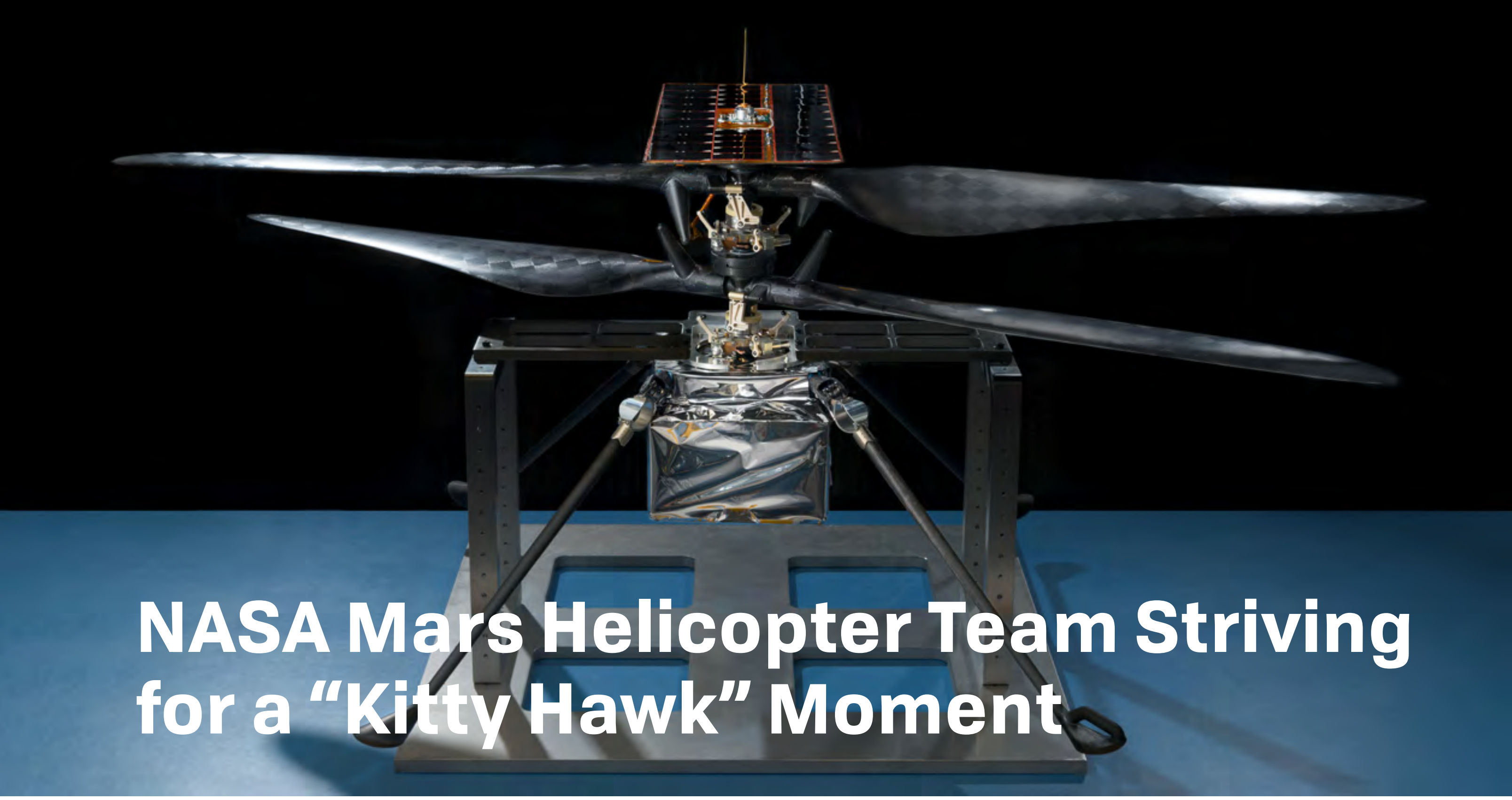


NASA Mars Helicopter Team Striving for a "Kitty Hawk" Moment

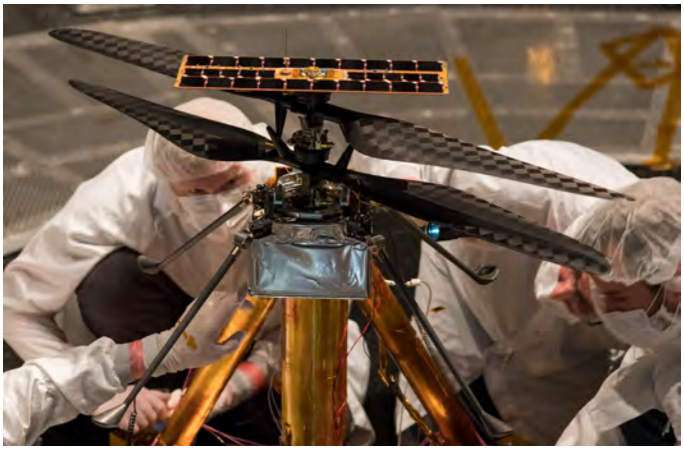
NASA's next Mars exploration ground vehicle, Mars 2020 Rover, will carry along what could become the first aircraft to fly on another planet.

By Richard Whittle

The world altitude record for a helicopter was set on June 12, 1972, when Aérospatiale chief test pilot Jean Boulet coaxed his company's first SA 315 Lama to a hair-raising 12,442 m (40,820 ft) above sea level at Aérodrome d'Istres, northwest of Marseille, France. Roughly a year from now, NASA hopes to fly an electric helicopter at altitudes equivalent to two and a half times Boulet's enduring record. But NASA's small, unmanned machine actually will fly only about five meters above the surface where it is to take off and land — the planet Mars.

The NASA Mars Helicopter is to make a seven-month trip to its destination folded up and attached to the underbelly of the Mars 2020 Rover, "Perseverance," a 10-foot-long (3 m), 9-foot-wide (2.7 m), 7-foot-tall (2.13 m), 2,260-lb (1,025-kg) ground exploration vehicle. The Rover is scheduled for launch from Cape Canaveral this July on a United Launch Alliance Atlas V rocket and targeted to land on Mars on Feb. 18, 2021. A month to six weeks or so after Perseverance lands and begins operation, "they will start looking for a place to drop us off," said Bob Balaram, chief engineer for the Mars Helicopter at NASA's Jet Propulsion Laboratory in California. "Then we'll do our thing for about a month."

The Mars helicopter's "thing" is a technology demonstration to prove such a rotorcraft can fly on the Red Planet and to validate JPL's specific design. If the experiment is successful, the NASA team hopes the data and experience will be used to design and build helicopters large enough to carry scientific instruments for future Mars missions. But first they have to prove a helicopter can in fact fly on Mars, and that's no slam dunk.



Members of NASA's Mars Helicopter team prepare the flight model (the actual vehicle going to Mars) for a test in the JPL Space Simulator on Jan. 18, 2019. (NASA photo)

The atmosphere of Mars — 95% carbon dioxide — is about one percent as dense as the atmosphere of Earth. That makes flying at five meters on Mars "equal to about 100,000 feet [30,480 m] above sea level here on Earth," noted Balaram. That leaves very little air to move, which is why the Mars helicopter's rotor will turn at up to 2,800 rpm, about 5-10 times the rate of a conventional helicopter rotor on Earth, depending on the model.

"Flying a helicopter up there is a huge challenge," noted aeronautical engineer J.C. Ledé, who from 2002-2006 ran an effort by Aurora Flight Sciences Corp. of Manassas, Virginia, to develop a Mars airplane for NASA. Aurora's MarsFlyer made a successful autonomous glide to Earth in 2002 after being dropped from a balloon at more than 103,500 feet over Oregon but was never sent to Mars. Flying a helicopter on Mars is a far more difficult challenge, Ledé noted, and "way more difficult" than the altitude record Boulet set in his stripped down Aérospatiale (now Airbus) Lama.

What will let NASA meet this challenge, NASA's Balaram said, is the fact that, in addition to its thin atmosphere, Mars has only a fraction of Earth's gravity — 38%, to be exact. "Our helicopter, here on Earth, this particular one, would have difficulty actually flying at 100,000 feet because of Earth's gravity," he said. "But because the Mars gravity is less, it does quite well."

Balaram can say this because NASA flight tested an engineering development model of the Mars Helicopter last year in JPL's Space Simulator, a 25-foot-wide (7.62 m) vacuum chamber whose air was mostly replaced with carbon dioxide and depressurized to simulate the Martian atmosphere. The as-yet-unnamed Mars Helicopter's gross takeoff weight is 1.8 kg (3.97 lb) on Earth but will be only 0.66 kg (1.45 lb) on Mars. To mimic that in its flight test, a motorized tether attached to the top of the helicopter provided a steady pull corresponding to the difference between Earth and Mars gravity. One test flight, in which the helicopter hovered at about two inches (5.08 cm) above the surface for one minute, was deemed sufficient.

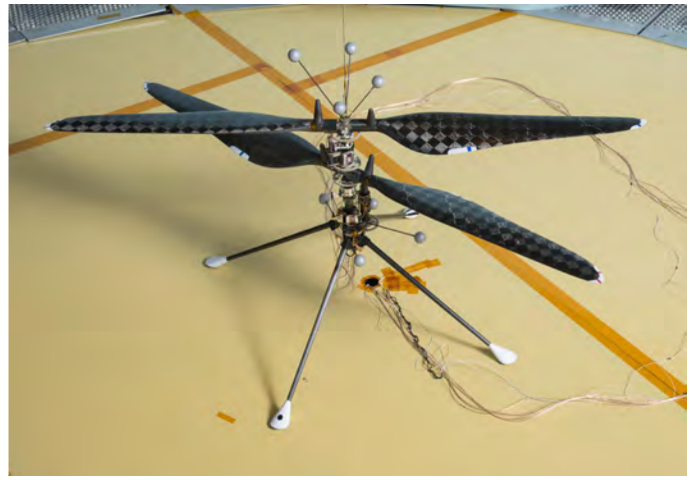
Big Things Sometimes Come in Small Packages

In size, the Mars Helicopter resembles the remote control helicopter that inventor Arthur Young developed in a Pennsylvania barn in the 1930s and demonstrated to engineers at Bell Aircraft Company on Sept. 3, 1941 — a seminal event in the birth of Bell Helicopter (now known simply as Bell). The little helicopter JPL hopes will make history on Mars has a coaxial rotor whose diameter is 47 inches (1.19 m). Built by Simi Valley drone company AeroVironment, the rotor system's two blades have a foam core, carbon composite skin, minimal twist and a chord of about 5.9 inches (150 mm) at their widest point.

Arthur Young with his remote-controlled helicopter, whose rotor was less than six feet (1.8 m) in diameter but inspired the development of the Bell helicopter. (Bell photo)

"They're very thin-section airfoils, essentially almost flat," Balaram said. "That's because in the very thin gas regime that we are flying, what they call low Reynolds Number regimes, those very thin cross-section — flat, almost — type of blades have the best performance."

Reynolds Number is a ratio that reflects the size, shape, weight and speed of an object compared to the viscosity of the fluid that object moves through, whether the object in question is a ship



The demonstration vehicle used to prove that controlled and sustained flight is feasible in a Martian atmosphere. The first free flight of this prototype Mars Helicopter in atmospheric conditions similar to Mars occurred on May 31, 2016, in the JPL Space Simulator. (NASA photo)

plowing through water or an airfoil spinning in the atmosphere of Mars.

JPL itself designed and built the "brains" of the Mars helicopter, Balaram said, which include four micro computers for vehicle operation and control and a "perception system" that employs a micro-electromechanical (MEMS) gyroscope, a MEMS accelerometer, a camera for visual navigation and a laser altimeter.

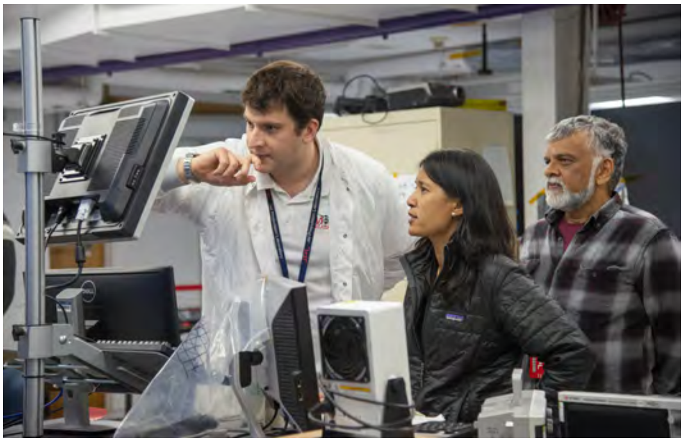
"We couldn't do this 20 years ago," Balaram said. "But with the technology that's in your cell phone, your drones — things have improved to the point where we can do this."

One of the four computers performs "low-level functions," Balaram said, such as turning other devices on and off. Two of the computers are "automotive-class controllers" that provide flight control. The fourth computer is "the equivalent of a cell phone-type of processor, which does all the high-end navigation and thinking that provides the autonomy," he said.

The helicopter's power supply is six Sony VTC4 lithium-ion batteries, each cell roughly the size of an AA alkaline battery, housed in a battery pack and charged by a solar panel that sits atop the rotor mast. Electronics boards holding the computers are wrapped around the battery pack, which keeps both the batteries and the electronics boards warm, Balaram said. The boards and batteries are also insulated by a layer of carbon dioxide gas within the skin of the fuselage, a cube roughly the size of a softball box. The fuselage has a carbon fiber frame but is covered by a thermal insulating film.

"It gets very cold in space; it gets very cold on Mars on the surface," Balaram noted. Heat from the Sun easily dissipates on Mars because of its thin atmosphere, and surface temperatures range from 70°F (21°C) to -225°F (-142.7°C). So, in addition to flight testing, NASA JPL has put the Mars Helicopter through thermal tests.

Using a couple of engineering development models, the Mars Helicopter team also put their design through other tests replicating the forces the vehicle will encounter on its space flight aboard the Mars 2020 Rover. "We are not only a helicopter, but we are also a spacecraft that has to launch and has to survive launch,



Teddy Tzanetos, MiMi Aung and Bob Balaram of NASA's Mars Helicopter project observe a flight test in Jan. 18, 2019, as the flight model of the Mars Helicopter was tested in the JPL Space Simulator. (NASA photo)

launch vibrations, launch G-forces, and then when we enter the Mars atmosphere, similar entry, descent and landing G-forces as the spacecraft that we are piggybacking on," Balaram said.

"The other thing that we have done is that we did a full deployment test where we successfully showed that we can get off the Rover onto the surface under Mars-like conditions," he added. "It was done here at JPL in our Space Simulator."

A carbon composite cover that, "looks like a guitar case," Balaram said, will shield the helicopter during launch, the months-long trip to Mars, and from debris kicked up by Perseverance's rockets as it lands. At deployment, Balaram said, the debris cover will be "jettisoned, and then the Rover moves forward to the center of this landing airfield that has been picked, and then it goes through a sequence where it releases the mechanical locks that are holding one side of the helicopter. Then there is a motor, which turns the helicopter so that it's vertical. Then the [four] legs of the helicopter, which were folded, are released and then there is a final release where the helicopter is dropped about six inches [15 cm] onto the ground underneath the belly of the Rover. And then the Rover drives away to a safe distance, and we then can start flying."

"If we do get a good flight," Balaram added, "it'll be our Kitty Hawk moment — we'll have a first controlled flight on anywhere but Earth. So, in that sense, it's a milestone."

Trust in Autonomy

The distance from Earth to Mars varies but on average is 140 million miles (225 million km), which means the Mars helicopter will in fact have to control itself in flight. "Depending on exactly the positions of the planets, it takes between five and twenty minutes just for the signal to get from us to the Rover and from the Rover back to us," Matt Muszinski, a JPL systems engineer working on the project, said in a Jan. 29 presentation at Heli-Expo in Anaheim, California. "You can't joystick anything at all because … you push the joystick and it's a minimum 10 minutes before you get any information back."

For that reason, the Mars helicopter's flight control system will execute preprogrammed commands to fly to waypoints. Those will be sent from Earth and relayed through a shoebox-sized "base station box" on the Rover, which the NASA team also has tested. The data needed to execute the commands are fed into the flight control computers by the helicopter's perception system — its gyroscope, accelerometer, camera and laser altimeter.

"Those are used to control the actuation system on the helicopter, which is basically a standard helicopter swashplate, so it's got a collective and cyclic on each rotor," Balaram said. "So, by activating collective only, you get what is called heave control, which is up and down motion, and by tilting the swashplate you can get the helicopter to pitch or roll, which allows it to move forward and back. There's an autonomous control algorithm that takes all the [data from the] sensors and does all the actuation, which is implemented in the computer. So, what we tell it from Earth is just, say, 'Go to waypoints in the sky.' For a rover we would just say 'go to the XY heading and a second XY heading.' For a helicopter, we will say, 'Go to XYZ.'"

Håvard Grip, a research technologist in the Robotics Controls and Estimations Group at JPL, told the Heli-Expo audience that NASA intends to fly the Mars helicopter only "five times, nominally." Moreover, because of differences in rotor performance compared to Earth and the impossibility of gauging winds on Mars in real time, those flights will be "limited to about 90 seconds at a time," with two or three days between flights to recharge the helicopter's batteries, Grip said.

NASA has started and stopped projects to develop Mars aircraft several times since the 1970s (see "Red Planet Rotorcraft: NASA Gives Go-Ahead to the Mars Helicopter," *Vertiflite*, July/August 2018), but this is the first attempt to fly a helicopter there.

An engineer works on attaching NASA's Mars Helicopter to the belly of the Mars 2020 rover — which has been flipped over for that purpose — on Aug. 28, 2019, at JPL. (NASA photo)

"As an airplane guy, I'm a little bit disappointed that that would be the first kind of aircraft to fly on another planet, because, of course, helicopters don't fly, they beat the air into submission," joked former Aurora Flight Sciences Mars airplane project manager Ledé. But NASA's Balaram said a helicopter clearly makes more sense for Mars exploration.

"When we have a good, nice, concrete paved runway on Mars, we can fly those planes," Balaram said in reply to Ledé's jest. "But in the meantime, you know, I don't send a plane to rescue people on Mount Everest. I don't send a plane to go inspect an interesting geological formation up close and personal. Helicopters have their own role and place."

Perhaps including Mars.