A NASA image of what the Mars Helicopter will look like when conducting an excursion from the rover. (All images courtesy of NASA, except where noted)

RED PLANET ROTORCRAFT:

NASA Gives Go-Ahead to the Mars Helicopter

Over the past 40 years, numerous aircraft designs have been considered to explore Mars. None have amounted to much, until now.

By Robert W. Moorman

As announcements go, this was a big one. In May, the US National Aeronautics and Space Administration (NASA) announced plans to demonstrate the viability of an autonomous, powered helicopter on Mars as part of its planned July 2020 rover mission — the first of interplanetary helicopter.

"NASA has a proud history of firsts," said NASA Administrator Jim Bridenstine. "The idea of a helicopter flying the skies of another planet is thrilling. The Mars Helicopter holds much promise for our future science, discovery and exploration missions to Mars."

What started as a technology development project in August 2013 at NASA's Jet Propulsion Laboratory (JPL) has morphed into a full-scale program that could have long-term implications for larger rotorcraft operations on the fourth planet from the sun.

The historical significance is not lost on the scientific and aviation communities. The helicopter flight, if successful, would represent the first time any country had flown powered, controlled aircraft on any celestial body.

"The primary mission of this Mars helicopter is to demonstrate its capability on Mars," said MiMi Aung, project manager of the NASA Mars Helicopter Program at JPL. "This is a standalone, first time demonstration of flight on Mars. We're quite excited about this program."

In this interview for *Vertiflite*, Aung's enthusiasm for this challenging project was evident. Her rapid-fire briefing clearly demonstrated that this is not just another research project. "We're showing that the algorithms we've developed and the helicopter design that we have built and tested to show working in our test chamber on Earth does work as predicted in true Mars environment. We will demonstrate that you can fly a helicopter on Mars and send pictures back to Earth."

MiMi Aung, project manager of the NASA Mars Helicopter Program.

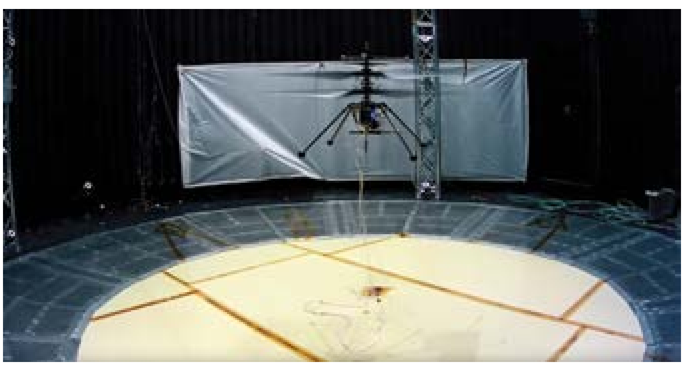
Thus far, there have been 15 NASA missions to Mars; four had rovers. "The science learned from those missions was valuable," said Anubhav Datta, associate professor, aerospace engineering, University of Maryland, who has co-authored several papers on rotorcraft flight on Mars. "But nothing captures the imagination of people more than flight. This is going to be an enormous achievement in aeronautics."

How to Fly on Mars

NASA assembled an experienced team to meet the challenge of landing, deploying and flying a helicopter on Mars. The Mars Helicopter team is comprised of personnel from JPL, which has numerous years of experience in space exploration; AeroVironment, an innovator and manufacturer of unmanned aircraft systems (UAS); NASA Ames Research Center; and NASA Langley Research Center.

Mars Helicopter Characteristics

Overall mass	4.0 lb	1,800 g
Battery mass	9.6 oz	273 g
Coaxial rotor diameter	47 in	120 cm
Rotor revolutions/min	~3,000 rpm	
Overall height	31 in	80 cm
Height minus landing gear length	26 in	67 cm
Fuselage dimensions	7.9 in x 6.3 in x 5.5 in	200 cm x 160 cm x 140 cm
Chassis volume	0.85 in^3	14 cm^3
Power	220 W (battery, solar power charged)	
Flight time	2–3 min, once per day	
Operational time	~5 flights in ~30 days	
Maximum range	2,000 ft	600 m
Maximum altitude	1,300 ft	400 m
Cameras	High resolution imagery in color. Navigation.	



A subscale Mars Helicopter was tested in the NASA JPL vacuum chamber.

AeroVironment is building the rotor system and composite landing gear for the Mars Helicopter. JPL is responsible for the fuselage and integrating the various systems onboard. Both NASA Ames and Langley bring their expertise in rotorcraft design, flight control system identification, computational rotorcraft capability and operational considerations to the team. The work of the NASA team is conducted under NASA's Revolutionary Vertical Lift Technology project, leveraging extensive expertise in helicopter research and design.

The team had to first answer the all-important question before building a full-scale flight test article: gravity is roughly one-third that of Earth, but is it possible to fly an autonomous helicopter in the thin atmosphere of Mars — which is about 100 times less dense than Earth's and comprised of more than 95% carbon dioxide?

To answer this question, the team built and flew a one-third-scale engineering development model in its 25-foot (7.6 m) diameter simulator chamber filled primarily with CO_2 to simulate most of the Mars atmosphere. The model used twin, counter-rotating blades to whip through the thin Martian atmosphere at 2,500–3,000 revolutions per minute — about ten times the rate of a manned helicopter on Earth. Tests were successful.

The team also had to determine if controlled flight on Mars could be maintained, said Aung. Flight tests revealed early on that control could not be sustained with a human using a joystick due to the long delays between transmission signals. Controlled flight could be achieved, however, with sensors and high-speed computers on board the helicopter. The sensors, "which are the equivalent of our eyes and ears," said Aung, would detect problems immediately and the computer would correct them.

On Earth, the pilot could make stability and course corrections, but the Mars Helicopter had to be autonomous, obeying general commands from JPL, from millions of miles away. Aung explained the dilemma: "To fly in the thin atmosphere of Mars, the vehicle has to be autonomous enough for us to be able to send commands from Earth to Mars. Then, the aircraft has to look at the commands and parse it into different actions it has to perform." All this has to be done by a helicopter that weighs less than four pounds (1.8 kg), with the brains of the craft contained in a fuselage the size of softball.

JPL is currently assembling the flight model. "We were able to come up with an integrated design that met the mass constraint," said Aung. "Which in itself is quite a challenge." The rotor diameter for the flight vehicle is 47 inches (1.2 m) and the rpm is set at about 3,000 rpm (which makes the tip speed 410–615 ft/s or 125–188 m/s). The blades are also designed with airfoils that can work in the very low density and high viscosity Martian atmosphere.

What is good for rotorcraft operations on Mars, however, wouldn't go over well on Earth. A fast turning rotor means the motor could likely be directly connected with no gearbox or with a small size gearbox, said Datta, who emphasized that he is not directly associated with the JPL-led program. The Mars Helicopter would be noisy, but that is not a factor on a planet with no known residents. The rotors could turn as fast as structural and tip transonic limits would allow. "Low density means less concern for aeroelastic instabilities found on Earth," said Datta.

"We will demonstrate that you can fly a helicopter on Mars and send pictures back to Earth," said NASA's Aung.

The Mars Helicopter will perform basic tasks during its short inaugural flight. JPL will command the helicopter to wake up, lift off, follow designated waypoints, return to the starting point and land. A three-way communications link between Earth, the rover and helicopter will be maintained. Data and photos from the helicopter will be sent to Earth via the rover.

Power sources for the Mars 2020 mission will likely be a combination of solar cells, lithium-ion (Li-ion) batteries and plutonium Pu-238 powered radioisotope thermoelectric generators (RTGs). RTGs will power the rover and Li-ion batteries will power the helicopter.

The Mars 2020 rover would be similar to that of Curiosity, a rover designed to explore the Gale Crater on Mars as part of NASA's Mars Science Laboratory mission launched in November 2011 (which continues today). The Curiosity RTG, stored at the back of the rover, had around 110 W of power at launch, and charges two on-board Li-ion batteries, each with a capacity of 42 A-h, which are used by the rover for peak power when needed.

From the Mars 2020 mission, JPL expects to gather significant data on whether the sensors and batteries can withstand the extreme temperature fluctuations and high winds of Mars. Those temperatures can vary by more than 200° F (100° C) in a single day. NASA noted that "The helicopter also contains built-in capabilities needed for operation at Mars, including solar cells to charge its lithium-ion batteries, and a heating mechanism to keep it warm through the cold Martian nights."

A primary goal of this mission is to determine if the Mars Helicopter can fly, maintain controlled flight and send pictures back to Earth. JPL hopes that later helicopter missions could gather samples and return them to the rover for analysis. Future helicopter flight also could explore caverns, canyons and other sites that can't be photographed properly from an orbiter or reached by a rover.

Many challenges that are being addressed for terrestrial helicopter systems must also be considered for the Mars Helicopter. The JPL-led design for the Mars Helicopter has to take full advantage of the latest understanding and advances in multi-rotor dynamics, simulations, lightweight composites, lightweight permanent magnet motors, batteries, solar cells, low Reynolds number aerodynamics, miniaturized compact power systems, and flight under adverse gusts, dust and degraded thermal dissipation.

The Reynolds number (Re) is the ratio of air density to its viscosity. In the case of the Mars Helicopter, the Reynolds number is the product of the density, the rotor blade chord and the velocity over the blade, divided by dynamic viscosity. The Reynolds number for the Mars Helicopter is between 500–1,000, compared to about 5 million for a conventional helicopter on Earth.

Scientists and engineers connected with the Mars Helicopter program will be "bringing to bear the best of what we learned on Earth on helicopters and micro electro-mechanical systems," said Datta. "Longer missions will force us to invent a variety of technologies from motors to autonomy."

That said, the one thing that could be of value back on Earth — say with drone package delivery for civil and military missions — is the packaging methodology and technology for shipping the Mars Helicopter. If the JPL-led team can package a complex dynamic system for the long voyage to Mars, have it arrive intact, open and fly the rotorcraft with no major problem, then that would be noteworthy.

Packaging all aspects of this upcoming mission is very important. Without this attention to detail, all could be lost before it begins. Earth is 33.89 million miles (54.54 million km) away from Mars at its closest point in orbit, 250 million miles (402 million km) at its farthest point. Average distance is 140 million miles (225 million km). Under optimum conditions, it will take a spacecraft six to eight months to reach Mars. The agency's Mars 2020 rover mission is currently scheduled to launch in July 2020 and is expected to reach Mars in February 2021, with the Mars Helicopter attached to the belly pan of the rover.

The Mars Helicopter will be stowed inside the belly of the rover and deposited on the ground before its first test flight.

Once the rover is safely on the planet's surface, a suitable location will be found to deploy the helicopter underneath the vehicle and place it onto the ground. The rover will then drive a short distance away to relay commands. After the Mars Helicopter's batteries are charged and a battery of tests is completed, controllers on Earth will command it to take its first autonomous flight into history.

On its first flight, the helicopter will make a short vertical climb to about 10 ft (3 m) and hover for about 30 seconds. Then it will commence a 30-day flight test campaign in which it makes up to five flights: it will fly incrementally farther distances, up to a few hundred meters at a time, with increasingly longer durations, up to 90 seconds.

Helicopters are Cool

Much is riding on the Mars 2020 rover mission. This a collaborative effort by various parties, equipped with significant data and technology, to bring the concept of flying a helicopter on Mars to fruition.

Dr. Thomas Zurbuchen, Associate Administrator for NASA's Science Mission Directorate, may have said it best: "Exploring the Red Planet with NASA's Mars Helicopter exemplifies a successful marriage of science and technology innovation and is a unique opportunity to advance Mars exploration for the future."

A successful first helicopter flight on Mars may not have the same historical significance as astronaut Neil Armstrong's walk on the moon a half-century before. But the accomplishment would

AeroVironment

AeroVironment President and CEO Wahid Nawabi with a full-scale model of the Mars Helicopter. (AeroVironment photo)

AeroVironment, Inc. is a technology company based in Monrovia, California, that is primarily involved in unmanned aircraft systems (UAS) and previously in energy systems and electric vehicles (sold in June 2018). The company was founded in 1971 by famed aircraft designer Paul B. MacCready, Jr. The company was originally most well-known for developing a series of lightweight human-powered and then solar-powered vehicles. Today, AeroVironment is the Pentagon's top supplier of small drones — including the Raven, Wasp and Puma models.

"AeroVironment's deep, rich and diverse history of innovation combined with our experience with near-space aircraft like Pathfinder and Helios make us uniquely suited to collaborate with NASA and JPL on this historic, interplanetary venture," said AeroVironment President and Chief Executive Officer Wahid Nawabi.

AeroVironment first developed subscale Mars helicopter prototypes to test and demonstrate the feasibility of lift in the thin Martian atmosphere. Flying at nearly 100,000 ft (30 km) above Earth is much like flying on the surface of Mars, so AeroVironment used airfoil design principles and simulation tools the technology company learned from record high-altitude flights and incorporated them into the Mars helicopter design.

In May 2016, AeroVironment delivered to JPL a Mars Helicopter rotor and landing gear prototype that was integrated with a JPL-developed controller and demonstrated free flight in the simulated Mars atmosphere, proving that it is possible to fly on the Red Planet. Next, AeroVironment delivered major helicopter subsystems in the fall of 2017 for integration into Mars-representative engineering development models. JPL built two Engineering Development Model Mars Helicopters, integrating the AeroVironment rotor, landing gear, fuselage shell and solar panel substrate together with JPL-developed fuselage composed of flight avionics, onboard power, telecom, flight control and sensors into two models.

"The Mars Helicopter effort also benefits from the ultra-lightweight and ultra-high-precision methods integral to our nano projects that have been developed in our MacCready Works laboratory," Nawabi said.

One of the development models was used for flight demonstration in JPL's large 25 ft (7.5 m) space simulator, and the other for environmental testing, including thermal tests to ensure the vehicle can endure the frigid Mars nights, and vibration tests to make sure it is rugged enough to survive launch. Both vehicles passed the rigorous tests, paving the way for the development and fabrication of the final, Mars-bound version.

The final Mars-bound helicopter is now in production at JPL. AeroVironment is currently building the flight versions of their subsystems, which will be integrated with other subsystems into the vehicle that JPL is building. The plan is for JPL to then install the finished Mars Helicopter into the Mars 2020 rover for its ride to a Martian landing site, which is still to be determined.

AeroVironment said it has worked closely with NASA rotorcraft experts at the NASA Ames and Langley research centers and with JPL electrical, mechanical, materials, vehicle flight controls, and systems engineers. AeroVironment's contributions to the first Mars drone include design and development of the helicopter's airframe and major subsystems, including its rotor, rotor blades, hub and control mechanism hardware. The company also developed and built high-efficiency, lightweight propulsion motors, power electronics, landing gear, load-bearing structures, and the thermal enclosure for NASA/JPL's avionics, sensors, and software systems.

certainly represent one of NASA's more memorable space programs.

While the main focus of the upcoming mission will be the rover, "we will look to amplify the cool factor of the Mars Helicopter," said Dwayne Brown of the NASA Office of Public Affairs in Washington, DC. This will include holding a contest to name the rover and helicopter, as well as developing outreach opportunities with the public and news media, he added.

On one point there is wide-ranging agreement. The Mars 2020 mission is a door opener for other, larger and more-capable rotorcraft flights on the Red Planet. "The ability to see clearly what lies beyond the next hill is crucial for future explorers," said Zurbuchen. "We already have great views of Mars from the surface as well as from orbit. With the added dimension of a bird's-eye view from a 'marscopter,' we can only imagine what future missions will achieve."

As a technology demonstration, the Mars Helicopter is considered a high-risk, high-reward project. If it does not work, the Mars 2020 mission will not be impacted. If it does work, helicopters may have a real future as low-flying scouts and aerial vehicles to access locations not reachable by ground travel.

Indeed, if all goes well, scientific-based helicopter operations on Mars could one day become routine. Who knows, when NASA one day begins human exploration of Mars, perhaps the helicopter will be the preferred means of travel.

About the Author

Robert W. Moorman is a freelance writer specializing in various facets of the fixed-wing and rotary-wing air transportation business. With 30 years of experience, his writing clients include several of the leading aviation magazines targeting the civil and military markets. He can be reached at *rwmassoc@verizon.net*.