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AFTER THE ISS

In orbit for 25 years, the Space Station is nearer its end than its beginning. What comes next?

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After the ISS

Approaching a quarter century in orbit, the International Space Station is nearer its end than its beginning. What comes next? **Sean Blair** finds out

All through the 21st century it has been above us, growing larger with the passing years. As the sunlight catches it, the sprawling structure becomes the brightest star of dusk or dawn.

The International Space Station's first segment was launched 25 years ago, on 20 November 1998. Since then, 15 further modules have been added to the initial foundation of Russia's Zarya FGB block and the ISS has grown into a 400-tonne behemoth. At 109 metres

across, it is longer than a football pitch. Continuously occupied since 2 November 2000, more than 260 people from 21 countries have lived and worked on the Space Station. But it was originally designed for just 15 years in orbit. It can't last forever. So what happens next? ►

GEORX/ALAMY STOCK PHOTO





The beginning of the end:
after 25 years, the race is
on to replace the ageing
International Space Station



Where it all started:
Russia's foundation
module Zarya, launched
on 20 November 1998

► The ageing station has generated negative headlines in recent years – micro-fractures triggering air leaks; a thruster misfiring that spun the ISS out of control; a greater number of space debris near-misses; coolant leaks from Soyuz and Progress craft, and a communications dropout this July – amid ongoing diplomatic strife between Russia and other ISS partners the US, the European Space Agency (ESA), Canada and Japan since Moscow's invasion of Ukraine.

But the severity of reported malfunctions is often overstated. As has been the case throughout the station's life, its international nature is a source of resilience. For instance, when NASA communications suffered a power cut in July, Moscow mission control stepped in. When Russian supply ships experienced coolant leaks – a Soyuz capsule in December 2022, then a Progress freighter in February – the US Dragon and Cygnus spacecraft remained available.

Countdown to a fiery finish

All but one of the international partners have signed on to keep the ISS flying until early 2031, with Russia's Roscosmos committing to 2028 so far (despite previous protesting). In practice, Roscosmos will be needed until the ISS's disposal, which is planned to take the form of a controlled deorbit. Depending on the solar-cycle-influenced density of the atmosphere, the ISS's altitude will be allowed to decay from the end of 2026 onwards so that, as seen from Earth, the ISS 'star' will grow brighter still.

Once it reaches as low as 333km (from its current 400km altitude) around the end of this decade, the ISS can no longer remain occupied. Into early 2031, thruster firings from the Moscow-controlled Zvezda service module will steer the station into atmospheric re-entry over Point Nemo in the South Pacific. This is Earth's remotest point, long employed as a watery spacecraft graveyard. The option of 'reorbiting' the ISS in higher orbit was rejected because the



uncontrolled station is bound to be struck by debris at some point.

"Simply put, it's getting old," explains Thomas Neil Sheasby, leading the engineering team of ESA's Low Earth Orbit Exploration Group.

"The ISS modules are being heated and cooled 16 times per day. There are micro-vibrations from dockings, reboosts and the crew moving around – all of this leads to fatigue. On the inside there's custom-made equipment that is becoming obsolete, making it harder to secure replacement parts.

"In space everything ages more rapidly: there's radiation damage, so items like solid-state drives in laptops get corrupted. Add to that the normal wear and tear of everything from air fans to water pumps. What we're doing now is performing an exercise to see where we can make do, where we still have spare parts, then coming up with a shopping list of what will need updating between now and 2031."

ESA's own ISS module – the Columbus laboratory – is holding up well, adds Richard Braeken, leading the agency's Sustaining Engineering Integration and

▲ Coolant leaks from Soyuz MS-22 docked to the ISS, after a suspected meteoroid hit in December 2022



▲ With its occupants similarly cooped up, a crowded jail smells much like the ISS, according to veteran astronaut Scott Kelly

What does the ISS smell like?

Unsurprisingly, it's tricky to keep a continuously occupied space station smelling sweet

The ISS, equivalent in volume to a Boeing 747, has been occupied continuously for more than 22 years. So what does it smell like? American astronaut Scott Kelly told *Wired* magazine: "I was touring the Harris County Jail [in Texas], and there's this room that smells like space station – combination of antiseptic, garbage, and body odour." He added that in the absence of gravity, bodily

smells – such as farts – tend to linger. UK astronaut Tim Peake said it smells "like a barbecue that's gone wrong", while Italian astronaut Samantha Cristoforetti mentioned a "peculiar odour" she had to adjust to.

Any odour can't be too bad, because of the ISS's atmospheric quality control: module air is circulated by fans through a filtration system that includes activated

charcoal beds (like Odor-Eaters in shoes) to remove unwanted chemicals and noxious smells. The ISS interior has weathered better than Russia's Mir space station. That reportedly mildew-scented station became notorious for mould and fungi in the latter part of its 15-year lifetime. Water-repelling coatings were added to ISS interiors to help stave off this problem.



▲ Cosmonaut Sergey Prokopyev exercises inside the Zvezda module. Fitness became especially important after the leak in the Soyuz module meant crew were stuck on the ISS for over a year

Maintenance team. "Columbus is situated on the forward 'ram' side of the ISS as it orbits, making it especially vulnerable to debris. Its primary structure is supplemented by a secondary protective structure, the Micrometeoroid/Space Debris Protection System, consisting of single- and double-bumper panels. In practice, however, we have encountered no structural issues whatsoever."

The same is true of the other US and Japanese modules, but in September 2019 Russia's Zvezda service module started leaking. Some ISS air loss is normal through dockings, spacewalks and ongoing purging of waste gases. The statistical standard is 0.27kg of lost air per day, but suddenly this loss doubled, and a year later increased to 1.3kg daily.

By systematically sealing hatches between sections, the loss was traced to the Zvezda module. Loose tea leaves were set floating to pinpoint the leak. These drifted towards the transfer tunnel connecting to the rear docking port. Three hairline cracks were identified here – the largest being 22mm across – then sealed. Some elevated air loss continued however, so that the transfer tunnel is now sealed during normal operations. According to a NASA Inspector General report, the leaks are less likely to have been created by micrometeorite damage than everyday metal fatigue, first encountered in terrestrial air travel, where structural stresses trigger micro-fractures.

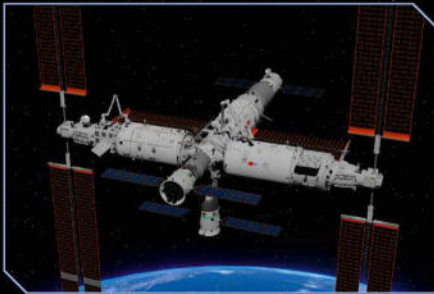
Showing its age

NASA's structural life assessment models failed to forecast this location as risky, raising concerns about other modules – although NASA modules have been safety certified until 2028 and Roscosmos's until 2024. Since then, Russian aerospace firm Energia has identified 'superficial fissures' in the nearly 25-year-old Zarya module as well, although it is unclear whether these are associated with any air loss.

In another age-related effect, the station's original solar arrays are degrading, reducing their power output. In response, a new generation of roller-blind-like solar arrays are being deployed on top of the previous arrays; six out of eight have been installed so far. These operate along with the unshaded elements of the old arrays to generate more electric power than ever – up to a maximum 250 kilowatts, ►

Space stations of the future

Once the ISS is deorbited, human access to low Earth orbit should go on uninterrupted. Various space stations are in development, starting with one already in flight



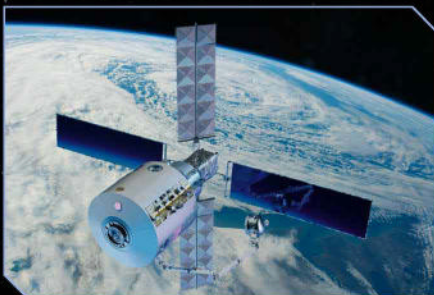
Tiangong space station (China)
The three-module permanently crewed Tiangong is set to outlive the ISS. A space telescope module will join it next year.
FEASIBILITY: In orbit since April 2021 and planned to last at least a decade, China hopes the station will be a new hub for international cooperation post-ISS.



Axiom space station (USA)
This four-module commercial station will be used for in-space manufacturing, experimentation and tourism.
FEASIBILITY: Backed by a NASA Space Act Agreement (SAA), it's due to be built while docked to the ISS. The first two modules have been manufactured.



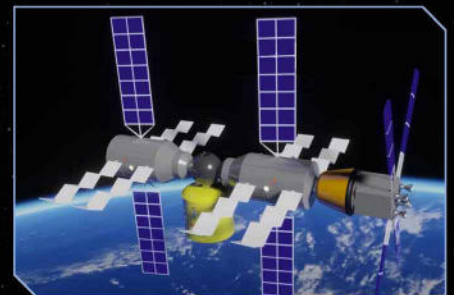
Orbital Reef (USA)
Led by Blue Origin and Sierra Space, this 'business park in space' is based on an expandable primary module.
FEASIBILITY: Backed by a NASA SAA, to be launched by Blue Origin's New Glenn and served by Sierra Space's Dreamchaser spaceplane (both unflown).



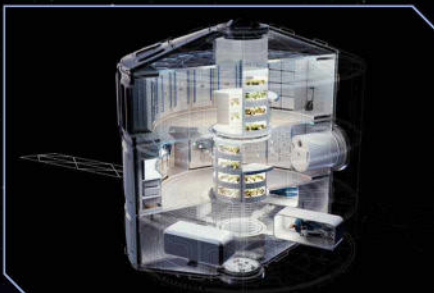
Starlab (USA)
Led by Nanoracks, Voyager Space and Lockheed Martin, a commercial station based around an inflatable main module and attached 'science park'.
FEASIBILITY: Backed by a NASA SAA, Nanoracks' Bishop airlock was the first commercial addition to the ISS. Due 2028.



Northrup Grumman station (USA)
A three-module commercial station serving multiple sectors including microgravity research, in-space manufacturing and space tourism.
FEASIBILITY: Backed by a NASA SAA, modules are to be based on the successful Cygnus craft. Stage 1 to launch late 2028.



ISRO Space Station (India)
Intended for 15–20-day stays, this single-module station at 400km will be serviced by crewed Gaganyaan spacecraft.
FEASIBILITY: Russia is providing technical assistance, but Gaganyaan has yet to fly. The space station is planned for the mid 2030s.



Airbus LOOP (Europe)
An 8m-diameter commercial single-module station with a spacious three-level design for long stays. Suitable for launch by Elon Musk's Starship.
FEASIBILITY: Based on strong European technical heritage, but the project has no customer announced as yet.

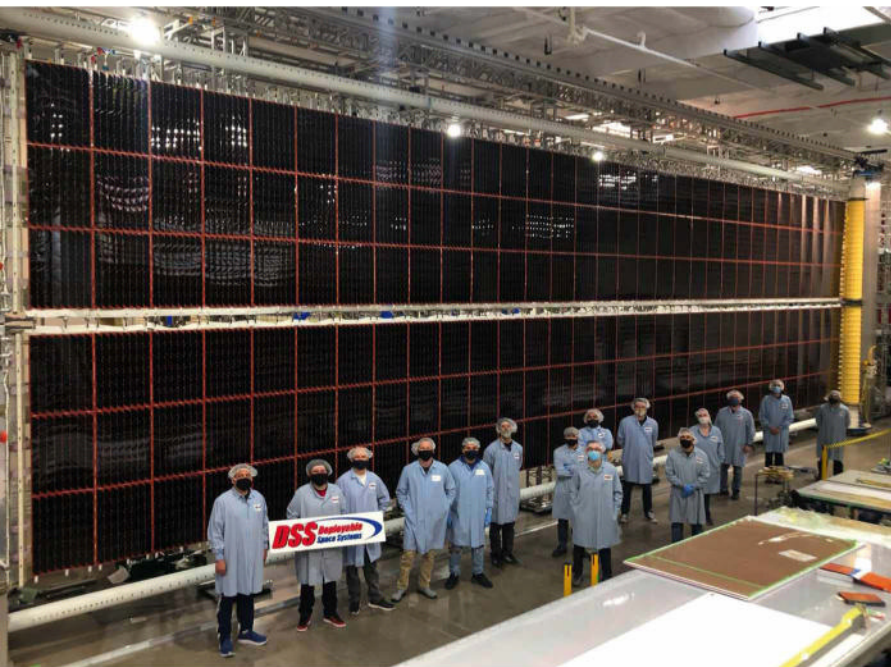


Vast space station (USA)
Artificial-gravity habitats for space tourism and manufacturing, to be launched and serviced using SpaceX's Falcon 9 and Crew Dragon. From late 2025.
FEASIBILITY: Backed by financier Jed McCaleb. Artificial gravity will make for a less desirable test environment.



Gateway (USA/Europe/Japan/Canada)
In lunar orbit, this five-module station will serve as a base camp on the way to the Moon's surface.
FEASIBILITY: Needs SLS or Falcon Heavy launches. First-module launches late 2025. NASA's Capstone CubeSat is currently trialling Gateway's elliptical orbit.

ALL IMAGES ARE ARTISTS' IMPRESSIONS



▲ Opportunities are booming for companies like Deployable Space Systems, who upgraded the ISS's solar array, to develop tech for its successors

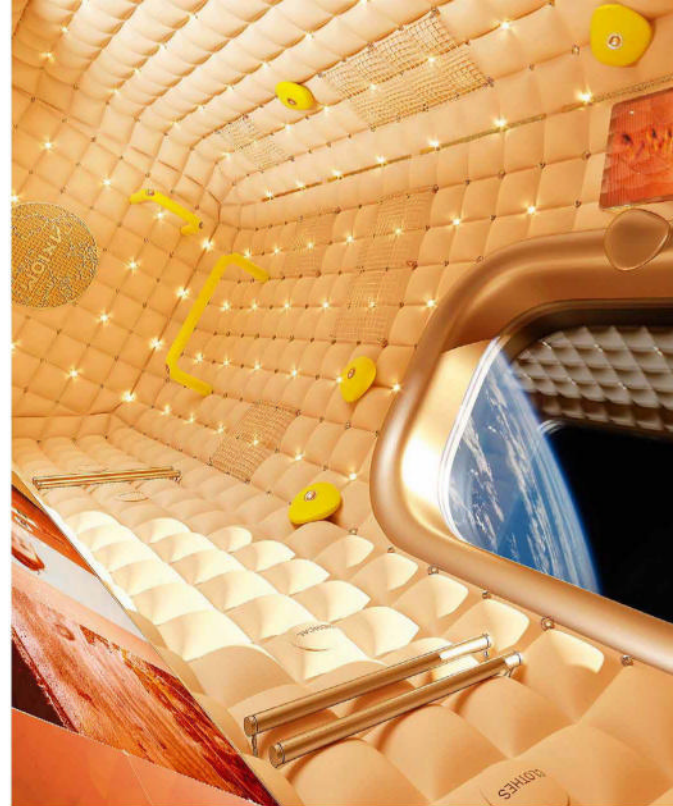
► a 30 per cent increase. This is stored in upgraded lithium-ion batteries for use whenever the station passes out of sunlight. The ISS's next addition will actually outlive it: the US-based Axiom Space company is due to dock four new modules to the station, starting in 2026 with the launch of Hab One. These combined modules will be tested out during the ISS's remaining years, then separated to become an independent free-floating commercial station. Axiom's is one of several private-sector stations supported through NASA Space Act Agreements (see Space stations of the future, left). Just as the US agency has pivoted to private sector crewed launches, the aim is to commercialise low Earth orbit as a destination, with NASA one customer among many.

Next-generation stations

If all goes to plan, continuous human occupation in space will extend well beyond the life of the ISS (and China's Tiangong station). Staffed by NASA veterans, Axiom has already undertaken the first entirely private ISS mission, while two station modules are completing construction at Thales Alenia Space in Turin – a world leader, having built multiple ISS modules, as well as the pressure shell of the ISS-supplying Cygnus transporter.

The company is also building Europe's contributions to the lunar Gateway, spiritual successor to the ISS, involving all ISS partners apart from Russia. Just one-sixth the size of the ISS, made up of compact modules, this station will operate in elliptical orbit around the Moon's south pole. Four astronauts will stay there for up to 30 days per visit, a limit imposed by the necessity to bring their own air and water aboard their Orion spacecraft.

Gateway might be smaller, but it will also be stronger, says ESA's Materials and Processes Engineer João Gandra: "The Gateway pressure shells, along



▲ The Philippe Starck-designed crew quarters planned for Axiom, the world's first commercial space station

with those of Axiom and the latest Cygnus versions, are much the same as their ISS predecessors, made from a standard aluminium-copper alloy. The big difference is that they are now welded using 'friction stir welding', a UK-devised technique which softens rather than melts metals, applying friction to join them. This results in stronger welds with improved performance."

Gateway will also be smarter. Unoccupied for much of any given year, it will operate more like a satellite than the current ISS, with a high level of onboard autonomy. The kind of maintenance performed on ISS spacewalks will be undertaken by the Gateway's own robotic arm. The first two modules are due to launch in late 2025, but the station won't even have an airlock until this decade's end.

The future will see not one space station but many. Commercialisation means that various stations may evolve their own specialist niches. The comparatively spacious, luxurious ISS may well be imparted with retrospective glamour. It will symbolise a vanished era when a large part of the world managed to work together as one. We'll miss the ISS when it's gone.



▲ Future space-dwellers may look back nostalgically on the spirit of international cooperation behind the ISS



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CNSA, AXIOM SPACE/INXC2, BLUE ORIGIN/LIC., VOYAGER SPACE HOLDINGS 2023, NORTHROP GRUMMAN, ISRO, ESA, AIRBUS, DEPLOYABLE SPACE SYSTEMS, VAST SPACE LIC, NASA