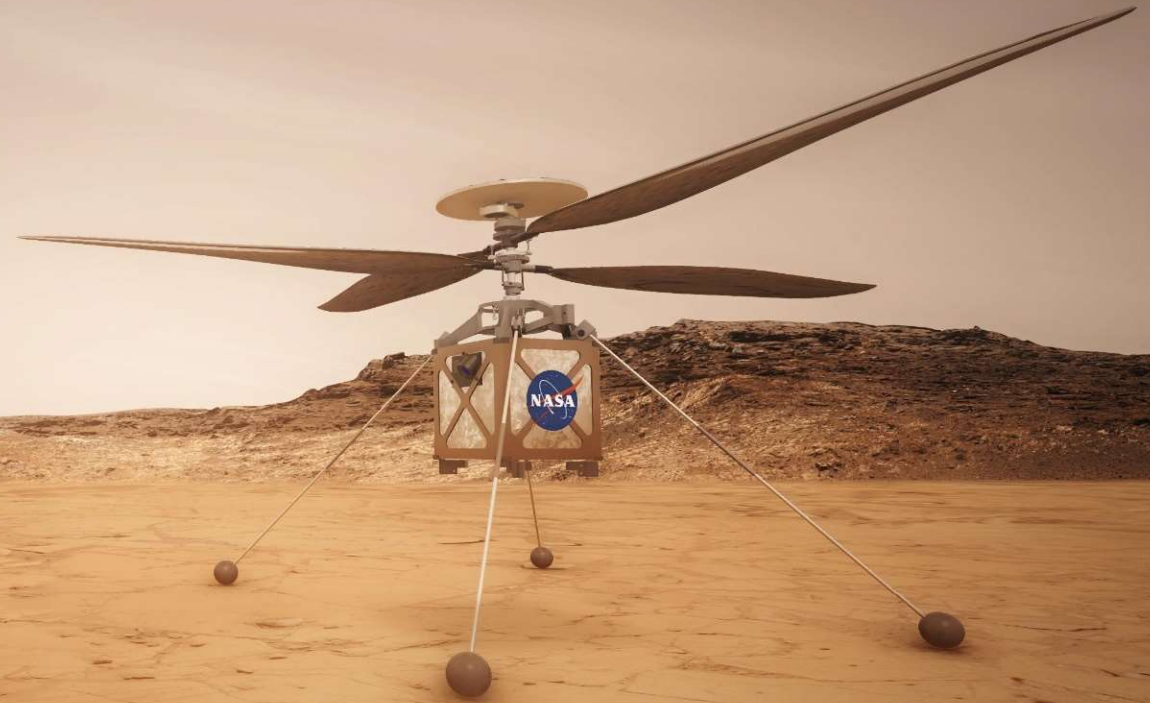


Mars Helicopter *Ingenuity*



Jet Propulsion Laboratory
California Institute of Technology

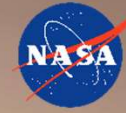


MiMi Aung

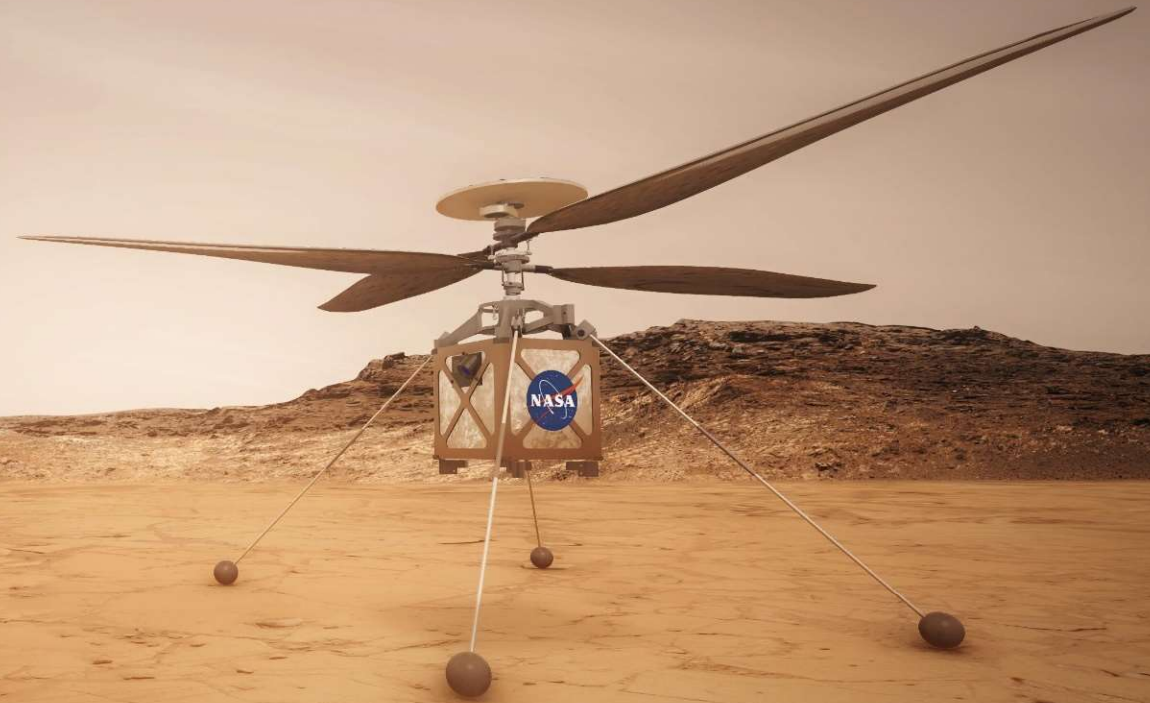
Mars Helicopter Project Manager

NASA Jet Propulsion Laboratory, California Institute of Technology

Mars Helicopter *Ingenuity*



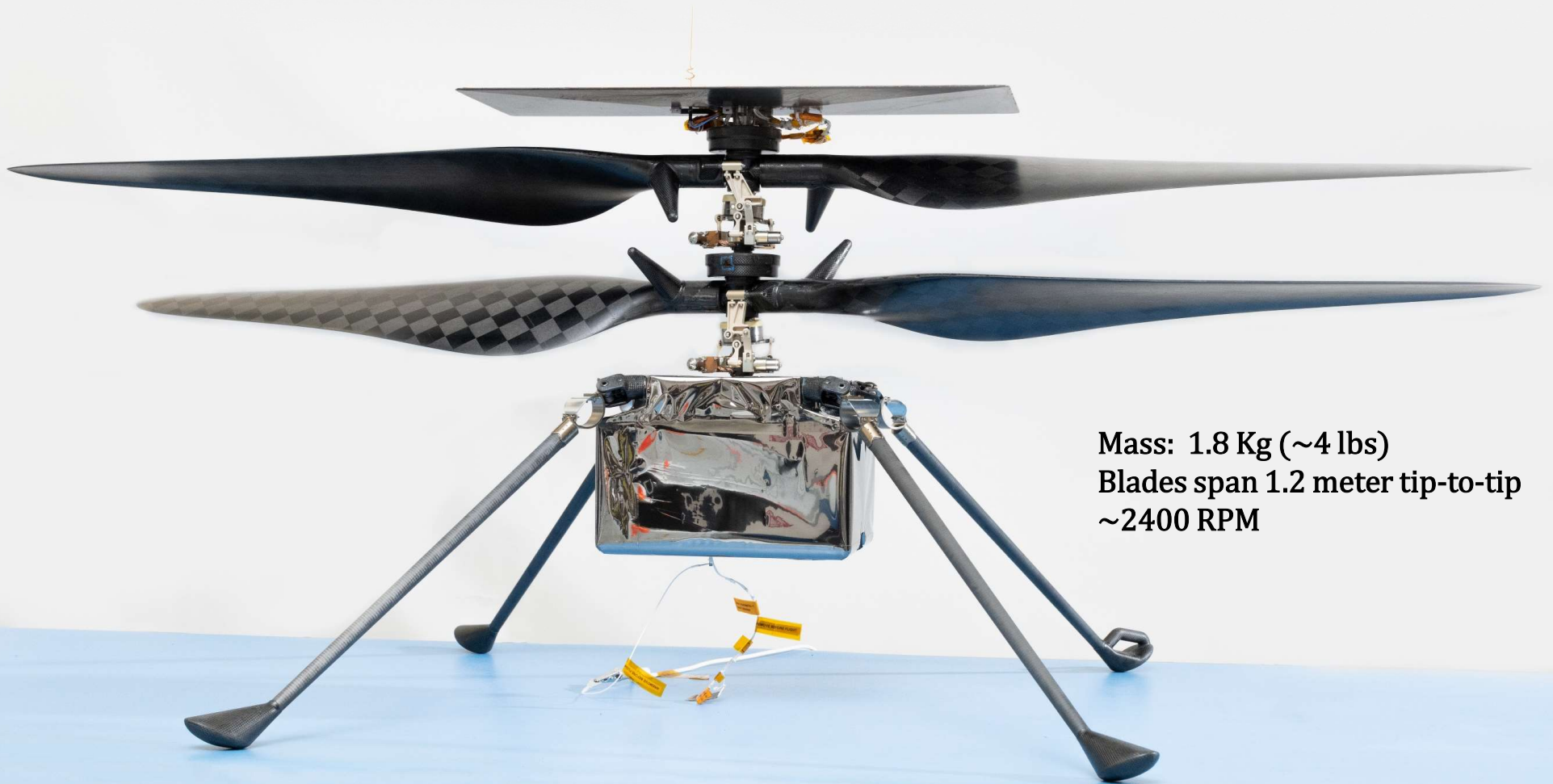
Jet Propulsion Laboratory
California Institute of Technology



Technology Demonstration on Mars 2020 Mission
-- First Rotorcraft Flight at Mars



Mars Helicopter *Ingenuity*



Mass: 1.8 Kg (~4 lbs)
Blades span 1.2 meter tip-to-tip
~2400 RPM

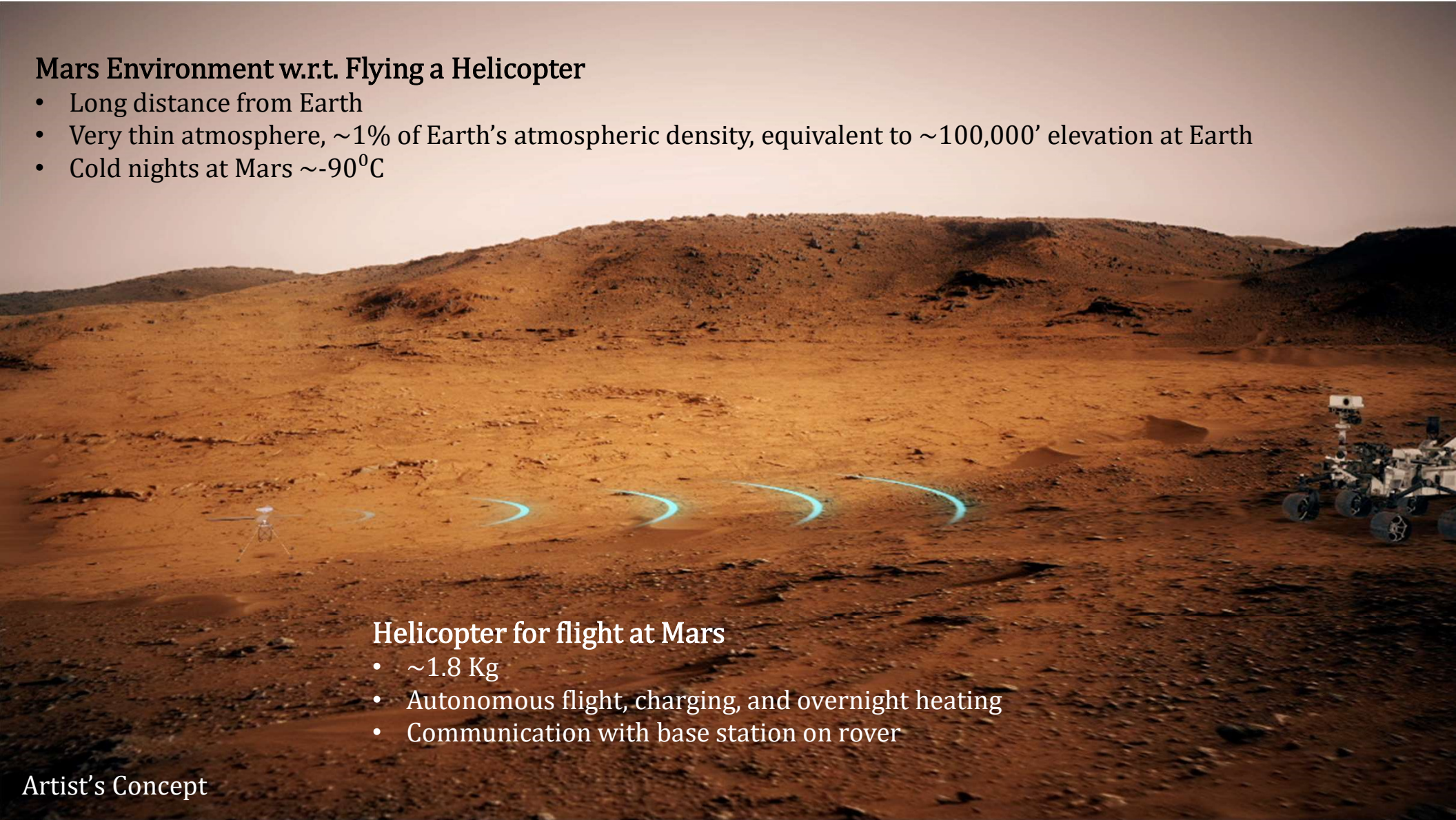
Mars Environment w.r.t. Flying a Helicopter

- Long distance from Earth
- Very thin atmosphere, $\sim 1\%$ of Earth's atmospheric density, equivalent to $\sim 100,000'$ elevation at Earth
- Cold nights at Mars $\sim -90^{\circ}\text{C}$

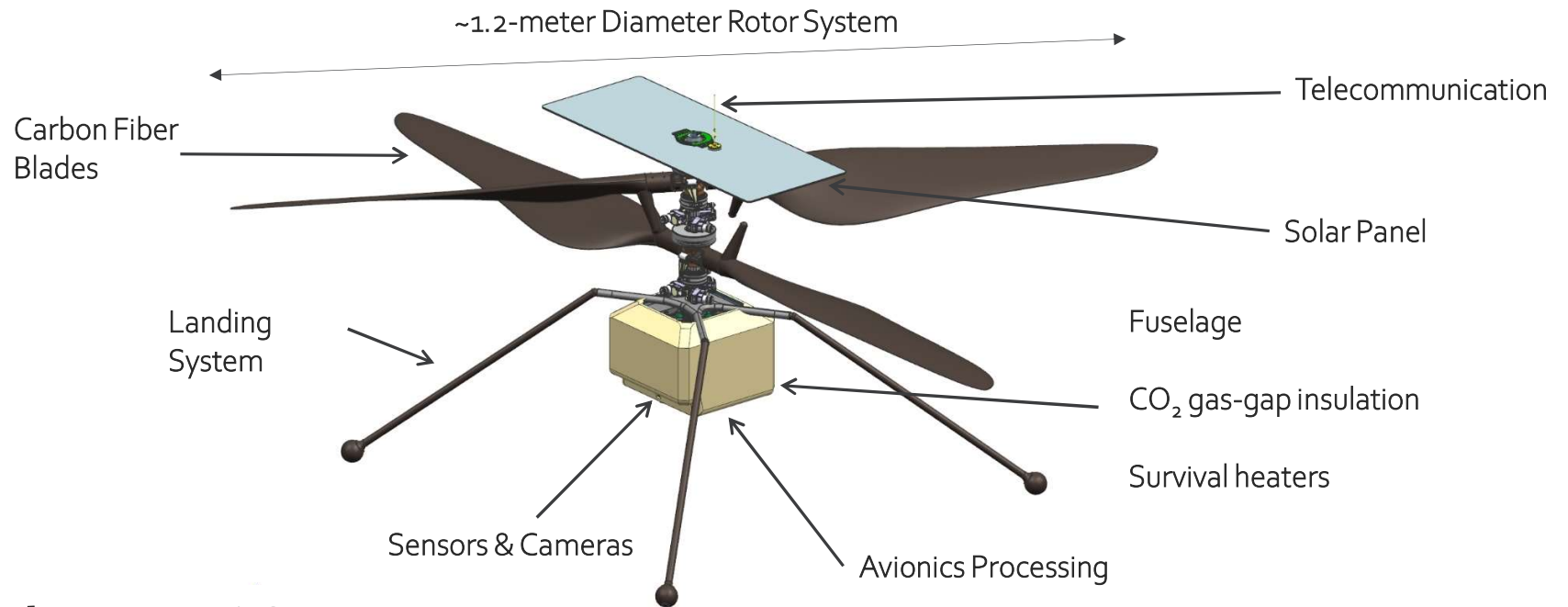
Helicopter for flight at Mars

- ~ 1.8 Kg
- Autonomous flight, charging, and overnight heating
- Communication with base station on rover

Artist's Concept



Anatomy of Mars Helicopter



- ✓ Total Mass < 1.8 Kg
- ✓ Rotor Speed: 1900-2800 RPM
- ✓ Blade Tip Mach Number: < 0.7

Fundamental First Question

“Can one really lift a helicopter in the thin Martian atmosphere?”

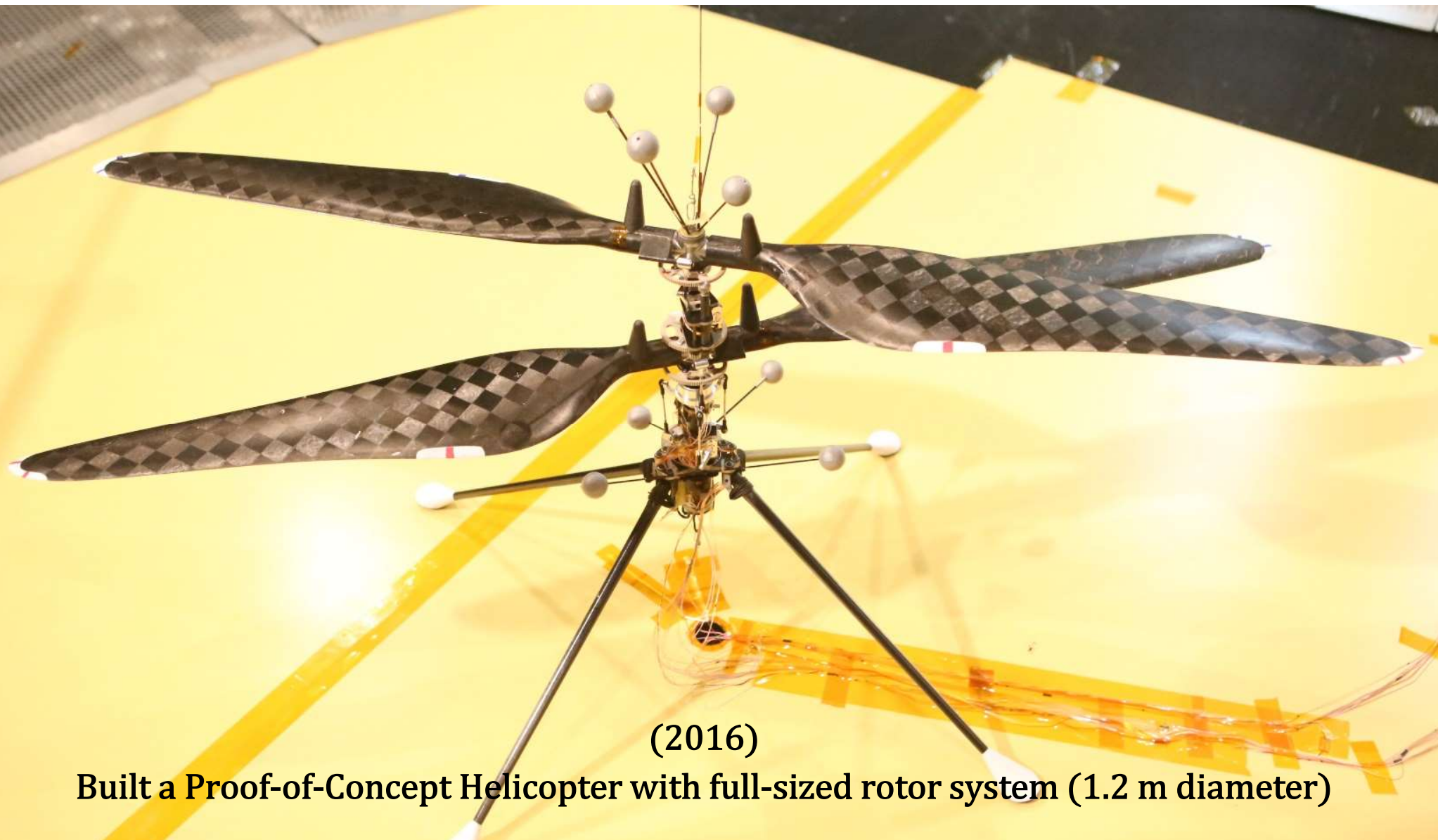
(December 2014)
Demonstrated Lift in Mars-like Atmospheric Density

We learned that stability and control of a helicopter in
Mars atmosphere is different than on Earth!



Next Question

“Can one fly a helicopter in a controlled manner in Martian atmosphere?”



(2016)

Built a Proof-of-Concept Helicopter with full-sized rotor system (1.2 m diameter)

Demonstrated Autonomous Controlled Flight

Leonardo Free Flight Demo

May 31, 2016

in Mars-like atmosphere

Next Question

“Can one fly a helicopter in a controlled manner in Martian atmosphere?”

And also ...

“Can one build that helicopter to survive the environment and operate and fly as designed at Mars?”

(2017)

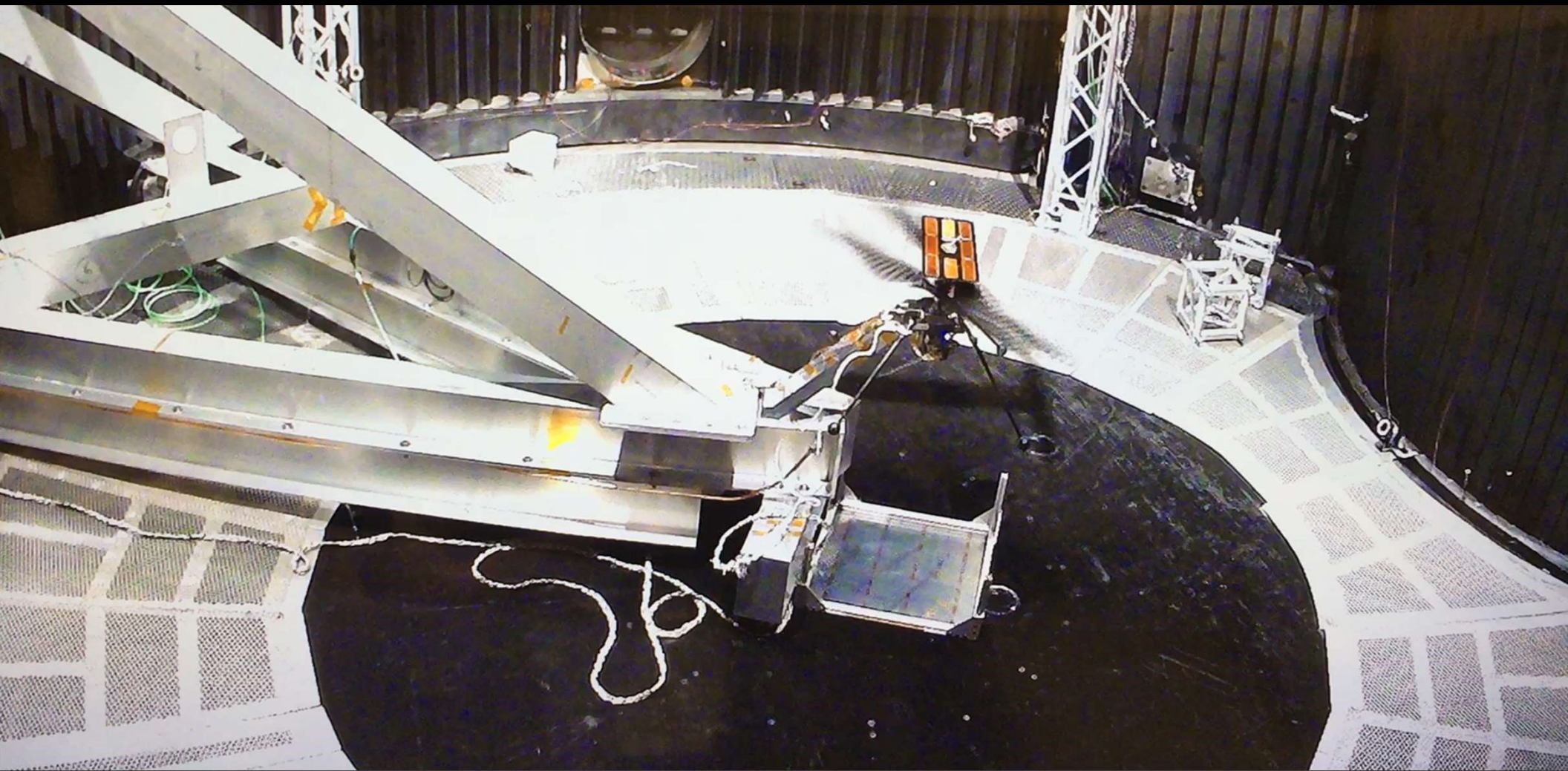
Successfully Designed and Built a Helicopter for Autonomous Flight at Mars



Mass <1.8 Kg (<4 lbs)
Blade speed 1900-2800 rpm

Engineering Development Model
Mars Helicopter

Extensive Incremental Model Validation Tests in Mars-like Atmosphere

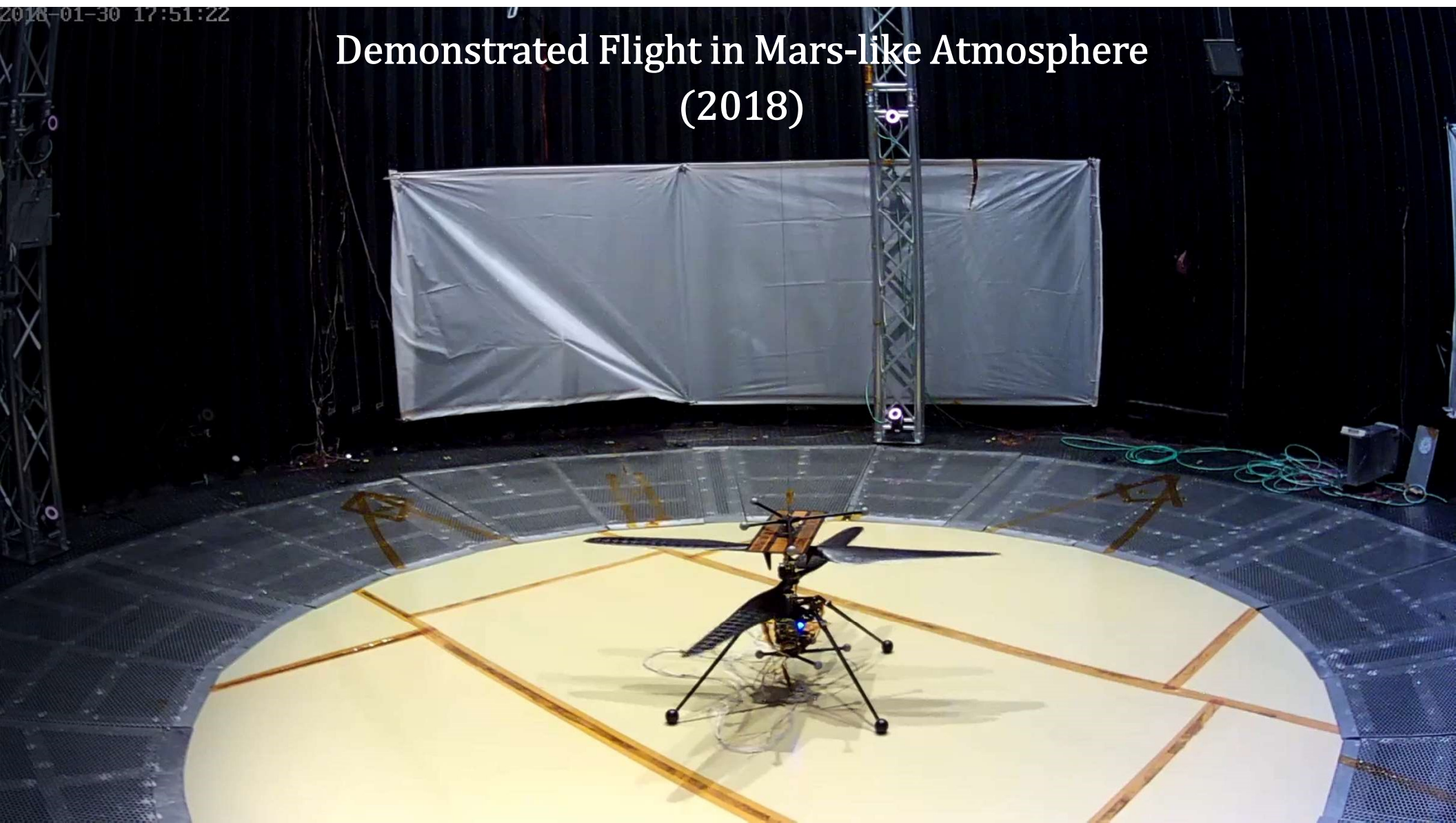


Extensive Incremental Model Validation Tests in Mars-like Atmosphere



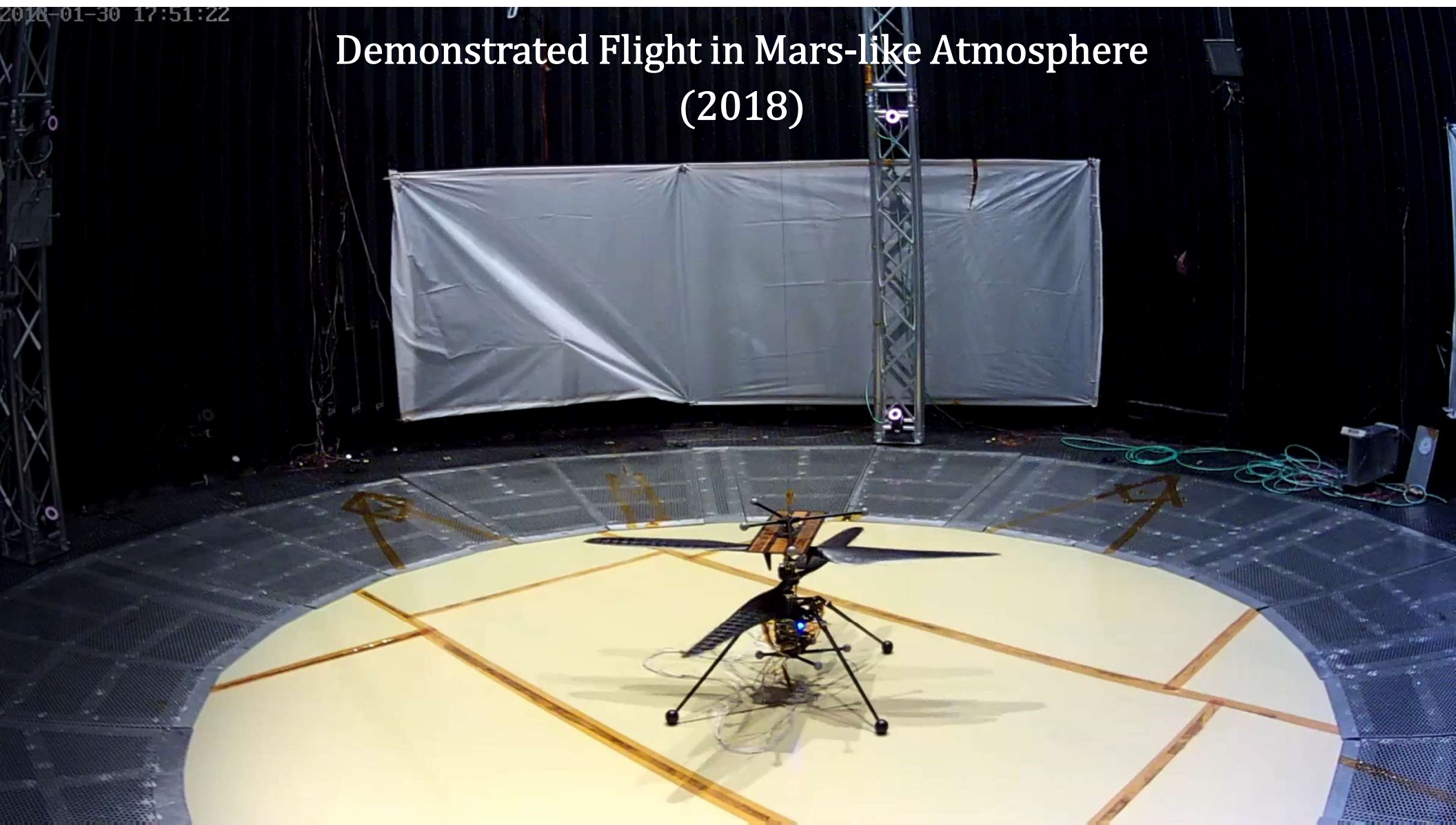
2018-01-30 17:51:22

Demonstrated Flight in Mars-like Atmosphere (2018)

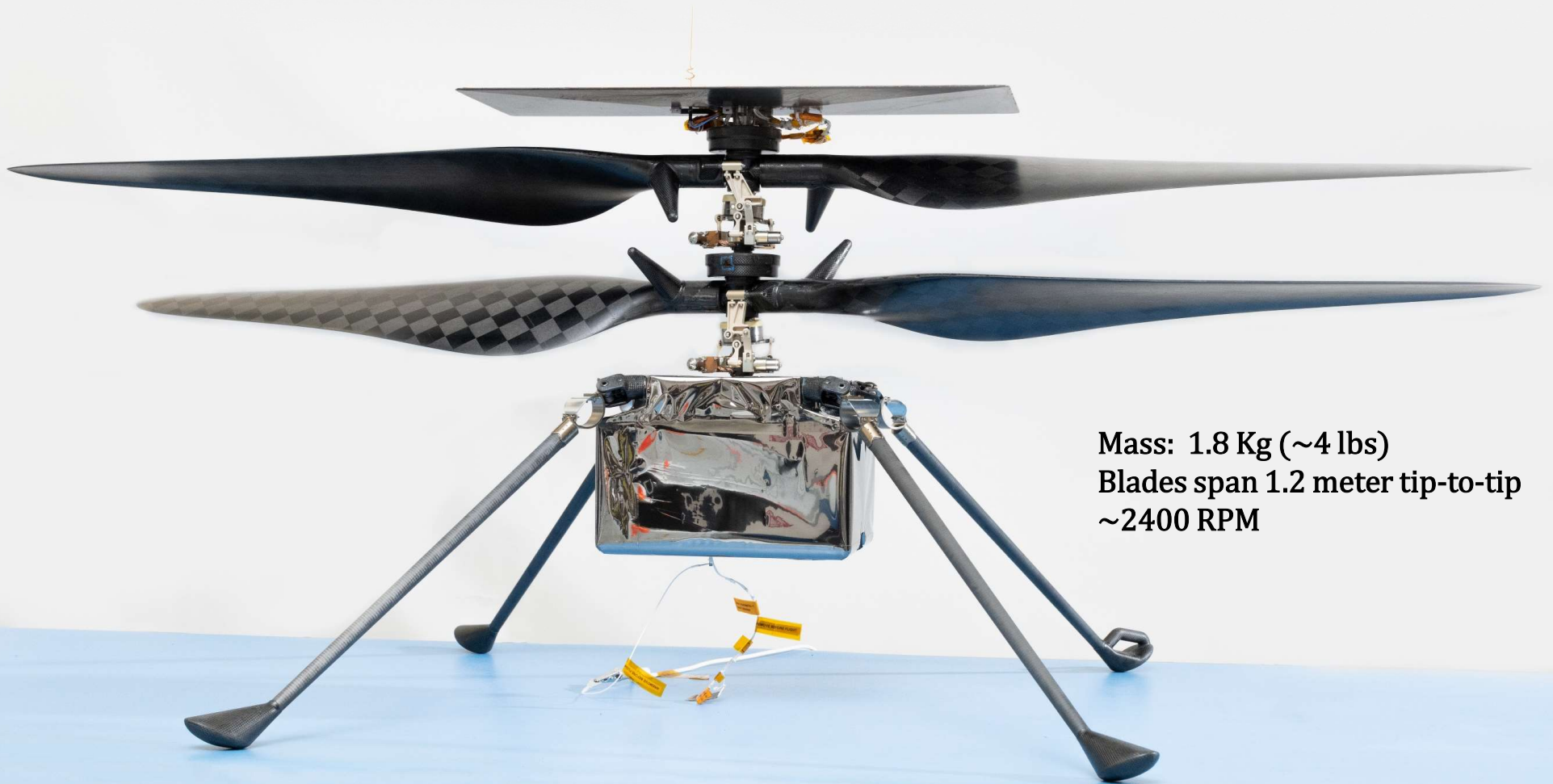


2018-01-30 17:51:22

Demonstrated Flight in Mars-like Atmosphere (2018)

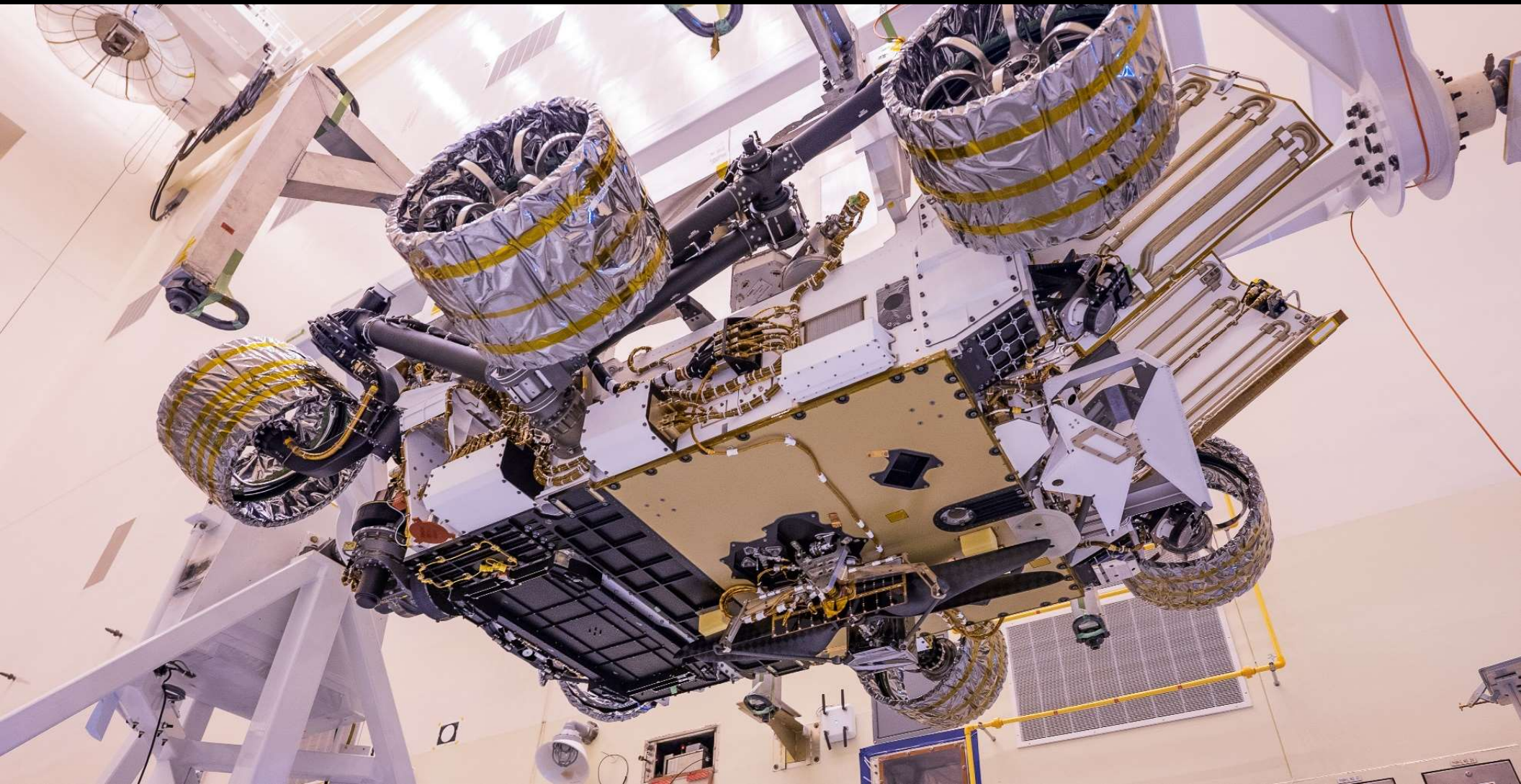


Mars Helicopter *Ingenuity*

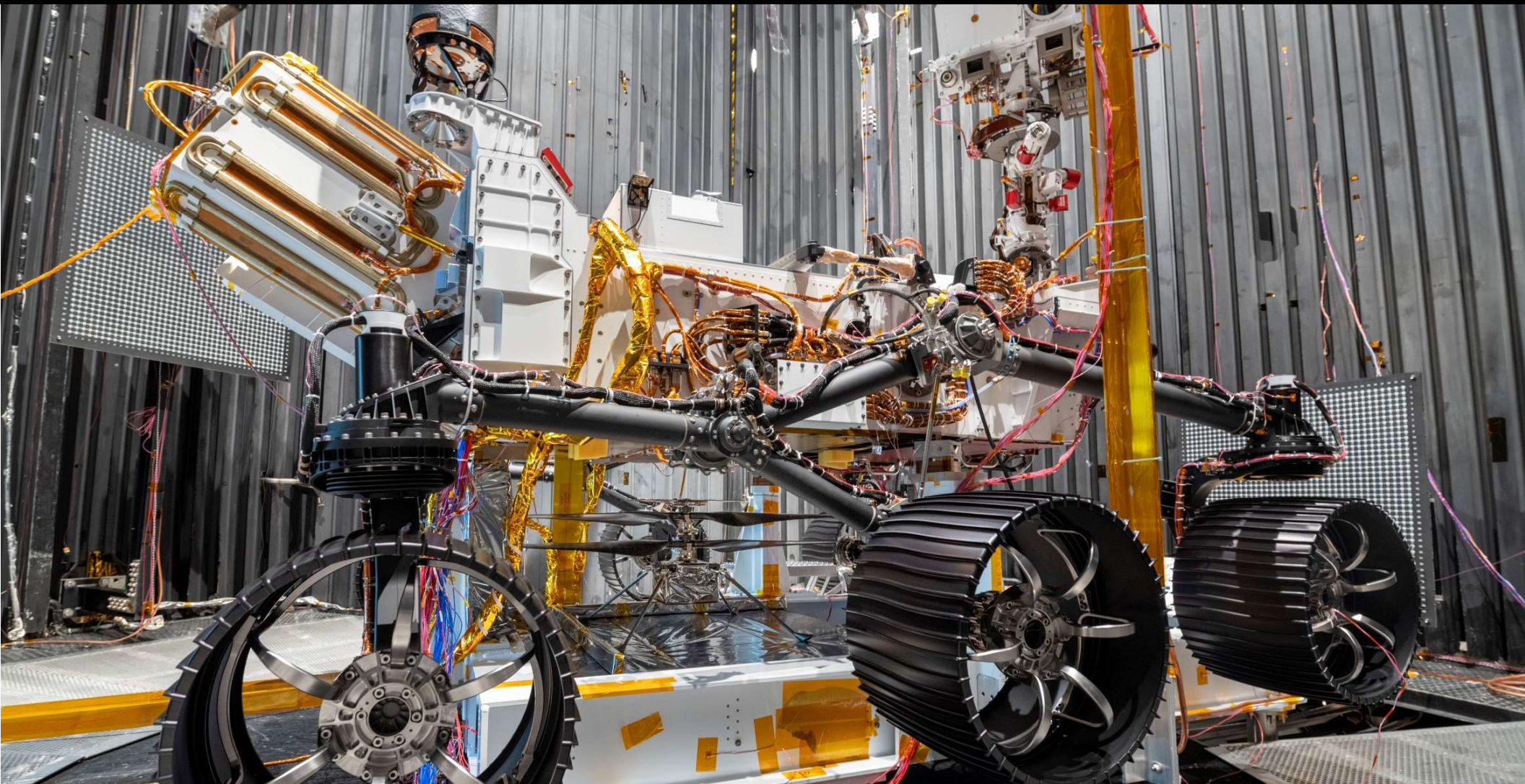


Mass: 1.8 Kg (~4 lbs)
Blades span 1.2 meter tip-to-tip
~2400 RPM

Ingenuity Helicopter integrated on *Perseverance* Rover



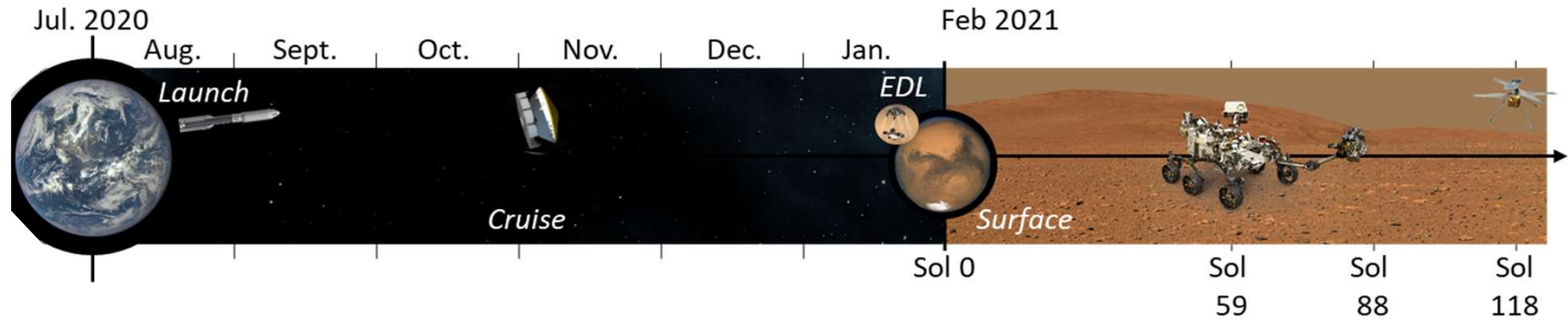
Ingenuity Helicopter Deployment from *Perseverance* Rover Tested



Launched onboard Mars 2020 Perseverance Rover July 30, 2020



Major Milestones Ahead ...



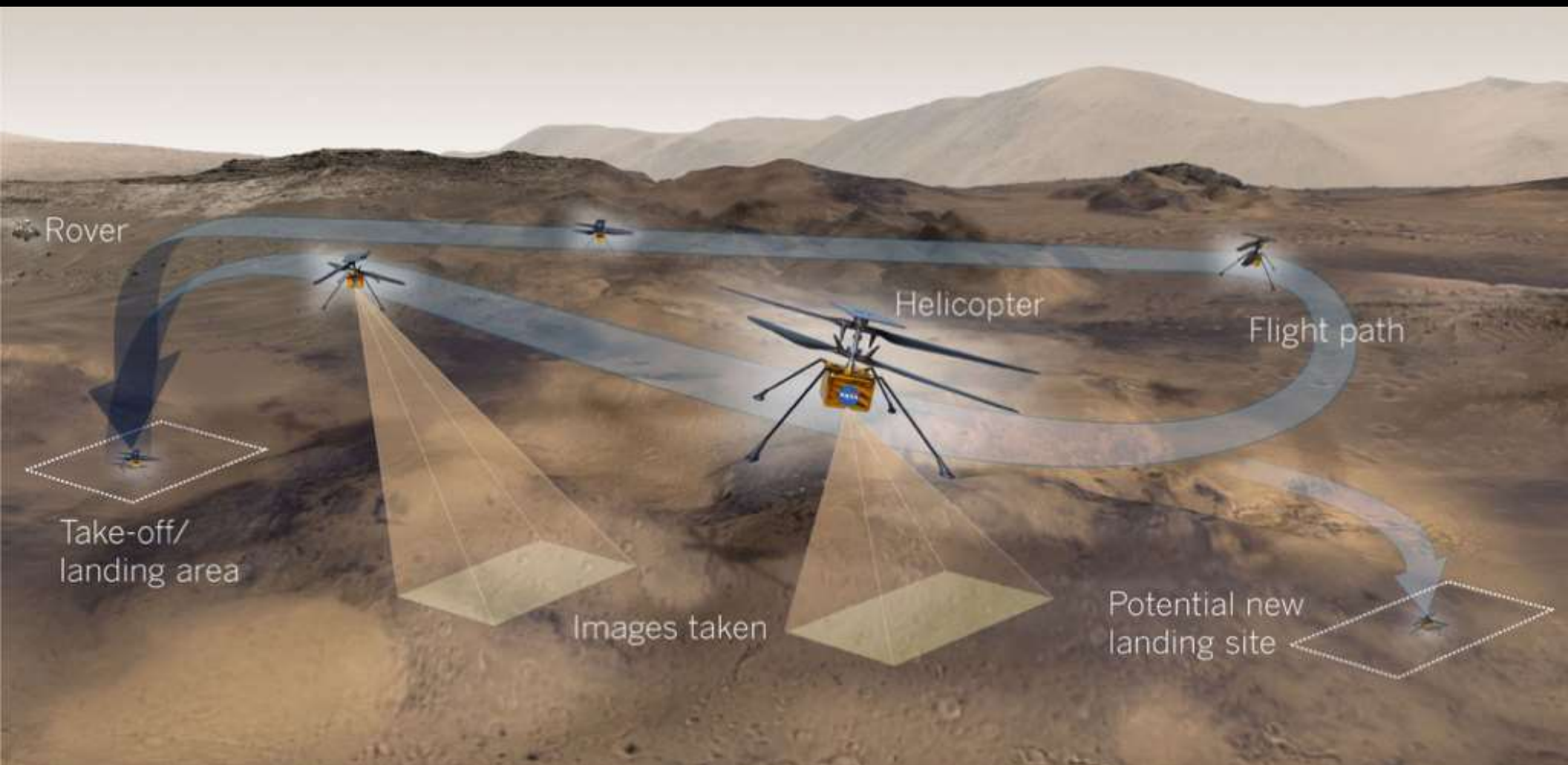
Helicopter battery maintenance and
temperature control
(In Progress)

Helicopter Deployment from
Rover's Mars Helicopter
Delivery System

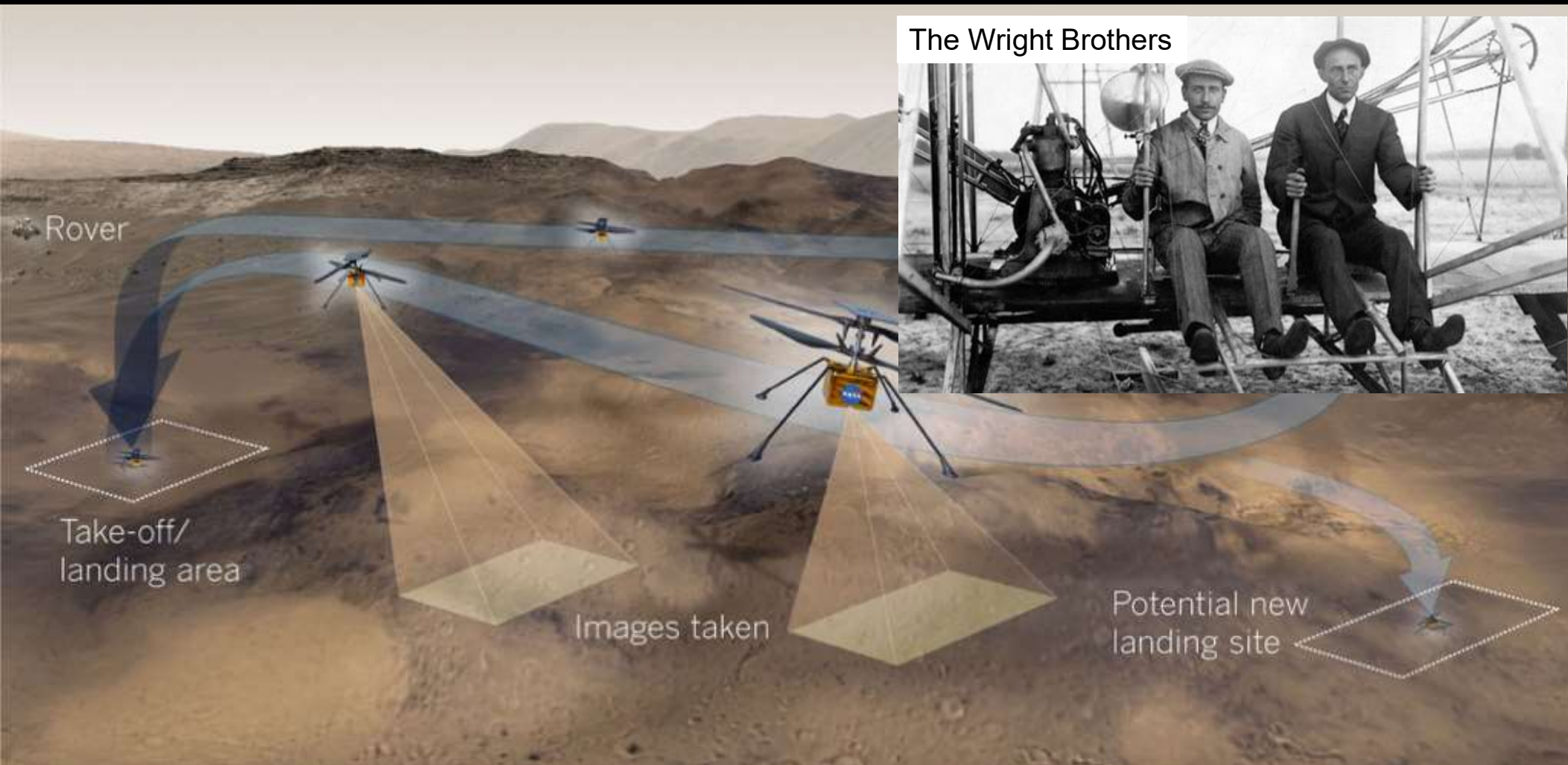
30 Martian Days for Mars Helicopter Experiments

- Thermal survival in stand-alone manner
- Charging battery autonomous via the solar panel
- Telecommunication with the Helicopter Base Station
- Helicopter check-out
- First flight
- Up to 5 test flights

Flight Tests at Mars!

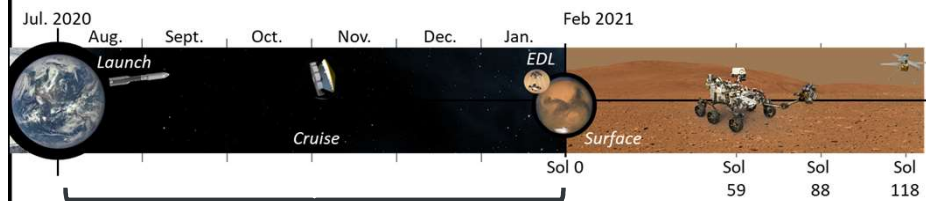


Flight Tests at Mars!



Time-Line

Show feasibi- lity of Helicop- -ter <u>Lift</u> at Mars	Proof-of- Concept Helicopter Controlled Flight Demonstration	Engineering Development Model Helicopter Flight Demonstration	Flight Model Mars Helicopter for Mars	Test w/ M2020 Rover Mars Helicop- -ter Delivery System	Support Integration onto M2020 Rover and System Tests
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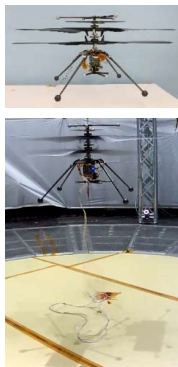
Completed
Dec '14



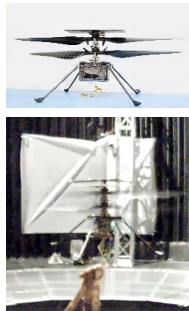
Completed
May '16



Completed
Jan '18



Completed
Feb '19



Completed
May '19



Launched
Jul '20

Cruise

*Landing on
Mars
Feb '21*

*Deployment
from Rover
~April/May
2021*

*30
Consecutive
Martian Days
of
Mars
Helicopter
Experiments*

*~April/May
2021*

Team

NASA

- NASA Science Mission Directorate – Mars Exploration Program
- NASA Aeronautics Mission Directorate – Revolutionary Vertical Lift Technology Program
- NASA Science Technology Mission Directorate

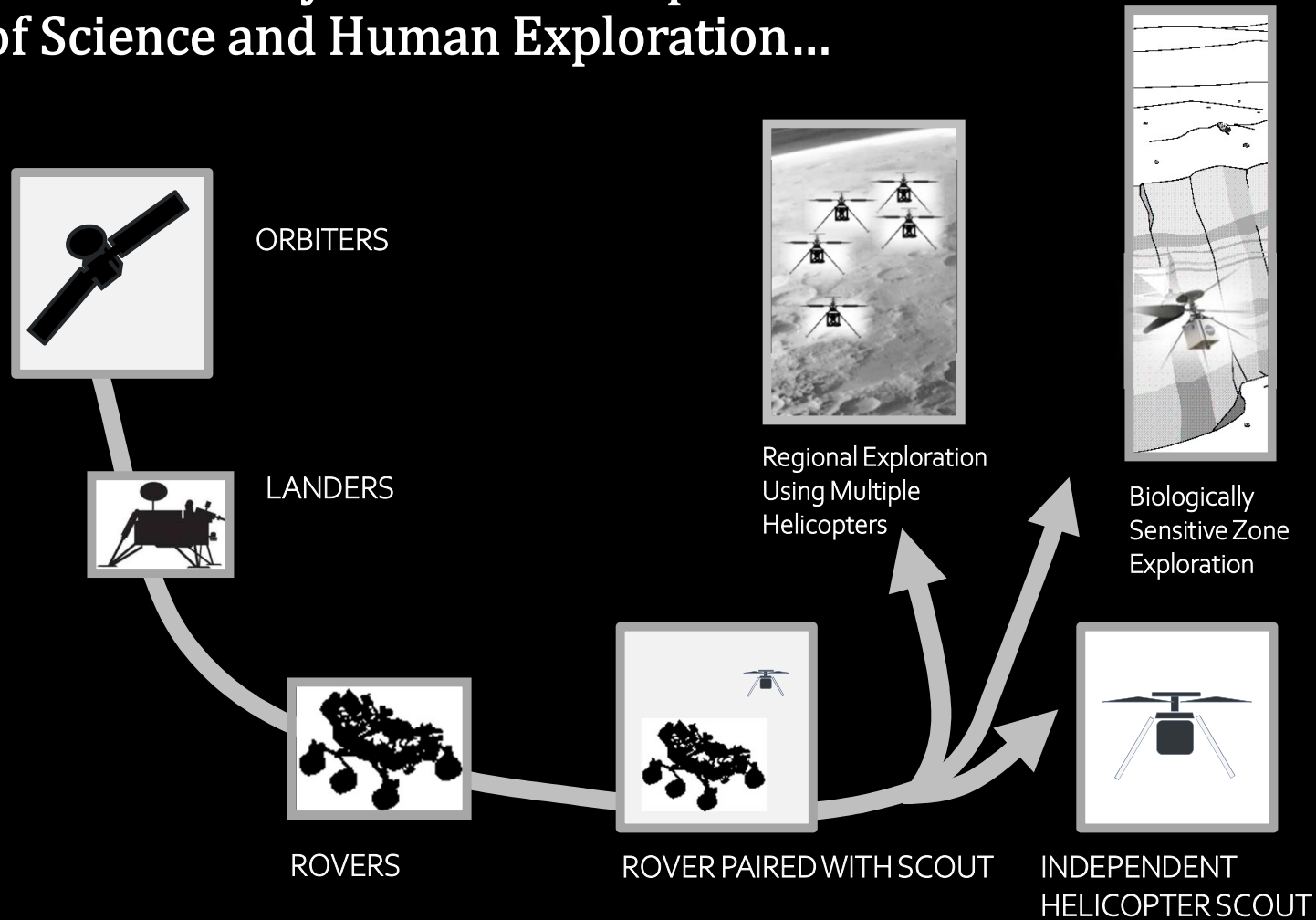
Team across multiple organizations

- NASA JPL
- NASA Ames Research Center
- NASA Langley Research Center
- AeroVironment Inc.
- Qualcomm
- Others ...



Mars Helicopter Team

Adding Aerial Mobility Promises to Open Doors to New Classes of Science and Human Exploration...





Thank you!