BBC **MEET THE ENGINEER BUILDING A HELICOPTER TO EXPLORE MARS**

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FLIGHT NAVIGATOR

In a space exploration first, NASA is preparing to deploy a chopper on the Red Planet. Flying in a fraction of Earth's gravity, it should be a sight to behold…

by **DR PAUL PARSONS**

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Whether disrupting air traffic, returning glorious vistas of Earth from above, or just spying on the neighbours (if that's your thing), drones have become a familiar sight in our skies. Now, for the first time, the US space agency NASA is poised to fly a drone-like helicopter in the atmosphere of another planet.

The craft, named Ingenuity, will hitch a ride to the Red Planet aboard the one-tonne Perseverance lander, NASA's latest wheeled robotic rover mission to drive across the planet's rugged surface. Perseverance will launch from Earth this summer, with touchdown on Mars scheduled for 18 February 2021.

Flying in the alien atmosphere of another world is a feat that poses a unique set of engineering challenges and yet, if this small technology test mission is successful, it will furnish scientists with a new and highly effective way to explore the planets and moons of our Solar System. That's because flying is a much faster way to get around than ground roving. Aircraft can gather aerial imagery that's much sharper than pictures returned by spacecraft. They can also serve as scouts to identify potential targets for ground-based rover vehicles, and they can even gather samples and bring them back to a central lander station for analysis.

And, of course, they can go where other probes simply can't.

"Larger Mars rotorcraft in the 5kg to 20kg class with small science payloads could access areas not reachable by rovers, and support wide-area surveys in shorter times," says Dr Bob Balaram, Ingenuity's chief engineer, based at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. "There is also a NASA mission to explore Saturn's moon Titan with a flying lander that will arrive in the early 2030s."

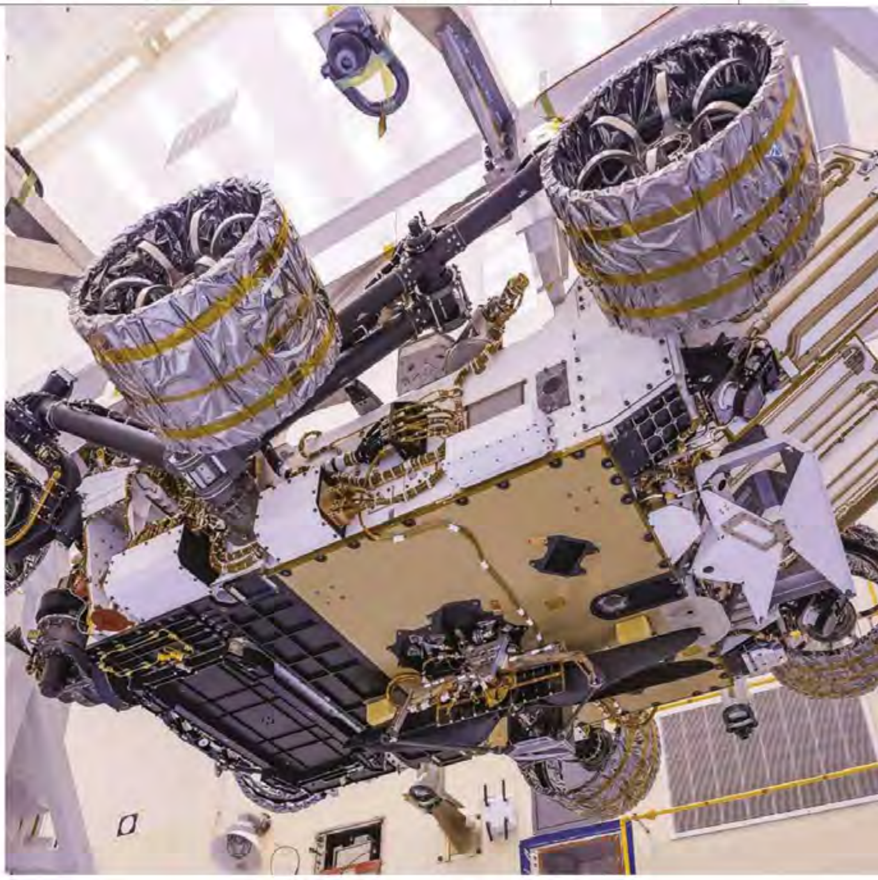
The Ingenuity craft is 50 centimetres high with four blades – one pair above the other – mounted on twin, counter-rotating rotors each spanning 1.2 metres. The size of the rotors (which need to be this big for the helicopter to fly in Mars's thin atmosphere) is the main reason why a more familiar drone-like quadcopter design was rejected – such a vehicle would be simply too large to fit on the rover.

Ingenuity is stowed beneath the body of Perseverance, from where it will be dropped onto the surface of Mars, probably a couple of months into the mission. The rover will then drive 100 metres away, to minimise collision risk, and the two will exchange radio signals to 'pair up' – a bit like pairing wireless earbuds to your phone – before the rover sends the command for Ingenuity to make its inaugural flight. This will likely be what Balaram calls a 'mutual selfie' – the two vehicles taking pictures of one another as the helicopter rises to a low hover and then lands again.

"FLYING IN THE ALIEN ATMOSPHERE OF ANOTHER WORLD IS A FEAT THAT POSES A UNIQUE SET OF ENGINEERING CHALLENGES"

MARS EXPLORER

Ingenuity carries a black-and-white navigation camera and a 4,208 x 3,120-pixel colour camera, comparable to what might be found in a mobile phone. Images are beamed by short-range radio link to Perseverance, which then relays them to one of a number of NASA spacecraft in Mars orbit, from where they are transmitted back to Earth. "Multiple images may be stitched into a panorama at some point using ground software tools," says Balaram.



Ingenuity, visible lower centre, attached to the Perseverance rover

The helicopter isn't going to make any actual scientific observations, however. Instead, the focus is to return engineering data from the test flights that will, it's hoped, validate the technology or at the very least provide valuable feedback to refine future designs.

The primary mission plan is for up to five flights over a period of 30 days, though this may be extended. The maximum horizontal range of the flights will be about 300 metres with a ceiling altitude of 10 metres and a max flight time of 90 seconds, after which the helicopter's six lithium-ion batteries need recharging. This is handled by a solar panel mounted directly above the rotor blades. A full charge takes a whole Martian day ➜

Land, sea and air *All-terrain exploration of the Solar System*

Lunokhod

The first wheeled rover to explore the surface of another world was the Soviet Lunokhod 1 probe, which landed in the Moon's Sea of Rains on 17 November 1970. Resembling a bathtub on wheels, its instruments included cameras and radiation detectors. It survived on the lunar surface for 322 days.

Vega

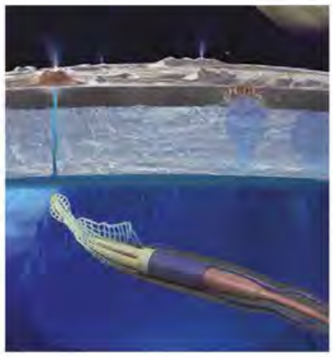
The helium-filled Vega balloons, each measuring 3.5 metres across, were two unpowered aircraft dropped into the atmosphere of Venus by the Soviet Union in 1985. They floated 50km above the planet for 46 hours before they succumbed to the corrosive atmosphere and their failing batteries.

Dragonfly

Due to leave Earth in 2026, NASA's Dragonfly is an octocopter drone that will drop into the skies of Saturn's largest moon, Titan, in 2034. With a nuclear battery on board, it will spend nearly three years surveying Titan, where conditions may resemble those in which life first emerged on Earth.

Europa submarine

There is good evidence that Jupiter's moon Europa harbours an ocean of liquid water beneath its icy surface, heated by the constant flexing of Jupiter's gravitational pull. Some engineers have come up with designs for submersibles to explore this ocean, although none have yet been selected to fly.



NASA/JPL, MASON PECK/CORNELL UNIVERSITY, NASA/GSFC/ARIZONA STATE UNIVERSITY, GEOFFREY LANDIS/WIKIPEDIA

Testing Ingenuity in the lab

to complete, and two-thirds of the power stored is needed to keep the aircraft's electronics warm during the bitterly cold Martian night, when temperatures can plunge to -100°C.

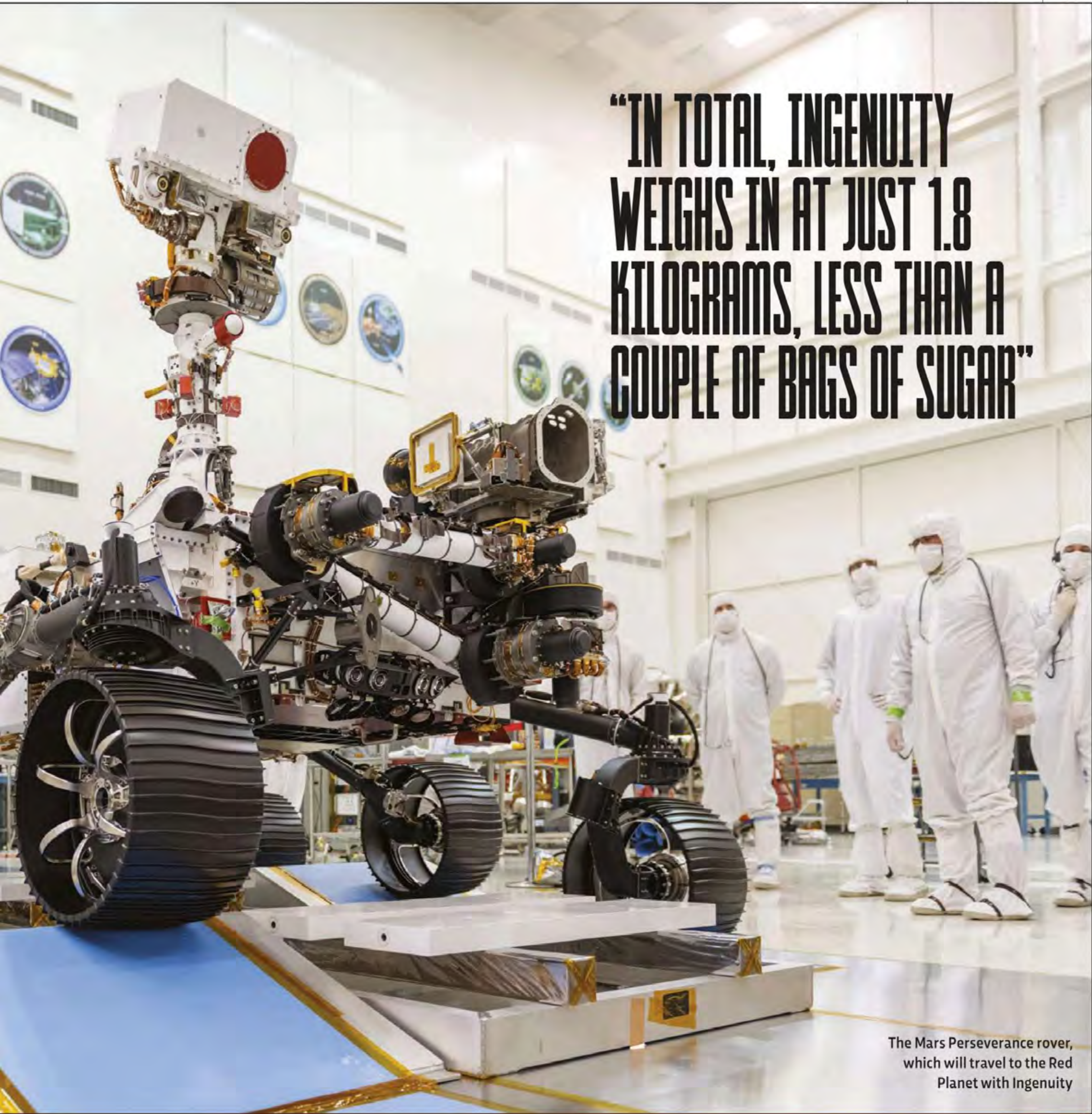
The low temperature is only the beginning of the problems facing a would-be Martian aviator. Aircraft take off using 'lift', an upward force created as air passes over a curved aerofoil. On a plane, the aerofoil is the wing; on a helicopter, it's the rotor blades. But the surface density of Mars's atmosphere is just 1 per cent of Earth's. A cubic metre of air at sea level on Earth weighs 1.2kg, but on Mars that figure drops to just a few grams – roughly equivalent to the tenuous atmosphere on Earth at an altitude of 30,000 metres (100,000 feet). And to generate enough lift to fly from such thin air means the engine has to work overtime. Whereas helicopters on Earth typically spin their blades at 500 revolutions per minute (rpm), on Mars you need to crank this up to around 2,500rpm.

For the same reason, the weight of the craft is kept to an absolute bare minimum. For example, each pair of rotor blades weighs just 56 grams – despite measuring over a metre in length. "Carbon composite layups within a foam core matrix were used to achieve lightweight but stiff blades," says Balaram. In total, Ingenuity weighs in at just 1.8 kilograms, less than a couple of bags of sugar. Balaram has even worked out the best time of day to fly the helicopter on Mars – mid-morning, as it turns out, roughly 11am. By this time, the craft has been

NASA/KSC, NASA/JPL

MARS ROCKS, PERSEVERANCE ROLLS

The new rover mission set to revolutionise the hunt for past life on Mars

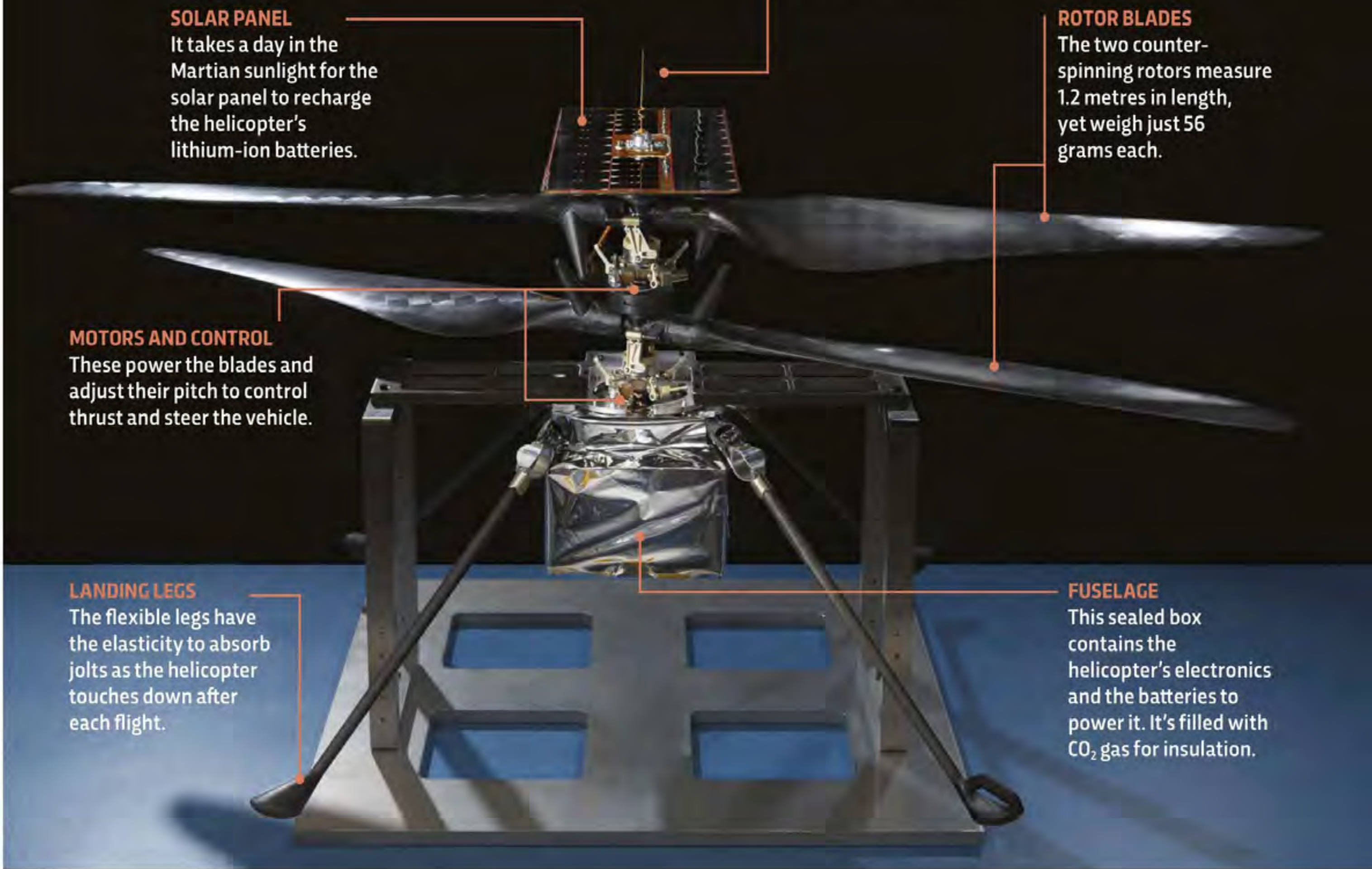


"IN TOTAL, INGENUITY WEIGHS IN AT JUST 1.8 KILOGRAMS, LESS THAN A COUPLE OF BAGS OF SUGAR"

The Mars Perseverance rover, which will travel to the Red Planet with Ingenuity

Ingenuity will fly to the Red Planet with NASA's Perseverance rover mission. It is scheduled to blast off from Cape Canaveral aboard an Atlas V rocket in a three-week launch window, beginning on 17 July 2020. The one-tonne wheeled vehicle, which is about the size of a small car, is due to touch down in Mars's Jezero Crater during February 2021. Although Mars is a dry, barren world today, between 3.5 and 4 billion years ago, it is suspected to have enjoyed a warm, wet climate suitable for fostering life. The Jezero Crater landing site is believed to have been the floor of a great lake at this time, awash with liquid water, and Perseverance will scour the site for any remaining biological signatures. The initial mission span is one Martian year (about 1.9 Earth years), during which Perseverance is expected to drive around 200 metres a day, examining soil and rocks. The rover is equipped with a coring drill which it'll use to extract rock samples, leaving them in canisters along its route for recovery by a future sample return mission.

HOW IT WORKS
INGENUITY



SPECIFICATIONS

MASS: 1.8kg
HEIGHT: 50cm
ROTOR SPAN: 1.2m
ROTOR SPEED: 2,300-2,900rpm

MAX ALTITUDE: 10m
BATTERIES: 6x Sony Li-ion, delivering 220W power

MAX FLIGHT TIME: 90s
RANGE PER FLIGHT: 300m
MAX FLIGHTS PER DAY: 1
MISSION DURATION: 30 days

"IF THE HELICOPTER'S TRIALS ON MARS ARE A SUCCESS, THEN IT WILL BE A GENUINELY HISTORIC ACHIEVEMENT – THE FIRST EVER POWERED FLIGHT BEYOND EARTH"

warmed by the Sun after the chilly Martian night, but the air is cool, keeping its density as high as possible and its wind speeds low, while the batteries still have a healthy charge. "After we get the first couple of flights under our belt, I'm sure we will try to fly in the afternoon, and do more exploratory things, but the most conservative thing we can do is to pick a mid-morning flight," he says.

ON TRIAL

The team tested their design inside the JPL's Space Simulation Chamber, a 25-metre-high, eight-metre-wide cylindrical test vessel in which the atmosphere could be precisely tuned to replicate the aerodynamic conditions on Mars. However, the low pressure was only one of the peculiarities of flying on Mars that had to be modelled. They still needed to account for the planet's gravity, which is only 0.38 (just over a third) of that found on Earth. They came up with a novel solution.

"A gravity off-load device was installed into the chamber and was used to provide a compensating force on the vehicle to account for the difference in gravity between Earth and Mars," says Balaram. This literally means attaching a lightweight thread to the top of the vehicle, which they pulled tight just enough to lift 0.62 of the helicopter's weight on Earth – leaving the remaining 0.38 (its weight on Mars) to be lifted aerodynamically by the rotors.

As well as demonstrating the basic feasibility of flight on Mars, these ground tests were crucial for another reason – allowing the team to fine-tune the Guidance, Navigation and Control (GNC) software that will actually have to pilot the helicopter on Mars. When the first real Martian flights begin, the light-travel time from Earth to Mars will be many minutes, making it impossible for controllers to steer the craft remotely.

Instead, the commands from ground control on Earth consist of a set of waypoints – coordinates selected by controllers – which the GNC software will follow while taking account of the stream of real-time data flooding in from the helicopter's sensors. These include gyroscopes, accelerometers, a navigation camera, an altimeter, and an inclinometer which measures the aircraft's tilt.

"Waypoints consist of an x-y position, a height above ground, a vehicle heading, and a desired time to arrive at each point," Balaram says. To test the software, his team even set up multiple high-energy lamps inside the simulator to recreate sunlight illumination at the Martian surface, as well as fans to simulate flight in windy conditions. On top of all this, Ingenuity must also be a spacecraft, certified to survive the stresses of launch, the seven-month journey to Mars during which it will be subjected to radiation and the harsh vacuum of interplanetary space, and then finally wracked by the high g-forces and scorching 2,200°C heat of entry, descent and landing through Mars's atmosphere.

But if it works and the helicopter's trials on Mars are a success, then it will be a genuinely historic achievement – the first-ever powered flight beyond Earth. And the expertise gained will lay the groundwork to fly bigger and better aircraft, capable of carrying a full payload of scientific instruments to explore the skies of distant worlds.

As Balaram puts it: "It's kind of a Wright Brothers' moment on another planet." **SF**

by **DR PAUL PARSONS** (@NasaProPlus)

Paul is a science journalist and author. His book, Ten Short Lessons In Space Travel, *will be published in June (£9.99, Michael O'Mara Books).*