WHAT WENT WRONG WITH AUSTRALIA'S VACCINE, AND WHY IT COULD SAVE THE WORLD

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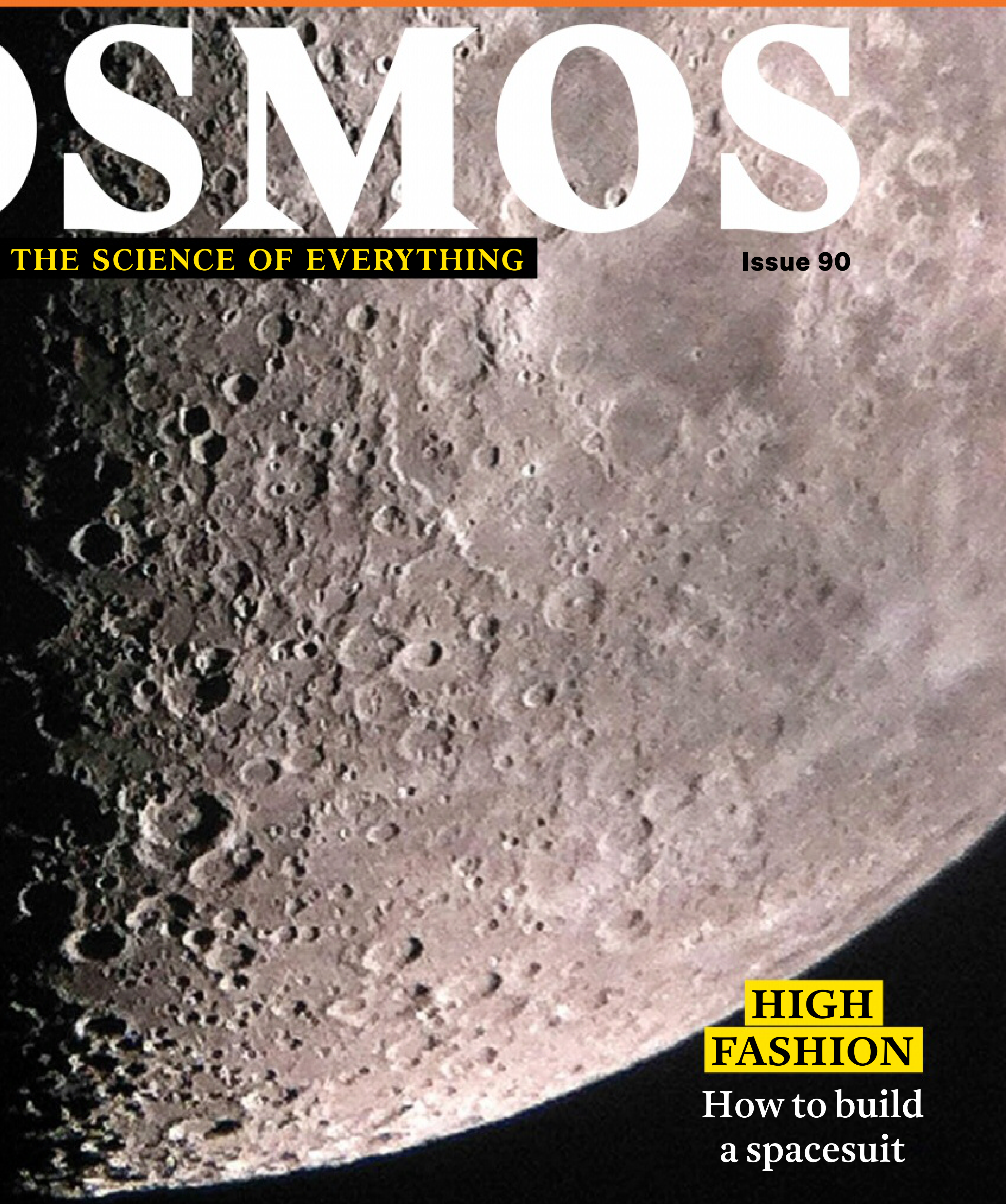

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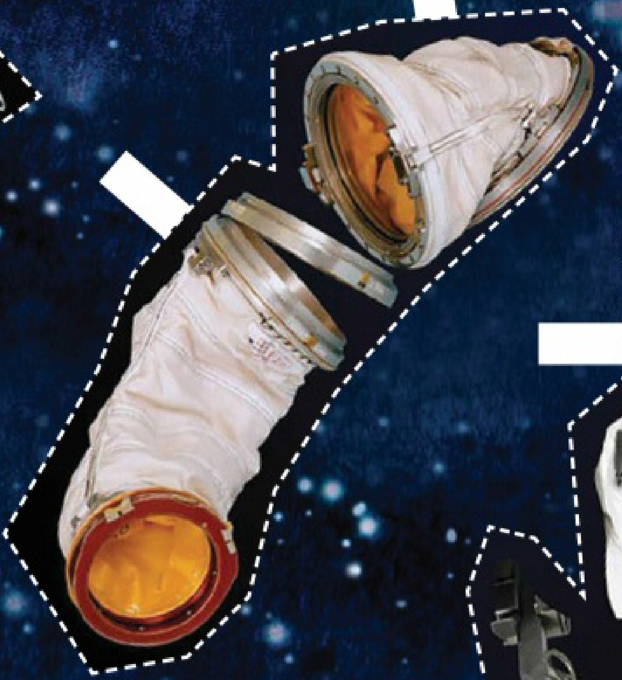
How to build a spacesuit

Few uniforms are as recognisable and inspiring as those worn for space travel. But as **Deborah Devis** discovers, the evolution of the spacesuit has taken decades of small, painstaking steps.

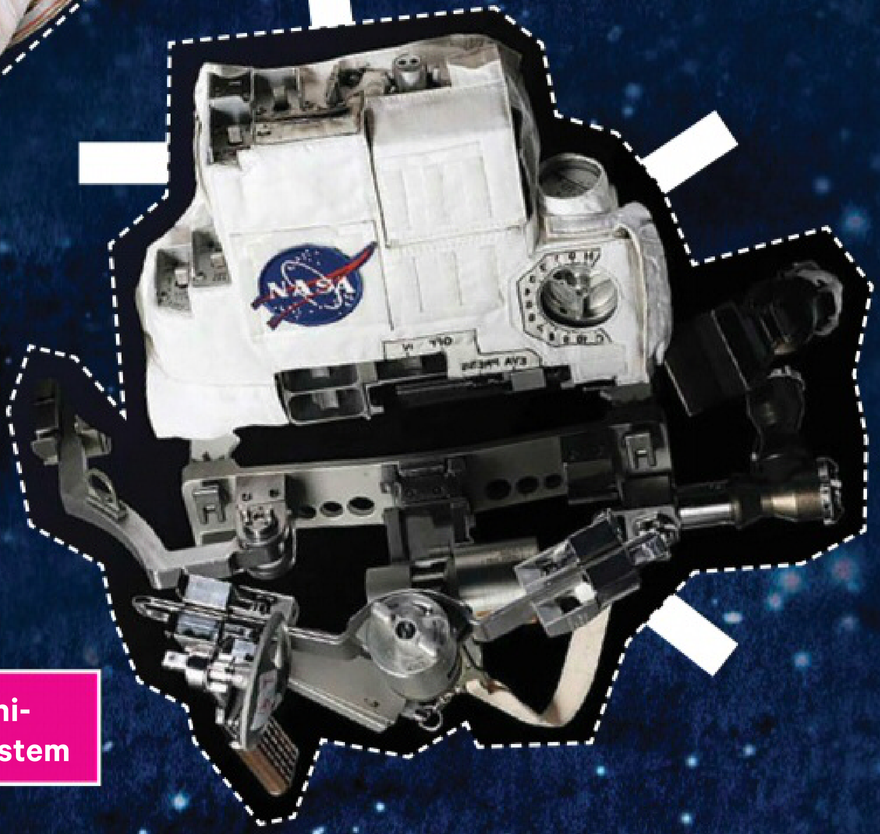
Extravehicular Mobility Unit

Helmet with camera and lights

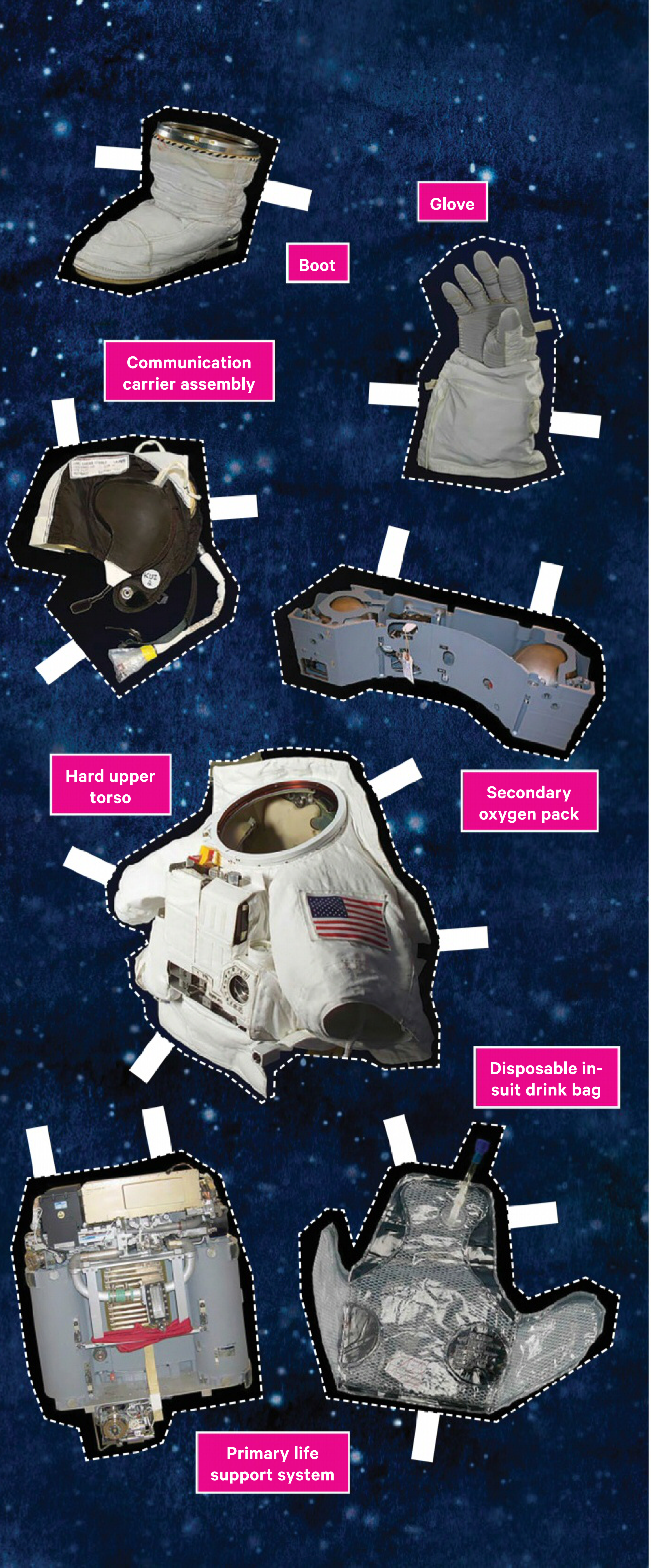
Liquid cooling and ventilation garment



Arm assembly



Modified mini-workstation system



(BACKGROUND) KHANEEROS/GETTY IMAGES. (PARTS) NASA.

Spacesuits need to keep people alive in the harshest environments humans have ventured. Each of their parts must function together to make a mobile system to sustain life. Perhaps it helps that they also look really cool. We often think of Neil Armstrong's bulky moonwalk outfit as "the" one, but there is no single, generic spacesuit. It isn't even a case of one suit evolving; the sleek SpaceX suits revealed recently serve an entirely different purpose to Armstrong's.

But here's the rub with spacesuit history and design: you just can't have one without the other.

High flyers

Before spaceflight, pioneering jet pilots wore proto-versions of today's suits to help overcome pressure and low oxygen problems at extreme altitudes. Made of rubber covered by a rigid fabric, these suits inflated like a bladder to keep a constant pressure inside the suit if the pressurised cabin failed. A hose fed oxygen in from pressurised cylinders.

For NASA's Project Mercury program (1958–63), this same principle was used, but extra aluminium-coated nylon layers, laced boots, gloves and a new helmet were added.

"The big concerns were thermal and radiation," says Les Padilla, hardware manager for NASA's Extravehicular Mobility Unit (EMU). "You'll see aluminised material on the suit early on, because they really wanted to make sure the guys were protected, so they went all out. As we got more data, we figured out what was needed." Collectively, the suit and helmet allowed for oxygen to enter the system through the "umbilical cord" at the waist and exit through a hose on the right of the helmet. This meant that the astronaut no longer needed a big rubber plug strapped to their face, and the oxygen provided extra cooling. Boots served a simple purpose – as comfortable shoes.

An external fan unit kept the suit cool. The suits were so rigid that it was difficult to move, but flexibility at that stage was a low priority.

NASA's Project Gemini (1965–66) brought another challenge: spacewalks. Suits were upgraded with an inner rubber bladder to seal in pressure, and an extended umbilical cord to feed in air. They were hot and extremely stiff; astronauts finished space walks exhausted. But everything was a first.

The icon

Project Apollo (1961–73) used suits similar to Project Gemini, but with an extra caveat: they needed to be Moon-proof. And so EMU suits were born.

"The suit itself is an engineering marvel," says Malcolm Collum, chief conservator for the Smithsonian's National Air and Space Museum. "Every single detail has a specific function." Boots were no longer ordinary. New overshoes had stronger, silicone soles woven with stainless steel uppers. Extra layers of thermal protection and a felt bottom protected astronauts' feet from jagged lunar rocks.

It can also get extremely hot and bright on the Moon's surface – lack of atmosphere will do that. "The suit's gold visor is like very fancy sunglasses," says Padilla. "It blocks harmful UV rays and other rays that come from the Sun. The outer layer of the suit is white because it reflects heat. If it were black it would get a lot hotter quicker."

Armstrong himself wrote to "the EMU Gang" who designed the suit: "It was tough, reliable and almost cuddly. To all of you who made it all that it was, I send a quarter century's worth of thanks and congratulations."

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Neil Armstrong's Apollo 11 suit, model A7L, serial number 056, comprises 21 layers of synthetics, neoprene rubber and metallised polyester films.

Pumpkins in space

Before you think about looking good in space, you need to actually get into space.

"Now there are intravehicular activity (IVA) suits, and they're worn during launch, re-entry, and docking," says James Waldie, co-founder and CEO of Cape Bionics and adjunct professor at Royal Melbourne Institute of Technology (RMIT).

By the time of the fifth space shuttle mission of *Columbia* in 1982, pressure suits were abandoned. After all, no American had died from not wearing one. *Columbia*'s crew wore blue flight suits with an oxygen helmet that looked a bit like a clam – much more comfortable.

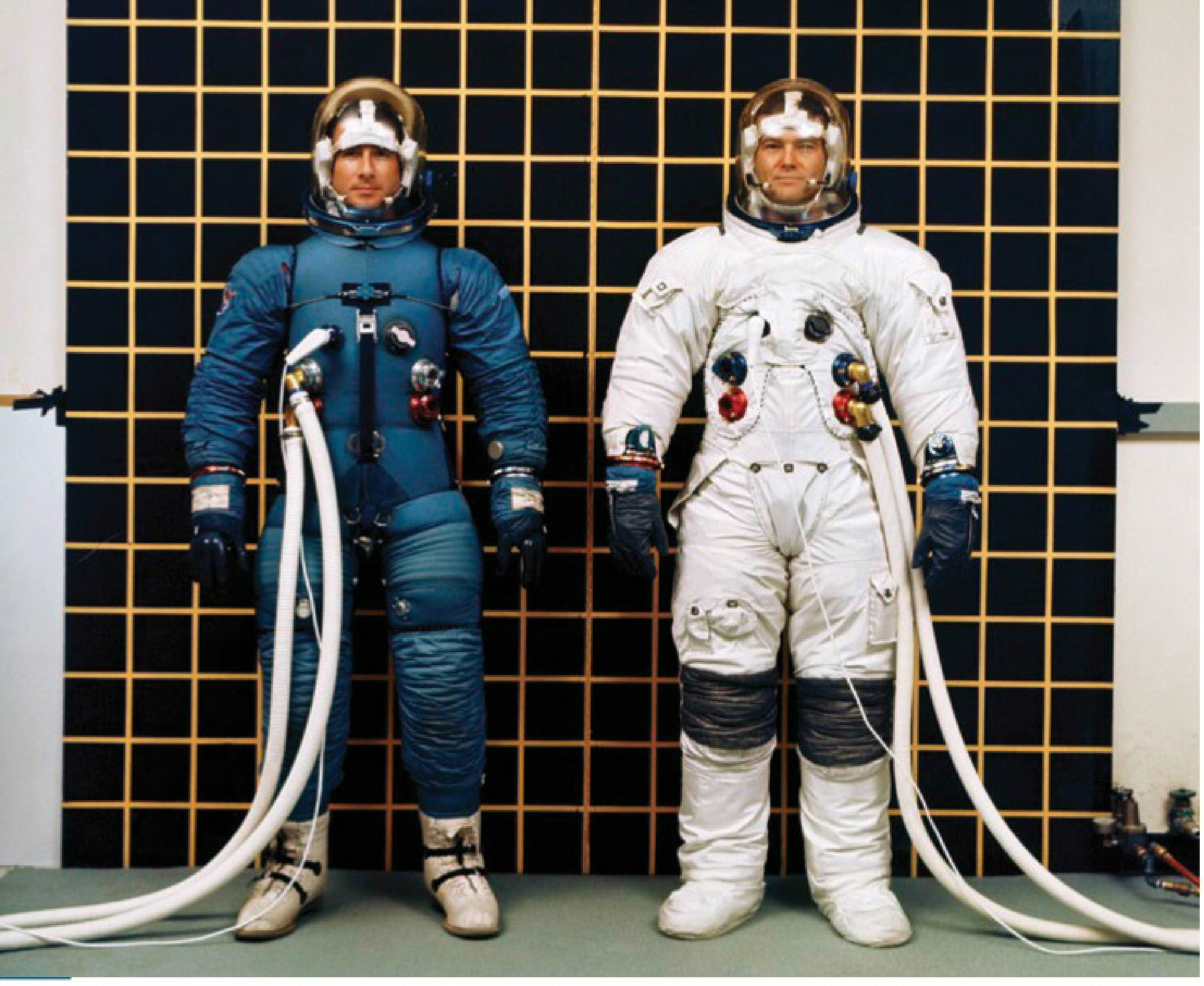
But in 1986, the *Challenger* space shuttle broke apart just 73 seconds after launch. The subsequent inquiry concluded that while the exact cause of death was unknown, there was evidence that some of the crew survived the initial explosion – it was unclear whether they died on impact with the ocean or through loss of cabin pressure. If they'd been wearing old-style suits that inflated upon cabin-pressure loss, some of the crew may have survived. Launch and re-entry suits became standard, causing spacesuit evolution to split into the interdependent paths of IVA and extravehicular activity – EVA – suits.

The *Discovery* shuttle mission in 1988 was seen as a way to reclaim the space-exploring spirit after the loss of *Challenger*. Safety was paramount. The suits were made of Nomax, a synthetic material also used for body armour fabrics and marine hull reinforcements. Its fibres, called aramids, are made of aromatic (forming a carbon ring) chain molecules that match the direction of the fibre, making strong chemical bonds that bump up the strength of the fibres – they won't melt until they reach temperatures above 500°C.

To the delight of survival enthusiasts, crews were also equipped with a knife, locator beacon and signalling kit filled with lights, a whistle, a mirror and a life-raft. The latest suits are the Orion Crew Survival

An educational resource for this story is available at **www.education.australiascience.tv**

TOP: SMITHSONIAN NATIONAL AIR AND SPACE MUSEUM X2. BOTTOM, FROM FAR LEFT: ALBIN MERLE/RENDERHUB, ALBIN MERLE/RENDERHUB, SCIENCE MUSEUM LONDON, ALBIN MERLE/RENDERHUB



Astronauts James Irwin (left) and John Bull demonstrate the Apollo A-6L spacesuit – Bull's suit incorporates the outer white thermal micrometeoroid protective layer (right), evolving the IVA to an EVA.

The 1960 Mercury spacesuit (opposite, left) was a custom-fitted, modified version of a military jet pressure suit, lined with neoprene-coated nylon and an outer shell of outer aluminised nylon. Even with special sewing it was difficult for a pilot to bend arms or legs. Russia's Sokol-KV-2 suits (opposite, centre), were developed after three unsuited cosmonauts asphyxiated on the 1971 Soyuz 11 mission. The suit is made for Soyuz seats, which prompts users into a foetal position – hence the "cosmonaut stoop" when they're vertical. It's analogous to the US "pumpkin suit" (opposite, right), which was developed after the 1986 *Columbia* shuttle disaster.

NASA

System (OCSS), built by NASA, that will be used for the Artemis program. They can keep an astronaut alive in a depressurised cabin for up to six days.

They're fire-resistant, and include thermal underwear cooled with embedded tubes of liquid.

While NASA hasn't released the materials used for these suits, they claim the helmets are made of a lighter, tougher and noise-cancelling material. We do know that the OCSS (nicknamed the Pumpkin suit, for its bright orange colour) comes with a re-engineered zipper to help the astronaut slip in easily in an emergency.

The Russian Sokol (meaning "falcon") suits are similar to these Pumpkin suits but are predominantly white with blue trims. The Sokols are worn onboard Soyuz, a shuttle craft that has logged 140 flights since the 1960s. The original rubber pressure layer has been upgraded to polycaprolactam, which is lighter than the rubber – the Sokol weighs only 10kg. The Pumpkin is a hefty 42kg – mostly due to its 29kg parachute and survival kit.

SpaceX: the age of the tech elite

The suits worn aboard SpaceX's Dragon were the first to be designed with aesthetics in mind. In fact, these "Starman" suits were designed partly by Hollywood costumier Jose Fernandez, who apparently didn't realise at first that he was designing for actual spaceflight – he thought it was for a movie.

"I then realised it's an actual space program," Fernandez said. "They had two weeks to present the suit to Elon Musk. I told them I couldn't do a full suit in two weeks but I may be able to do a helmet." At just 9kg, it is sleek, white and made from Nomex and Kevlar – another aramid-based synthetic material. A connection point on the suit's thigh allows easy input of both air and power from the seat.

Like the Pumpkins, Starmans are tailored individually to astronauts for optimal comfort, complete with 3D printed helmets. The suit's gloves are touch-screen compatible to work with the capsule's dashboard. "It's not just a piece of hardware, it's a very personal thing. It's Bob's suit. It's Doug's suit," said Chris Trigg, SpaceX's spacesuits and crew equipment manager. "Elon Musk wanted it to look stylish," Fernandez said. "It had to be practical but also needed to look great. You look heroic in it."

Space-age leisurewear

Getting to and from space is one thing, but staying up there for any length of time brings other challenges. While it might look like the crew on the International Space Station (ISS) wears comfy tracksuits, the reality is rather more sophisticated.

As creatures of Earth, our bodies are adapted to its gravity. This means our health is affected in the absence of gravity, too. Lack of gravity causes astronauts to lose body mass, so they need to wear a gravity-loading suit.

"Those suits are designed to load the skeletal system the same way that our body weight loads the bones here on Earth." says Waldie. "Astronauts lose up to 2% bone mass per month in space, because they're just floating around, and bones and muscles atrophy as they adapt to this new environment.

"We have to consider each astronaut's body size and the weight of the limbs, so we can calculate the normal loading regime on Earth. And then we have to consider their size at every few millimetres of height in order to design a suit that can load them vertically, but have the appropriate horizontal tension to hold the suit comfortably in place and transfer the loads."

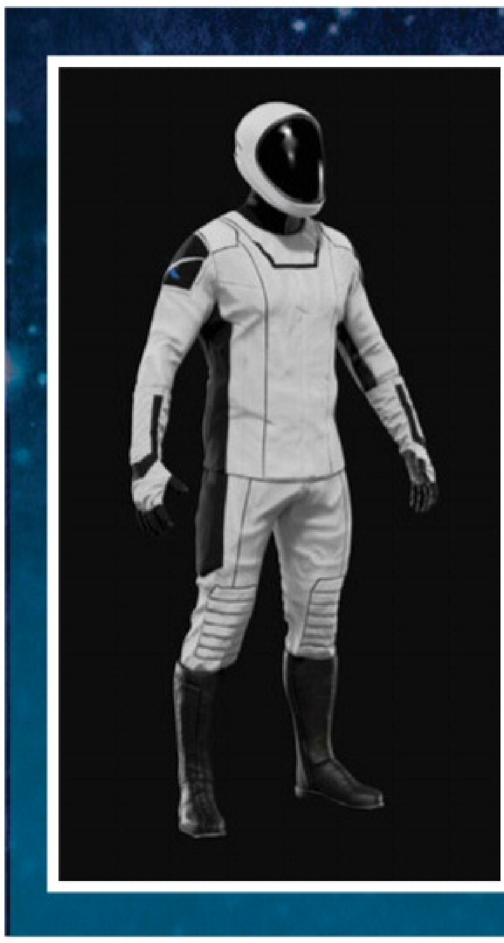
This is a task made more complex because calculations for the gravity loading of an astronaut taken on Earth will be different to their body shape in space.

"In space, the fluids redistribute equally over the height of the body," says Waldie. "You get thinner legs and a puffy face. Because the leg size decreases, we need to accommodate that into the suit design."

Spacewalking

EVA suits are arguably the most complicated suits to design because they're solely responsible for the survival of astronauts during spacewalks. "Their purpose is like a miniature aircraft, but they must allow mobility, flexibility and manoeuvrability so that a crew member can function when they're working," says Padilla.

Space has a different pressure to the Earth's surface. On the ground, the internal pressure of our bodies matches the external pressure of the air, creating a balance. In space, there's almost no pressure; the air



inside our bodies will dangerously expand as it tries to fill that vacuum, while the boiling point of liquids is so reduced that blood can literally boil. To overcome this, the EVA suits need to be pressurised.

But, as Waldie explains, once suits are inflated they can become rigid, like a car tyre. "And the more you inflate them, the stiffer they become. So it is a big challenge trying to design gas-pressurised suits which offer good mobility while still being light and robust."

Our bodies also change in volume as we move. If we flex a muscle to move an arm, the volume of our body increases and takes up more space. That air compresses the astronaut, which makes movement in spacewalks very tiring.

"It's fatiguing," says Padilla. "You've got pressure on your hands, your body. To move, you've got 1.95 kilograms of pressure over all of your body that you're working against."

The EVA suits are designed for different outside tasks, as it would be impractical to put every tool on a single suit. "EVA suits come in different sizes and then the components can be tuned from there," says Waldie.

The dexterity and fine motor skills needed to hold and operate tools to maintain or repair the spacecraft from the outside are essential, making the glove a key component. "The gloves, in particular, go through a very rigorous tuning. The finger lengths must be adjusted to give the astronaut maximum mobility and tactility," says Waldie. "Glove design is very difficult because the hand is perhaps the most complex, jointed geometry of the body."

Not only is the dexterity integral, it is also downright dangerous for gloves to fit poorly. "I worked at NASA on a study which was looking at injuries caused to astronauts through users using EVA gloves, principally looking at nail delaminations – having nails die and fall off through training and flight use with the gloves," Waldie explains. "The problem is so bad that one astronaut had their nails removed before flight."

This is because fingers change in length and size as they bend. The glove needs to be built around a model of the hand in an ideal pose where the finger length is perfect, but when the astronaut opens and closes their fingers, their position in the glove changes.

The fingertips can go from losing contact with the glove, making work very difficult, to the nail rubbing against the fabric and being essentially "filed off".

Gloves must be of a soft material to aid flexibility, but the fibreglass body of NASA EMUs and polycarbonate helmets must protect the astronaut from space debris.

The front of the helmet is a clear plastic that has wide-field vision, as neck movement is difficult. It also has a purge valve to remove carbon dioxide, which becomes toxic at high levels. The helmet even comes with a hard straw linked to a drink pack, because hydration is vital. And no worries if you need to be out there for a few hours without a toilet – the suit comes equipped with a space nappy.

SUITS ARE SEWN, NOT GROWN

Spacesuits aren't "built". In fact they are sewn. So how do you sew a space suit?

The Apollo suits were sewn by expert craftswomen such as Jeanne Wilson, who meticulously handstitched the torso, arms and legs of the Moon-landing suits.

At her previous job, sewing suitcases, everything was fast, she says. But on the Apollo spacesuits, "everything was very slow. Every time you sewed a seam, it had to be inspected because of the importance of what we were doing.

"They had to take two X-rays to make sure there were no pins or anything else left in the suits. There were nights we'd go home and worry, 'Oh my God, did I leave a pin in it?' And you would lose a little bit of sleep at night sometimes. You actually broke down and cried – I know I did."

The highly detailed nature and shape of gloves required seamstresses to specialise.

"Each astronaut had their own moulds made from their hands," says Joanne Thompson, a glove specialist. "The palm part had long strips that went through the fingers and attached to the knock part and there was an opening to the thumb, and you had to stitch around that."

The gloves had fabric ridges like an accordion, called convolutes, so the astronaut had maximum dexterity.

Multiple gloves had to be made for all stages of testing, well before the astronauts even boarded a rocket for space. "We had to make different types of seam samples and they would test them until they tore," says Thompson. "We used to make them all day long and knew they were going to be trashed. But we knew a man's life was going to depend on it, so we just kept on going."

NASA flight engineer Anne McClain (below) is helped into her Russian Sokol suit as she prepares for a Soyuz launch to the International Space Station, in 2018.

GCTC/NASA/ANDREY SHELEPIN

> "We need to be able to turn bolts. We need to be able to pull out large batteries and replace them. So they need suits that offer dexterity and yet protection."

What about the women?

The first all-female spacewalk, completed in 2019, highlighted a problem that had existed for the 36 years since Sally Ride became the first American woman in space. Put bluntly, spacesuits were designed for men.

The walk was originally supposed to happen in March 2019, but astronauts Christina Koch and Anne McClain realised they didn't have the right suits.

McClain noticed that the medium EVA "shirt" fit her better than the large, but there weren't enough on board for both her and Koch. Since it was easier to switch the astronaut than the suit, she was substituted out for a male colleague.

It is not an uncommon outcome.

"There are some physical reasons that make it harder sometimes for women to do spacewalks," explained Ken Bowersox, the acting associate administrator for human exploration at NASA. "It's a little bit like playing in the NBA. You know, I'm too short to play in the NBA, and sometimes physical characteristics make a difference in certain activities.

"And spacewalks are one of those areas where just how your body is built in shape, it makes a difference in how well you can work a suit."

Is it, Ken? After all, suits are built, not bodies. If we can build spacecraft to work for people and not require people to be "built" for spacecraft, can't we do the same for suits? "These repairs and tasks can be performed by anyone in the astronaut corps, that's for sure," said Dava Newman, the former NASA deputy administrator who's working on a new spacesuit design at MIT. "That is, if they're in the right suit."

This might be addressed for Artemis as NASA's next-generation xEMU suits accommodate a range of bodies from the "first percentile female to the 99th percentile male", according to Kristine Davis, an advanced spacesuit engineer at NASA.

"We want every person who dreams of going into space to be able to say to themselves, that yes, they have that opportunity," added Jim Bridenstine, NASA administrator.

SpaceX's Starman IVA suits (above, opposite) come with 3D-printed helmets and touchscreen compatible gloves – but only in one gender. The xEMU suits are upgrades of the Apollo era EVA suits designed for returning to the Moon and planning for Mars. Improvements include better mobility, hiking-style boots, enhanced communication and a modular system (see torso variations above) for different gravity, temperature or expedition requirements.

Looking to the future

The next generation of spacesuits will be focused on walking on celestial bodies.

"Designing suits that are functional, but still allow mobility, is a huge challenge," says Waldie. "Particularly as we look towards Moon and Mars suits, which require light and flexible boots." Both Mars and the Moon have a lower gravity than Earth, but more gravity than space, so explorers will require suits that provide a precise level of gravity-loading.

Scientists have good information about gravity on Earth and gravity in space, but not much for the levels of gravity in between.

"It's going to be important to consider when we go to the Moon for long periods," says Waldie. "We don't know if Martian gravity is enough to keep someone healthy for a two-and-a-half-year mission." Landed missions need astronauts who can "do more than just fly around and enjoy the scenery", says Padilla. "We need to be able to turn bolts. We need to be able to pull out large batteries and replace them. And so they need suits that offer dexterity and yet protection from the very harsh space environment."

The process will probably resemble the IVA evolution. One small step, and then another small step, and maybe a medium step here and there.

But their core function is not about inspiration, fashion or fancy. They are the end product of decades of development and thousands of people contributing to one single mission: keep the astronaut alive. ⊙

DEBORAH DEVIS is a journalist at *Cosmos*, writing regularly on cosmosmagazine.com. This is her first magazine feature.

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