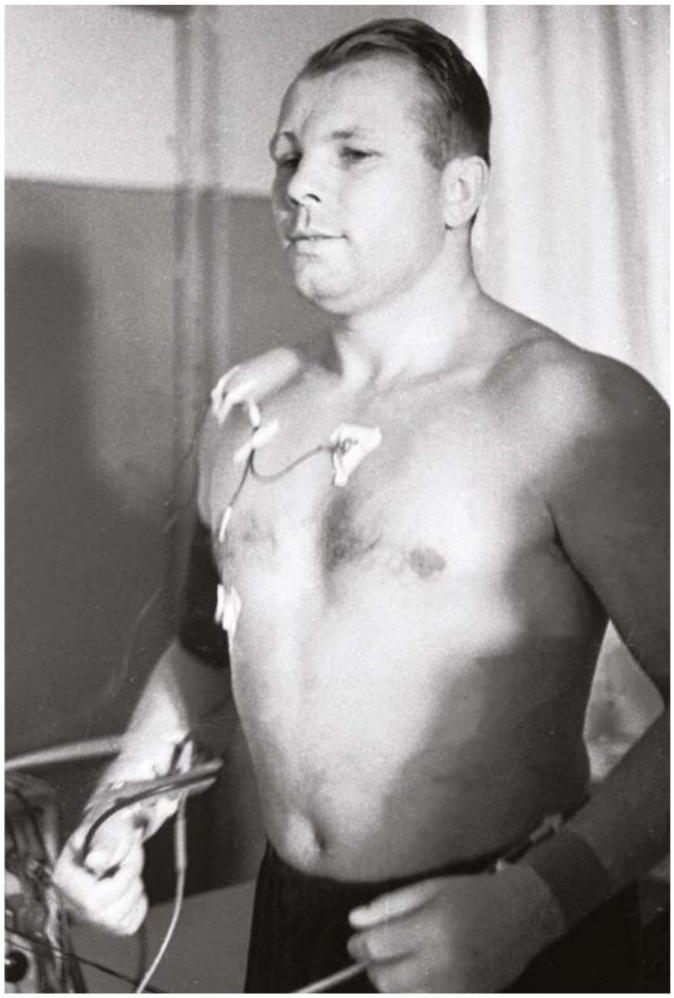
He replied: "As a matter of fact, I have!"

▲ The scorched Vostok 1 descent module after landing in the Saratov region of Russia

# IN PICTURES: YURI GAGARIN **FIRST MAN IN SPACE**

▲ Gagarin swims in 1960 to get himself in shape for his spaceflight the following year

◀ Parachute training for his mission at the Chkalovskaya air base in 1960



▲ Aged 25, Gagarin undergoes medical testing at Star City, Russia's cosmonaut training base, in 1959


◀ The spacecraft receives final checks prior to Gagarin's mission – the writing on the side reads 'USSR Vostok'

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◀ Yuri Gagarin in the cabin before lift-off. The launch was slightly delayed to re-fit the hatch

▼ The R-7 rocket carrying Vostok 1 blasts off from the Baikonur launch site in Kazakhstan on 12 April 1961. Gagarin's flight lasted 108 minutes

▲ The empty Vostok capsule landed in the Saratov region of Russia. Gagarin came down separately, parachuting from an altitude of 7km

◀ Still wearing his flight suit, Gagarin is feted by soldiers of the Soviet Union on his return to Earth

▶ Soviet premier Nikita Khrushchev savours a report of the cosmonaut's exploits. Gagarin and wife Valentina (left) look on

RIA NOVOSTI/SCIENCE PHOTO LIBRARY X 3, PA PHOTOS, GETTY X 3

▼ Gagarin toured the world in the months following his spaceflight. Here he embraces the Cuban leader Fidel Castro


▶ Gagarin enjoys another high-altitude view of Earth – this time from the Eiffel Tower, Paris, on 28 September 1963

▲ Gagarin is introduced to the Italian actress Gina Lollobrigida at the 2nd International Film Festival, Moscow, in 1961

◀ The newly promoted Major Gagarin meets British Prime Minister Harold Macmillan during a visit to Admiralty House in London on 13 July 1961


NASA

◀ The first American to orbit the Earth, John Glenn, clambers into the Friendship 7 capsule shortly before launch

# FLYING SOLO

**THE UNITED STATES** may have lost the race to put a man in orbit but it fought back to enter the Space Race in earnest. The early years of the 1960s saw a game of one-upmanship between the superpowers as they achieved ever more ambitious feats of engineering. In the process, human endurance was pushed to the limit and astronauts became firmly established as superstars

# The race to space

NASA's Mercury missions saw astronauts carry out experiments in orbit, while the Soviet Union's Vostok programme set new space records

WORDS: SEAN BLAIR

**THE SOVIET PREMIER** Nikita Khrushchev positively crowed after Yuri Gagarin's 108-minute orbital flight: "Let the whole world look and see what our great country is capable of. Let the capitalist countries catch up with us!"

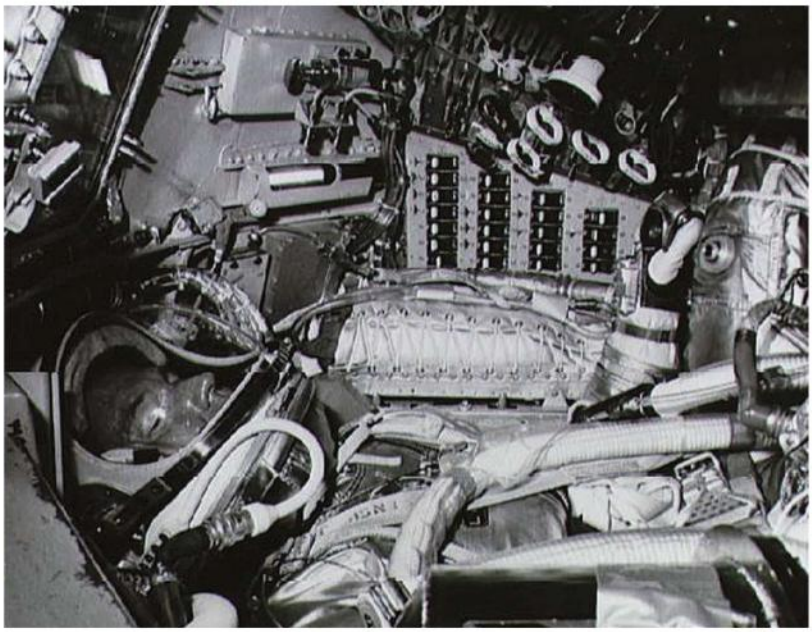
Over in the US, project Mercury was intended to do just that. It had been the 'man-in-space-soonest' project until it transferred from the US Air Force to a newly established NASA. After flying a chimpanzee called Ham in January 1961, Mercury had almost placed an astronaut into suborbital space ahead of Gagarin's 12 April flight. In the event, lingering safety fears meant its 24 March launch was unmanned.

After Gagarin, the race was really on. In the two extraordinary years that followed, cosmonauts and astronauts became what Tom Wolfe, author of *The Right Stuff*, termed 'single combat warriors'. It was, he wrote, an elaborate ritual challenge between warring tribes. They climbed to the top of elongated bombs where they encased themselves in metal capsules to be fired into the vacuum.

American rocketry laboured at a disadvantage: the Soviets had the powerful R-7, an intercontinental ballistic missile initially designed to fire hydrogen bombs at American cities. The Russian physicist Andrei Sakharov had been asked how much future H-bombs were likely to weigh. His back-of-the-envelope estimate was

The Mercury-Atlas rocket fires the Friendship 7 capsule carrying John Glenn into orbit

NASA X 3



▲ Gordon Cooper carries out numerous checks prior to his Mercury flight in Faith 7 on 15 May 1963

5 tonnes, so that became the R-7's payload. In fact, actual bombs weighed nothing like as much, but Soviet space engineers made the most of this surplus capacity.

Designed for daintier warheads, US rockets ended up smaller and, as a consequence, so did their spacecraft. "You didn't get into the Mercury capsule, you wore it," explained astronaut John Glenn. The capsule had a blunt cone and the habitable volume of a telephone box – it could have fitted inside a Space Shuttle engine nozzle. So crammed was it with instrumentation that pilots sometimes pressed the wrong switches by accident. But astronauts themselves helped in the Mercury design process, insisting on being active pilots rather than simply 'spam in a can', as some had witheringly described them.

In contrast, cosmonauts sat back as passengers, only taking control of their Vostok spacecraft in an emergency. Their padded capsule was streamlined, with a bare minimum of gauges and controls, with subsystems housed in a module of their own. Lacking the re-entry manoeuvring of Mercury capsules, the Vostok descent module was spherical and could re-enter the atmosphere in any configuration. And because it came down on land instead of over the ocean, cosmonauts were ejected automatically 7km up, parachuting the rest of the way.

Not that early US astronauts did much active piloting. The first two Mercury flyers were launched on a Redstone booster – a next-generation V-2 – on a modest suborbital trajectory, tracing a 15-minute ballistic curve from Cape Canaveral to the Bahamas. On 5 May 1961, Alan Shepard became the first American in space, reaching a maximum altitude of 187km aboard Freedom 7 and experiencing five minutes of weightlessness in the process. Shepard fired his thrusters and braking rockets but, as the Apollo 13 crew later remarked, Isaac Newton did the real driving.

## Publicity machines

Unlike Soviet space shots, the mission was undertaken in the full glare of publicity. Shepard had felt impelled to satisfy popular expectations, remarking on a "beautiful view" through his periscope (this early Mercury lacked a decent window). On his safe return, Shepard enjoyed ticker-tape parades and received a White House medal. But Gus Grissom, whose Liberty Bell 7 launched 77 days later on 21 July 1961, fared less well.

Grissom's flight went fine, but after splashing down in the Atlantic his exit hatch blew open, flooding the capsule. Liberty Bell 7 sank to the ocean floor (it was eventually salvaged in 1999) and Grissom came close to drowning inside his spacesuit. For the short remainder of his life, Grissom felt under suspicion of blundering. Tragically, he perished in the Apollo 1 fire of 1967.

Further suborbital flights were scheduled... until the Soviets flexed their muscles. On 6 August 1961, Gagarin's back-up Gherman Titov followed his comrade up on Vostok 2. Just 25 years old, the youngest person to fly in space, Titov stayed up for an entire day of 17 orbits. He took a movie camera into space and manually turned his spacecraft on its axis. On his last orbit, Titov's retro rockets triggered automatically and he experienced a bumpy re-entry because the Vostok's instrument module failed to completely disengage, as had happened to Gagarin.

In response, NASA prioritised its more powerful Mercury-Atlas launcher. Enos, a chimpanzee, tested the ride to orbit that November, but technical snags delayed John Glenn's follow-up flight until 20 February 1962. Glenn's Friendship 7 hurtled east with an orbital velocity of 28,000km/h – some 3.5 ►

▲ Alan Shepard (right) receives a NASA Distinguished Service Award from President John F Kennedy in 1961

▲ Cosmonaut Pavel Popovich demonstrates weightlessness with a floating pen as he orbits Earth in Vostok 4 in 1962

► times faster than his suborbital predecessors – for three orbits of Earth. The former marine then switched his capsule forward in the direction of flight, savouring the view, but reported mysterious 'fireflies' swarming.

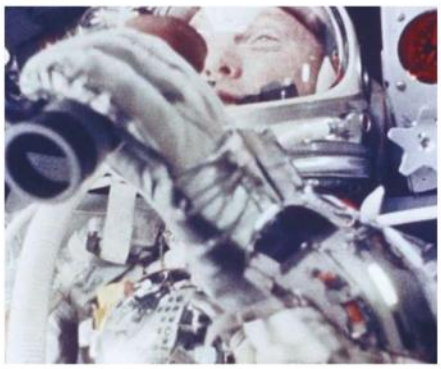
Malfunctioning automatic controls induced a slight drift, but manual compensations were too fuel-hungry to continue. More seriously, a sensor alerted ground control that Glenn's heat shield may be coming loose. If so, he would be incinerated on re-entry. Wary controllers told Glenn not to jettison his retro-rocket pack as usual, hoping its straps would keep the shield in place. Glenn heard molten fragments of retro-rocket bump against his hull, but completed his descent safely (the sensor was faulty).

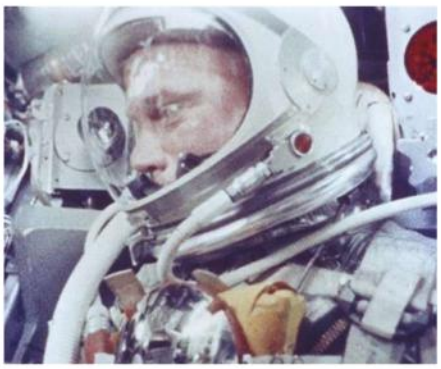
Scott Carpenter's Aurora 7, launched on 24 May 1962, was another three-orbit flight, this time focused on science objectives. Carpenter observed terrestrial features, sunrises and sunsets and atmospheric skyglow. He tried (and failed) to inflate a balloon out of his capsule's nose to measure vestigial atmospheric drag. He also solved the mystery of Glenn's fireflies: a knock on the hull sparked their reappearance, so Carpenter realised they were ice particles. But a distracted astronaut had burned a lot of fuel and was forced to make a manual re-entry, with splashdown 463km off target. It took an anxious 45 minutes to find out that he'd returned safely, but he never flew in space again.

## The Soviets strike back

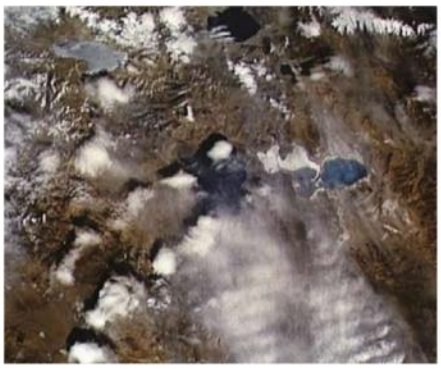
As NASA vowed to do better, its Soviet rival scored another spectacular. On 11 August 1962, Andrian Nikolayev launched to orbit on Vostok 3, followed into space the very next day by Pavel Popovich aboard Vostok 4. At their closest, the two spacecraft were 6.5km apart. Astonished Western experts wondered if the pair might attempt docking – not knowing that Vostok, like Mercury, could not alter its orbit. The two Vostoks gradually drifted apart over the course of three days in space. These cosmonauts were the first to slip their straps and float freely, and Nikolayev performed the first live TV broadcast from orbit. But both spacecraft grew uncomfortably cold and humid and the cosmonauts came home after 94 and 71 hours respectively.

▼ Aboard Friendship 7 with John Glenn, as he uses a photometer to view the Sun during sunset





RIA NOVOSTI/SCIENCE PHOTO LIBRARY X 2, NASA X 6, VOSTOK ILLUSTRATION BY PAUL WOOTTON



▲ **Above, from left to right: a Tibetan lake, the southern portion of Taiwan and the Tibetan plateau, as photographed by Gordon Cooper from Faith 7**

Wally Schirra's nine-hour Sigma 7 flight on 3 October 1962 seemed comparatively pedestrian, although he faced a novel danger: a high-altitude nuclear test had pumped up radiation levels. Thankfully, they were above Schirra's maximum altitude. He even successfully managed to deploy the inflated balloon that had evaded Carpenter, and system refinements meant he re-entered with more than half his onboard fuel left.

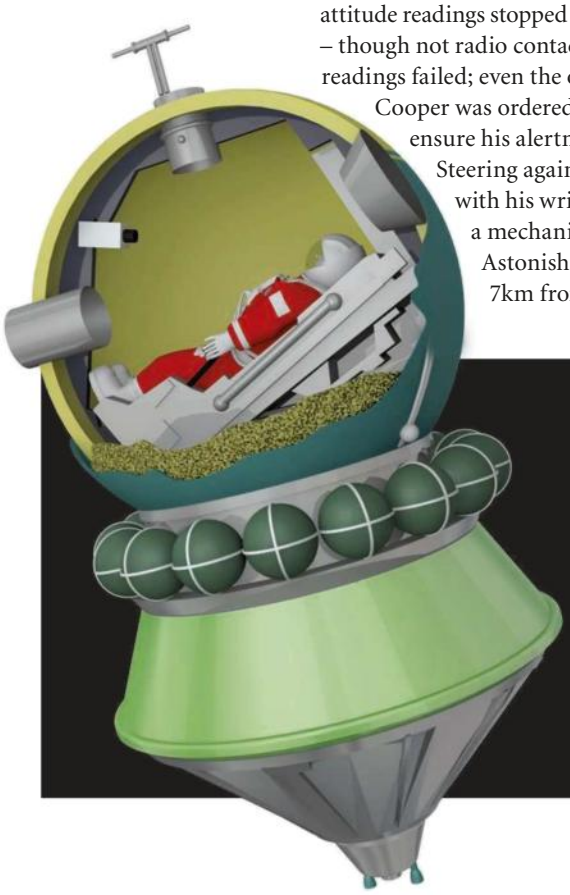
Next, NASA eyed a long-duration mission. On 15 May 1963, Gordon Cooper began an intended three-day flight – only to be forced down in less than half that time. He was notably relaxed, falling asleep on the launch pad and using up much less oxygen than his predecessors – supposedly because he was the first non-smoking astronaut. Cooper hosted the first (snowy) US TV broadcast from orbit, deployed a strobing microsatellite for visibility tests. He also made scarcely believable observations of the ground – tracing chimney smoke back to a single Tibetan cottage, for instance.

Cooper's spacecraft fared worse than he did – its cabin temperature and carbon dioxide levels crept up. On his 19th orbit, an alarm falsely indicated that Faith 7's orbit had dropped and its electrical system began to fail. Automatic control systems and attitude readings stopped working and then telemetry – though not radio contact – was lost. Attitude readings failed; even the onboard clock stopped. Cooper was ordered to take amphetamines to ensure his alertness for what came next. Steering against the stars and timing with his wristwatch, Cooper undertook a mechanical manual re-entry. Astonishingly, Faith 7 landed just 7km from the recovery ship.

Further three-day flights were discussed, but Cooper's experience convinced planners they had hit the Mercury capsule's limits. NASA then moved to its next-generation two-man Gemini, and then to the three-man Apollo spacecraft.

Space single 'combats' were almost over – with one last flourish. On 14 June 1963, Valery Bykovsky launched on Vostok 5. He was followed two days later by Valentina Tereshkova – the first woman in space – on Vostok 6. It was another Soviet propaganda coup, although Tereshkova, a factory worker and amateur parachutist, was reportedly distressed and ill during her flight. She remains the sole female Russian cosmonaut. Despite steadily falling cabin temperatures, Bykovsky had a better time, setting a five-day record for lone spaceflight. It is a record unlikely to be broken, as solo flights were by then at an end in the USSR as well.

▲ **The first woman in space, Valentina Tereshkova, represented another first for Russia and the world**



## Room with a view

Two-thirds larger than its Mercury rival, Vostok was also far roomier. Vostok's single cosmonaut sat within a 2.4m-diameter aluminium sphere covered by ablative shielding. This descent module was connected to a cylindrical instrument module that housed all spacecraft subsystems and retro-rockets, and was separated from the main craft before re-entry.

The Vostok's occupant slid through a round hatch to sit in their ejection seat. Instrumentation covered a minimal part of the otherwise padded interior – cosmonauts were not expected to play an active flight role – while three portholes fitted with blinds offered exterior views.

While the Vostok's manned spaceflight career ended in June 1963, hundreds of unmanned variants flew during succeeding decades, including reconnaissance Zenits and scientific Bion, Resurs and Foton capsules.


# Meet the Mercury 7

## America's first superstar astronauts proved they had the 'right stuff'

WORDS: CLIVE SOMERVILLE

### Alan Shepard

America's first man in space was a Navy test pilot who had also served in the Pacific during World War II. With more than 8,000 hours flying time in his naval career, he was chosen for NASA's first mission into space. Originally planned for 1960, the Mercury-Redstone 3 mission was delayed by technical problems, and Shepard could only look on as Yuri Gagarin went down in history as the first man in space ahead of him. But 45 million Americans were at least able to celebrate Shepard become their first countryman to achieve that feat, on 5 May 1961, piloting the delayed mission aboard Freedom 7.

The flight lasted barely 15 minutes but Shepard had made history. When asked what had gone through his mind as he waited for lift-off, Shepard replied: "The fact that every part of the ship was built by the low bidder." He made his second spaceflight in 1971 as commander of Apollo 14, famously hitting golf balls on the Moon, before retiring in 1974. He died in 1998.

### Virgil 'Gus' Grissom

The second American in space, Virgil 'Gus' Grissom was born in 1926 and joined the newly established United States Air Force in 1950, after attaining a mechanical engineering degree. He served in Korea, where he was cited for "superlative airmanship" and, having made Air Force Captain by 1959, was assigned to Project Mercury the same year.

In 1961 he piloted Liberty Bell 7 (Mercury-Redstone 4), NASA's second sub-orbital spaceflight. The flight itself went well but Grissom nearly drowned on splashdown when the hatch release suddenly activated, flooding the capsule and sinking it moments after he escaped. "I was scared a good portion of the time," Grissom admitted. It was perhaps a warning of things to come. His next mission in 1965 (the first of the Gemini programme) was successful, but tragedy struck in 1967 when Grissom and his crew were killed in a fire aboard Apollo 1 during a pre-launch test. It was set to be the first manned flight of the Apollo programme.

### John Glenn

Born in 1921, Glenn was the fifth man in space and the first American to orbit the Earth. He dropped out of college in 1941 to join up after the attack on Pearl Harbor, flying 59 combat missions as a Marine pilot in the South Pacific, then doing two tours of duty in the Korean War before becoming a Navy test pilot. In 1957, he completed the first supersonic transcontinental flight, from Los Alamitos, California to New York.

Despite not having the requisite college degree, he was selected for Project Mercury in recognition of his achievements as a pilot. America held its breath as Glenn blasted off on Mercury's Friendship 7 (Mercury-Atlas 6) on 20 February 1962, becoming the country's first citizen to orbit the Earth. Glenn was forced to take manual control after the autopilot failed on two of the three orbits, and feared for

NASA X 9

his life when a heat shield appeared to be loose during re-entry. Such calmness under pressure made him something of a national hero and he became a senator in 1974, serving for 25 years. In 1998, aged 77, he became the oldest man in space, flying aboard Space Shuttle Discovery. He and Malcolm Scott Carpenter are the last surviving Mercury 7 astronauts.

## Malcolm Scott Carpenter

As the first American to eat solid food in space, Carpenter can perhaps claim a more obscure achievement than his Project Mercury colleagues. Born in 1925, Carpenter trained as a Navy pilot during World War II. He served in Korea, then became a Navy test pilot in 1954. Five years later he was recruited as back-up for John Glenn. When fellow astronaut Donald 'Deke' Slayton withdrew for medical reasons from Aurora 7 (the mission following Glenn's), Carpenter replaced him.

On 24 May 1962 he achieved his dream and blasted off for a five-hour mission on Mercury-Atlas 7. However, on return to Earth a system malfunction pulled the craft to the right, causing it to overshoot the re-entry point. There were anxious moments as Carpenter manually corrected the re-entry angle, but despite an overshoot of 400km, he splashed down safely. An injury sustained in a motorbike accident in 1964 ended hopes of further flights, so the astronaut turned aquanaut the following year, spending 30 days on the ocean floor as part of the Navy's Sealab project. Retiring from the Navy in 1969, he set up Sea Sciences Inc to develop the ocean's resources.

## Walter 'Wally' Schirra

Born into an aviation family in 1923 (his father was a stunt pilot for his wing-walking mother!), Schirra inherited their flying skills and sense of fun. Graduating in aeronautical engineering in 1944, he served in Korea before becoming a Navy test pilot. He joined Mercury in the specialist area of life support systems, and on 3 October 1962 piloted Sigma 7 (Mercury-Atlas 8) on a nine-hour mission to evaluate systems and equipment. NASA's longest mission at the time paved the way for Mercury-Atlas 9's full-day flight – the original aim of Project Mercury – the following year.

On his return to Earth, Schirra found his achievement eclipsed by the Cuban Missile Crisis. But he would go on to enjoy two further missions – one with Gemini 6 in 1965 and another commanding Apollo 7 in 1968 – becoming the first person to go into space three times. His humour was evident in both: he played *Jingle Bells* on harmonica during Gemini 6A and became a spokesman for Actifed after catching a cold aboard Apollo 7. With Walter Cronkite he commentated on the 1969 Moon landing for TV. He died in 2007 and has a Naval cargo ship, the USNS Wally Schirra, named in his honour.

## L Gordon Cooper

The first man to make two Earth orbits, Cooper was born in 1927 and counted treasure-hunting and archaeology among his interests, as well as aviation. He joined the Army after graduating in aeronautical engineering but transferred to the Air Force as a test pilot. A colonel by the time Project Mercury recruited him in April 1959, he piloted the final Mercury mission, Faith 7 (Mercury-Atlas 9) on 15 May 1963, to see if a manned craft could remain in space for an entire day. Some 34 hours and 22 Earth orbits later, Cooper had proved it could, but not without some difficulties: an electrical fault on the penultimate orbit left his control system without power, and there were high levels of $CO_2$ in the cockpit – a problem that would return to haunt Apollo 13. "Things are beginning to stack up a little," remarked Cooper to mission control, before calmly firing the retro rockets manually for a successful re-entry.

Project Mercury had fulfilled its purpose, but Cooper established a new endurance record just two years later with Mercury's successor, commanding Gemini 5 in an eight-day, 120-Earth orbit mission, and flying a record 5,331,745km in the process. By the time he retired in 1970 (after serving as back-up commander for both Gemini 12 and Apollo 10), Cooper had clocked up 222 hours in space. He died in 2004 at the age of 77.

## The Mercury capsule

At 3.5m long and having a volume of just 1.7m$^3$, it was said that you wore the Mercury capsule rather than flew in it. With a fuelled mass of 1,355kg, it weighed less than a third of Gagarin's Vostok craft. For test pilots used to controlling every aspect of a flight, there was precious little for them to do, except to control attitude (orientation) with thrusters. As a result, air force pilots like the legendary Chuck Yeager dubbed the astronauts "spam in a can". The Mercury 7 men did, however, lobby successfully for a larger window and manual re-entry controls. An internal thermal control system regulated the temperature inside the capsule, while its titanium outer casing was protected for re-entry by a fibreglass resin heatshield.

## Donald 'Deke' Slayton

Born in 1924, Slayton was the Mercury astronaut who never was. Joining the programme after serving as a bomber pilot, then an instructor, in World War II, a heart condition robbed him of the chance to pilot Aurora 7, with Malcolm Scott Carpenter replacing him. Instead, he served the Mercury, Gemini and Apollo missions in senior but ground-based roles.

Slayton was determined to regain his flight status, exercising daily, quitting smoking and cutting down on alcohol. It worked – he regained his flight status in 1972, and finally realised his ambition as the docking pilot for the Apollo-Soyuz Test Project in 1975. It was the first meeting in space between the Americans and Soviets, as an Apollo craft docked successfully with Soyuz 19 for 44 hours. Slayton's sole flight lasted 217 hours, 28 minutes and 24 seconds. From 1977 until his retirement in 1982, Slayton served as NASA's Manager for Orbital Flight Test. He died of cancer in 1993.

# IN PICTURES:
# THE SPACE RACE 1961-1963
# VOSTOK AND MERCURY

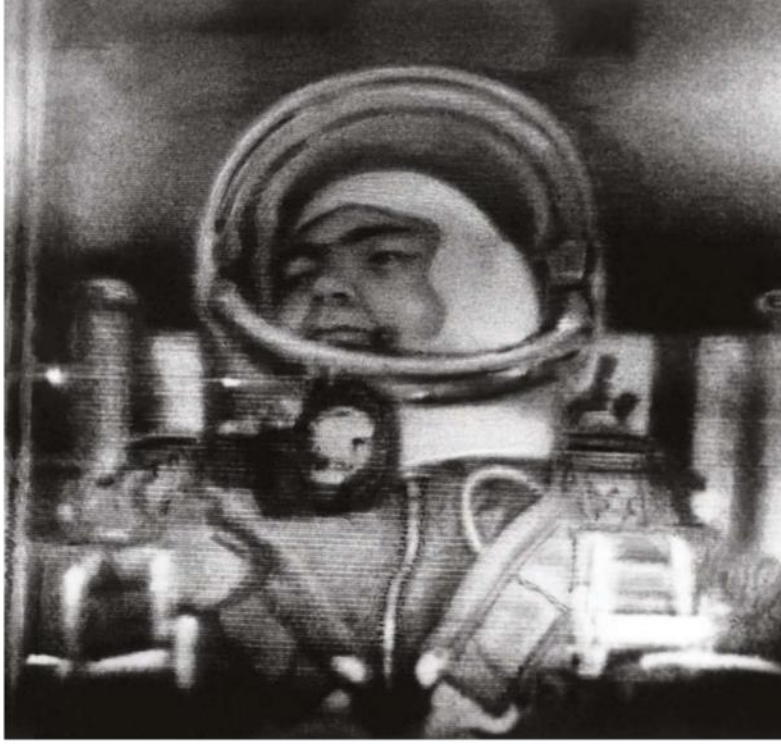
▲ These 11 people were the first Soviet cosmonauts, crewing Vostok and Voskhod missions. The Vostok cosmonauts are on the left hand side: (L-R) Gagarin, Titov, Nikolayev, Popovich, Bykovsky and Tereshkova

◀ Yuri Gagarin prepares for the world's first spaceflight inside the Vostok 1 capsule on 12 April 1961. It was his only space mission

▲ On 6 August 1961, 25-year-old Gherman Titov became only the second person to orbit Earth after Yuri Gagarin. He described how he felt 'homesick' for Earth while in space

RIA NOVOSTI/SCIENCE PHOTO LIBRARY X 8

▲ Soviet mission control during the Vostok 2 mission of August 1961. Cosmonaut Gherman Titov orbited Earth 17 times, spending 25 hours in space, eating two meals and even sleeping during the mission



▲ Andrian Nikolayev during Vostok 3 on 11 August 1962. With Vostok 4, it was the first mission in which two manned spacecraft were in orbit simultaneously

◀ Pavel Popovich in Vostok 4, which launched just a day after Vostok 3. He kept in radio contact with Nikolayev in the other spacecraft


◀ Valentina Tereshkova, pictured in front of Vostok 6, became the first woman in space, spending nearly three days in space and making 48 orbits

▼ Tereshkova eating in Vostok 6, which launched on 16 June 1963. She is reported to have thrown up in the cramped capsule


◀ The Mercury-Redstone rocket carrying Alan Shepard, the first American in space, sets off on its suborbital hop. Freedom 7 set off on 5 May 1961 from Cape Canaveral in Florida

▲ This still from a movie camera captured Alan Shepard inside the Freedom 7 spacecraft on his historic first flight. He's about to raise the shield in front of his face after opening the parachute during descent

▼ Virgil 'Gus' Grissom gets into Liberty Bell 7, the Mercury capsule used for NASA's second suborbital flight on 21 July 1961


▶ US marines rescue astronaut Grissom after a near-fatal splashdown. He was almost drowned when explosive bolts blew prematurely and water flooded in


NASA X 9

▲ John Glenn is weightless during his Mercury mission, Friendship 7, on 20 February 1962. Glenn was the first American to orbit the Earth and later flew on the Shuttle, aged 77

▲ Gordon Cooper on his way into space from Launch Pad 14 at Cape Canaveral, Florida, on 15 May 1963. His Faith 7 mission was the first time Americans had seen TV pictures from space

▲ Scott Carpenter inside Aurora 7 prior to his mission on 24 May 1962. The capsule came down hundreds of kilometres off target

▲ Gordon Cooper's Faith 7 capsule is recovered by US Navy frogmen on 16 May 1963. It landed 6km from the recovery ship, briefly floundering before righting itself

▲ Gordon Cooper is all smiles back on the ground after orbiting the Earth 22 times in Faith 7 – the last Mercury mission

NASA

◀ Tethered to Gemini 4 by a 7.6m umbilical cord, Ed White manoeuvres his way around America's first spacewalk

# THE NEXT STEP

**AFTER THE SUCCESS** of Vostok and Mercury, both the US and Soviet Union had their eyes firmly fixed on the Moon. To get there, they would need to send spacecraft with multiple crew members into orbit, demonstrate docking manoeuvres and practice spacewalks. The rewards were great but so were the risks, as both sides were about to find out…

# Teaming up in space

## Gemini took two astronauts into orbit and Voskhod three. The Soviets made the first spacewalk but there was trouble ahead

WORDS: SEAN BLAIR

**THE FIRST MANNED** spacecraft had simply to prove that people could survive in space. "We didn't really contribute very much to the flight of the vehicle," conceded Mercury astronaut Wally Schirra. "We were lab specimens." With the Mercury and Vostok spacecraft, a solitary pilot could manually rotate them but not change their flight direction, except to fire retro rockets that braked them out of orbit altogether.

Once it was proven that people could indeed survive in space, having them do useful work was the logical next step. This would require many people, not solo flyers, because it would take more than one crewman to master the techniques needed to go to the Moon. This essential Apollo to-do list included changing orbits, extended spaceflights, rendezvous and docking, and extra-vehicular activity (EVA) – spacewalks.

On the American side, a modest two-man Mercury Mark II concept ended up as the fully fledged Gemini programme. Smarting over the loss of his Liberty Bell 7 spacecraft, astronaut Gus Grissom was determined to fly in space again. So he worked closely with the Gemini team, applying his experience to its design. The result was what other astronauts called the 'Gusmobile' – a craft

The Gemini 7 spacecraft seen from Gemini 6 during their rendezvous on 15 December 1965

NASA X 2, ALAMY


▲ McDivitt and White are seated in the Gemini 4 capsule hours before the first American spacewalk

so closely designed around Grissom that its seats needed enlarging to accommodate taller occupants.

Over a frenzied 30 months, the first true spacecraft took shape. Gemini had thrusters for active piloting and carried the first onboard computer to calculate orbital mechanics. Gemini was twice as heavy as Mercury and needed to be launched on the powerful Titan II rocket. For astronauts it was cramped, having just 50 per cent more cabin space than Mercury, but it appeared less cluttered because its subsystems were in a dedicated equipment module, with the thrusters housed in the hindmost section. Only the astronauts' re-entry module returned at the end of the mission.

Instrumentation followed a cockpit-style configuration. Gemini's Canadian design team had been responsible for the legendary Avro Arrow jet and borrowed concepts from fighter planes. They included stick controllers, rendezvous radar, access hatches for easier maintenance and ejection seats to replace Mercury's launch escape tower. A wary John Young witnessed one ejection seat test in which Gemini's cabin hatch stayed shut. "That's one hell of a headache – but a short one!" he quipped, drily.

▼ Cosmonauts Boris Yegorov, Konstantin Feoktistov and Vladimir Komarov return from Voskhod 1 in the clothes they wore in space

Meanwhile, the USSR was developing its own Gemini equivalent: the three-man Soyuz (Russian for 'Union'). The initial plan involved docking a trio of Soyuz spacecraft in Earth orbit, forming a 'space train' to head to the Moon. But the Soviet effort was under-resourced and, in reality, Soyuz was years away from flying. The USSR's lead in the Space Race was about to vanish, so Chief Designer Sergei Korolev took a reckless gamble.

## The first spacewalk

On 12 October 1964, six months after America's first, unmanned Gemini test flight, Moscow announced the launch of a brand new spacecraft called Voskhod (Russian for 'sunrise'). It had not two but three crew members – Boris Yegorov, the first doctor in space, engineer Konstantin Feoktistov and pilot Vladimir Komarov.

Voskhod's 24-hour flight achieved another propaganda coup, but in truth the craft was no great leap forward. Korolev had simply crammed the trio into a modified Vostok. To fit in, they wore wool garments instead of spacesuits and their ejection seats were replaced with a retro-rocket touchdown system. The hurriedly fitted Voskhod couches were at right angles to the original layout, so the cosmonauts had to crane their necks to read instruments. They could barely move in the cramped cabin, which became uncomfortably hot and humid. An anxious Korolev could hardly believe it when Voskhod 1 made it down safely.

A two-man Voskhod 2 followed on 18 March 1965, five days before the first manned Gemini mission. "The sailor on the ship should be able to swim," declared Korolev, in advance of what was to be the first spacewalk. An inflatable airlock was extended from the capsule and Alexei Leonov floated in space for 12 minutes.

Officially the spacewalk was a success. In reality, his spacesuit had ballooned until movement became impossible. Leonov had to reduce its pressure by a third to squeeze back inside the airlock, almost suffering heatstroke in the process. Cosmonaut Pavel Belyayev helped the exhausted Leonov back inside. They ejected the airlock as planned but the hatch didn't seal properly. Pure oxygen pumped in automatically to compensate, posing a fire risk. Then their automatic re-entry guidance system failed. Performing manual re-entry meant leaving their couches to reach the controls, then clambering back to preserve the Voskhod's delicate centre of gravity. They plummeted down, far off course, and it was two days before they could be rescued from thick Siberian forest. Korolev had tentative plans for Voskhod 3, but he died in January 1966. ►


▲ Russian cosmonaut Alexei Leonov performs history's first spacewalk. Getting back into Voskhod proved hairy

► The launch on 23 March 1965 of Gemini 3 with Gus Grissom and John Young (the first of the astronauts dubbed the 'Next Nine' following the Mercury 7) was thoroughly overshadowed by Russia's success, despite it performing history's first ever orbital change. But over the nine Gemini missions that followed, it became clear that the US was opening up a decisive technical lead. Gemini 4, on 3 June 1965, bore witness to Ed White's 22-minute spacewalk. And August's Gemini 5 was an eight-day mission, made possible with onboard fuel cells replacing batteries.

## Armstrong stays cool

Gemini 7, launching on 4 December 1965, was Jim Lovell and Frank Borman's long-duration mission. Borman famously described it as: "Spending two weeks eating, sleeping, working and going to the bathroom stuffed into the front seat of a sports car wearing an overcoat." The dry atmosphere induced runaway dandruff, plus the pair had to share a toothbrush when one drifted away.

Their spacecraft served as a rendezvous goal for Gemini 6A, which finally launched out of sequence on 15 December. The computer guided Wally Schirra and Tom Stafford though 35,000 separate thruster firings to home in on Gemini 7. This was the real thing. Vostok 3 and 4 had been placed into adjacent orbits during their supposed 1962 'rendezvous' but had soon drifted apart, like cars driving parallel on divergent highways. In contrast, the two Geminis came as close as 30cm and kept station for more than five hours. Both spacecraft were seen to have booster cords dangling untidily behind, accounting for the mysterious clanging sounds heard on previous missions.

The next step was docking. On 16 March 1966, Gemini 8 closed on its orbital target: an unmanned Agena booster. Within 6.5 hours of launch, Neil Armstrong and Dave Scott had docked, but then the combined vehicle began tumbling through space. A concerned Armstrong separated them, but the Gemini began spinning even faster. At one turn per second, their vision blurred – they were in danger of blacking out. But Armstrong stayed cool. He realised the spin must come from a faulty Gemini thruster, not Agena. He deactivated all attitude thrusters and fired the re-entry thrusters to bring the spacecraft back under control.

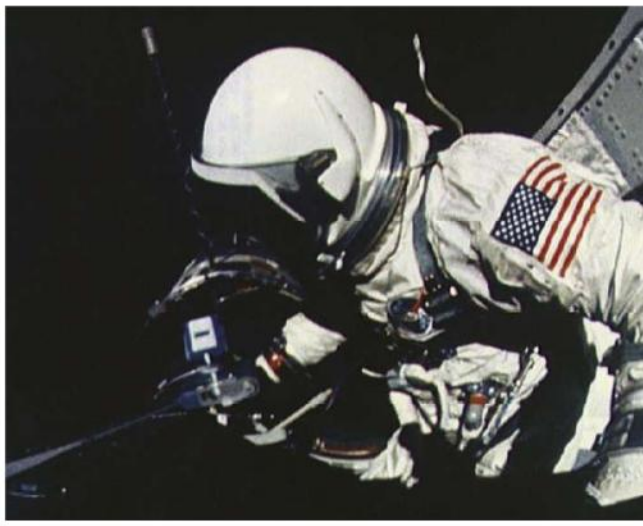
This setback meant a scheduled spacewalk was cancelled, but Gemini 9A, flown on 3 June, included an ambitious foray into space. Eugene

▼ Frank Borman tested the effects of spaceflight on human vision during the Gemini 7 mission

PA PHOTOS, NASA X 5

◀ Gemini 4 sets off on 3 June 1965 with James McDivitt and Ed White, the first US spacewalker

▶ Buzz Aldrin stands in the open hatch of his spacecraft on the final Gemini mission



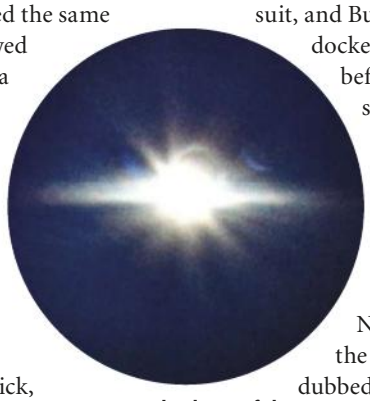
Cernan climbed to the back of the Gemini to fly an Air Force-designed manoeuvring jetpack. That was the idea, at least, but Ed White had made it look too easy. Cernan struggled against his rigid suit and couldn't control his movements. His visor fogged up as his struggles exceeded the capability of the suit's cooling system. Effectively blinded, Cernan's spacewalk was curtailed and the jetpack abandoned. He felt his way back to the hatch, having lost over 4kg in weight during the two-hour spacewalk, his back burned in places by torn insulation that had let sunlight through.

Launching on 18 July, Michael Collins was Gemini 10's spacewalk guinea pig. His first involved simply standing up in the hatch; the second was to collect experiment packages from the side of a docked Agena. Collins used the same 'zip gun' as Ed White but still showed a lack of control that sent the Agena into a spin. He pulled himself back along his umbilical but while securing himself, Collins lost the camera recording his EVA.

More successfully, the Gemini 10 crew fired their docked Agena's thrusters to take them to a second Agena, left over from Gemini 8. Gemini 11, flown on 12 September 1966, repeated the trick, rocketing up to a record-breaking 1,374.1km. "The world's round!" confirmed a happy Pete Conrad.

Earlier, Dick Gordon's walk hadn't gone so well: he ended up exhausted just placing a camera. He managed to attach a tether to the Agena but, like Cernan, was blinded by a fogged-up visor. The tethered Agena was put into a spin to create artificial gravity in space for the first time. The effect was tiny – not enough for the astronauts to feel but just sufficient to propel a camera towards one end of the spacecraft.

On the final Gemini 12 mission on 11 November, Jim Lovell had 'The' written on the back of his suit, and Buzz Aldrin had 'End' on his. They docked with an Agena on their first orbit before lining up to observe a total solar eclipse, showing how much skill had been gained.



▲ A total eclipse of the Sun photographed by Gemini 12

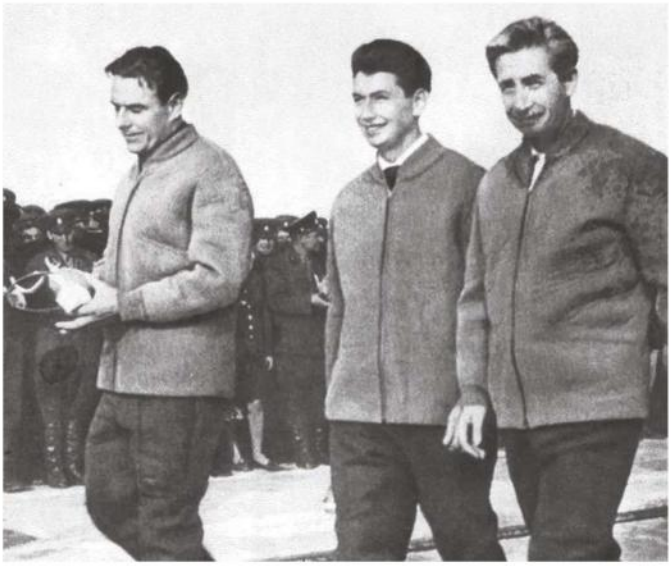
A spacewalk was the last, stubborn challenge. In preparation for the flight, Aldrin had practiced extensively underwater in NASA's new Neutral Buoyancy Laboratory and the newly designed foot restraints, dubbed 'golden slippers' helped by keeping him braced in place so that he could comfortably achieve all his spacewalking goals.

After four days in orbit, the final Gemini splashed down within 5km of its main recovery vessel. There were proposals to fly more – a lunar orbit was one idea – but NASA believed Gemini had achieved its objective, amassing practical experience for Apollo. Now, the way to the Moon was clear.

## First American steps in space

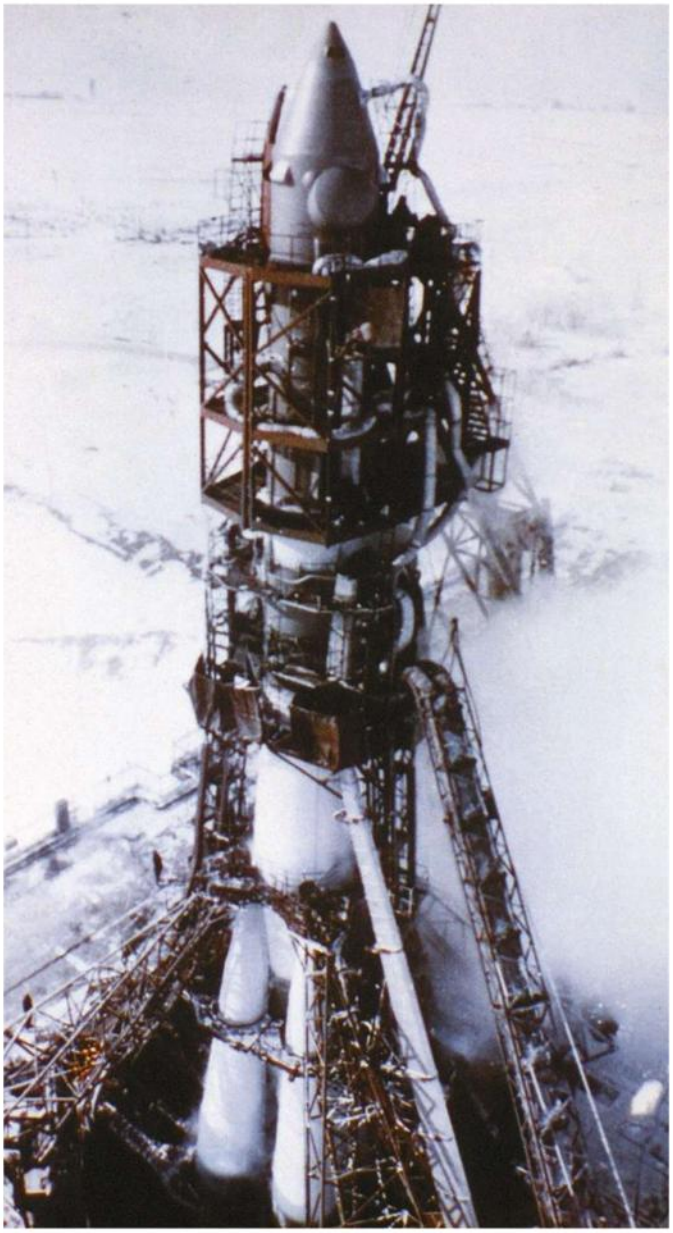
Cosmonaut Alexei Leonov's first spacewalk was a propaganda triumph that had nearly ended in disaster. On 3 June 1965, it was astronaut Ed White's turn. His Gemini 4 spacecraft had no airlock. White and Jim McDivitt depressurised the cabin, then White opened his hatch to step out into the vacuum of space. Equipped with a gas-powered 'zip gun' for manoeuvering, White made his 22-minute spacewalk look fun. Making him return was hard: "Get back in!" hollered Gus Grissom from Mission Control. "This is the saddest moment of my life," replied White. Shutting the hatch after him was the hardest part – White's heart rate went up to 178 during the five-minute struggle. It was a hint of spacewalk troubles to come.

# IN PICTURES:
# THE SPACE RACE 1964-1966
# VOSKHOD AND GEMINI



◀ Soviet cosmonauts get ready to board Voskhod 1 – the first spacecraft to take multiple crew members into space – on 12 October 1964. Vladimir Komarov, Boris Yegorov and Konstantin Feoktistov (shown L-R) didn't wear spacesuits during the mission

▲ Boris Yegorov, seen here inside Voskhod 1, was the first trained medical doctor in space. His fellow cosmonaut Konstantin Feoktistov had been a designer of space hardware



▲ Voskhod 2 is prepared for launch from the Baikonur cosmodrome on 18 March 1965. The Voskhod rocket was based on the R-7 intercontinental ballistic missile, adapted for human spaceflight

◀ Pavel Belyayev and Alexei Leonov in the Voskhod 2 capsule, which was launched on 18 March 1965. The cosmonauts spent 26 hours in space but two days in thick forest after the mission, as the capsule overshot its landing site by several hundred kilometres

NASA/ASIF SIDDIQI, ALAMY, RIA NOVOSTI/SCIENCE PHOTO LIBRARY, X 2, VIDEOCOSMOS, ASIF SIDIDI X 3, NASA X 3

▲ Above and right, Soviet cosmonaut Alexei Leonov performs the first spacewalk on 18 March 1965. He spent 12 minutes in space, but only just managed to get back inside Voskhod 2 when his spacesuit over-inflated




▼ Ed White was the first American to walk in space, on 3 June 1965. White manoeuvred outside the Gemini 4 spacecraft while connected by a 7m-long tether line

▲ The first manned Gemini mission, Gemini 3, took this photo of Arizona and Mexico on its second of three orbits around the Earth

▲ Ed White (left) and James McDivitt inside the Gemini 4 spacecraft, only the second manned Gemini mission, prior to takeoff. The pair spent four days in space

▶ Charles 'Pete' Conrad inside Gemini 5, as photographed by his fellow astronaut Gordon Cooper. The mission would evaluate the effects of weightlessness over eight days

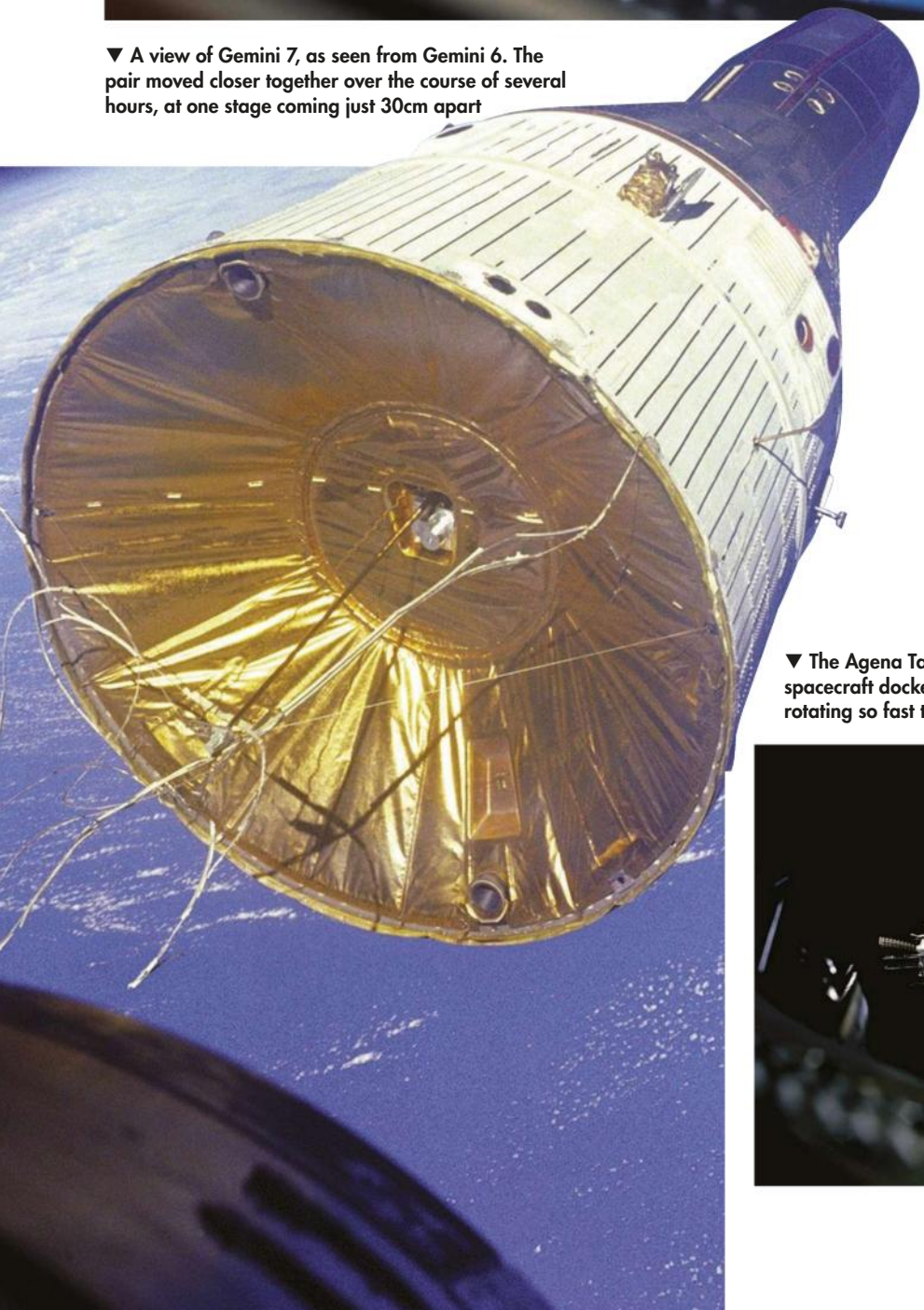
▼ Gemini 6A lifts off on 15 December 1965 on its way to a rendezvous with Gemini 7, which was already in orbit

NASA X 7

◀ Gemini 7 and Gemini 6 rendezvous some 300km above Earth. Gemini 7's Frank Borman and Jim Lovell spent over 13 days in orbit

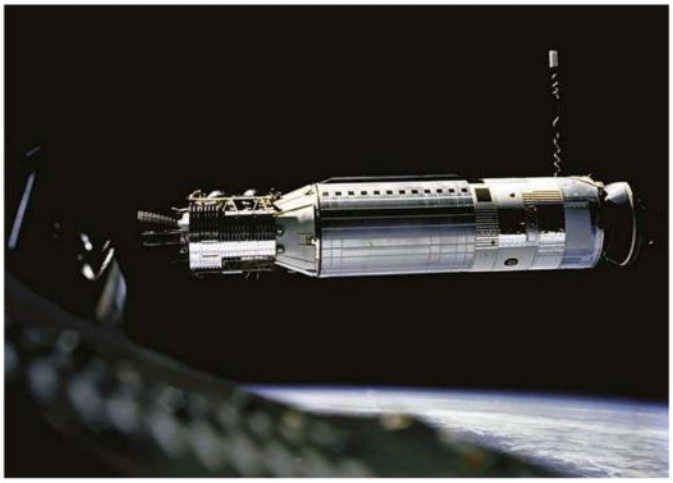
▲ The Andes mountains seen from Gemini 7. Clouds lit by a low Sun glow orange

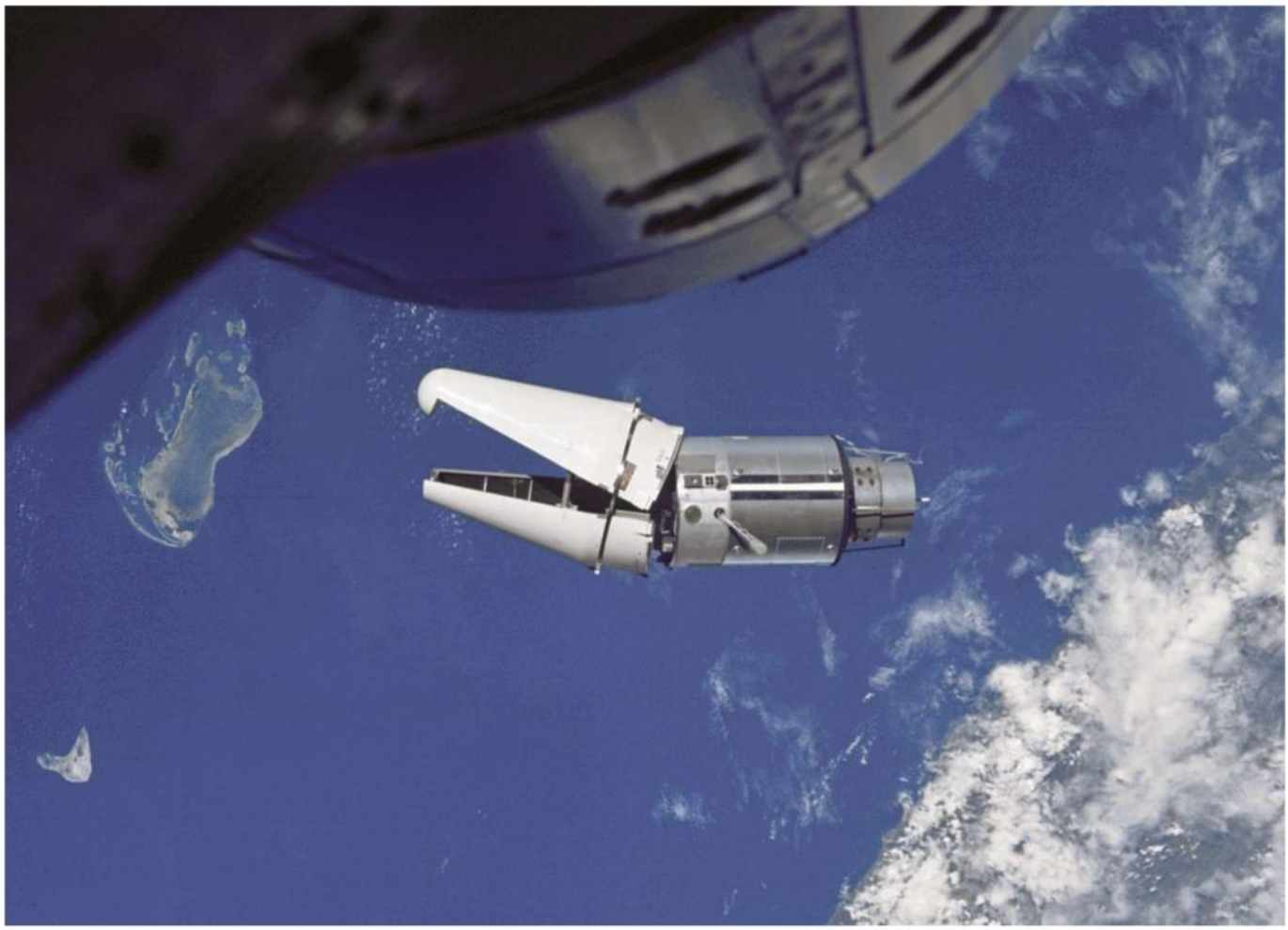
▼ A view of Gemini 7, as seen from Gemini 6. The pair moved closer together over the course of several hours, at one stage coming just 30cm apart



▼ Neil Armstrong makes final checks prior to the launch of Gemini 8 on 16 March 1966. He would later save the mission from catastrophe

▼ The Agena Target Vehicle seen from Gemini 8. The two spacecraft docked successfully but Gemini 8 went into a spin, rotating so fast the astronauts were in danger of blacking out



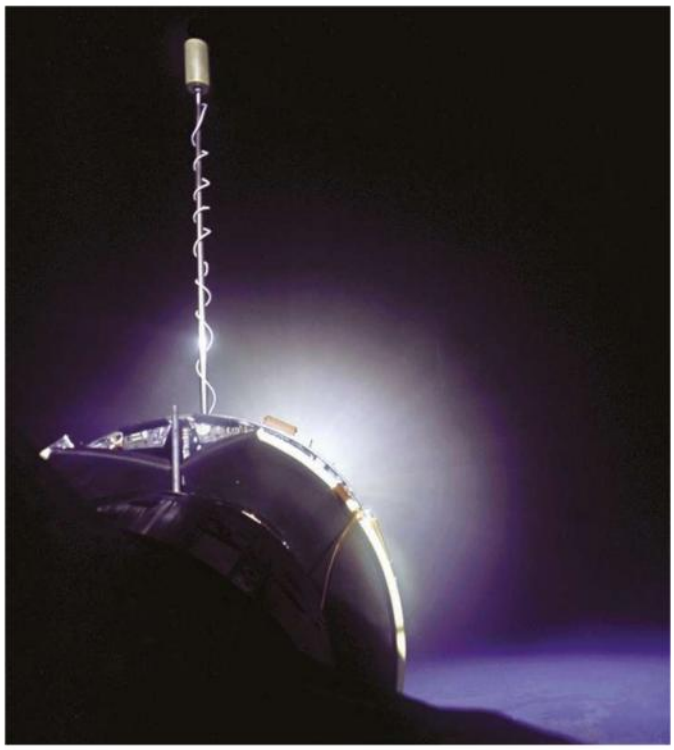


NASA X 10

▲ The Augmented Target Docking Adaptor, described by the crew of Gemini 9A as an "angry alligator". Its protective cover failed, preventing it docking with the Gemini craft

◀ Eugene Cernan pilots the Gemini 9A mission. The photograph was taken by the command pilot, astronaut Thomas P Stafford

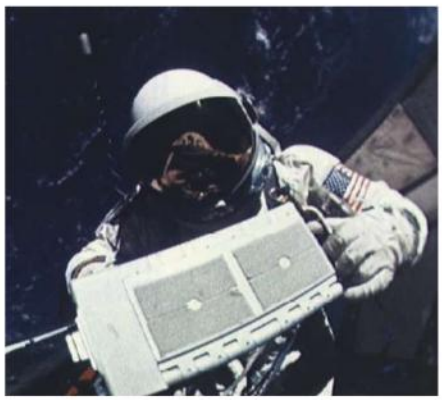
▲ Debris on the window, as seen from inside Gemini 10 on 18 July 1966. The spacecraft was docked with the Agena Target Vehicle

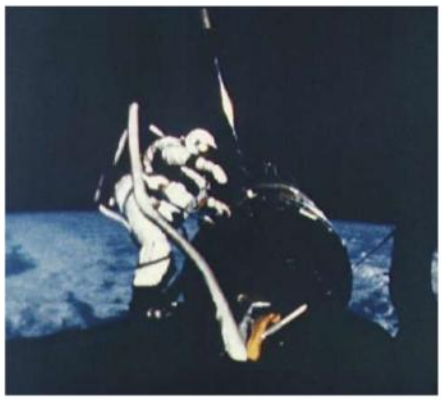


▶ Top: Richard Gordon performs a spacewalk above the Atlantic Ocean on 13 September 1966. Bottom: he returns to Gemini 11's hatch, cutting short his EVA

◀ The Agena Target Vehicle, its propulsion system glowing, is docked with Gemini 10

▼ Edwin 'Buzz' Aldrin performs an EVA during the second day of the four-day Gemini 12 mission





◀ Top: Buzz Aldrin in the hatch during an EVA, preparing a camera for installing outside. Middle: his EVA on the second day of the mission. Bottom: with a JA Maurer camera in the open hatch

NASA

◀ The 93km-wide Daedalus Crater on the far side of the Moon, as photographed by the Apollo 11 mission

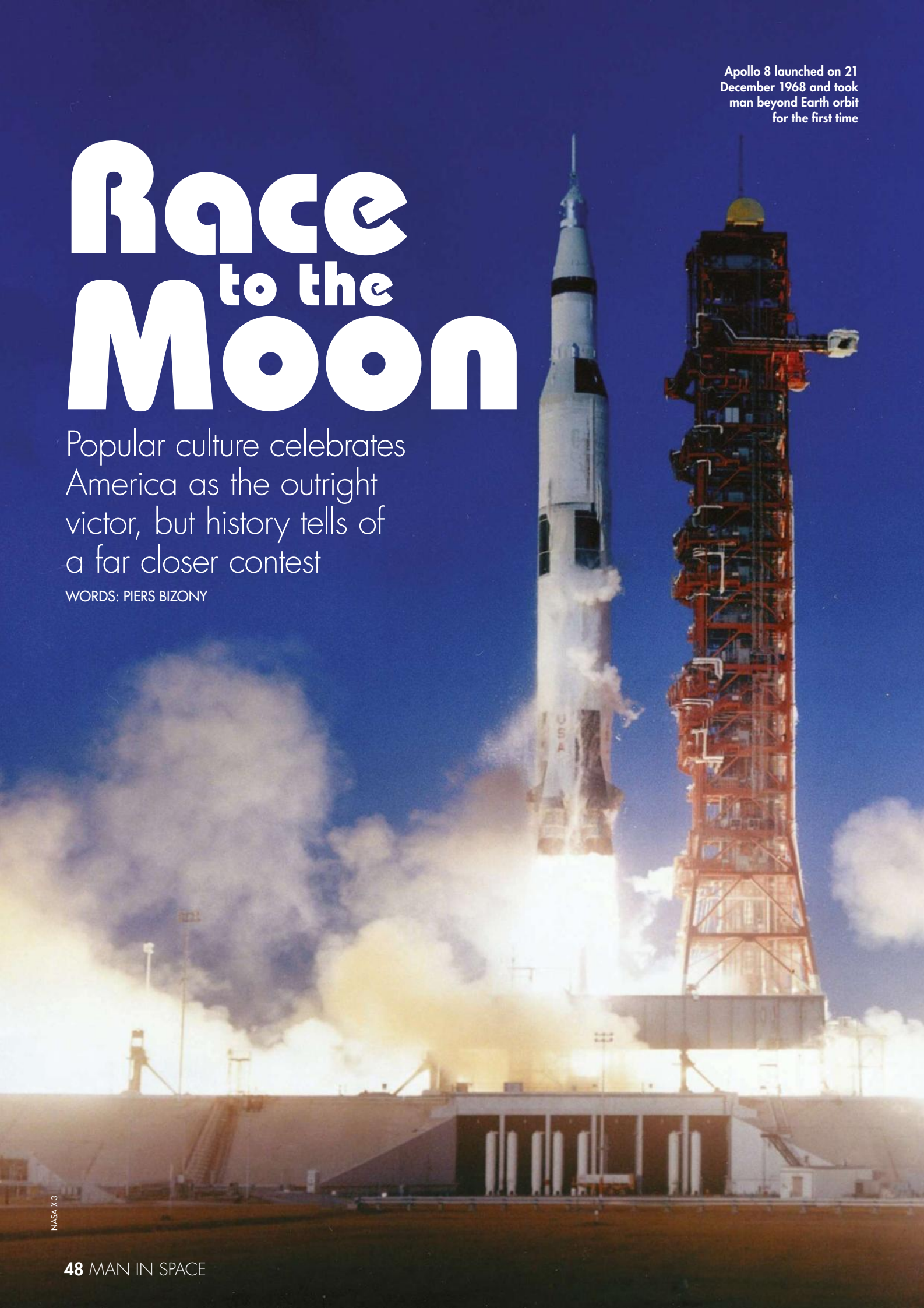
# TWO SIDES OF THE MOON

**NEIL ARMSTRONG'S HISTORIC** step on the lunar surface in July 1969 marked the end of an era, with America having surpassed the Soviet Union's earlier triumphs. The race to the Moon had been fraught with difficulty and disaster as both superpowers pushed know-how and technology to the limits. The Soviet Union developed its most powerful rocket but it was too little, too late

# Race to the Moon

## Popular culture celebrates America as the outright victor, but history tells of a far closer contest

WORDS: PIERS BIZONY



Apollo 8 launched on 21 December 1968 and took man beyond Earth orbit for the first time

NASA X 3

▲ After the Bay of Pigs fiasco, John F Kennedy seized upon space as a means of winning back political credibility

**YURI GAGARIN'S FLIGHT** on 12 April 1961 was a major embarrassment for John F Kennedy, the White House's new occupant. Until that point, he hadn't taken the Space Race seriously, and he was alarmed at the global response to Russia's triumph. He paced the White House asking his advisors, "What can we do? How can we catch up?"

Just one week later, Kennedy suffered another defeat. A 1,300-strong force of exiled Cubans, supported by the CIA, landed at the Bay of Pigs in Cuba with the intention of destroying Fidel Castro's regime. Kennedy had approved the invasion, but Castro's troops knew what was coming and were waiting on the beaches. The raid was a complete disaster.

There was some encouragement for the new president, however. On 5 May 1961, NASA astronaut Alan Shepard was launched atop a small Redstone booster. His flight wasn't a full orbit, merely a ballistic arc lasting about 15 minutes. Gagarin's Vostok craft had circled the world, while Shepard's little Mercury capsule splashed into the Atlantic just a few hundred kilometres from its launch site. But it was enough to prove NASA's capabilities.

Kennedy now turned to space as a means of bolstering his credibility. On 25 May 1961, he made his landmark speech pledging America to a Moon landing "before this decade is out" and the Apollo project was born. The popular assumption is that Russia never came anywhere near landing men on the Moon. But since the fall of the Soviet empire in 1989, startling truths have emerged about how incredibly hard they tried to beat Apollo.

## The post-Korolev era

Sergei Korolev's death in January 1966 brought chaos to the Soviet space effort. In the absence of his leadership, rival schemes emerged for sending cosmonauts to the Moon. One team wanted to try for a landing, another believed a circumlunar flight without a landing attempt was a more realistic goal.

In contrast, NASA in the 1960s was under the leadership of James Webb, a strong, determined boss who made sure that just one approach was chosen for America's attempt on the Moon. Many ►

## The US takes a chance

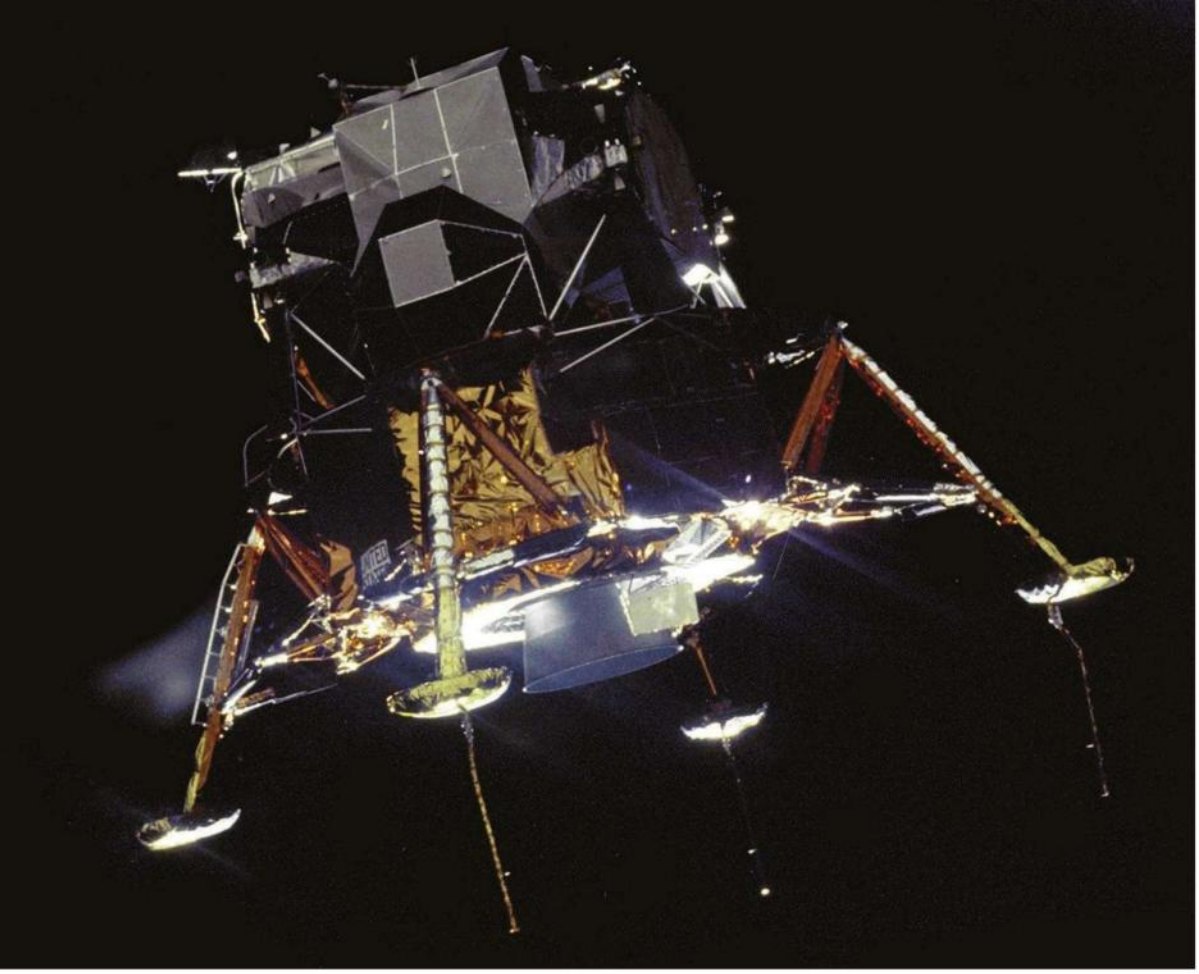
In 1968, NASA was recovering from 1967's terrible on-board fire (pictured above), which had killed the first Apollo crew – Gus Grissom, Ed White and Roger Chaffee. Their rocket, a half-sized version of the Saturn V, had simply been sitting on the launch pad.

A successful manned Earth orbital mission of the Apollo capsule in October 1968 proved that it was now ready for longer test flights. The same could not be said of the full-scale Saturn V rocket. Unmanned tests revealed serious problems with its engines and control systems. Even so, NASA committed a human crew to the next flight of the Saturn V.

NASA chief James Webb was under immense strain, trying to protect Apollo's reputation after the fire. When senior colleagues suggested flying a Saturn V, with a crew on board, all the way to the Moon, his initial response was furious. "Are you out of your mind? You're putting our agency and the whole Apollo project at risk!" he said. Then he looked at the latest intelligence reports and knew there was no choice but to get NASA astronauts to the Moon as fast as possible, just in case the Russians pulled off a surprise.

The Apollo 8 crew of Frank Borman, Bill Anders and Jim Lovell, made a circumlunar voyage during Christmas 1968, flying a relatively untested capsule on a gigantic rocket that had spun out of control on its last flight. The mission could easily have gone wrong. If it had, the Soviet Union might well have pushed with more confidence to make its secret Zond project a success.

Sergei Korolev, Chief Designer of Russia's early space programme



◀ The spider-like lunar module triumphed over other methods of landing, including an enormous rocket that would touch down on the Moon

► people, including Saturn V mastermind Wernher von Braun, had different ideas about the mission, but Webb put his faith in Apollo's spider-like lunar lander. He insisted that everyone within NASA had to support that design – or leave.

Despite the Soviet programme being in disarray, there was a reasonable chance it could send a specially adapted Soyuz spacecraft around the Moon, even if the crew capsule had to be so laden with extra fuel and oxygen that only one cosmonaut could fit in its cramped confines. If Russia had managed this makeshift trip before Apollo's first touchdown, the world's media may not have cared very much about the distinction between a circumlunar trip and an actual landing. Russia would have scored another huge propaganda victory and we can only guess what the geopolitical consequences of such a 'victory' might have been.

On 18 September 1968, Russia succeeded in swinging the unmanned Zond 5 spacecraft around the Moon and back towards Earth. The capsule splashed down in the Indian Ocean and was successfully recovered. Two months later, NASA announced that its next flight, Apollo 8, would take off a few days before the coming Christmas and head straight for the Moon, even though it would carry no lunar landing module. NASA was desperate to get men into the vicinity of the Moon as fast as possible. The race was closer than many people realised at the time.

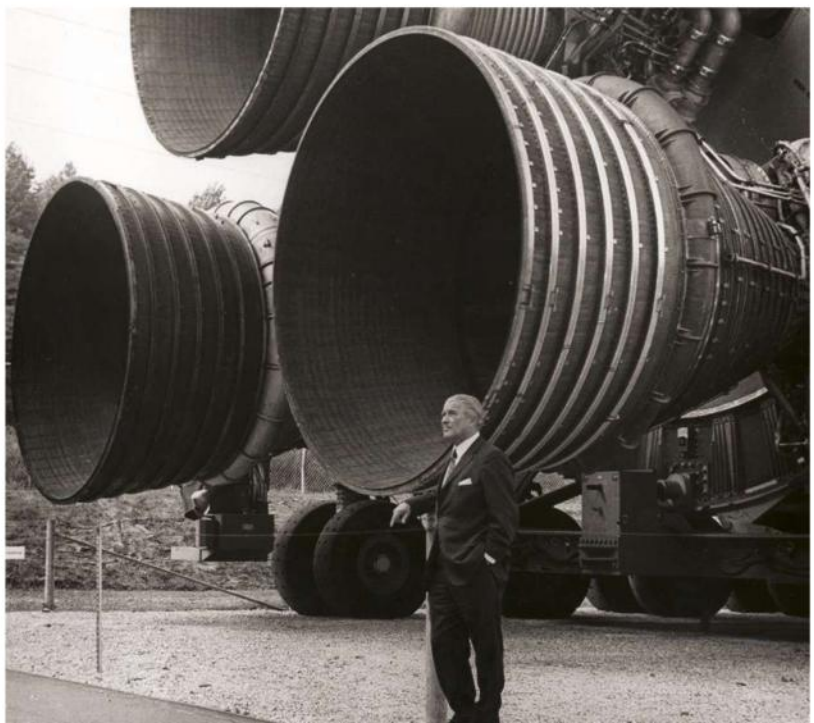
The name of Sergei Korolev will be forever linked with the flights of Sputnik and Yuri Gagarin, but these were just the opening shots in his planned assault on the Moon. As early as 1959, he had a lunar booster on the drawing boards. In the mid-1960s, the Kremlin pushed him to proceed with new 'firsts', using ever more dangerous versions of the R-7 rocket and Vostok hardware. He agreed, and in return was authorised to build the N-1, a lunar rocket almost as tall as von Braun's Saturn V.

## The end of N-1

Wernher von Braun's masterpiece, the Saturn V, employed five large main F-1 engines, running at temperatures and pressures that even the great Korolev couldn't match. His best engine designer and bitterest rival, Valentin Glushko, refused to have anything to do with the N-1.

The N-1 rocket carried a Soyuz-like command ship with two seats and a tiny lunar lander that accommodated one cosmonaut. The ships would dock in space for the lunar voyage, but there was

▼ Wernher von Braun standing next to an F-1 jet engine, five of which powered Saturn V. The rocket is still the most powerful ever built



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▲ **The first of four N-1 test flights, in February 1969. All four ended in failure, leading to the cancellation of the whole programme**

no tunnel linking the two craft. The cosmonaut destined for the landing would have made a brief spacewalk to get from one craft to the other.

Korolev did not live to see the humiliating collapse of his lunar dream. After his death in 1966, and with Glushko by then working on rival projects, the N-1's problems multiplied fast. A cluster of 30 underpowered engines at its base refused to work in harmony. The rocket's innards were a poorly tested maze of pipes, pumps and valves. The electrical control systems struggled to keep the rocket stable, especially when individual engine failures disrupted the overall thrust.

The N-1 flew for the first time on 21 February 1969, making its longest flight of just over a minute before spiralling out of control and exploding. A second test flight in the summer of that year destroyed the launch gantry. Two more test flights failed – the last on 23 November 1972 – and the entire N-1 programme was cancelled.

It wasn't just superior hardware but skills such as systems analysis and software design that gave NASA victory. Its engineers could discuss problems without fear of reprisal, whereas in the Soviet Union no-one wanted to admit failure. An open society proved more effective than a closed one.

## Zond: a Soviet secret

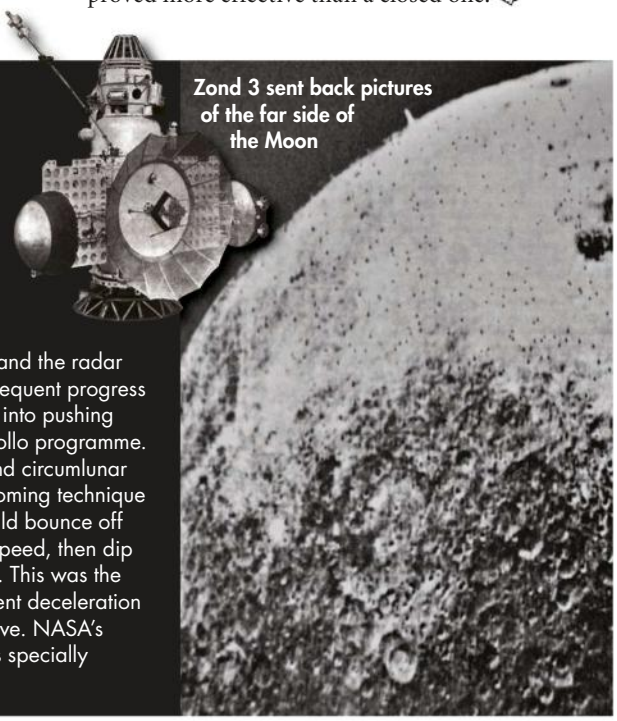
In the Soviet era, secrecy was paramount and few details of spacecraft were released. When the US heard of a series of missions called 'Zond', meaning 'probe', it stoked the embers of the Space Race once again.

The first three Zonds were small, unmanned spacecraft sent to Mars, Venus and the Moon. Two were lost in space but Zond 3 (inset, right) successfully sent back pictures of the lunar far side.

Zond 4 was a much larger machine, derived from Soyuz technology. Launched in March 1968 on a Proton rocket, it went into parking orbit around the Earth before being blasted into deep space in the opposite direction from the Moon, so as not to give NASA any clues about its true purpose. Zond 4's re-entry capsule went off course and it was deliberately exploded high over the Bay of Biscay to prevent it falling into US hands.

Zond 5 in September 1968 was more of a success. After flying around the Moon, its capsule returned to Earth and it was recovered intact by Russian naval forces. Secret intelligence reports about the preparations for this mission, and the radar tracks of the spacecraft's subsequent progress through space, scared NASA into pushing ahead even faster with its Apollo programme.

The main hurdle for the Zond circumlunar effort was refining the homecoming technique so that the return capsule would bounce off Earth's atmosphere and lose speed, then dip in again for a gentler re-entry. This was the only way of preventing a violent deceleration that no cosmonaut could survive. NASA's Apollo command module was specially shaped to solve this problem.



**Zond 3 sent back pictures of the far side of the Moon**

# Apollo the missions

## Beginning with tragedy and ending in triumph, the Apollo missions are the pinnacle of mankind's space adventure

WORDS: CLIVE SOMERVILLE

### Apollo 1
27 Jan 1967


The first manned Apollo mission, designed to orbit Earth, ended in tragedy before it began. On 27 January 1967, during a pre-launch training exercise, a fire broke out in the module, killing the three astronauts aboard – commander Gus Grissom, command module pilot Ed White and lunar module pilot Roger B Chaffee. Grissom was one of the original astronauts of the first American manned spaceflight programme, Project Mercury, while White had become the first American to walk in space during the 1965 Gemini 4 mission. Apollo 1 would have been Chaffee's debut mission. All three received the Congressional Space Medal of Honor posthumously. The cause of the fire was never found, but the outcome was blamed on a lethal combination of design flaws including the module's highly pressurised oxygen atmosphere, electrical faults, a faulty escape hatch and flammable materials.

### Apollo 7
11 Oct 1968 – 22 Oct 1968


Following the Apollo 1 disaster, Apollo 7 became the first successful manned Apollo mission, orbiting Earth for nearly 11 days from 11 October 1968. The crew, commander Wally Schirra, command module pilot Donn F Eisele and lunar module pilot Walter Cunningham, complained of nothing more than a cold during their time in space. As well as being the first successful American three-man mission, it also marked the first use of the Saturn IB rocket to propel a manned spacecraft onto orbit. Along with the rocket, the mission allowed the crew to test the module's newly designed life support and control systems and, despite reported tensions between crew and mission control back on Earth, the mission was declared a success. After the devastating setback of Apollo 1, it was a huge test not just of the redesigned Apollo module itself, but of the future of America's manned space programme. Buoyed by the outcome, NASA launched Apollo 8 just two months later.

> "We came all this way to the Moon and the most important thing is that we discovered the Earth"

### Apollo 8
21 Dec 1968 – 27 Dec 1968


Apollo 8 went beyond its predecessor, becoming the first manned Apollo mission to orbit the Moon on Christmas Eve 1968 (and the first to use the famous Saturn V rocket), three days after launch and just seven months before Apollo 11 would land there. And so Commander Frank Borman, command module pilot Jim Lovell and lunar module pilot William A Anders became the first humans to view the far side of the Moon and witness an earthrise. "We came all this way to explore the Moon, and the most important thing is that we discovered the Earth," remarked Anders, who also took the first photos of our planet from space.

The nausea and lack of sleep the crew experienced in orbit seemed a small price to pay for such wonders. Originally planned as an Earth orbit for early 1969, the mission was advanced to a full lunar mission and brought forward two or three months, with NASA fearing the Soviet advance in the Space Race.

### Apollo 9
3 Mar 1969 – 13 Mar 1969


If NASA was to land astronauts on the Moon in a lunar module, it needed to test that the vehicle could detach from – and re-dock with – the orbiting command module. During a 10-day lunar orbit, mission commander Jim McDivitt, command module pilot David R Scott and lunar module pilot Rusty Schweickart

NASA X 8

performed the first manned spaceflight of a lunar module, detaching and re-docking it across a distance of more than 160km.

After overcoming nausea, Schweickart also performed the first spacewalk to test the backpack life-support system, while Scott tested his backpack by spacewalking in the open hatch of the command module. Crucially, the mission proved that the lunar module concept worked and that astronauts could move freely outside the modules using their backpacks. Apollo 9 was a watershed mission, moving the programme beyond lunar orbit to the real possibility of a landing.

## Apollo 10

18 May 1969 – 26 May 1969


If Apollo 9 set the scene for a Moon landing, then Apollo 10 was the dress rehearsal. On 18 May 1969 the mission launched with a clear aim ahead of it – to test the full process of landing on the Moon, without actually landing. But commander Thomas P Stafford, command module pilot John W Young and lunar module pilot Eugene Cernan came tantalisingly close – just 14.5km from the lunar surface. For the most experienced crew of the Apollo programme, it must have seemed like touching distance and they certainly seemed confident of landing if permitted.

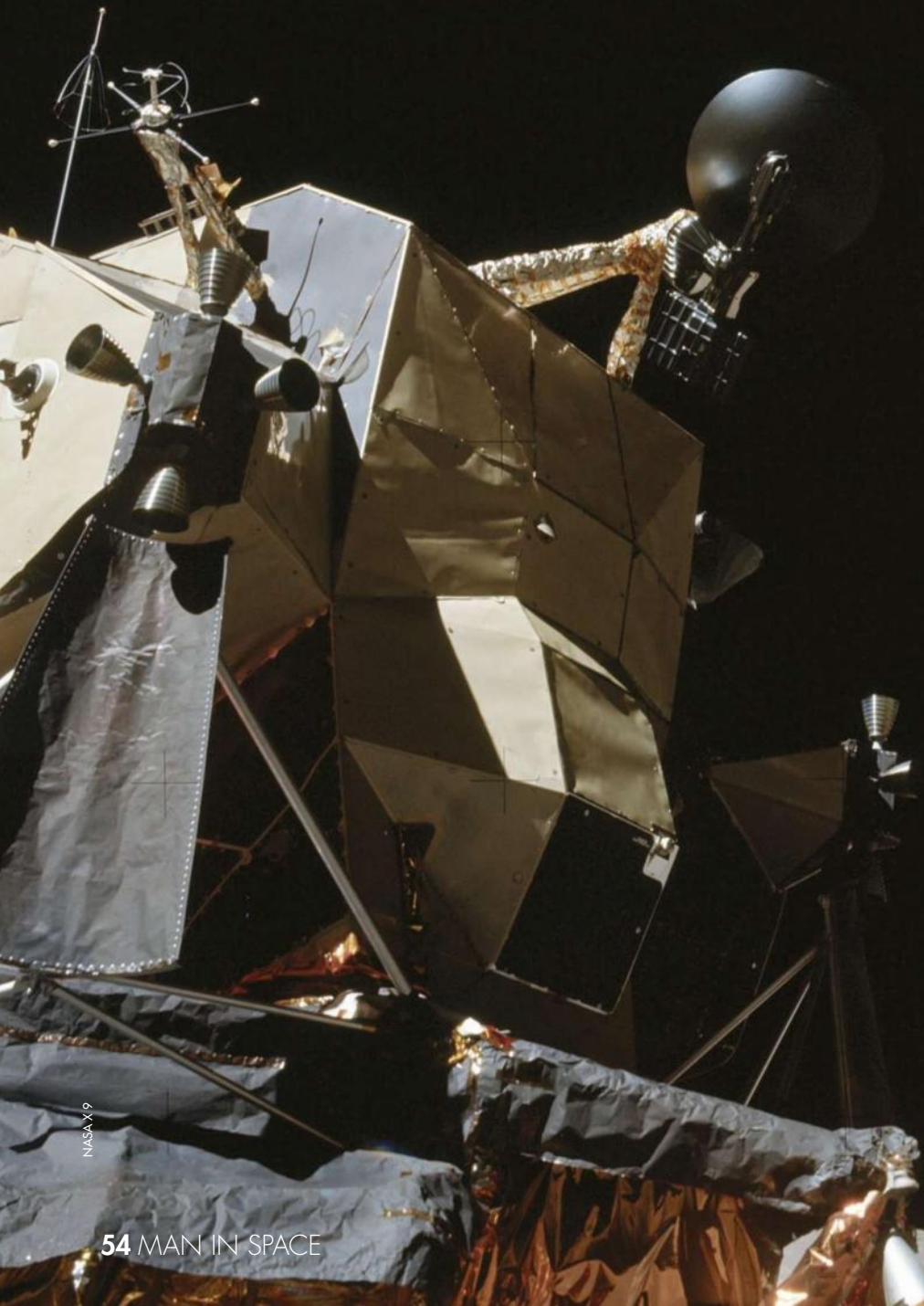
But, aside from the vitally important success of their 'dry run' mission they had to content themselves with achieving the highest recorded speed for a manned vehicle, 39,897km/h, during their return ▸

► to Earth. Cernan would later claim another landmark: the last man to leave a footprint on the Moon, as commander of Apollo 17 in 1972. But for now, the stage was all set for Apollo 11's historic achievement.

## Apollo 11

16 Jul 1969 – 24 Jul 1969


If NASA was to realise the late President Kennedy's goal ("...before this decade is out, of landing a man on the Moon and returning him safely to Earth") the pressure was on. But on 20 July 1969, commander Neil Armstrong and command module pilot Buzz Aldrin touched down triumphantly in the lunar Sea of Tranquility while command module pilot Michael Collins orbited above. Popular belief records the first words spoken on the Moon as, "The Eagle has landed!" – in fact, it was Aldrin's rather more prosaic, "Contact light!" as a probe on one of the module's legs touched the surface. They had done it with seconds to spare – just 25 seconds of remaining fuel – and narrowly avoided a boulder-strewn crater. And so it was that at 10.56pm EDT, Armstrong set his left foot on the surface of the Moon and made history in front of 600 million viewers. He and Aldrin spent the next 21.5 hours there before returning to Earth with Collins and 21.5kg of lunar material on 24 July.



NASA/X9

## Apollo 12

14 Nov 1969 – 24 Nov 1969


Four months after its predecessor realised the dream, Apollo 12 answered the question on everyone's lips: what now? Commander Charles 'Pete' Conrad and lunar module pilot Alan Bean landed their lunar module on the rugged Ocean of Storms about 1,500km west of the Apollo 11 site as command module pilot Richard F Gordon orbited above.

The aim was to see if a module could be landed on a pre-determined spot with rougher terrain, since this was often the most geologically interesting. Conrad and Bean achieved a textbook landing in contrast to the heart-in-mouth touchdown of Apollo 11. Climbing down the ladder, the less-than-statuesque Conrad looked down at the lunar surface a metre below and joked, "Man, that may have been a small one for Neil, but that's a long one for me!" The duo completed the mission by retrieving the camera from the nearby Surveyor 3 probe, which had been sent to explore the Moon's surface two years earlier.

## Apollo 13

11 Apr 1970 – 17 Apr 1970


If Apollo 12 had been a relaxed mission, its successor was anything but. Launched on 11 April 1970, Apollo 13's aim was a third lunar landing. But this was overtaken by a rather more pressing mission – survival – when an oxygen tank exploded in the command service module. The unfortunate crew, commander Jim Lovell (a veteran of the Apollo 8 mission) command module pilot Jack Swigert and lunar module pilot Fred Haise, were forced to shut down the command module to conserve any remaining power and oxygen for re-entry, and use the lunar module as a lifeboat.

Along with freezing temperatures and a shortage of water, the crew faced asphyxiation from the carbon dioxide they were exhaling into the confined space. Mission control's engineering

team devised an ad hoc filtration system, using the lunar module's cleaning facility, and calmly instructed the Apollo crew how to construct it. Such was the euphoria in returning the astronauts safely to Earth, the mission was deemed a 'successful failure'.

## Apollo 14

31 Jan 1971 – 9 Feb 1971


NASA's eighth manned mission launched on 31 January 1971, successfully landing on the Moon's hilly Fra Mauro formation, intended for its ill-fated predecessor. As well as a reminder of NASA's ability to land a module on a very uneven sixpence, Apollo 14 provided the first colour images of the Moon and a chance to study the Moon's geological history through the rocks surrounding the landing site. Commander Alan Shepard and lunar module pilot Edgar Mitchell carried out several surface studies of the material and collected over 42kg of rocks for further analysis, as command module pilot Stuart Roosa orbited above.

As well as a scientific success, the mission held personal significance for Shepard, who had overcome Ménière's Disease – an inner ear disorder – to be there. He celebrated by being the first man to hit a golf ball on the Moon. Indeed, the crew were originally scheduled for the previous mission, so they had fate to thank that they were there at all.

## Apollo 15

26 Jul 1971 – 7 Aug 1971


Having landed on the Moon, NASA was beginning to think that was the easy bit – the hardest part was staying there. To this end, Apollo 15 launched on 26 July 1971 as the first of the 'J' missions, designed for a longer stay. Commander David Scott and lunar module pilot James Irwin spent nearly three days on the surface, using the iconic lunar roving vehicle (LRV) for the first time to gather rock samples from much further afield, and conduct more detailed scientific studies, than ever before.

Command module pilot Alfred Worden was also busy in orbit using a scientific instrument module (SIM) to study the Moon from above. The SIM included, among other cutting-edge technology, a panoramic camera that provided stunning lunar images and a lunar sub-satellite to measure the Moon's gravity field and solar particles. As it splashed down on 7 August, NASA proudly declared Apollo 15 to be the most successful manned flight ever.

## Apollo 16

16 Apr 1972 – 27 Apr 1972

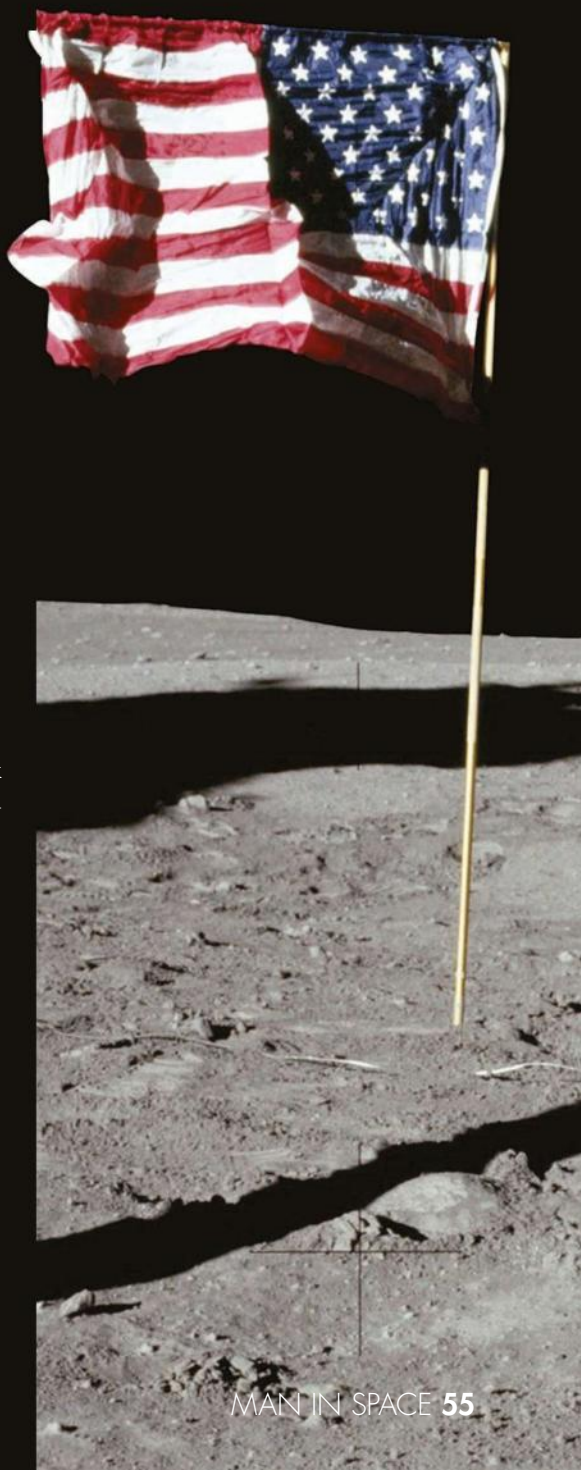

Its predecessor had focused NASA's thoughts on the possibility of extended lunar stays, but a command module malfunction meant Apollo 16's stay was cut short – and, in fact, nearly didn't happen at all. "I'd practised the landing 2,000 times – and crashed 1,000 times – in a simulator," recalls lunar module pilot Charles Duke. "But just before we were about to do it for real, we got the signal to abort. We were so close! Fortunately, mission control solved the problem and four hours later we were cleared to land."

Duke and commander John Young made a descent into the Descartes Highlands, the only lunar landing on high ground. As with Apollo 15, the mission deployed the lunar rover vehicle and a sub-surface satellite, with the crew conducting 26 separate experiments. In orbit, command module pilot Ken Mattingly mapped an area around the lunar equator and completed a spacewalk on the return journey to retrieve film and data from the module's SIM bay.

## Apollo 17

7 Dec 1972 – 19 Dec 1972


The final lunar landing to date was also the first night launch of an American manned spaceflight, at 12.33am EST on 7 December 1972. It was fitting that it broke other records too – the longest manned lunar landing flight, the greatest distance by a lunar vehicle (35km), the largest haul of lunar material (110.4kg) and the longest lunar orbit. Lunar module pilot (and geologist) Harrison Schmitt was also the only scientist on the Moon. And, of course, as the last man back in the lunar module, commander Eugene Cernan has the distinction of leaving the last set of footprints on the lunar surface. For command module pilot Ron Evans, it was to be his only space flight, having been backup for Apollo 14. For posterity, the crew left a plaque, signed by them and President Nixon, which read: "Here man completed his first explorations of the Moon. December 1972 AD. May the spirit of peace in which we came be reflected in the lives of all mankind".



# IN PICTURES:
# MOON MISSIONS 1968-1972
# THE APOLLO PROGRAMME

▲ Apollo 7 clears the gantry, carrying Wally Schirra, Donn Eisele and Walter Cunningham into orbit on 11 October 1968. It was the first manned mission after the tragedy of Apollo 1's fatal fire during ground-based tests in 1967

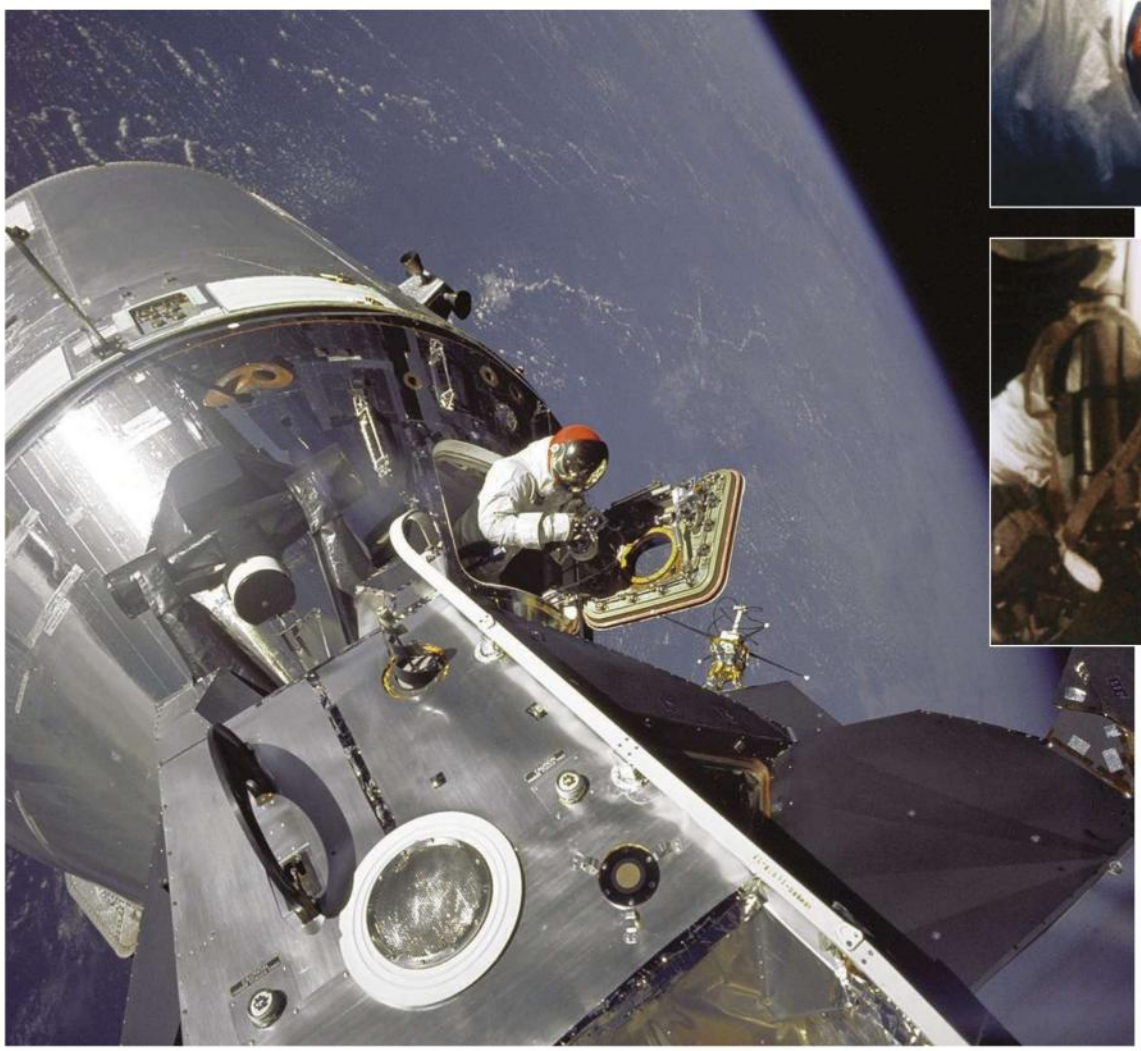
▲ The Saturn IB rocket of Apollo 7, snapped at over 10km above the Atlantic Ocean on its way into space. The 68m-tall Saturn IB was the forerunner of the 110m-high Saturn V, a far more powerful rocket capable of lifting the lunar and command/service modules into orbit

▶ Lunar module pilot Walter Cunningham at work during Apollo 7. The mission carried no lunar module, but Cunningham performed a number of system tests

MASA X 8

▲ The crew of Apollo 8 were the first men to see the full globe of Earth in the blackness of space. Astronaut William Anders took this famous photo of our planet rising over the Moon's horizon

▼ Still pictures from film shot aboard Apollo 8 capture, from top to bottom, mission commander Frank Borman, lunar module pilot William Anders and command module pilot Jim Lovell



◀ David Scott stands in the hatch during Apollo 9, a mission to test the lunar module by flying it in Earth orbit. The lunar module is docked to the command/ service module

◀ The command/service module of Apollo 10, photographed from the lunar module. Apollo 10 was a dry run for the Moon landing

▼ Apollo 10 passed just 14km above the lunar surface. The astronauts photographed spectacular features like this 'rille' (channel)

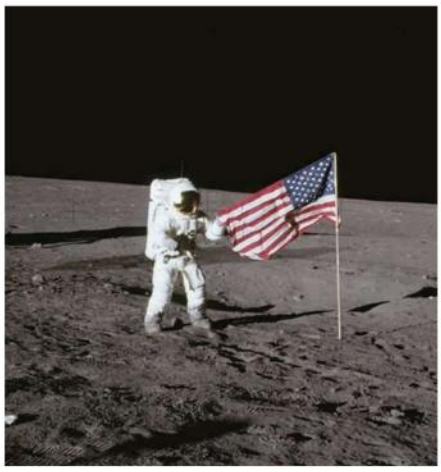
▼ A bootprint on the lunar surface left by Buzz Aldrin, the second man on the Moon. This photo was taken on 21 July 1969

NASA X 9

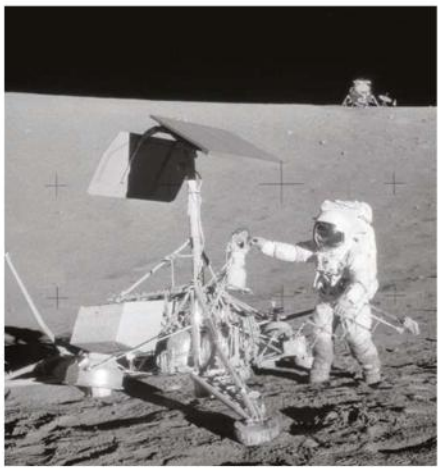
◀ Buzz Aldrin is photographed during the Apollo 11 mission by commander Neil Armstrong, who is visible in his visor

▲ Apollo 11's Neil Armstrong (top) and Buzz Aldrin (bottom) in the lunar module after the historic first moonwalk, which lasted for two hours and 15 minutes

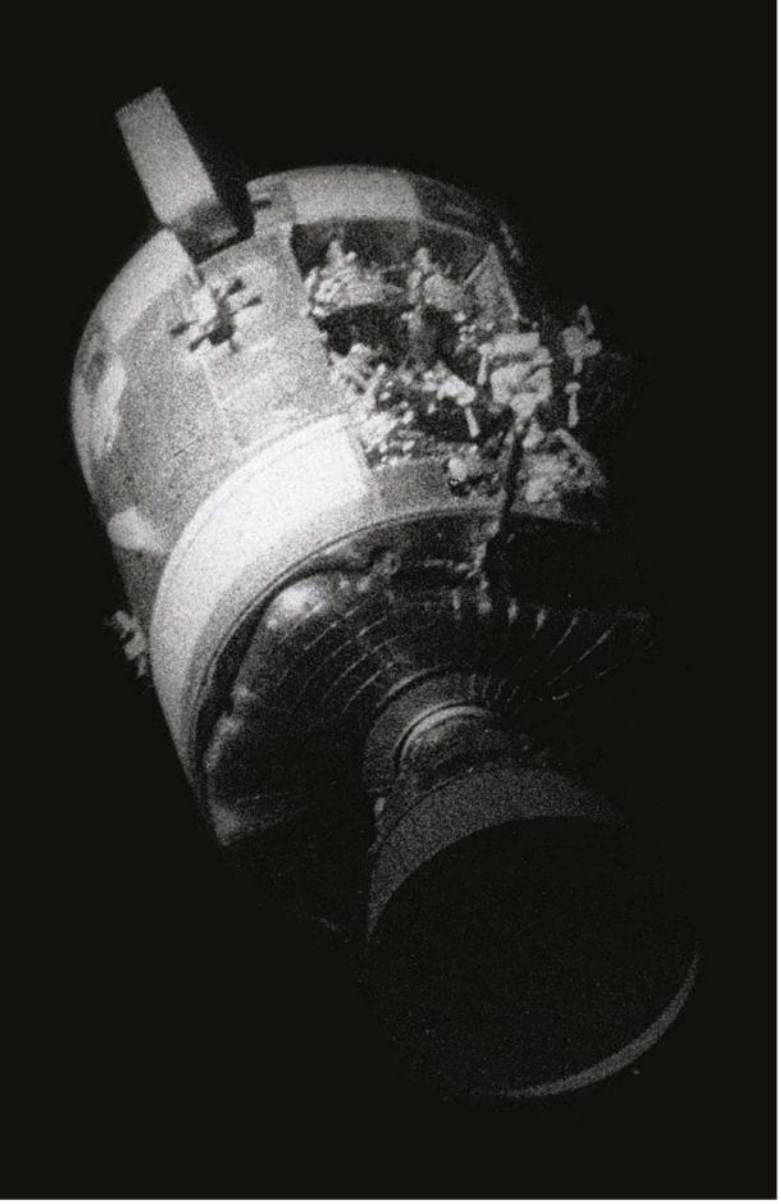
▲ Apollo 12's Alan Bean collects samples of lunar soil. Bean and Pete Conrad spent over seven hours on the lunar surface



▲ Commander Pete Conrad plants the flag during Apollo 12 in November 1969. There was no TV footage as the camera burned out



▲ Pete Conrad reaches the unmanned Surveyor 3 probe during Apollo 12. Surveyor 3 had arrived on the Moon two years earlier



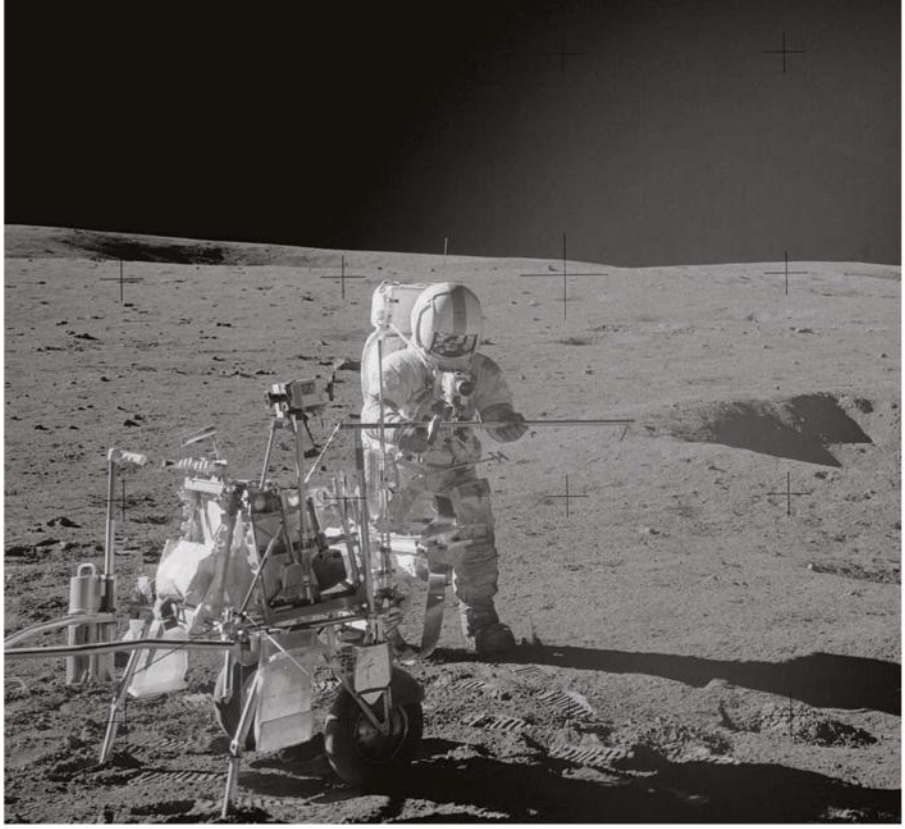
◀ The damage to Apollo 13's service module was caused by an oxygen tank that exploded, ripping the outer aluminium skin. The lunar module had to be used as a 'lifeboat'

▶ Following the Apollo 13 explosion, mission control (top) devised a makeshift apparatus, which was built by the crew (middle) to filter poisonous carbon dioxide from the lunar module's air. Despite several near-catastrophic events, astronauts Jim Lovell, Fred Haise and Jack Swigert returned safely to Earth (bottom)

NASA X 10, NASA/SCIENCE PHOTO LIBRARY

◀ The Saturn V rocket of Apollo 14 powers away from the launch tower on 31 January 1971, nine months after the eventful Apollo 13

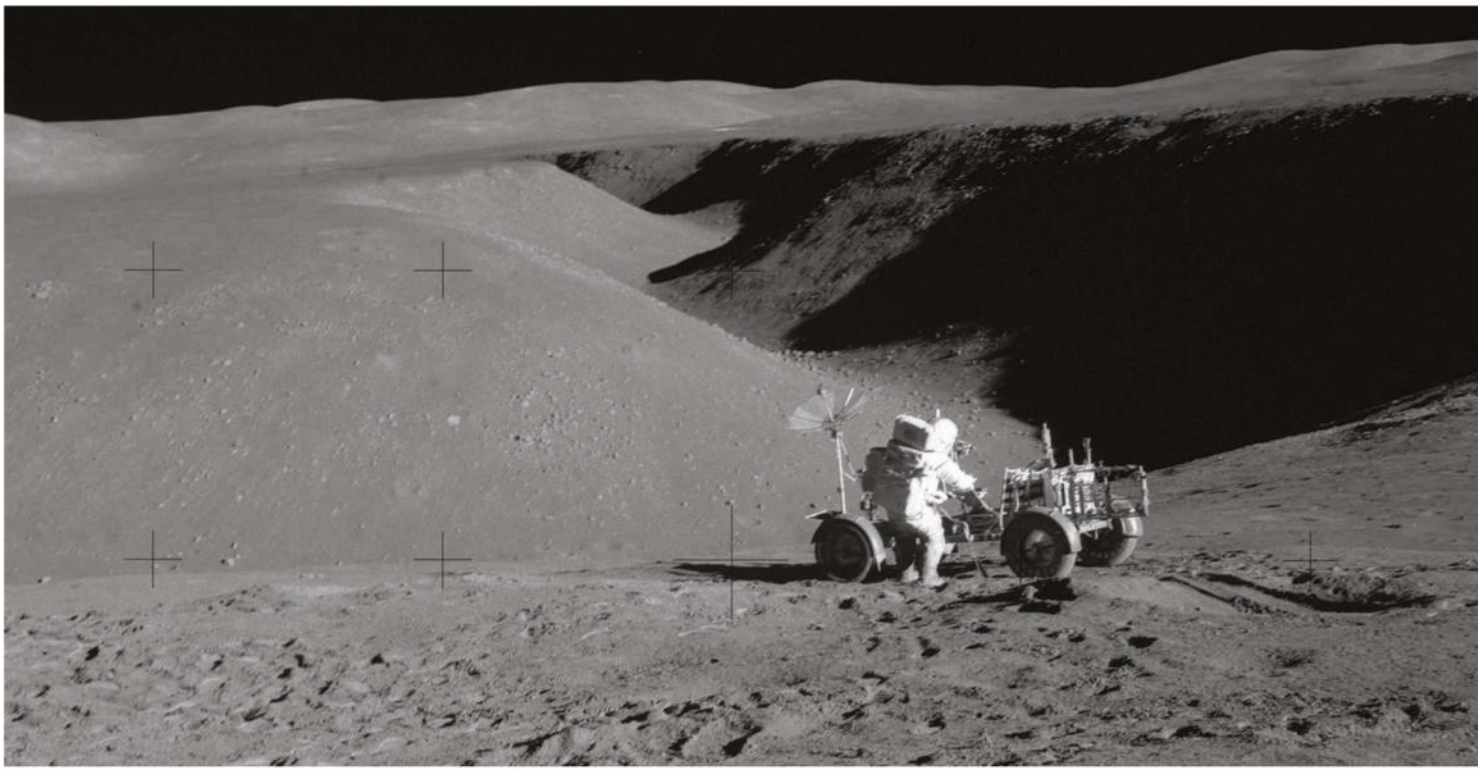
▲ Apollo 14 performed significantly more science than its predecessors. The crew walked to 13 lunar locations to perform experiments

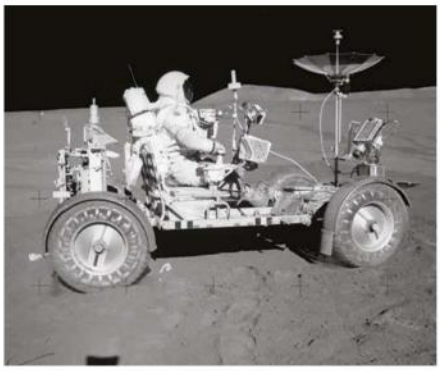


◀ Alan Shepard with the modular equipment transporter, which was used to haul tools and samples of lunar material during Apollo 14

▼ Apollo 14's iconic moment: Alan Shepard shows off his golf swing in the Moon's low gravity by hitting a golf ball over 200m

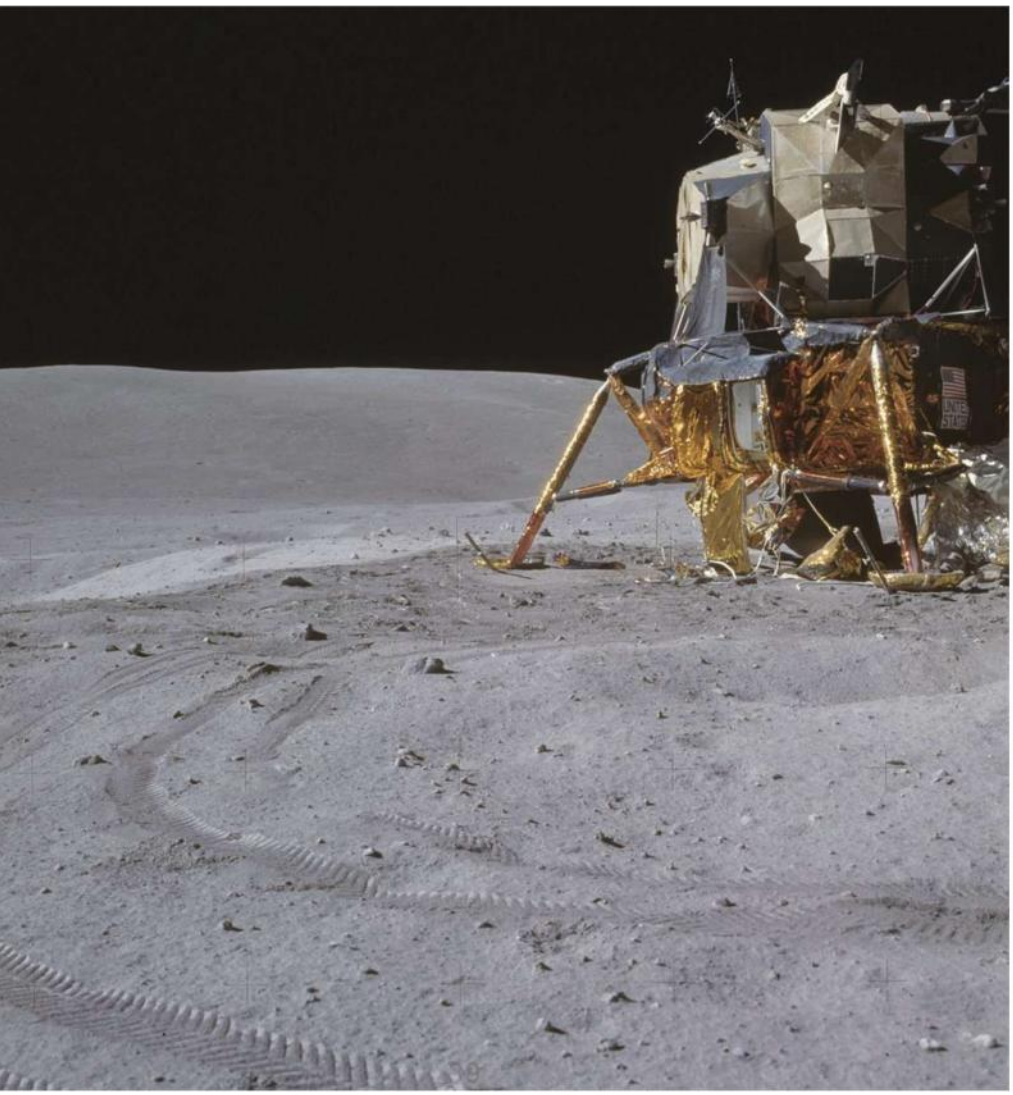
▼ Apollo 15 was the first mission to deploy a lunar rover. Here it is at Hadley Rille, a V-shaped gorge averaging 400m deep





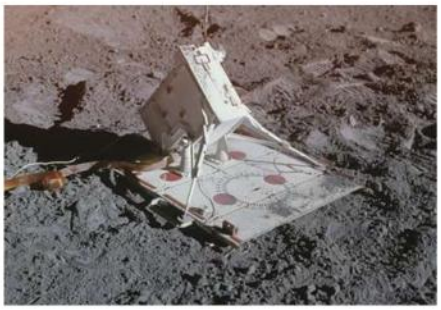
◀ Apollo 15's David Scott collects geological samples at a site 125m from the lunar module. He's seen here using a surface drill

◀ Astronaut David Scott drives the lunar rover during Apollo 15. The battery-powered buggy had to be unfolded before it could be used



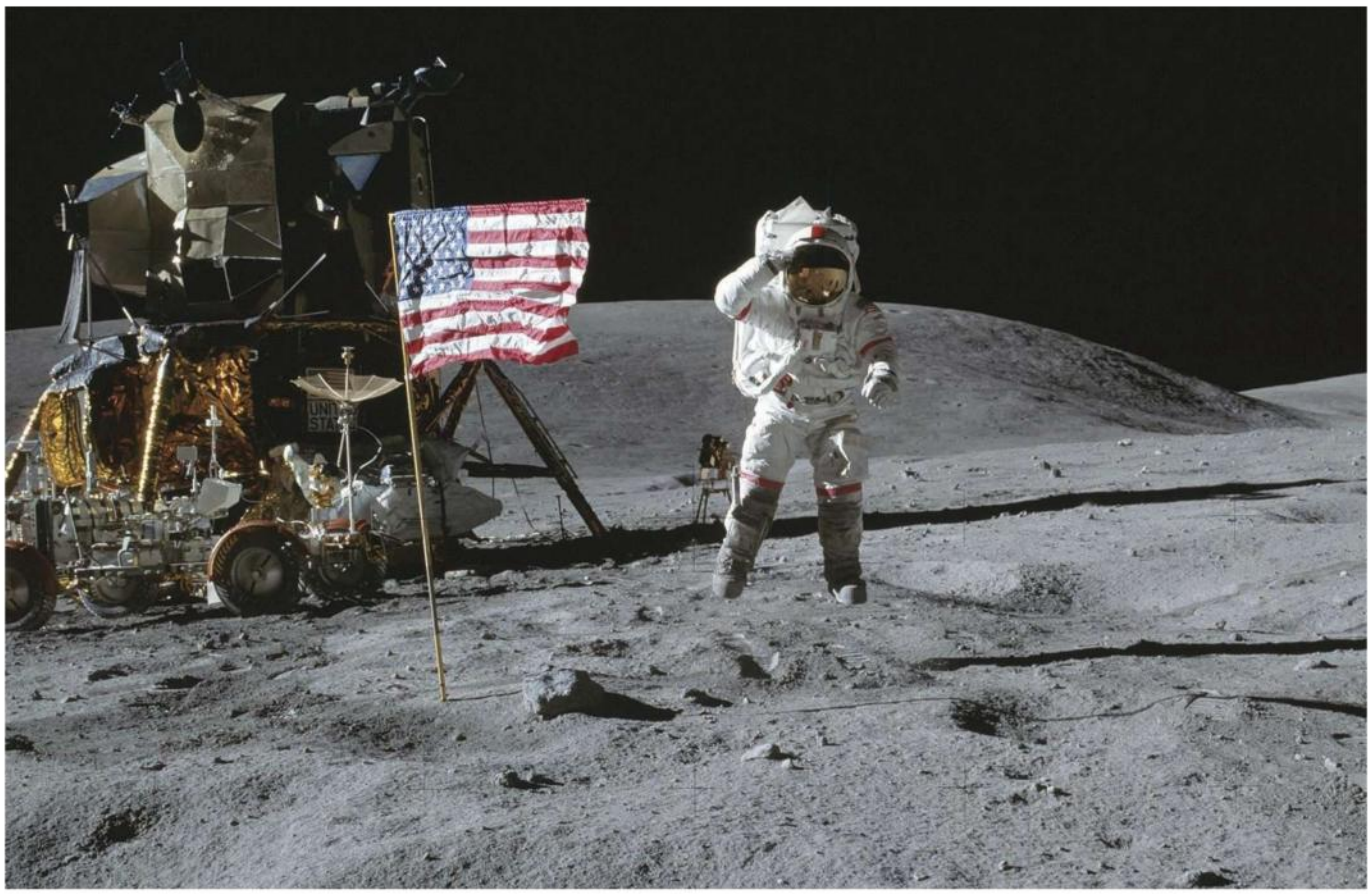
◀ Apollo 16's lunar module in the Descartes Highlands. It was the first Apollo mission to explore a different type of lunar terrain

▼ During Apollo 16, John Young put the rover through a 'grand prix' test of its capabilities, including hairpin turns and sudden stops



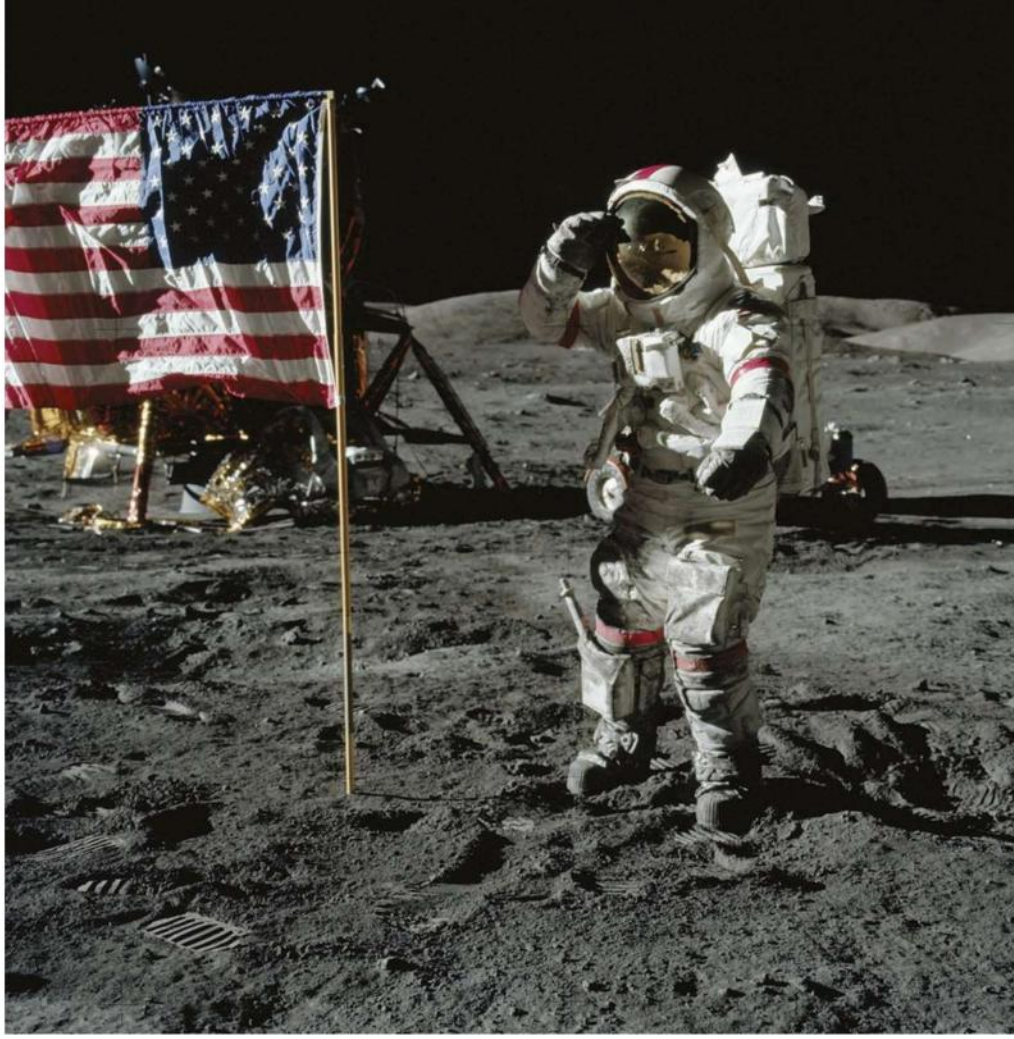
▲ Apollo 16 left a pack of four grenades, which were remotely detonated to determine the rock's structure by studying seismic waves

▼ Apollo 16 commander John Young captured in mid-jump as he salutes the US flag



NASA X 10

▼ Lifting off on 7 December 1972, Apollo 17 was the final Apollo mission and also the first night launch of a US manned spaceflight



▲ Apollo 17's Eugene Cernan salutes the US flag. Commander Cernan is the last man to have left a footprint in the lunar surface

◀ Eugene Cernan, commander of Apollo 17. With Harrison Schmitt, he spent a total of 22 hours exploring areas of geological interest

▲ Originally a geologist, Apollo 17 astronaut Harrison Schmitt was the first and only scientist to walk on the Moon

▶ The lunar rover, controlled by a stick between the two seats, was driven 36km across the Moon's surface during Apollo 17. Harrison Schmitt is pictured jumping in

▲ Harrison Schmitt stands next to the US flag, with Earth above, on 11 December 1972. Three days later, Apollo 17 left the Moon

NASA

◀ Astronaut Paul Weitz takes the blood pressure of fellow crew member Joseph Kerwin aboard the Skylab space station

# LIVING IN SPACE

**WITH THE MOON** missions now over, long-duration stays in Earth orbit became the new focus of space programmes either side of the Cold War divide. NASA's Skylab was a glorious last hurrah for the Saturn V launcher that had carried men to orbit and beyond. But it was the Soviets who excelled at endurance missions, albeit not before suffering a terrible tragedy

# Station to station

## Through seven Salyuts to Mir, the Soviet Union learned how to live in space the hard way

WORDS: SEAN BLAIR

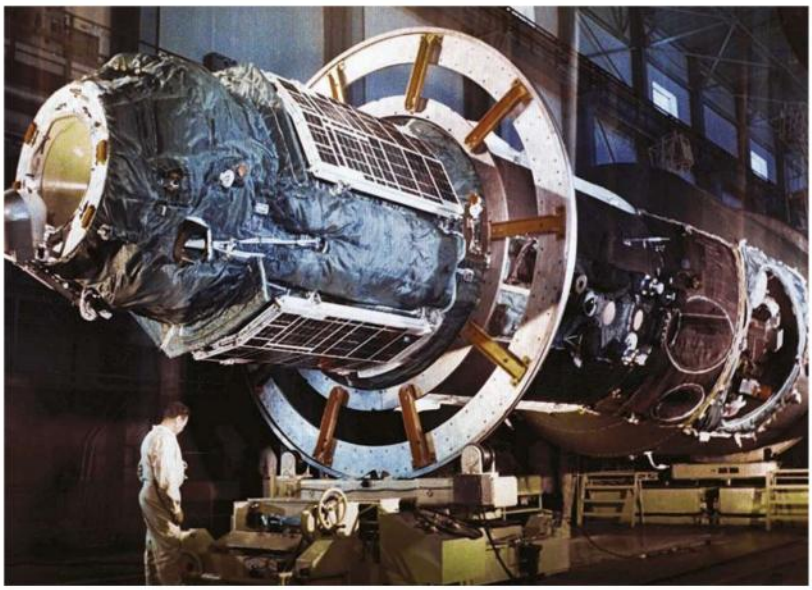
**AFTER THE MOON** landing, Earth-orbiting space stations became the new focus of the space race. Soviet efforts were marred by early tragedy, but with their US rivals hamstrung by lack of funds, the USSR recovered to become the undisputed leader in long-term orbital living.

"Development of the space station is as inevitable as the rising of the Sun," wrote Wernher von Braun for *Collier's* magazine in 1952. In less than 20 years, he was proved right.

The idea of a long-duration orbital outpost dates back to US journalist Edward Everett Hale's 1869 short story *The Brick Moon*, in which a group of technicians are trapped inside an artificial satellite. The accidental passengers jump up and down to send Morse code signals to Earth, receiving supplies in return.

In Russia, deaf science teacher Konstantin Tsiolkovsky developed the concept. During the early part of the 20th century, the theoretical father of spaceflight put together blueprints for rotating stations with artificial gravity and lush greenhouses. Today, Tsiolkovsky's portrait adorns the International Space Station.

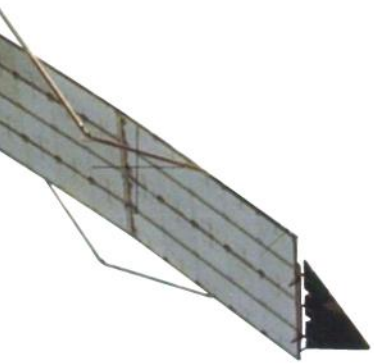
Von Braun's hero, Romanian-born Hermann Oberth, proposed space wheels for Earth



▲ A Salyut station being assembled at the Khrunichev space production facility in September 1971

observation, military interventions and mirror-based weather control. And when Arthur C Clarke proposed geostationary communications in 1945, he assumed manned stations not satellites – crewmen were needed to change blown vacuum tubes.

Von Braun himself believed orbital base camps represented the logical first steps into space. In *Collier's*, he suggested an initial space station crewed by monkeys to test space-based living. But the 1960s Space Race changed all that, and men walked on the Moon without the need for a staging post. Automated satellites took on the communications and weather forecasting tasks proposed for manned bases, though the Cold War superpowers kept a strong interest in the concept. In 1963, the Pentagon announced plans for a two-person Manned Orbital Laboratory. This military project was later cancelled, but provoked a Soviet reaction.



## Russia's response

Soviet space efforts were decentralised into competing 'design bureaus'. Space station development was split between a military-sponsored Almaz ('Diamond') Orbital Piloted Station and a civilian Long-Duration Orbital Station (DOS, in Russian), prepared by the late Sergei Korolev's OKB-1 bureau.

The Soviets had reacted to the US Moon landing by denying that they had ever been in the race. "Soviet science regards the setting up of orbital stations, with changeable crews, as man's main road into outer space," remarked premier Leonid Brezhnev in October 1969. Then the US announced plans for Skylab. To beat Skylab into orbit, the rival Soviet space designers hastily agreed to collaborate.

The result was an Almaz hull fitted with Soyuz-derived equipment, including solar panels. Salyut 1 ('Salute 1', acknowledging the 10th anniversary of Yuri Gagarin's flight) launched on 19 April 1971. It was about 15m long with a maximum 4.15m diameter – its size dictated by that of its Proton launcher and Russian rail infrastructure.

Salyut 1 was Earth's first space station, but its destiny was to prove tragic. On 23 April, Soyuz 10 aborted its occupation due to docking failure. Six weeks on, the three-man Soyuz 11 crew fared better. Cosmonauts Georgi Dobrovolsky, Viktor Patsayev and Vladislav Volkov lived on Salyut 1 for 23 days.

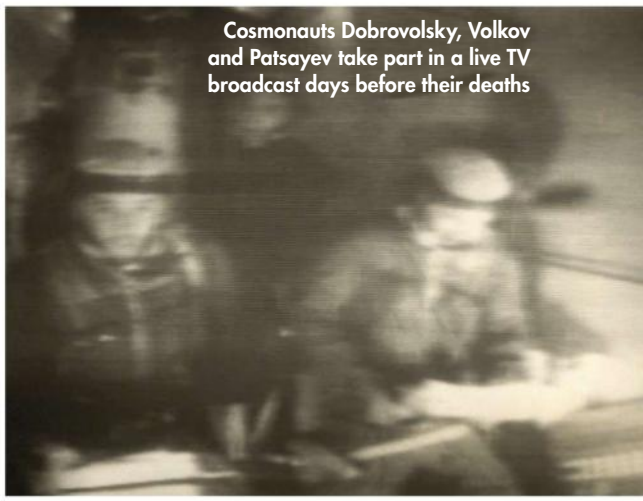
By today's standards, Salyut 1 was crude: weighted to maintain a roughly terrestrial orientation, it had rocket thrusters for manual steering and its operating lifetime was limited by non-replaceable fuel. But compared to the claustrophobic space capsules that had been built before, Salyut 1 was a palace. It was equipped with well-stocked refrigerators, a dining table, library, exercise treadmill, a semi-private toilet and even a greenhouse to cultivate the first weightless plants. Through a shift system, its crew performed Earth monitoring and biological, astronomical and defence-related experiments round the clock.

TV broadcasts brought the crew national fame, but various problems they met were not communicated. A cover failed to jettison from their main telescope, rendering many instruments useless, and on first boarding Salyut 1 they smelled something burning. Cycling the air got rid of the odour, but 10 days later they had to tackle a small electrical fire, making them feel unsafe.

On 29 June 1971, the crew left Salyut 1, but upon reaching the ground all three were dead. A faulty Soyuz valve had sucked away their air and the trio had not worn spacesuits. Salyut 1 de-orbited that October.

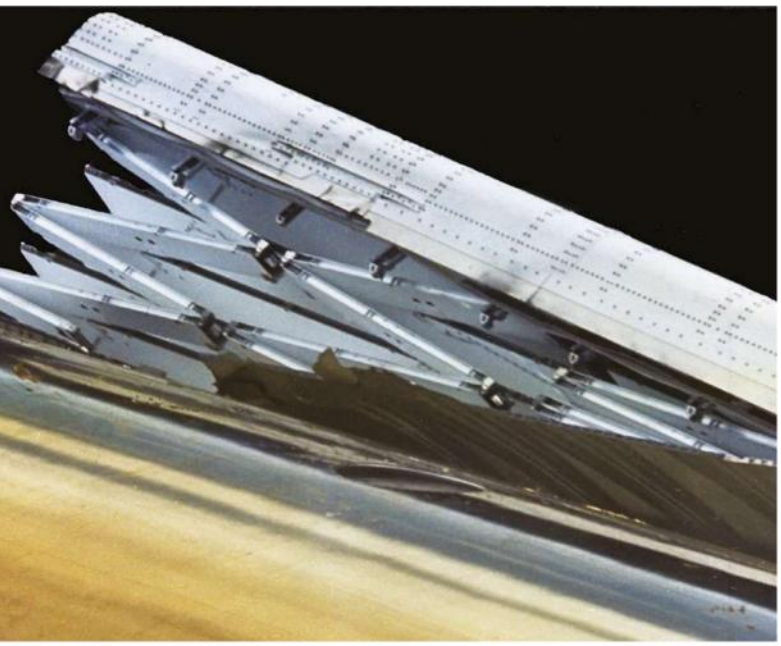
The Soviets tried and failed to get two more stations up before NASA, with both Almaz and DOS designs now called Salyuts. The third, Salyut 2, made orbit a month earlier than Skylab, but catastrophically depressurised a fortnight later, perhaps due to debris from its own rocket.

Accordingly, when Skylab launched on 14 May 1973 it was alone. Lacking the budget to construct a station from scratch, von Braun had converted a Saturn upper stage into a fully-fledged 'orbital workshop' incorporating a large solar telescope and a gyroscope-based orientation system. ►



Cosmonauts Dobrovolsky, Volkov and Patsayev take part in a live TV broadcast days before their deaths

◄ Launched on 14 May 1973, Skylab was NASA's first space station, but the US would soon lag behind in long-stay missions



▲ On launch, one of Skylab's solar arrays failed to deploy (left). A detached heat shield also meant a 'parasol' (right) had to be installed by the Skylab 3 mission

► A turbulent trip into orbit saw Skylab lose a sunshield and one of two main solar wings, while the other stayed jammed in its folded position. Overheated and underpowered, Skylab appeared to be doomed. But the three-man crew sent in an Apollo capsule to repair it disagreed. "We can fix anything," was lunar veteran Pete Conrad's slogan.

Astronaut Paul Weitz unsuccessfully tried to free the solar wing during an initial Apollo spacecraft flyby. Boarding Skylab felt like entering a blast furnace, with interior temperatures up to 52°C. So the astronauts extended a parasol through the airlock, reducing the heat. Next, Conrad and Joe Kerwin performed an EVA to pull the solar wing out. It released suddenly, sending both men flying. But their tethers jerked them safely back to the station, which became their home for a then record-breaking 28 days. Two further crews dwelt there for 60 and 84 days, respectively.

## Life on Skylab

While Salyut 1 resembled a train carriage, the two-storey Skylab was more like a family home, complete with kitchen and shower. Measuring 36.1m by a maximum 6.6m, Skylab was so large that astronauts test-flew jetpacks inside, jogged on its walls *2001*-style (Skylab's gyroscopes dampened the unexpected oscillations) and employed a PA system to communicate – sound didn't carry well in the thin, pure-oxygen air. The experiments with which crew members were tasked ranged from observations of solar flares and Comet Kohoutek, to watching spiders spin webs in microgravity.

Skylab fell empty for the last time in February 1974. NASA had completed a second station but had no money to fly it. Skylab itself de-orbited in July 1979, littering the Australian outback with debris. From then on, the USSR had no competition.

Salyut 3 – the second Almaz – made orbit on 25 June 1974. Aiding its surveillance function, the station had Skylab-style gyroscopes to actively maintain its orientation, and a film return capsule. Moveable solar panels boosted available power. And remarkably, a 23mm calibre machine gun was built into its hull. It was only test-fired while the station was unmanned; occupants would have experienced serious reverberation. The two-man Soyuz 14 crew spent 15 days aboard, but Soyuz 15's docking was aborted after nearly colliding at 72km/h.

Salyut 3 de-orbited in January 1975, by which time the civilian Salyut 4 had already been up for a month. It became the first Soviet station to host two separate expeditions: the Soyuz 17 crew stayed 29 days, while reluctant Soyuz 18 cosmonauts stuck it out a total of 62 days, even as the interior environment deteriorated, with portholes fogging up and mould growing along walls.

They remained in space to coincide with the first joint US–USSR space mission. On 17 July 1975, Apollo and Soyuz spacecraft performed a

▼ (L-R) Skylab 3 astronauts Alan Bean and Jack Lousma float in Skylab's Orbital Workshop, while Edward Gibson (Skylab 4) sails through a hatch

NASA X 7, RIA NOVOSTI/SCIENCE PHOTO LIBRARY, CORBIS

▲ Russian space station Salyut 7 with the Soyuz T-14 'ferry' craft docked in September 1985

deceptively simple docking. No-one foresaw how big an influence this achievement would be on future space station evolution. Meanwhile, that November saw the first unmanned Soyuz docking with Salyut 4. It lingered for three months as an endurance test.

The last Almaz, Salyut 5, flew on 22 June 1976. Its first occupants had their stay cut short after a personality clash and complaints of sickening smells. Soyuz 23's docking was aborted due to a malfunction, so it was left to Soyuz 24 to investigate in February 1977. They entered wearing breathing apparatus but Salyut 5's environment turned out to be fine. Salyut 5's re-entry in August 1977 marked the end of military Salyuts, which had proven less productive than spy satellites.

## The second wave

For just over a month there was no station in orbit. Then, on 29 September 1977 came Salyut 6. This second-generation station combined features from both Almaz and Soyuz designs and incorporated docking ports on both sides, meaning two crews could be hosted simultaneously. Its air, water and fuel could also be re-supplied using an unmanned Soyuz called Progress. Its resulting lifetime spanned almost five years, instead of a few months. A total of 16 crews visited it. Once its last occupants left, Salyut 6's size grew with the docking of a military-developed TKS 'ferry' craft.

▼ (Right to left) Original Salyut 6 cosmonauts Yuri Romanenko and Georgi Grechko welcome visitors Aleksey Gubarev and Vladimir Remek

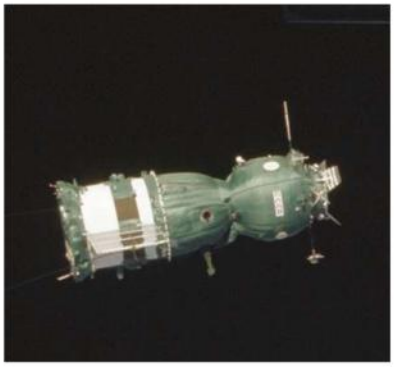
Salyut 6 was still in space when Salyut 7 reached orbit on 19 April 1982. Resupplied by Progress and TKS spacecraft, the station hosted five long-term crews (one chalking up 237 days in orbit) and an equal number of shorter-stay visitors. Over more than eight years of life, Salyut 7 proved exceptionally robust, not least because cosmonauts made some challenging on-site repairs. In 1983, a severed fuel line leaked corrosive propellant. A total of five EVAs repaired the damage, proving that Soviet spacewalkers were the equal of US Shuttle crews.

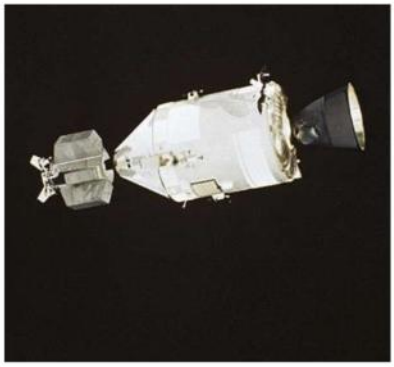
In 1985, the entire station needed salvage. The unmanned Salyut 7 lost power and drifted derelict in space. In a daring move, Vladimir Dzhanibekov and Viktor Savinykh boarded the dead station from Soyuz T-13. Wearing furs, they found the cabin frozen, with stagnant air and studded with icicles. The pair brought the station back online – though it took over a week to bring its temperature above freezing. The failure was explained by a single faulty battery sensor. The restored Salyut 7 went on to host two further crews.

On 19 February 1986, Salyut 7 was joined in space by its third-generation successor, Mir. Derived from Salyut, Mir's 'base block' had six docking ports, enabling the construction of a multi-module space station. In May 1986, the first two-man Mir crew performed a day-long trip to Salyut 7. They stayed aboard the older station for 50 days, stripping it of 350 kg of equipment for reuse on Mir.

This abandoned last Salyut stayed in orbit until February 1991, but these experimental stations had served their purpose, preparing for the operational – and steadily growing – Mir space station.

▼ On 17 July 1975, Soyuz (L) and Apollo (R) craft docked in space, marking a new era of collaboration between the USSR and the US





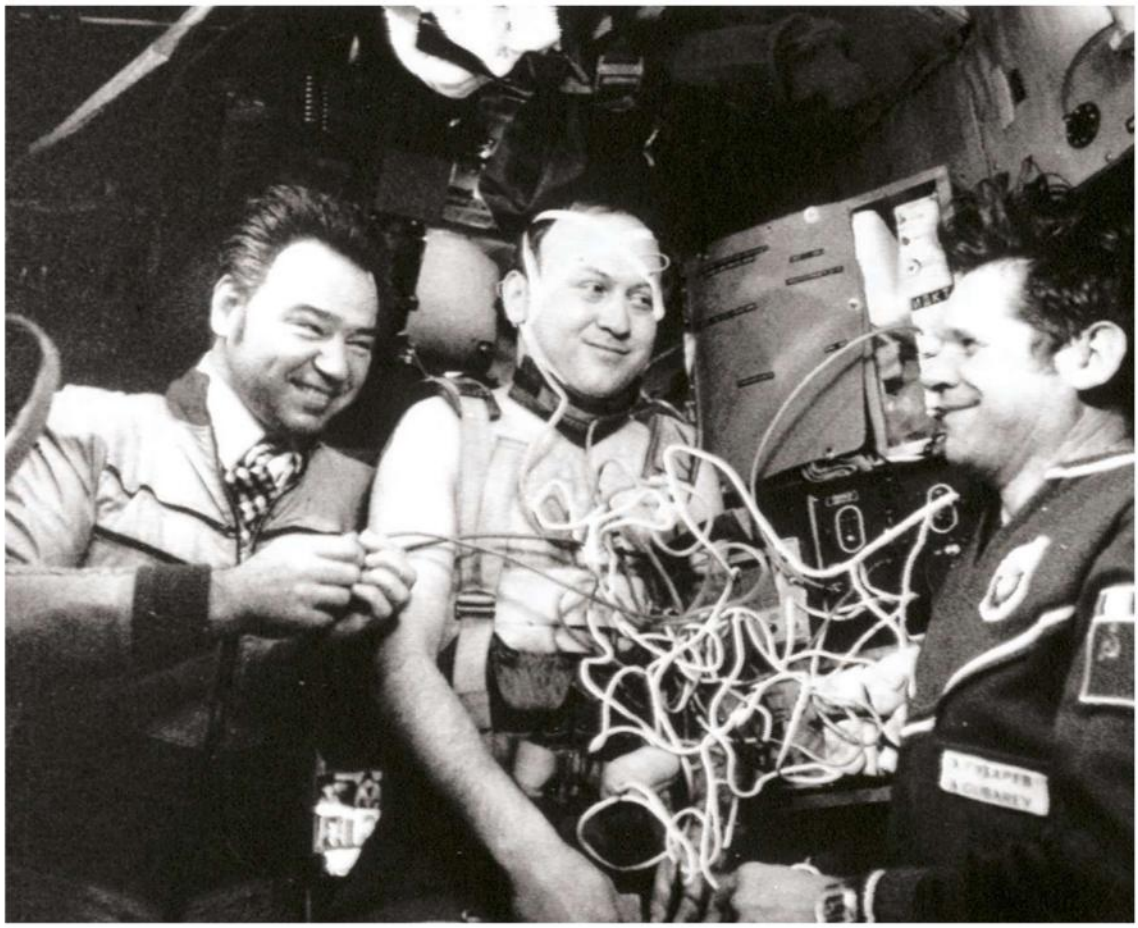
# IN PICTURES:
# THE FIRST SPACE STATIONS
# SALYUT AND SKYLAB

◀ Salyut 7, the Soviet Union's final Salyut space station, with a Soyuz spacecraft attached. It was manned between 1982 and 1986 and, like Salyut 6, had two docking ports

▲ Soviet cosmonaut Viktor Gorbatko (left) and Pham Tuan (right), the first Vietnamese in space. On 23 July 1980 they flew to Salyut 6, where Tuan grew plants and photographed Vietnam for mapping purposes

RIA NOVOSTI/ALAMY, RIA NOVOSTI/SCIENCE PHOTO LIBRARY X 3, BETTMAN/CORBIS

▲ Soviet mission control at Baikonur, Kazakhstan, maps the progress of a manned Salyut space mission



◀ Czech cosmonaut Vladimir Remek tests a pressure suit aboard Salyut 6 in March 1978. Russian cosmonauts Aleksey Gubarev and Georgi Grechko look on

▶ Svetlana Savitskaya was the first woman to walk in space, on 25 July 1984. She spent over three and a half hours outside the Salyut 7 space station

▲ The curve of the Earth seen from the Salyut 6 space station. The station's second docking port enabled visiting crews to make short, week-long stays in orbit

▼ Crowds pack Red Square, Moscow, to mourn the deaths of Georgi Dobrovolsky, Vladislav Volkov and Viktor Patsayev in July 1971. They died in space when their cabin depressurised prior to re-entry

RIA NOVOSTI/SCIENCE PHOTO LIBRARY X 2, BETTMAN/CORBIS, NASA

▼ NASA's Skylab space station in 1974. Skylab was in orbit from 1973 to 1979, although it was only manned for 171 days. Its crews performed many scientific experiments, including detailed studies of the Sun

▲ The final Skylab spacewalk took place on 3 February 1974. Astronaut Edward Gibson is seen here above the hatch, with a tether line extending from inside the space station to supply him with oxygen

◀ Astronaut Gerald Carr carries out the manoeuvring equipment experiment (M509) on Skylab. The experiment was designed to select the best hardware for future EVAs (extravehicular activity)

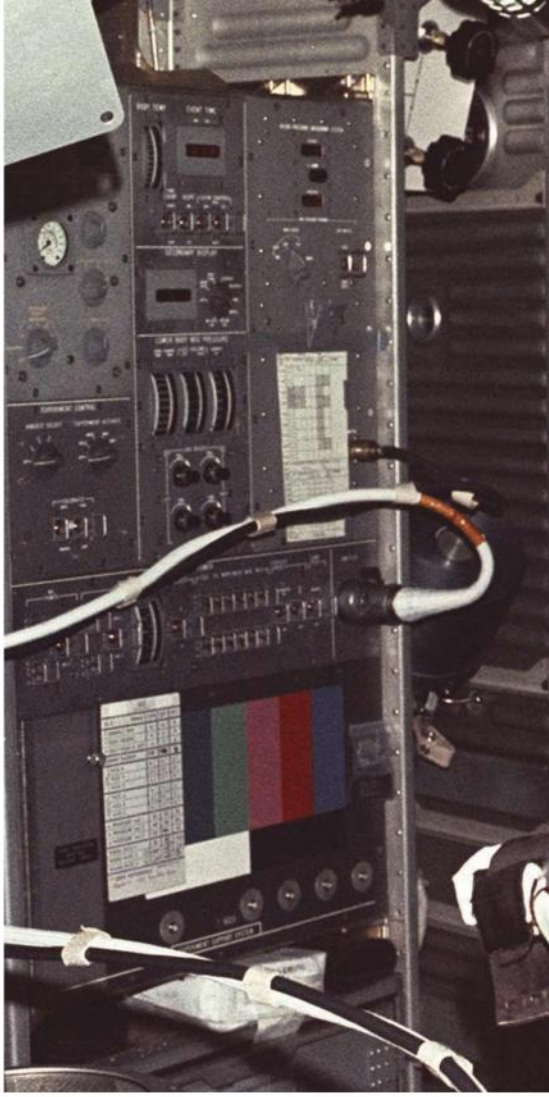
▲ The food aboard Skylab was far superior to the liquefied refreshments of previous NASA missions. Astronauts had a tray that could heat individual portions, enabling them to customise their menus

NASA X 6

◀ Commander of the Skylab 4 mission, Gerald Carr, balances William Pogue on his finger in the zero gravity of Skylab

▼ Ed Gibson monitors the control console for the Apollo Telescope Mount aboard Skylab. It was used to monitor events such as solar flares

▼ Gerald Carr floats in the forward dome area of Skylab's Orbital Workshop – the biggest section of the space station, made from an empty stage of a Saturn IB rocket



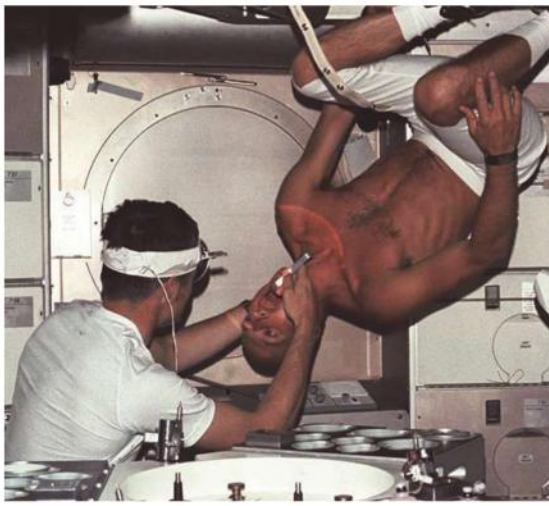
◀ Astronaut Joseph P Kerwin is strapped into sleep restraints in Skylab. The special cap monitored his sleep patterns by measuring electrical activity in the brain

NASA X 6

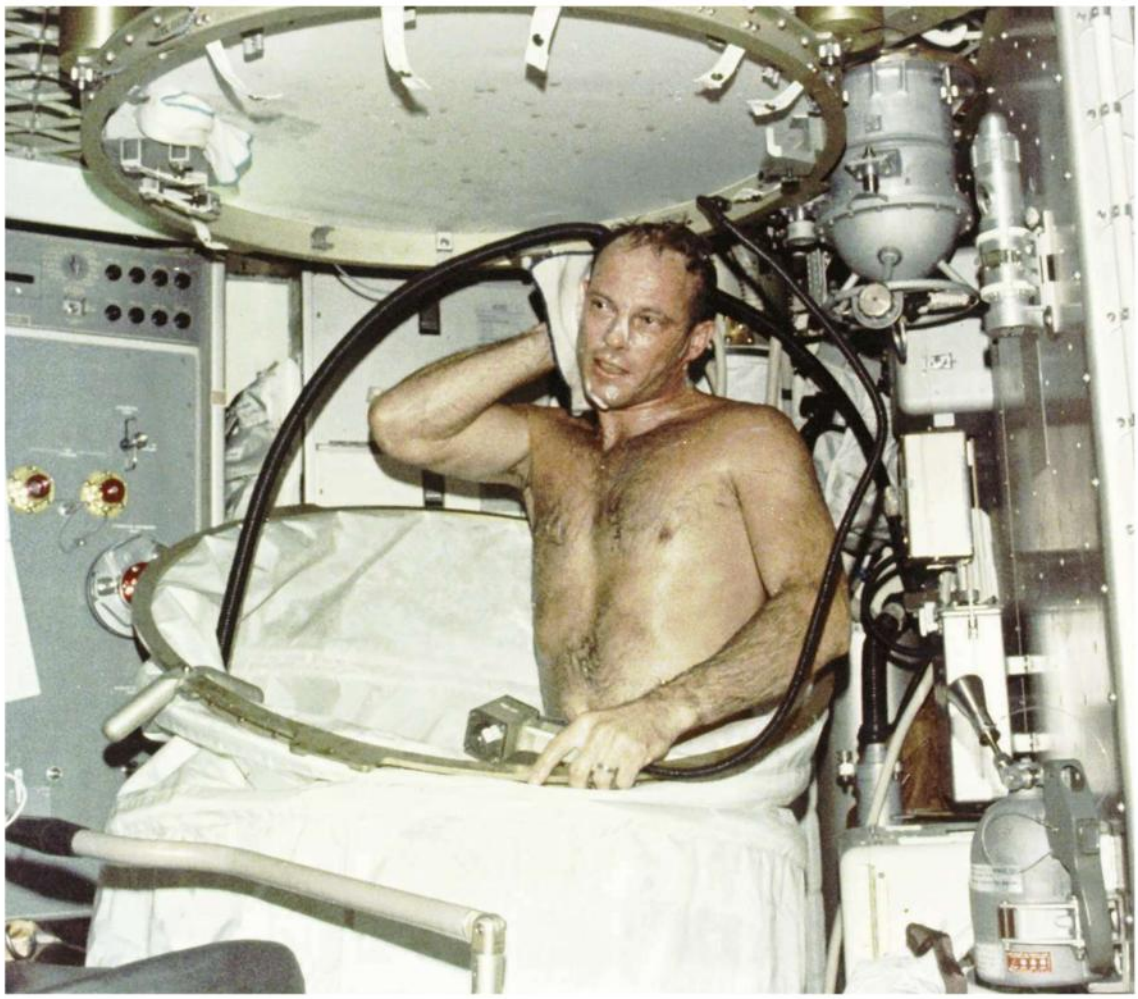
▲ Spider Arabella finally spins a symmetrical web aboard Skylab in 1973, after a previous, unsuccessful attempt. The experiment showed the web wasn't uniform in thickness, unlike those produced on Earth

▲ This photograph of Comet Kohoutek was taken in December 1973 by an astronaut aboard Skylab. The crew's photographic studies helped scientists determine the comet's intrinsic brightness

◀ Pete Conrad keeps in trim shape on Skylab. Conrad had previously gone to the Moon with Apollo but said he was prouder of Skylab because of its scientific accomplishments



▲ Commander of the Skylab 2 mission, Pete Conrad, floats upside down for a dental examination in June 1973



◀ Astronaut Jack Lousma enjoys a hot shower on Skylab in 1973. The shower curtain pulled up from the floor, while the water was drawn off by a vacuum system

NASA

◀ Columbia blasts off on 12 April 1981 – the very first Space Shuttle mission and arguably the riskiest spaceflight ever attempted

# A NEW SET OF WINGS

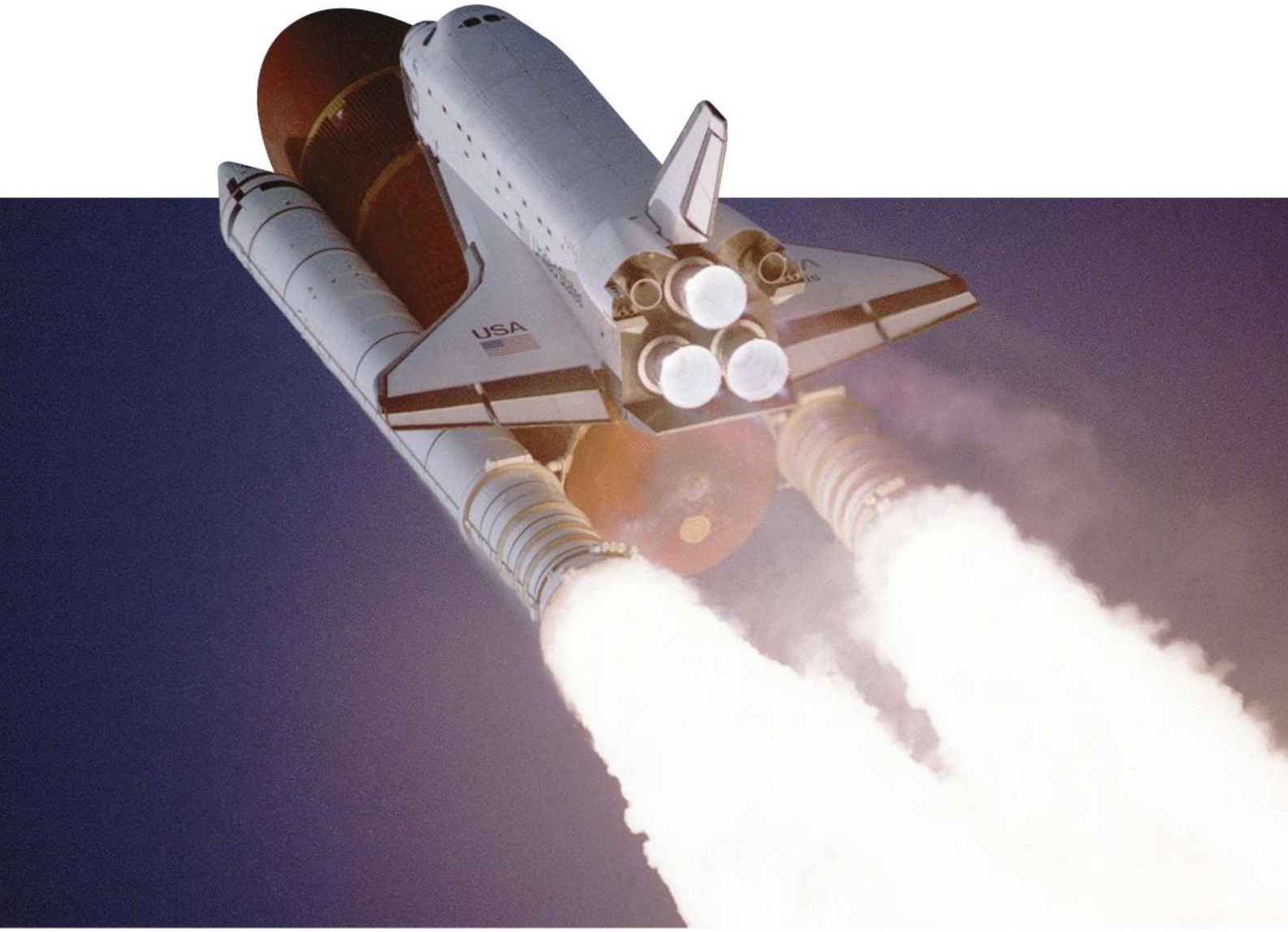
**THE SPACE SHUTTLE** achieved much in its 30-year career. It launched and repaired an array of satellites including the beloved Hubble Space Telescope, and was instrumental in constructing the International Space Station. But the cost of this versatility was high. Readying it for new missions proved hugely expensive and its record was blemished by two fatal disasters

# The first spaceplane

The Space Shuttle was the most advanced spacecraft ever and its crews among the most daring astronauts to operate in orbit

WORDS: SEAN BLAIR

NASA X 2




▲ Atlantis soars into space, its twin solid rocket boosters augmenting the three main engines in the early stages of the launch

**ABOUT HALF THE** length of a 747 jet airplane, it takes off like a rocket and lands like an aircraft. It performs variously as a delivery truck, a salvage vessel, a military resource and a science lab, not to mention an essential construction vehicle for the International Space Station (ISS).

It is, of course, the Space Shuttle and it still seems futuristic compared to any other kind of spacecraft. Time, though, has not been kind to this venerable space vehicle. Now in its third decade of operation, 2011 is very likely to be the last year the world witnesses the drama of a Shuttle launch.

This versatility is hugely expensive, however. While it is partially reusable, the Shuttle ended up being costlier than the expendable rockets it replaced. According to NASA, each Shuttle launch comes with a $450 million price tag, which is over five times the cost of the Russian heavy lift Proton rocket. NASA has long sacrificed research spending to maintain Shuttle operations.

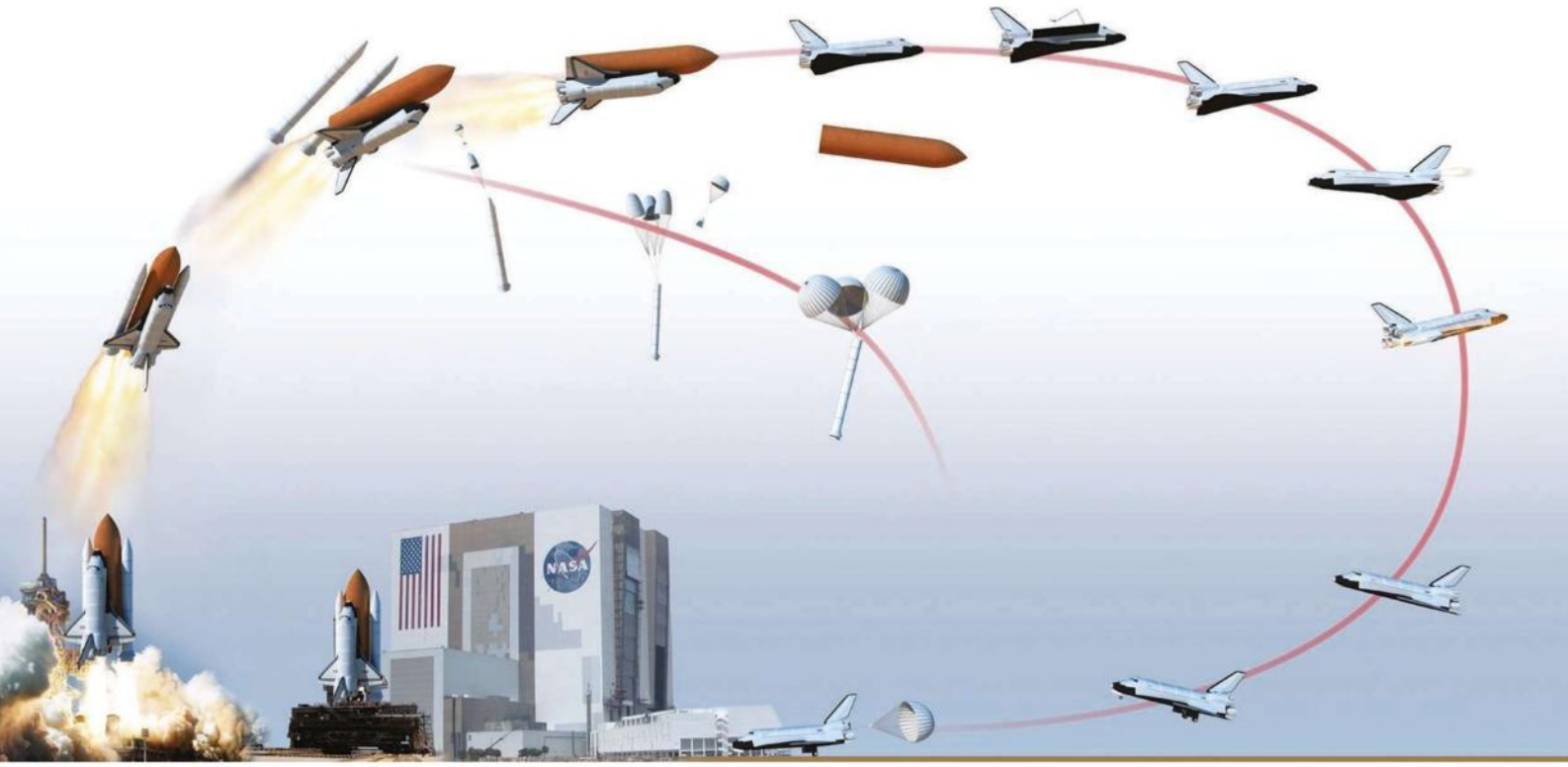
To get into orbit, the Shuttle has to accelerate to nearly 8km/s – or 23 times the speed of sound – in under nine minutes. The orbiter's three main engines burn liquid hydrogen and liquid oxygen pumped from a massive external tank at a rate that would empty a garden swimming pool in 25 seconds. Even so, their thrust is insufficient to lift the entire 2,030-tonne stack skyward. A pair of solid rocket boosters provides the remaining 71 per cent of thrust required.

There is a snag, however. Once ignited, the boosters burn non-stop, like fireworks. They're ejected after an anxious couple of minutes, later to be retrieved and reused, and the ride becomes noticeably smoother. About seven minutes later, manoeuvring thrusters push the Shuttle into orbit as the disposable external tank is detached. Most of the tank distintegrates in the atmosphere.

In orbit, the Shuttle flies 'backwards', tail before nose to protect its fragile Thermal Protection System (TPS). The TPS insulates the spacecraft on re-entry, enabling it to return safely. Moving 10 times faster than a bullet, the returning orbiter transforms its velocity into heat by making a series of turns in the atmosphere, banking first one way then the other. Peak temperatures reach 1,600°C, but the TPS blocks that heat from melting the Shuttle's aluminium skeleton.

Instead of a traditional 'ablative' heat shield, the TPS is as reusable as the rest of the orbiter. Some 24,300 silica heat tiles are glued to its underside, with insulation blankets for surface areas and reinforced carbon–carbon composite for the wing edges and nose. But on 1 February 2003, Columbia's TPS was breached at its left wing, causing superheated fragments to shower the southern ►

◄ Space Shuttle Discovery on a mission to the ISS. The orbiters were versatile, delivering new satellites and repairing old ones




▲ **The solid rocket boosters separate after two minutes, followed by the external fuel tank nine minutes into the flight. To land, the orbiter glides unpowered to a runway**

► US from 63km high and killing all seven of the astronauts onboard.

Flying the Shuttle is undoubtedly risky. Two lost vehicles and 14 fatalities in 133 flights are grim statistics. In his book *Riding Rockets*, astronaut Mike Mullane revealed he was more frightened in "the most dangerous manned spacecraft ever flown" than combat flying for the US Air Force. Not that it stopped him, or the rest of NASA, from carrying on.

But it was the loss of Columbia in 2003 that signalled the end. The resulting inquiry decreed that the ageing Shuttle fleet be retired around the end of the decade. Since that time, production lines for its components have stopped.

In 2005, the then-boss of NASA, Michael Griffin, looked back on the Shuttle as a mistake. "It is now commonly accepted that it was not the right path… It was a design that was very aggressive and just barely possible." Yet Griffin's planned replacement for the Shuttle, Ares I, was projected to have double the Shuttle's launch cost, with no capacity for carrying heavy cargo. Perhaps not surprisingly, Ares I was cancelled in 2010.

## Roots of a spaceplane

The Shuttle concept originated as one element of a grand, post-Apollo infrastructure presented to US President Richard Nixon in September 1969. A fully reusable Shuttle, launched on a piloted booster, was to make trips to a space station, with a space 'tug' providing access to higher orbits. Nixon rejected everything in this plan but the Shuttle, praising its reusability as taking "the astronomical costs out of astronautics". The consequence of this decision, however, was to confine space explorers to low-Earth orbit.

To provide the hoped-for savings, the Shuttle would need to fly frequently – weekly was the original aim. It would be the US Government's sole space transportation system, so the US Air Force became a partner – it would use the Shuttle to launch military payloads.

The Air Force, though, demanded changes: the Shuttle's cargo bay had to be three times larger than NASA had originally envisaged to accommodate the largest reconnaissance satellites. Its wings, originally designed to be stubby, had to be extended for maximum manoeuvrability. The booster was supposed to fly itself back to Earth, but the new design made this idea impractical. The concept was ditched for a partially reusable system. Mass restrictions meant the orbiters themselves had to glide, unpowered, back to Earth.

The final design was so complex that the Shuttle possessed more than 2.5 million components, including nearly 370km of wiring. As a knock-on effect, the turn-around time between flights would now take months, not days. The swollen orbiter had to be side-bolted onto its stack, risking potential damage every time it was launched.

The Shuttle orbiters were made in Downey, California, and the first was unveiled in September 1976. Enterprise, its name suggested by fans of the TV sci-fi show *Star Trek*, was not built for space. Instead, it piggybacked on a 747 aircraft to perform glide tests from altitudes of up to 7.9km. The unpromising aerodynamics of what pilots dubbed a 'flying brick' were, however, bolstered by a pioneering computerised 'fly-by-wire' system – a technology now commonplace in modern aircraft.

Building the orbiter was easy, relatively speaking, but integrating the combined system took years. The Skylab space station fell out of the sky in 1979, having waited in vain for the Shuttle to save it. Because of this, Shuttle Columbia flew on the first mission, designated STS-1, two years behind

GETTY, NASA X 3

◀ A veteran of Apollo, John Young was the commander of Columbia on the first Shuttle flight

▼ Enterprise never flew into space – it was dropped from a 747 to test the Shuttle's gliding capability



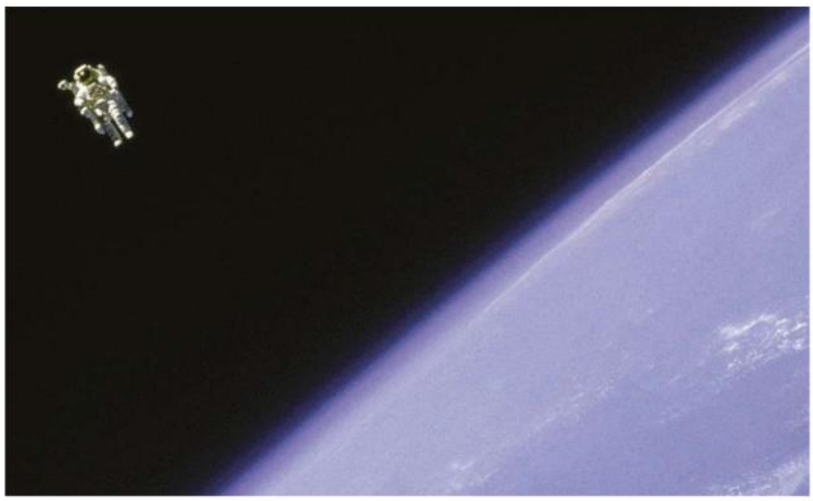

schedule on 12 April 1981. An unmanned launch was not an option for this pilot-dependent design, so astronauts John Young and Robert Crippen were chosen for the single riskiest US manned mission ever flown: an entirely untried combination of spacecraft and rocket to orbit... and back.

The courageous pair did have ejector seats, albeit also untried, and a spy satellite would scan the Shuttle's Thermal Protection System in orbit to check it was still intact. All went well. Just three further shakedown flights followed before the Shuttle was declared 'fully operational' on Independence Day 1982. The ejector seats were removed when the crews expanded from two to seven.

Three hectic and successful years followed. The Shuttle delivered numerous satellites into orbit and fixed faulty ones. Spacewalkers literally grabbed target satellites for refurbishment or return, using jetpacks called Manned Manoeuvring Units (MMUs). These turned them into one-man spaceships, allowing them to float free in space.

In 1985, the programme achieved a record nine launches, with more scheduled for the following year. The Air Force even prepped its own Shuttle launchpad at Vandenberg, California, in order to access the polar orbits favoured by spy satellites.

▼ Bruce McCandless II makes the first untethered spacewalk in 1984, using a 'jetpack' to float 98m from Shuttle Challenger



## Past the point of safety

But the Shuttle infrastructure was being pushed past safe limits. Two main engines failed, a landing tyre suffered a blowout and several solid rocket boosters narrowly missed burning through. Dangers were dismissed in the rush to keep to schedule. But then, in January 1986, Challenger exploded 73 seconds after lift-off. The accident put the spotlight on the way NASA's management communicated with its engineers. Serving on the investigating enquiry was Nobel prize-winning physicist Richard Feynman, who saw through the ▸

► spin: "Reality must take precedence over public relations, for Nature cannot be fooled," he said.

It was two years before the Shuttle flew again. New safety margins lowered the maximum payloads the Shuttle could carry, forcing military and commercial launches back onto unmanned rockets. Even the MMU jetpacks were retired for potentially being too dangerous.

On its return to action, NASA focused on reducing the backlog of special missions to be launched by Shuttle, including the Galileo probe to Jupiter, Magellan to Venus, Ulysses to the Sun's poles and the Hubble Space Telescope.

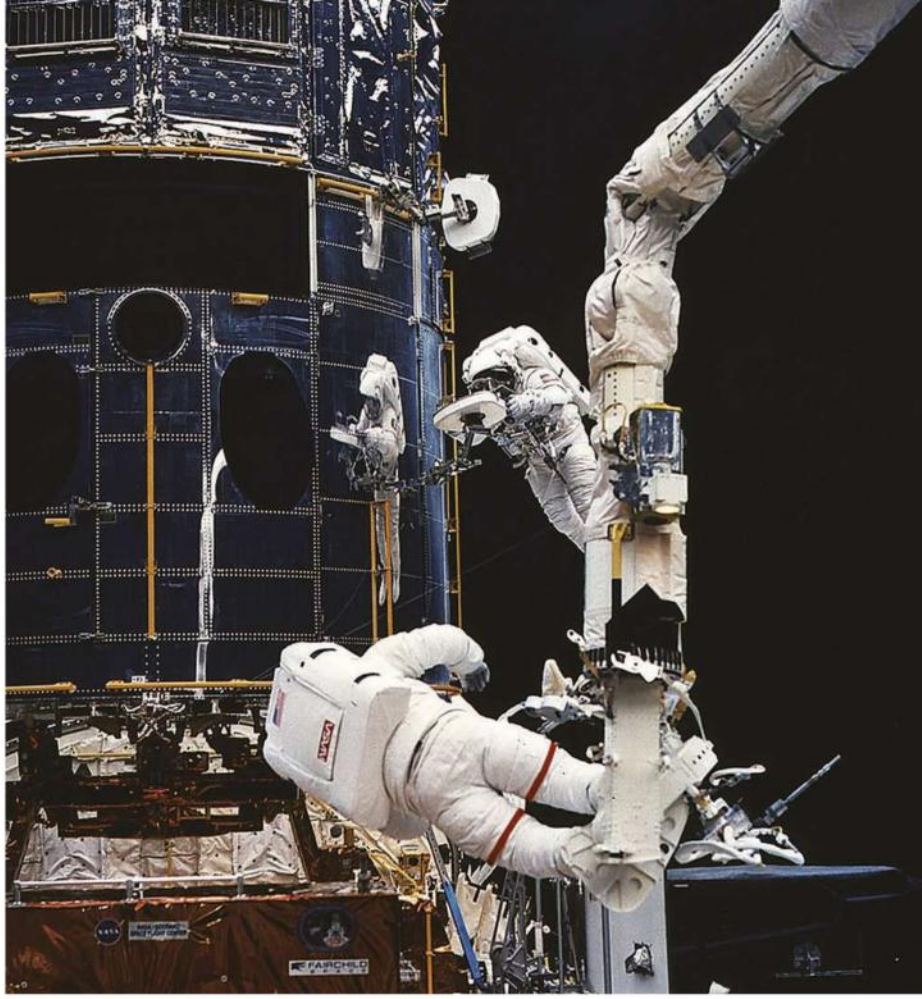
## Shuttle heals Cold War wounds

It was Hubble that ultimately brought the Shuttle salvation. When its main mirror was found to be warped, an audacious repair mission was mooted. The US Congress was wary, worried that clumsy spacewalkers might wreck the $2.5 billion instrument. But the servicing mission in 1993 was a triumph. Astronauts added a corrective lens, opening up hitherto unimaginable views of the Universe.

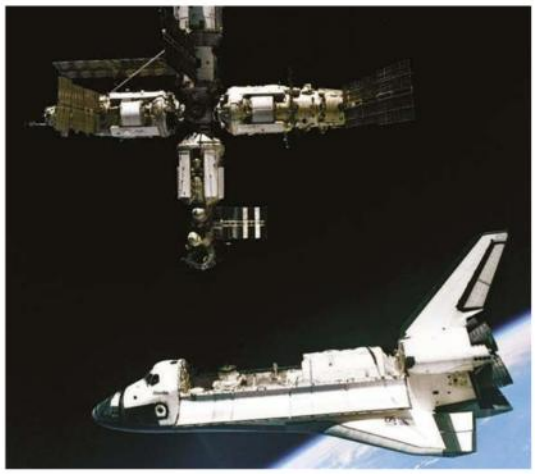
Four further servicing missions followed, considerably extending the telescope's lifespan. The total cost would have paid for several brand new space telescopes, but it demonstrated that Shuttle crews had the skills to build a space station in orbit.

Back in 1984, President Reagan had correctly predicted that the Shuttle would be serving a space station a decade later, but that station turned out to be Russian – Mir. The former enemies put aside their differences, with Russia's Mir station hosting US astronauts. In February 1995, STS-63 performed a 'near-Mir' dry run, coming just 11m from the Russian station. By 1998, the Shuttle had chalked up a total of nine dockings, equipping the complex with a docking module, solar arrays and supplies.

The experience with Mir left NASA eager to start construction of the International Space Station. By 2000, the Shuttle fleet could be devoted to this single task. But one Shuttle orbiter was kept away from ISS duties. Columbia was assigned the purely scientific STS-107 mission. It didn't seem particularly risky, but Shuttle managers had underestimated risk before. And in February 2003, history repeated itself when Columbia perished, burning up in the atmosphere on its return to Earth. NASA's safety culture was once again under the spotlight and it emerged that Columbia had



▲ Anchored to Space Shuttle Endeavour, Jeffrey Hoffman installs a new camera in the Hubble Space Telescope in 1993



◀ Shuttle Atlantis departs Mir on 4 July 1995. The mission was the first time a Shuttle had docked with the Russian space station

The immediate aftermath of the explosion that destroyed Challenger in January 1986

NASA X 9

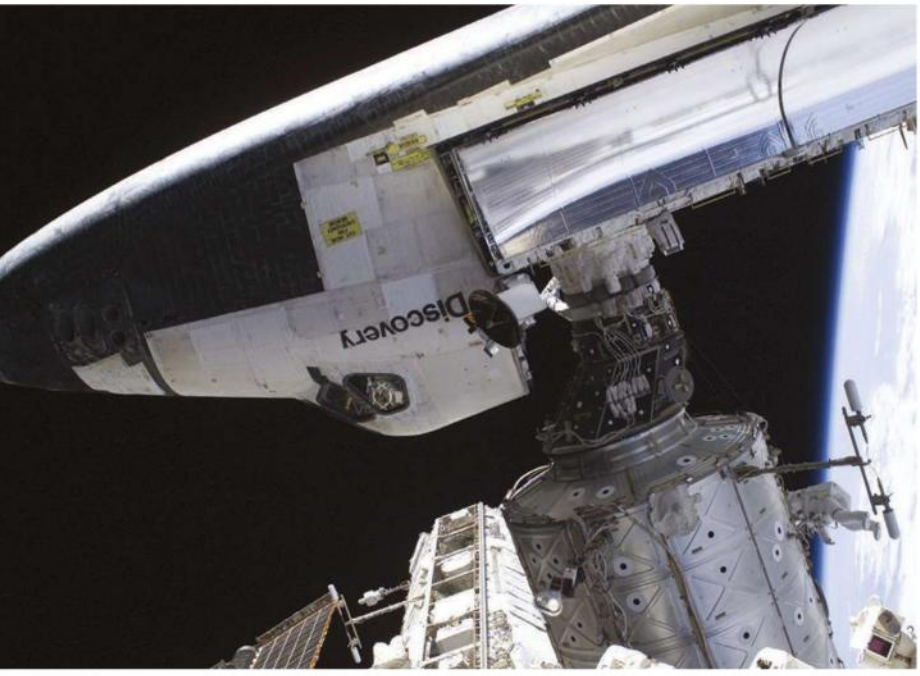
flown with more than 6,000 potentially dangerous faults. These were permitted by 'safety waivers', enabling management to pass the Shuttle fit to fly.

Both the Challenger and Columbia disasters had much in common. For starters, both were triggered by severe weather conditions. Challenger's solid rocket rubber 'O-ring' had been weakened by sub-zero temperatures, while the supposedly lightweight insulation that struck Columbia's wing was full of ice. On both occasions, NASA management failed to act on warnings.

## Return to active spaceflight

The remaining Shuttles returned to flight two years later. To prevent launch debris putting more orbiters at risk, NASA instituted rigorous hull checks in orbit, while a rescue Shuttle stood ready on the pad. All remaining flights were devoted to completing the ISS, except for one last Hubble refurbishment. To date, the Shuttle has made 35 rendezvous with the ISS. The very last flight will be Endeavour's delivery of scientific apparatus in April 2011, unless a supply run by Atlantis gets the go-ahead.

The Shuttle's legacy will cast a long shadow – the space station it built will be a permanent reminder of its lost capabilities. It's not certain what will replace it, but the US Congress has ordered NASA to build a 'Shuttle-derived' heavy lift launcher. One such spacecraft is already flying: the unmanned X-37B spaceplane. It was launched atop a US Air Force Atlas 5 rocket in April 2010 and spent seven months in orbit before automatically gliding home, protected by a next-generation heat shield. The X-37B remains a military secret, but it could be the shape of Shuttles to come.




▼ **The Shuttle was instrumental in building the ISS. Here, Discovery is seen docked with the Destiny lab in 2005**

# The Shuttle fleet

**COLUMBIA 1981-2003**
NASA's first space-capable orbiter achieved great things, flying the first Spacelab full-scale research station and launching the Chandra X-Ray Observatory. Some 84,000 pieces of the orbiter were retrieved after it was destroyed in the atmosphere.

**CHALLENGER 1983-1986**
Challenger hosted the first space activity outside a Shuttle during its first flight and the first untethered spacewalk on its fourth. On its fifth it performed the earliest Shuttle rescue: it took two spacewalks to place the Solar Max satellite into the cargo bay.

**DISCOVERY 1984-2011**
The single most flown orbiter, Discovery deployed Hubble in 1990, trialled the Wake Shield Facility (creating a vacuum for industrial experiments) and hosted 77-year-old John Glenn in 1998. It also returned the fleet to action after the loss of Challenger.

**ATLANTIS 1985-2011**
Atlantis delivered several classified satellites for military reconnissance. Its civilian duties included the deployment of the Galileo mission to Jupiter in 1989 and Compton Gamma Ray Observatory in 1991. It also delivered the US Destiny module to the ISS in 2001.

**ENDEAVOUR 1992-2011**
The last Shuttle orbiter was made from spare parts to replace the lost Challenger. It carried out the first servicing mission to Hubble in 1993 and, the following year, radar mapping of the Earth. In 1998 it deployed Unity, the first US-made module of the Space Station.

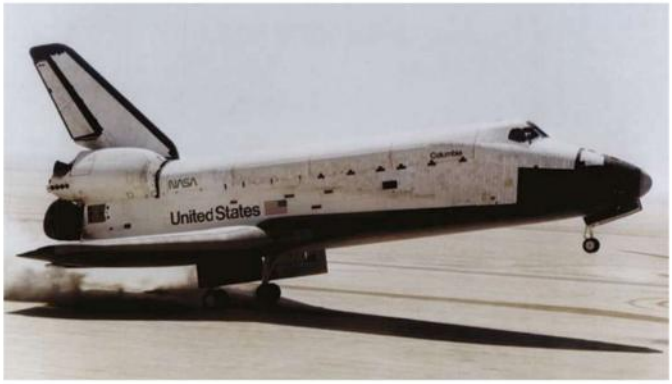
# IN PICTURES:
# THE SPACEPLANE 1979-2011
# NASA'S SPACE SHUTTLE

▲ The prototype Space Shuttle Enterprise flies over Rogers Dry Lake, California, in September 1977 to test the Shuttle's ability to glide in for a landing. These approach and landing tests lasted nine months

▲ Enterprise rolls out to the launch pad on 1 May 1979. A test machine, it had no engine or heat shield and never flew into space

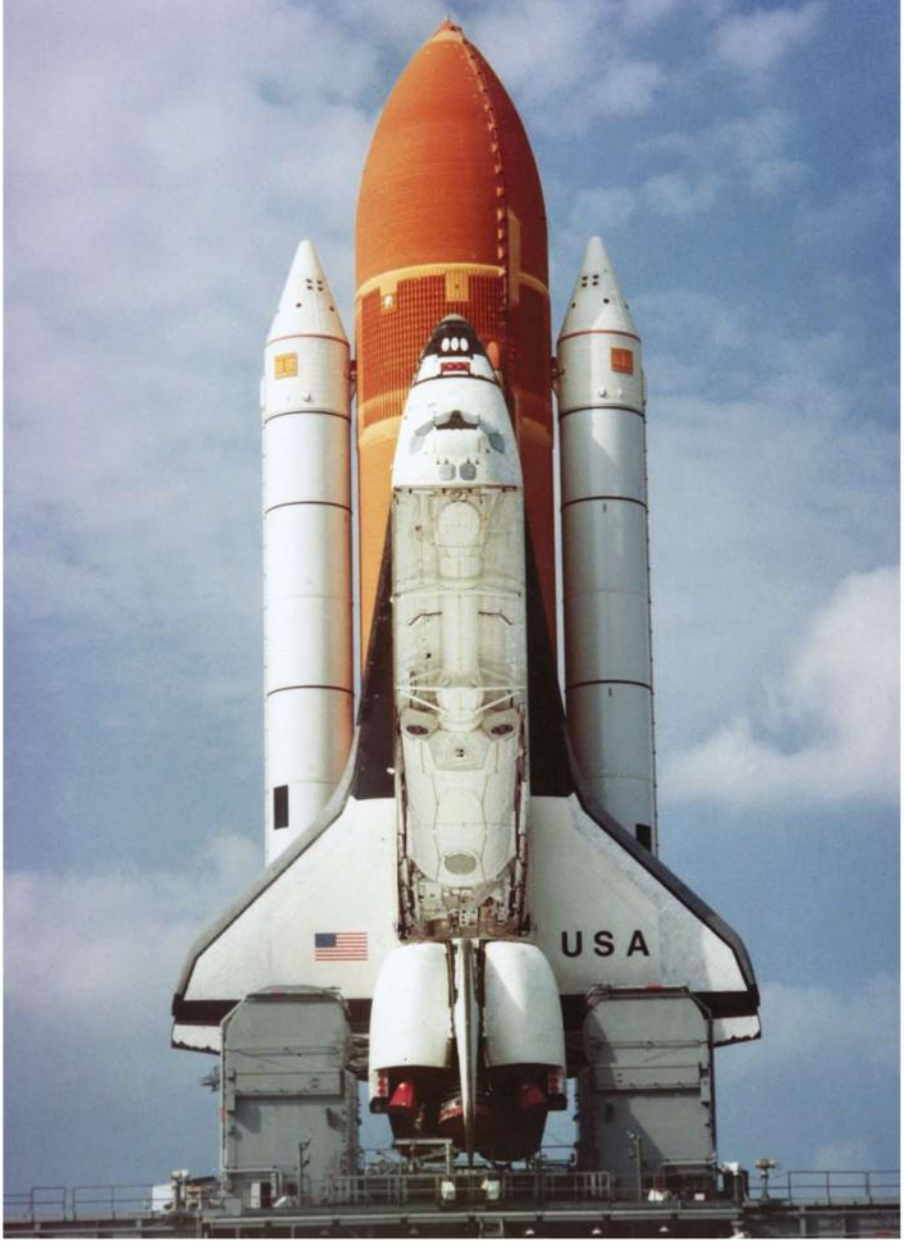
▲ Commander John Young shaves in zero gravity on the mid-deck of Columbia during the first Shuttle mission in April 1981

▲ Robert Crippen, pilot of the first Space Shuttle mission, performs acrobatics in zero gravity aboard Columbia. The mission lasted just over two days




▶ Columbia touches down at Edwards Air Force Base, California on 14 April 1981 at the end of the first Shuttle mission to successfully fly into orbit

ALL PHOTOS: NASA




◀ The reusable Spacelab laboratory is revealed in this double-exposure photo of Shuttle Columbia. Spacelab flew 22 times between 1983 and 1998

▲ Robert Parker, Byron Lichtenberg, Owen Garriott and Ulf Merbold inside Spacelab, where they performed over 70 experiments

▲ The first African American astronaut, Guion Bluford, exercises on a treadmill aboard Shuttle Challenger on 5 September 1983

▲ The crew of the tragic Shuttle mission STS-51L. Back row left–right: Ellison S Onizuka, Christa McAuliffe, Greg Jarvis, Judy Resnik. Front row left–right: Mike Smith, Dick Scobee, Ron McNair

▲ Teacher Christa McAuliffe trains for the ill-fated Challenger mission in January 1986

▲ Space Shuttle Challenger explodes over the Atlantic Ocean 73 seconds into its flight on 28 January 1986, killing all seven crew

▲ The Hubble Space Telescope is deployed from the cargo bay in April 1990. Discovery soared to 610km, the Shuttle's highest altitude to date

▲ The Hubble Space Telescope floats free on 25 April 1990. Two months later, astronomers discovered that its mirror had a serious flaw

▲ Story Musgrave holds on to Shuttle Endeavour in December 1993 during repairs to the Hubble Space Telescope

ALL PHOTOS: NASA

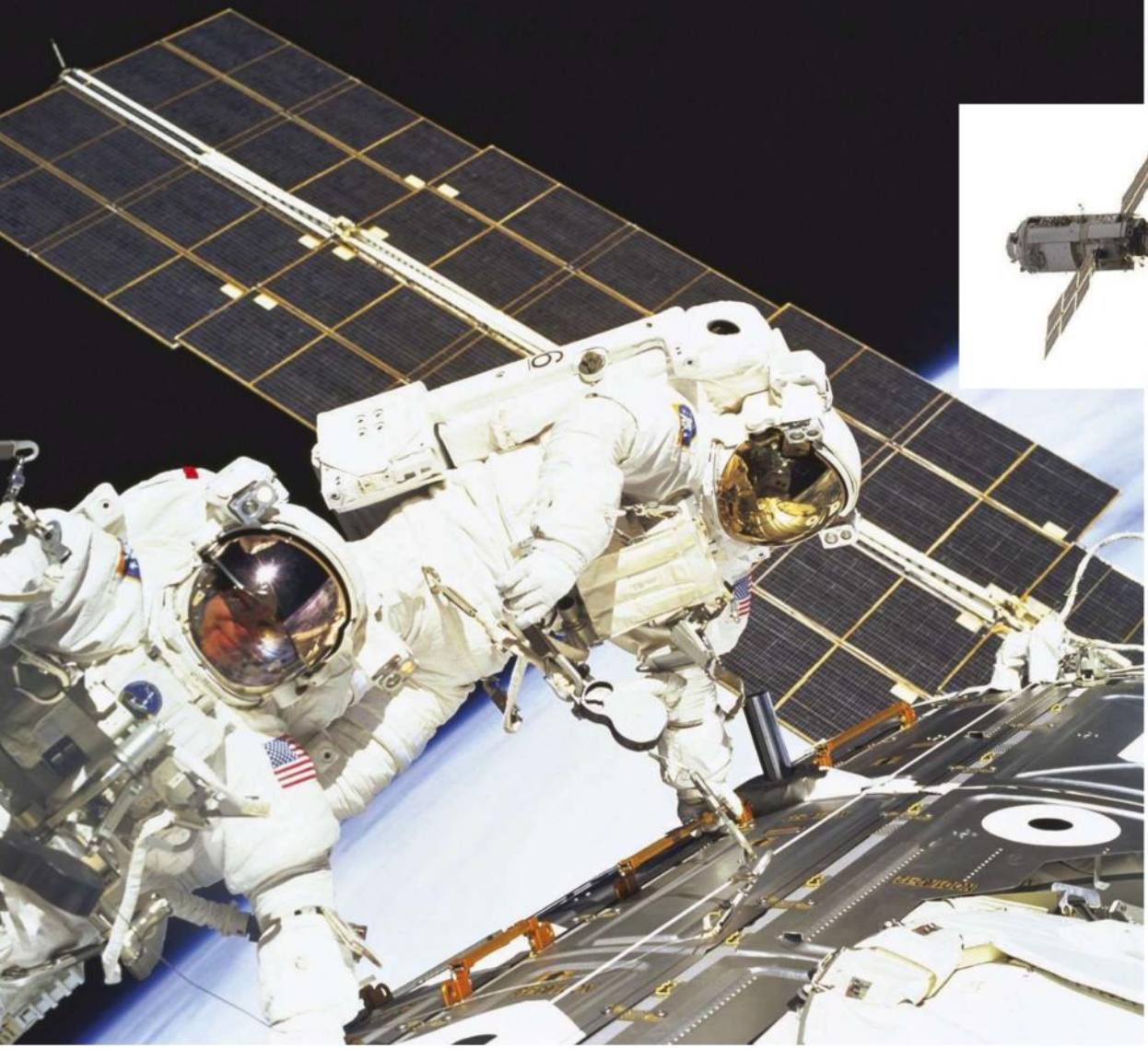
◀ Endeavour's Kathryn Thornton spends over six hours replacing solar arrays on the Hubble Space Telescope on 8 December 1993

▲ Story Musgrave and Jeffrey Hoffman perch on Shuttle Endeavour's robot arm 600km above Earth on 9 December 1993

▶ On 3 February 1994, Sergei Krikalev (second from left) becomes the first Russian cosmonaut to fly aboard a Shuttle. Clockwise from his left: Kenneth Reightler, Commander Charles Bolden, Ronald Sega, Nancy Davis, Franklin Chang-Diaz


◀ Mir photographed from Discovery in February 1995 on STS-63, the Space Shuttle's second visit to the Russian space station

▲ Eileen Collins is the first woman to fly the Shuttle on mission STS-63, taking Discovery to a rendezvous with space station Mir in 1995



▲ The first Shuttle mission to the International Space Station saw the Russian-built Zarya and US Unity modules joined up. Zarya is on the left and Unity on the right of this photo, taken on 13 December 1998

◀ Jerry Ross (left) and James Newman carry out a spacewalk on the first ISS assembly mission in December 1998. Zarya's solar panel runs through the photo

ALL PHOTOS: NASA

▲ The crew of the ill-fated Space Shuttle Columbia. Blue shirts (L-R): David Brown, William McCool and Michael Anderson; red shirts (L-R): Kalpana Chawla, Rick Husband, Laurel Clark and Ilan Ramon. This photo was on unprocessed film recovered from the wreckage

▲ Commander Rick Husband on the flight deck of Shuttle Columbia, whose crew perished when it disintegrated on 1 February 2003

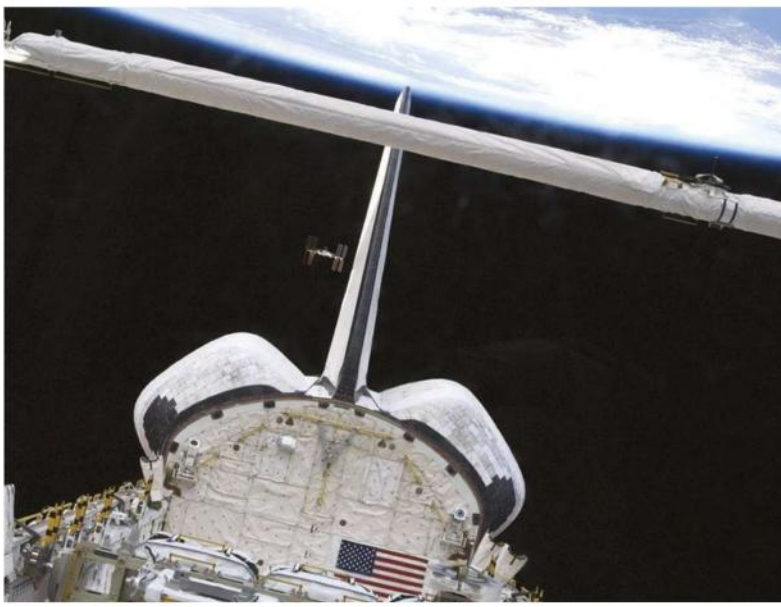
▲ Debris from the Space Shuttle Columbia is collected and catalogued in a hangar at Barksdale Air Force Base, Louisiana in February 2003


▲ Thomas Reiter, pictured holding a laboratory freezer, was the first European on a long-duration ISS mission, spending almost six months working in the Destiny lab on the Station in 2006

▲ Robert Curbeam exits through an airlock during an ISS assembly mission on 18 December 2006. He performed a record four EVAs during the mission

▶ Endeavour astronaut Steve Bowen cleans a solar panel joint during a six-hour EVA outside the ISS on November 2008. The mission would also install new crew quarters

◀ Atlantis sets off for the ISS on 14 May 2010 on its last scheduled flight carrying six astronauts, including British-born Piers Sellers



▲ The International Space Station vanishes into the distance from Atlantis on 23 May 2010, with the Shuttle's robot arm extension above


ESA

◀ The Russian Soyuz rocket symbolises the co-operation between many nations and is still used today to transport supplies to the ISS

# UNITED IN SPACE

**NASA HAD THE** Space Shuttle, Russia the Mir space station. But the changing political landscape and economic realities led to a partnership between the former rivals. They would soon be joined by European nations in a new era that saw the construction of the biggest space station to date and science put at the forefront of manned activity in Earth orbit

# Birth of a Station

Old enemies finally joined forces, sending the Shuttle to Mir and then on a far bigger project

WORDS: PIERS BIZONY

**EVEN AS THE FINAL** Apollo mission made its way to the Moon in 1972, America's Space Shuttle was on the drawing board as a potential successor. NASA hoped to use the Shuttle for building a huge orbiting outpost. Unfortunately, the Moon race with Russia was over and political support for such an expensive project was thin on the ground.

In 1983, NASA's administrator at the time, James Beggs, thought it might be a good idea to find support for a space station beyond America's shores. He met with the West German minister for research and technology, Heinz Riesenhuber, and discussed possible European collaboration for activities in orbit. A few months later, Italy's prime minister Bettino Craxi told President Ronald Reagan that Italy was keen to help build a space station.

Russia may have lost the lunar race but it was now seeking to dominate in Earth orbit. With this in mind, Reagan made an announcement on 25 January 1984. "I am directing NASA to develop a permanently crewed space station, and to do it within a decade. We want our friends to help us

NASA/ESA X 6, ITAR-TASS PHOTO AGENCY/ALAMY STOCK PHOTO, REUTERS/ALAMY STOCK PHOTO

**Space Shuttle Atlantis docks with Mir, as photographed by cosmonauts Anatoly Solovyev and Nikolai Budarin from their circling Soyuz spacecraft**

# The ISS in numbers

**35** The number of Space Shuttle flights dedicated to ISS assembly and crew rotation between 1998 and 2003. In addition, Russia has flown two heavy-lift cargo rockets, 41 Progress supply capsules and 25 crew missions.

**1,248** The number of hours astronauts have racked up in ISS-related space walks. Space Shuttle crews made 38 space walks, while ISS crews have conducted 161.

**26 million** The number of people involved with the ISS globally, working from 500 research facilities, universities, space centres and factories.

**22,000** The number of space meals sucked and munched through by ISS crews.

**417,300** The ISS's weight in kilograms if it were on Earth.

**27,744** The station's average orbital velocity in kilometres per hour. Each orbit takes between 91 and 93 minutes, varying with orbital altitude.

**837** The ISS's internal volume in cubic metres, roughly the same size as the passenger and crew areas of a Boeing 747.

**879** The record number of days that cosmonaut Gennady Padalka has spent in space. He lived on Mir and served on four ISS expeditions, with a fifth scheduled for September 2018.

▲ Cosmonauts Leonid Kizim (right) and Vladimir Solovyov prepare to become Mir's first crew

meet this challenge and share in the benefits. NASA will invite other countries to participate so we can strengthen peace, build prosperity and expand freedom for all who share our goals," he said.

On 19 February 1986, Russia launched the first component of its Mir (Russian for 'peace') space station. Three weeks later, Mir's first crew – Leonid Kizim and Vladimir Solovyov – blasted off for a rendezvous. After six weeks aboard Mir, they took their Soyuz capsule for a 50-day visit to Russia's old station, Salyut 7, then flew back to Mir for three weeks before heading for home. It was an impressive accomplishment.

Although the orbital realm is as quiet and seemingly unchanging as only a perfect vacuum can be, back on Earth, amid all the air and pollution and noise, circumstances were changing fast. In 1990, the Soviet empire began to fall apart, just as the Reagan administration gave way to George Bush Senior's era, then Bill Clinton's. In June 1992, a new NASA administrator, Dan Goldin, held a discreet meeting with the Russian space chief Yuri Koptev. Could Russia and America become allies in orbit now that the Cold War was over?

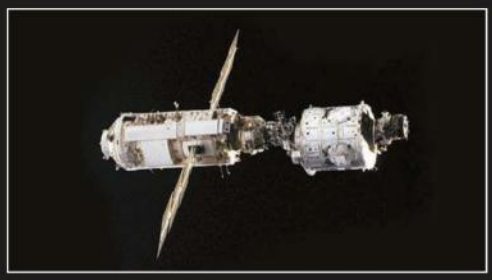
## The hand of friendship

By this stage, post-Communist Russia was nearly bankrupt and Mir was operating not merely in the vacuum of space but in an equivalent political void. Russia, though, was unwilling to abandon its proudest space achievement, even when turmoil on the ground disrupted the launching of Soyuz capsules and Progress cargo ferries.

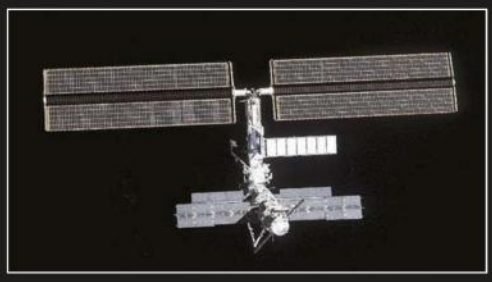
President Clinton saw an opportunity to lend a helping hand. NASA also needed support; not just cash but something even more valuable – a better political reason for building a new space station. Clinton was struggling because many politicians in Washington were angry about its projected costs and apparently limited usefulness for science. ►

▶ NASA head Dan Goldin (left) and his Russian counterpart Yuri Koptev announce the launch of the first ISS module

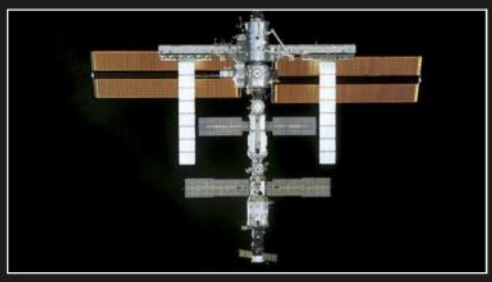
# ISS under construction



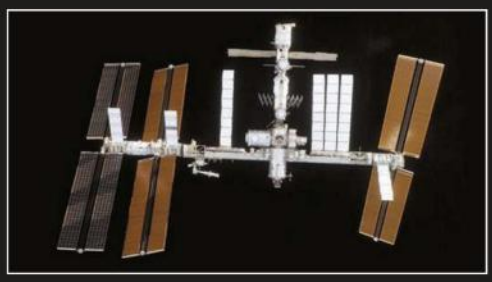
**DECEMBER 1998** The first two ISS modules are connected – the US's Unity, right, and Russia's Zarya. The station is left unmanned.



**APRIL 2001** Canadarm2 is installed, the first of several robotic systems on the ISS able to rearrange modules and other equipment.



**AUGUST 2005** The first Space Shuttle mission after the 2003 Columbia disaster suspended the ISS's construction arrives with supplies.



**OCTOBER 2007** The Harmony module is delivered, increasing living space by 20 per cent and making future expansions possible.

**FEBRUARY 2010** The Cupola window is fitted during Space Shuttle mission STS-130, giving the crew 360° views of Earth.

► America had plenty of motivation for extending the hand of friendship to its old enemy. One factor was the need to protect Russia's huge rocket industry from economic turbulence and especially to prevent its expertise being sold to undesirable buyers elsewhere in the world. On a business level, US satellite companies hoped that a wide range of excellent Russian launch vehicles would become available to the Western space community.

The new space station now became a tool for American global diplomacy. The somewhat aggressive Reaganite name 'Freedom' was dropped, as there was no longer any suggestion that Russia might still be a rival in orbit. The project was renamed Alpha and finally became known as the International Space Station (ISS).

## International collaboration

Today 18 countries are involved in the ISS, working through five space agencies on three continents. The diplomacy is almost as complex as the hardware, but these peaceful alliances were a major justification for building the station.

As hardware construction got underway in the 1990s, the final hurdle was to decide a scientific purpose for the ISS. Was it to be a staging post for future manned Mars missions? That only made sense if such a mission was on the cards, which it definitely wasn't. The other big justification was to use the ISS to conduct microgravity research, but many scientists complained that this was better suited to robotic platforms – astronauts create vibrations as they move, disrupting the calm environment that microgravity experiments are designed to exploit.

NASA X 7, NASA/ESA X 2


▲ **Currently astronauts rely on Russia's Soyuz spacecraft to travel to and from the International Space Station**

There was also was vicious fighting within NASA. We're so used to thinking of the US space agency as one organisation that it's easy to forget the geographically scattered reality, with mission control specialists in Houston, rocket designers at the Marshall Center in Alabama, the launch complex in Florida and headquarters in Washington DC. The mission specialists argued for building the ISS from the inside out, starting with a module that could be crewed as soon as possible and expand from there; the rocket designers wanted to launch the solar panels and power systems first, then add the crew modules later. Houston won the argument, but it took several years of wasted time and money to settle the matter.

No wonder that 14 years passed between Reagan's announcement and the first hardware launch. The debut component, the Russian-built control module Zarya, was sent into orbit by a Proton rocket launched from Baikonur, Kazakhstan, on 20 November 1998. Two weeks later, Space Shuttle

## Science on the ISS

### Material and fluid science

The manufacture of most metal objects and semiconductors is affected by convection, where the cooler regions of a fluid sink. Tests in microgravity reveal how to cool materials in a more even way to make them purer.

### Fundamental physics

Solids, liquids and gases are distinct, but the transition between them creates a fleeting state called 'phase transition'. In space, this area of atomic physics can be studied in an environment where no other forces are at work.

### Biology

How does life sense gravity and respond to it? Taking away the effects of gravity helps us to figure out how plants and other organisms distinguish between up and down, specifically how roots and shoots grow in the correct direction.

### Medicine

It's the medical research that might make us grateful for the ISS one day. In space, bones shed calcium at an alarming rate. Monitoring astronauts' health is valuable as they temporarily suffer from a condition similar to bone disease osteoporosis.

# Day-to-day life in low Earth orbit

▲ ISS crew members keep fit with two hours of exercise on a treadmill each day

▲ Chopsticks, hard to use on Earth, present a sizeable challenge when your food is floating

▲ Sleeping bags have to be pinned down like everything else; this one's attached to a wall

The ISS operates on Greenwich Mean Time (GMT), although from the crew's point of view the Sun rises and sets 16 times a day. In space, timekeeping is relative, but astronauts are hardwired to live in 24-hour cycles just like the rest of us. According to ESA astronaut Paolo Nespoli, the choice of GMT comes down to practicality, a compromise between US and Russian time zones. It also allows European astronauts to wake up at more or less the same time as their fellow citizens on the ground.

Not that it's easy to sleep – Nespoli says that the crew has to use earplugs in the loudest compartments. "There is a continuous aircraft-like hum in the air, mostly coming from ventilation and life support systems," he explains. All this noise aside, there is no vibration transmitted through the structure of the ISS, and no sense of being inside a spacecraft rapidly orbiting Earth.

Before a mission, each crew member is allowed to choose a 10-day menu cycle, selected from dried or tinned pre-cooked foods, which are heated or hydrated before eating. "Microgravity dulls the taste buds, so spicy foods are preferred," says Nespoli.

Even after their assigned seven-hour work shifts are finished, ISS crew members cannot relax until they have completed a minimum of two hours of hard physical exercise on the treadmill. Nespoli (and almost anyone who's ever been on board the ISS) says that relaxation time is spent, as often as possible, "gazing at Earth whenever the external shutters are open, through the huge Cupola windows".

Endeavour delivered the Unity docking node. The first three-person crew arrived in a Russian Soyuz capsule in November 2000 and the ISS has been crewed ever since.

## Completing the ISS puzzle

Meanwhile, NASA and the Russian Federal Space Agency needed to practise orbital collaboration. Between 1995 and 1997, eight US astronauts visited the last great Soviet craft, the Mir station. The 'Shuttle-Mir' project allowed NASA to practise linking their winged orbiter with a space station's docking module, and to find a way of surmounting the tremendous cultural and technical differences.

Today, the ISS awaits two more components. Russia's Nauka multi-purpose module will be delivered into orbit sometime in 2018 by a Proton cargo rocket, and will dock with the ISS using a small propulsion and control stage. The Uzlovoy 'docking' module is expected to follow in the same year.

The Space Shuttle, with its seven crew seats and large payload bay, was the mainstay of ISS construction and staff changes, but the venerable system was retired in 2011. NASA doesn't yet have a new spacecraft to replace the Shuttle, so astronauts depend on Russia's Soyuz capsules to access the ISS.

Resupply missions are undertaken by Russia, Japan, Europe and private industry. ESA's 20-tonne Automated Transfer Vehicle, the most complex spacecraft ever developed in Europe, is able to deliver up to 7.5 tonnes of supplies, propellant and scientific equipment in a single trip, and has about three times the payload capability of its Russian counterpart, the Progress cargo capsule. Japan also has an automated cargo carrier, the H-II Transfer Vehicle.

In 2012 SpaceX, founded by PayPal entrepreneur Elon Musk, became the first commercial entity to resupply the ISS – using a cargo capsule called Dragon, launched from its own launch vehicle, the Falcon 9 rocket. Since then, Orbital Sciences has followed suit with its Cygnus spacecraft, launched on its Antares rocket. But none of these vehicles can carry astronauts – at least, not yet.

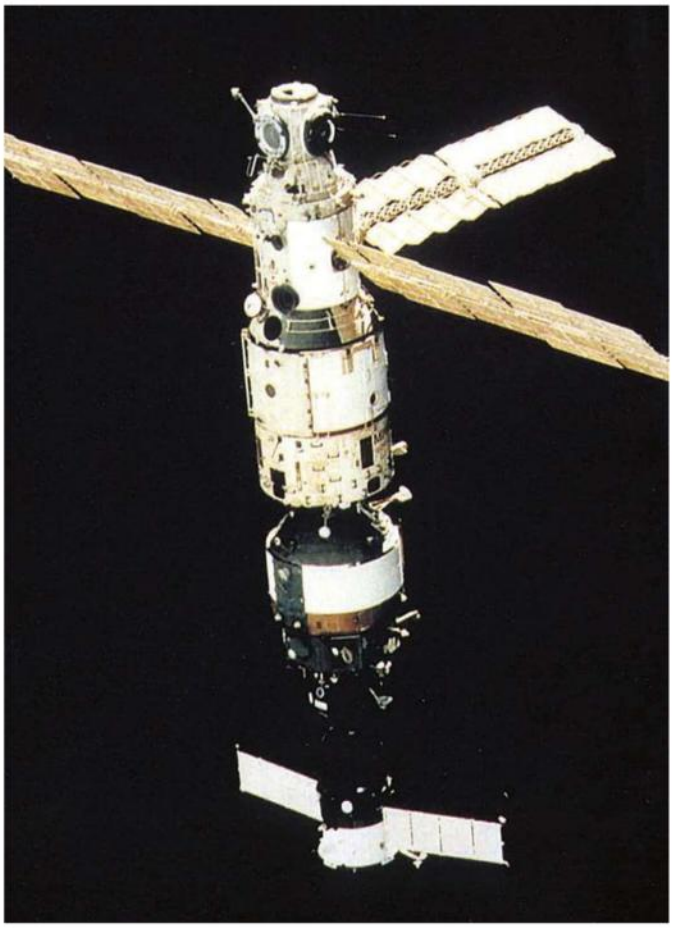
▼ A cargo variant of SpaceX's Dragon capsule became the first commercial spacecraft to resupply the ISS in 2012

# IN PICTURES: BASES IN SPACE 1986-2017
# MIR AND ISS

◀ Mir's first two cosmonauts, Vladimir Solovyov and Leonid Kizim train with French astronaut Patrick Baudry (right). The pair had previously spent time aboard Salyut 7

▼ Musa Manarov (left) and Vladimir Titov (centre) in 1988 on their return from Mir

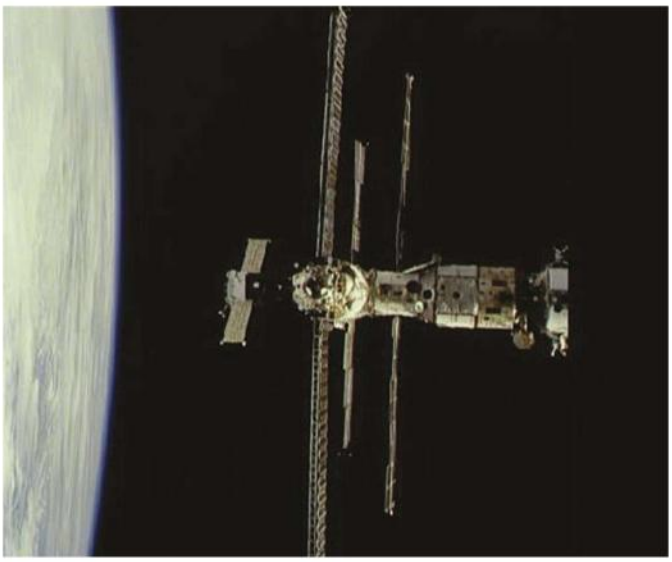
▼ Kvant-1, Mir's second module, is seen here docked with the space station's base component and a Soyuz spacecraft in April 1987



◀ Food scientist Helen Sharman spent eight days on board Mir in May 1991, becoming the first Briton in space

▼ Alexandr Volkov and Sergei Krikalev (seen with Jean-Loup Chrétien, right) became "the last Soviet citizens" as they were on Mir when the USSR broke up in 1991

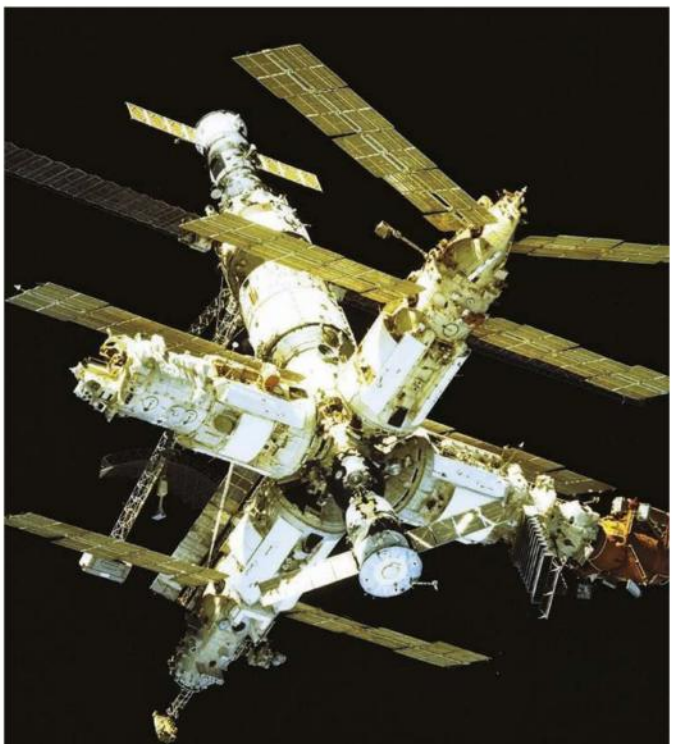
RIA NOVOSTI/SCIENCE PHOTO LIBRARY, TOPFOTO X 2, ALAMY, WWW.CAPCOMESPACE.NET, NASA X 3, NASA/SCIENCE PHOTO LIBRARY X 2

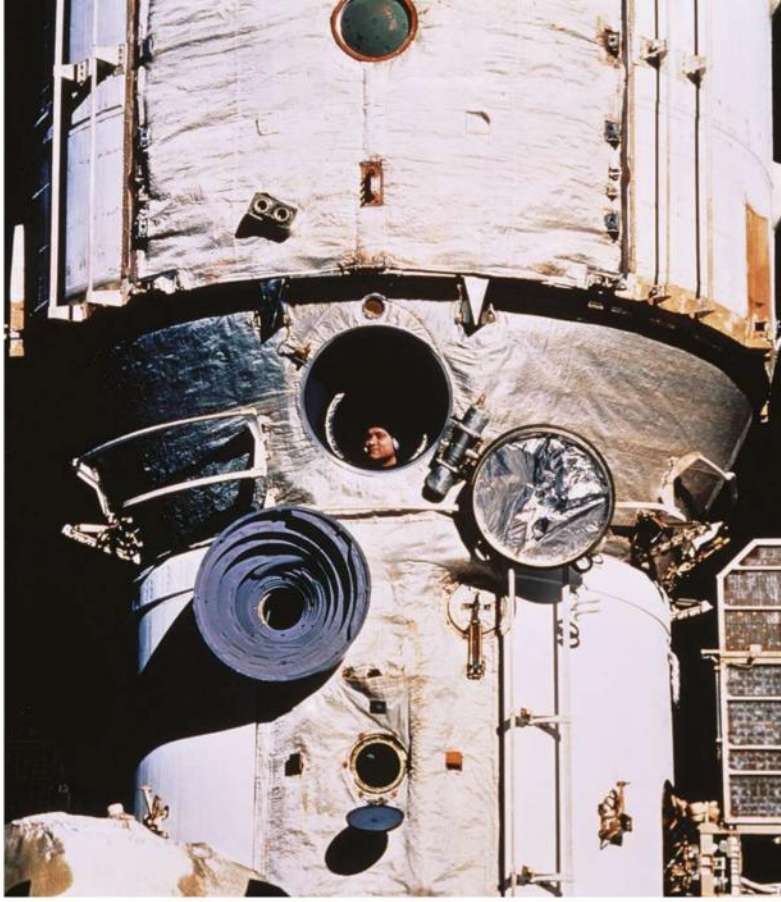


▲ The US and Russia demonstrate close co-operation as Discovery approaches Mir in February 1995. The second of 11 Shuttle flights to Mir, it saw the US spacecraft come within 11m of the station

▼ US astronaut Shannon Lucid exercises on a treadmill in Mir's base block in March 1996. She spent six months on Russia's station

▼ Mir's seventh and last module, Priroda, was added in April 1996. Positioned opposite the module tipped with an orange docking port, Priroda would carry out remote sensing of Earth

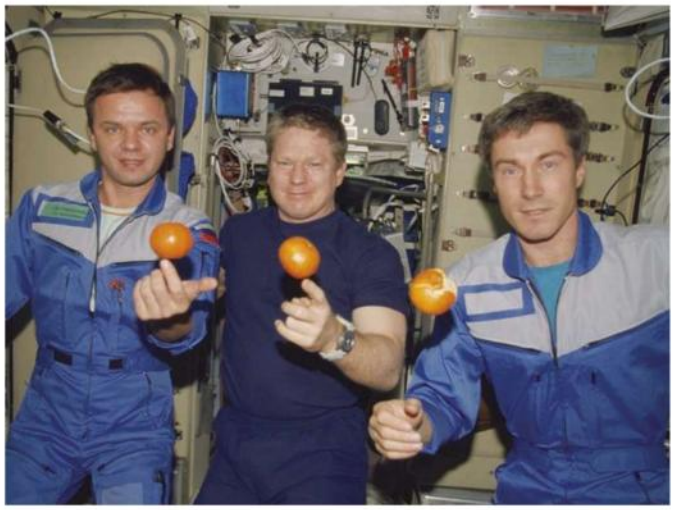




▲ Russian cosmonaut Valeri Polyakov peers through a window of Mir, as photographed from Space Shuttle Discovery in February 1995

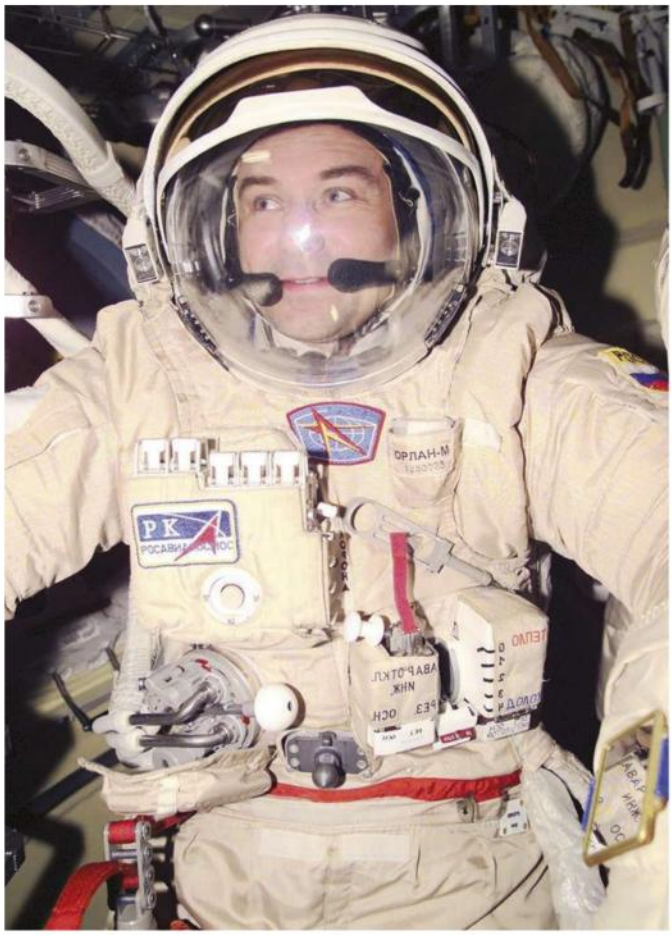
▲ British-born astronaut Michael Foale operates a video camera on Mir in May 1997. He spent more than four months on the station, and helped to repair exterior damage during a six-hour spacewalk

▲ December 1998 saw the first modules of the International Space Station bolted together – the Russian Zarya (left) and US Unity (right)



NASA/ESA X 7

▲ Yuri Gidzenko, William Shepherd and Sergei Krikalev (left to right), the first ISS crew, have fun in the living quarters on 4 December 2000



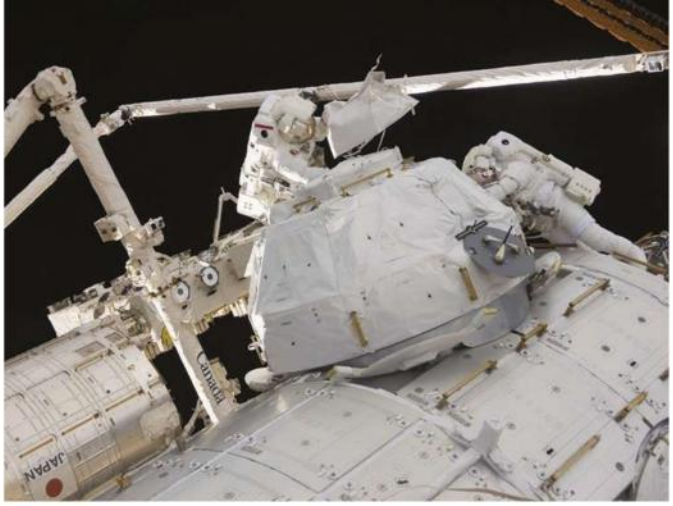
▲ Vladimir Dezhurov prepares for the first spacewalk from the ISS carried out without a Space Shuttle present on 8 October 2001

◀ A riot of colour on 26 April 2001 as the second ISS crew and the astronauts of Shuttle Endeavour get together in the Raffaello module

◀ Against the blackness of space and Earth's limb, the new Soyuz TMA-1 spacecraft approaches the ISS on 1 November 2002

▼ Michael Foale performs hand posture experiments in April 2004 in the ISS Destiny module, a US research laboratory

▼ The first European long-duration crew member on the ISS, Thomas Reiter, reads the Zvezda module procedures checklist in July 2006




▲ Robert Behnken (left) and Nicholas Patrick install the European Space Agency's Cupola – the largest window ever flown in space

▲ Terry Virts (left) and Jeffrey Williams pose in front of the Cupola's windows in February 2010

◀ Nicholas Patrick prepares the Cupola for action, removing thermal covers and restraining bolts from all seven windows

NASA X 9

▼ The Blue Planet, as photographed by a member of the Expedition 22 crew in March 2010

▲ The spectacular Aurora Australis, seen from the ISS shortly after a solar storm

▲ Hurricane Lili, with its 30km eye, seen in 2002 from the ISS before hitting Louisiana

▲ The Popocatépetl volcano southeast of Mexico City erupts on 23 January 2001, giving ISS crew a great view of its 9km-high plume

▼ The US Gulf Coast cities of Mobile, New Orleans and Houston shine at night beneath the solar panel of a docked Soyuz spacecraft

◀ Japan's tallest volcano, the 3,776m-high Mount Fuji with its 250m-deep summit crater, seen from the ISS in February 2004

▲ Chris Hadfield tunes up in the Cupola on Christmas Day 2012 before joining other ISS crew members for some carol singing

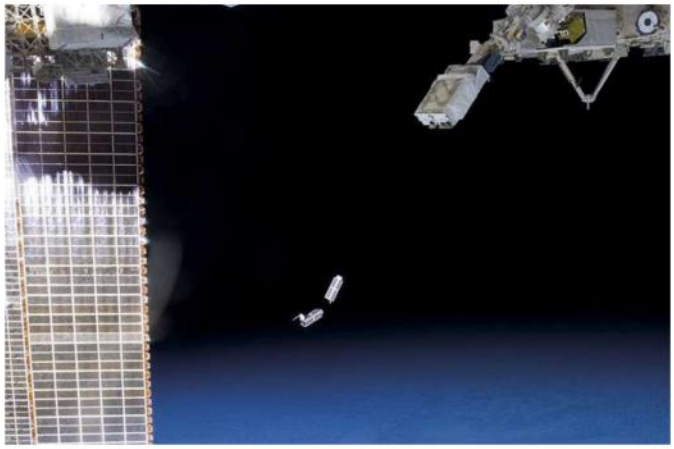
▲ ISS crewmembers frantically struggle to free Luca Parmitano from his spacesuit after his EVA was cut short by a water leak in his helmet on 16 July 2013

▶ The ISS's robotic arm pulls in a SpaceX Dragon capsule as it arrives on 18 April 2014 to deliver supplies and experiments

NASA/ESA X 8

▲ Humanoid robot Robotnaut 2 allows astronauts to perform sensitive tasks remotely, as Chris Cassidy demonstrates in this shot from 2013

▲ British astronaut Tim Peake took a break between tasks to snap this selfie outside the ISS during his space walk on 15 January 2016



▲ Two batches of CubeSats, small satellites containing scientific experiments, are deployed from the ISS in February 2014

▲ Scott Kelly in the Cupola in October 2015. Along with his genetically identical twin Mark, Scott is taking part in the 'Twins Study' to find out how long-term space travel might effect the human body

◀ Peggy Whitson (centre) is currently aboard the ISS – she is poised to break the record for the cumulative number of days in space for a US astronaut, currently 534; the Russian record is 879

BBC

# Sky at Night MAGAZINE

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IMAGE COURTESY OF VYONYX LTD, SPACEPORT AMERICA DESIGNED BY URS/FOSTER AND PARTNERS

◀ Spaceport America in the desert of New Mexico, as it could look in the future when flights by Virgin Galactic take tourists into space

# FLYING INTO THE FUTURE

**THE STORY OF HUMAN SPACEFLIGHT** faces a period of uncertainty. The US and Russia remain major players but they're being joined by other nations, including China and India. There's also an increasing focus on commercial activities, including space tourism. This decade could be the one in which you go to space

# The future of manned spaceflight

The retirement of the ISS is on the horizon, but that doesn't mean that human space exploration will abruptly come to an end – far from it

WORDS: ASH DOVE-JAY

ISTOCK, NASA, XINHUA/ALAMY STOCK PHOTO

Long-term plans include commercially exploiting the resources on other planets, so mining on Mars could become a reality

▲ The largest man-made object orbiting Earth, the ISS is visible from the surface of our planet with the naked-eye

**THE INTERNATIONAL SPACE STATION (ISS)** stands as the single greatest achievement of international collaboration. No single nation could build such a spacecraft; it was only possible through deep and transparent cooperation. But all good things come to an end and the station is no exception; it is expected to be decommissioned by the mid-2020s. Yet this is far from the end of human spaceflight.

The Russian space agency, Roscosmos, is expected to launch two modules – Uzlovoy and Nauka – for integration with the ISS in 2018. Uzlovoy is a 'building block' that allows for multiple modules to be connected, but Nauka will almost be a stand-alone platform, containing a science lab, working area, crew quarters and life support equipment, as well as guidance, navigation and control systems.

With decommissioning looming, you might wonder why Roscosmos is adding new modules to the ISS at all. Before the space station is finally de-orbited, the Russian agency plans to undock many of its newer modules, including Uzlovoy and Nauka. Those modules, already tested in orbit, will be reassembled into a new Russian space station, named the Orbital Piloted Assembly and Experiment Complex (OPSEK), minimising interruption to Russia's human presence in space.

▼ China has already launched and crewed Tiangong 2, a testbed lab for the nation's first modular space station


With a more poetic flair for names, the Chinese National Space Administration (CNSA) plans to begin the construction of its own large modular space station in 2018 by launching its Tianhe (Harmony of the Heavens) core module. China has been quietly launching manned missions into orbit for more than a decade, beginning with Shenzhou 5 on 15 October 2003. Taikonaut Yang Liwei was pitched in low-Earth orbit, just like Yuri Gagarin some 40 years before, completing 14 loops around our planet in 21 hours. China's prototype station, Tiangong 1 (Heavenly Palace 1), was launched in 2011 and hosted two taikonaut crews over its lifetime. The lab's mission officially ended in March 2016 and it is expected to burn up as it falls into Earth's atmosphere in late 2017. A second precursor, Tiangong 2 (Heavenly Palace 2), launched in September 2016, and a month later Shenzhou 11 docked with the space lab. Taikonauts Jing Haipeng and Chen Dong remained aboard Tiangong 2 for 30 days before returning to Earth, making this China's longest manned mission to date.

## Another palace in the Heavens

The launch of Tianhe will be the first of a dozen required to build the Chinese Space Station (CSS). The first crew of Taikonaut builders is scheduled for launch in 2019 and the CSS is expected to be fully operational by 2022. Similar to the ISS, it will be capable of hosting up to six taikonauts at a time.

Key to the success of the CSS is its cargo resupply spacecraft, Tianzhou 1 (Heavenly Vessel), ▸

# Why do we bother?

**Three of the biggest reasons put forward to justify the expense and risk of human spaceflight**

## Socio-economic benefits

During NASA's Apollo programme, the number of science and engineering graduates in the US doubled, from high-school through to PhD. Igniting the imagination of that generation, in a world becoming ever more dependent on technology, helped propel the US into the position of dominance it has held since the second half of the 20th century. From this perspective alone, the Apollo programme has paid for itself many times over.

## Resources

The Sun releases about 10,000 times more energy every second than we've consumed since the dawn of humanity. There are about a dozen worlds in our Solar System with more water than the Earth. Titan has seas of liquefied natural gas equivalent to a hundred-fold the oil and gas reserves on Earth. Mars has all the basic resources necessary to sustain a technological civilisation. If we engage in exploration beyond our planet, an era of abundance awaits.

## Existential risk mitigation

On one planet, life is vulnerable to a multitude of natural and artificial extinction events. Expanding humanity's footing beyond planet Earth is the single most effective action we can take to ensuring our continued survival and development as a sentient species. PayPal and SpaceX founder Elon Musk insists that Mars is our next logical and step that colonising the Red Planet represents a "long-term insurance policy" for "the light of consciousness".

► which was launched from Hainen province on 20 April 2017, atop a Long March 7 rocket. Its maiden mission will see it dock with Tiangong 2.

India, the other rapidly rising space-faring nation of the East, has been making steady progress with its rockets and crew capsule. In 2017 the Indian Space Research Organisation (ISRO) plans to use the latest version of its Geosynchronous Satellite Launch Vehicle rocket to launch GSAT-19 (a radiation spectrometer) into orbit and conduct launch-abort safety tests for the crew capsule its developing.

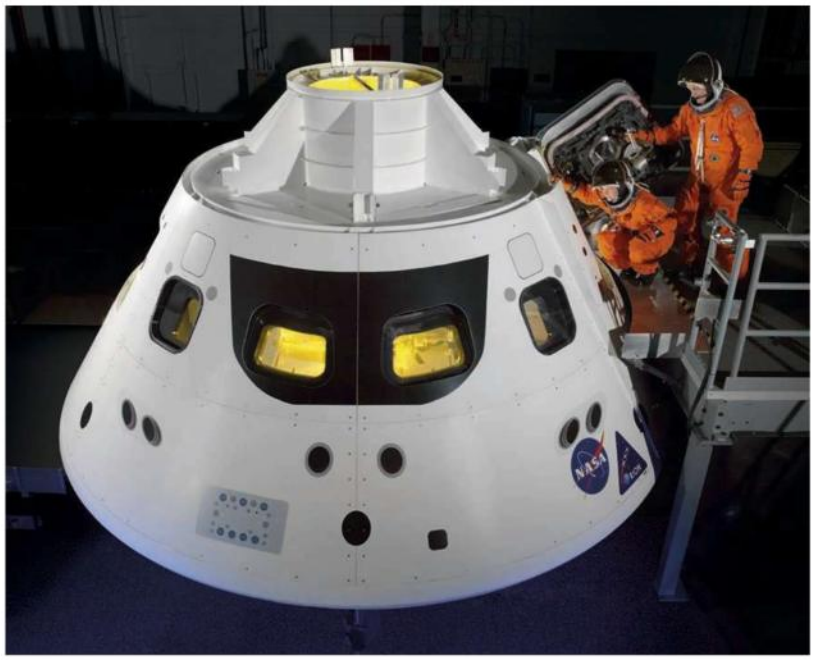
Unlike Roscosmos, CNSA and ISRO, the European Space Agency (ESA) has no coherent plans for its astronauts after the ISS is decommissioned. A few years ago ESA proposed a vague ambition to create a Moon Village, a concept that was aired again at ESA's Ministerial Council in 2016 but is still very much at the study level. ESA was developing a crew capsule with Russia a decade ago, but geopolitical uneasiness killed the partnership. Roscosmos has since moved on to developing its own crew capsule, called Federation, while ESA is working on the service module for NASA's Orion spacecraft – the Apollo-esque four-person crew vehicle designed to fill the void left by the Space Shuttle. The module will contain Orion's power, propulsion, cargo and life support systems for the crew capsule.

## A gateway to deep space

Orion was scheduled for an unmanned test-flight around the Moon in October 2018, but NASA has announced that it may have to postpone that until mid-2019. Such a delay, however, would introduce the possibility of including two astronauts on the flight, turning it into a manned test. Weight constraints of the early Orion designs ruled out the possibility of having a crew aboard for the first lunar test-flight, but as the design has matured, the spacecraft has become much lighter.

Orion and the launch vehicle being developed in parallel to it, the Space Launch System (SLS) rocket, are essential enablers for NASA's plans beyond the ISS. Within the next decade NASA wants to lead the construction of a new space station, or 'Deep Space Gateway', on the far side of the Moon.

**▼ NASA's Orion module will serve as a transport pod and habitat for astronauts during future long-duration missions**



NASA X 2, ISTOCK, NASA/JPL-CALTECH/MSSS, SPACEX X 2, NASA/BILL INGALLS

▲ SpaceX has successfully demonstrated the landing capabilities of its reusable Falcon 9 rocket

NASA's ultimate plan for the Orion, SLS and the Deep Space Gateway is for them to form part of a larger mission architecture that would deliver astronauts into an orbit around Mars and return them to Earth, likely via a fly-by of Venus. The date tentatively set for the launch of this three-year mission is 2033. The last major piece of this puzzle is a Deep Space Habitat module that astronauts would need for the long journey.

NASA has committed $65 million (approximately £50.6m) to half a dozen US aerospace companies to explore and mature to prototype level their take on what such a Deep Space Habitat module would be. We can expect these to be showcased in late 2018. It's likely that the Deep Space Gateway would be used as a test bed for the Deep Space Habitat module before it's used on a Mars mission.

One of the companies developing a Deep Space Habitat is Bigelow Aerospace. Bigelow specialises in expandable space modules and is putting forward its B330 habitat, which has an internal usable volume of 330m$^3$, roughly one-third the size of the ISS. This is amazig – consider that it would take one medium-sized rocket could launch a B330, whereas around 40 launches were required for the construction of the ISS.

Private industry is not only aiding space agencies in sending humans to space; it's leading the charge. One of the most exciting companies right now is SpaceX, which is transforming the space industry in a radical way. Having successfully developed and demonstrated its own partially reusable rockets – the Falcon series – SpaceX is dramatically reducing the cost of launching things into space. Think of how expensive a flight on an aircraft or ride in a taxi would be if the vehicles had to be thrown away after one journey. That's the basis upon which the space launch industry current operates, and what SpaceX is trying to change. It was SpaceX that launched an inflatable Bigelow module for testing to the ISS, via its Dragon capsule atop a Falcon 9 rocket.

## Commercialising the cosmos

SpaceX also ambitions for Mars, but they are far grander than NASA's. In 2016, SpaceX founder and CEO Elon Musk walked onto the stage at the International Astronautical Congress and during an hour-long keynote speech laid out the mission ▸

▼ Inflatable pods, such as those made by Bigelow Aerospace, are easier to launch than pre-built units


SpaceX is hoping its Dragon capsule will take 'tourist' astronauts on a trip around the Moon in a few years' time

# The challenges of deep space

**Travelling to the Moon is difficult, but reaching Mars brings its own set of challenges to overcome**

### Reliable systems

If things go wrong in deep space, there's no feasible way to get direct help or to return home quickly. On a 500-day mission to Mars and back, if your water recycling system fails on day one, you'll need to wait until day 500 before you can get a new one. Accounting for these risks adds enormous cost to a mission and can never be truly mitigated.

### Radiation

From cosmic rays to solar events we cannot reliably forecast, space is a hostile radiation-rich environment for astronauts and the electronic systems needed to keep them alive. There's no single solution, but with reasonable shielding, the increased cancer risk to astronauts in deep space due to chronic radiation exposure is roughly equivalent to what it would be if they smoked.

### Health issues

Research on the ISS has been effective in mitigating the identified potential long-term health problems associated with living in microgravity; namely muscle and bone degradation. But doing so takes much time out of an astronaut's day. If the spacecraft is spun centrifugally to generate an artificial gravity, these health issues could potentially be avoided altogether.

### Space debris

Finding and tracking debris in orbit around Earth is proving a monumental challenge. When hurtling through space at speeds close to 96,500km/h, hitting a stray golf-ball-sized piece of space rock could be catastrophic to a mission. Very little progress has been made in figuring out to how find and avoid or destroy such debris quickly enough.

► architecture, road map, spacecraft and rockets SpaceX are building to deliver a million settlers to Mars in the coming decades.

More immediately, SpaceX announced that it'll be launching two paying passengers (and more are lined up), with their Falcon Heavy rocket in the Dragon 2 capsule (the human-rated variant of the cargo Dragon), on a week-long journey around the Moon and back. This trip is provisionally in the diary for 2018, but it's likely to slip as neither the still-in-development Falcon Heavy rocket nor Dragon 2 capsule has been flight-tested. With that in mind, if NASA decides to go with the manned variant of the Orion capsule test-flight around the Moon, we may soon find ourselves witnessing another space race; not between competing superpowers, but between government and private industry.

**▼ Blue Origin's reusable New Shepard booster takes off for its fourth launch on 19 June 2016**


ISTOCK X 2, SOHO/NASA AND ESA, NASA, BLUE ORIGIN

## Space: a tourist destination

Of course, space tourism isn't anything new – Dennis Tito became the first person to buy a ticket to space in 2001 – and SpaceX isn't the only private company offering spaceflight tickets to the public. Blue Origin is to launch its test-astronauts in New Shepard, its reusable suborbital rocket and crew capsule system, in late 2017. Commercial flights are to start next year. Though these are only brief trips to the edge of space, the ultimate goal as stated by founder Jeff Bezos (also founder of Amazon) is, "millions of people living and working in space". The orbital-class launch vehicle Blue Origin intends to use to make this happen is named New Glenn, and testing of its enormous engines is to start imminently, with flight-tests a few years away.

Another private company offering suborbital flights to the edge of space is Richard Branson's Virgin Galactic. A crash during a rocket-powered test-flight in 2014 killed co-pilot Michael Alsbury and delayed progress by several years, but as of late 2016 glide test-flights had resumed on an upgraded variant of the Virgin Galactic spaceplane, named VSS Unity, and rocket-powered test-flights should recommence soon.

Due to the enormous upfront cost and technical complexity associated with human spaceflight, private industry has teetered on the edge of the cosmos for decades. But with the rise of companies such as SpaceX and Blue Origin, it seems as if we now have strong contenders ready to take the next step. The ISS may be slowing approaching its end, but human endeavours in space are just beginning.

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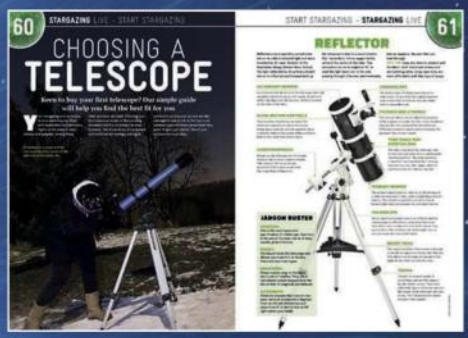


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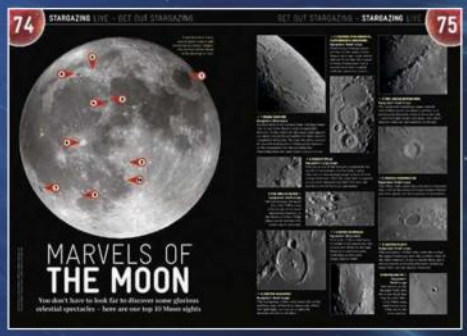


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