Jet Propulsion Laboratory
California Institute of Technology

Ingenuity Mars Helicopter

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Jet Propulsion Laboratory
California Institute of Technology

AIAA Small Satellite Conference
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The Team

NASA Directorates

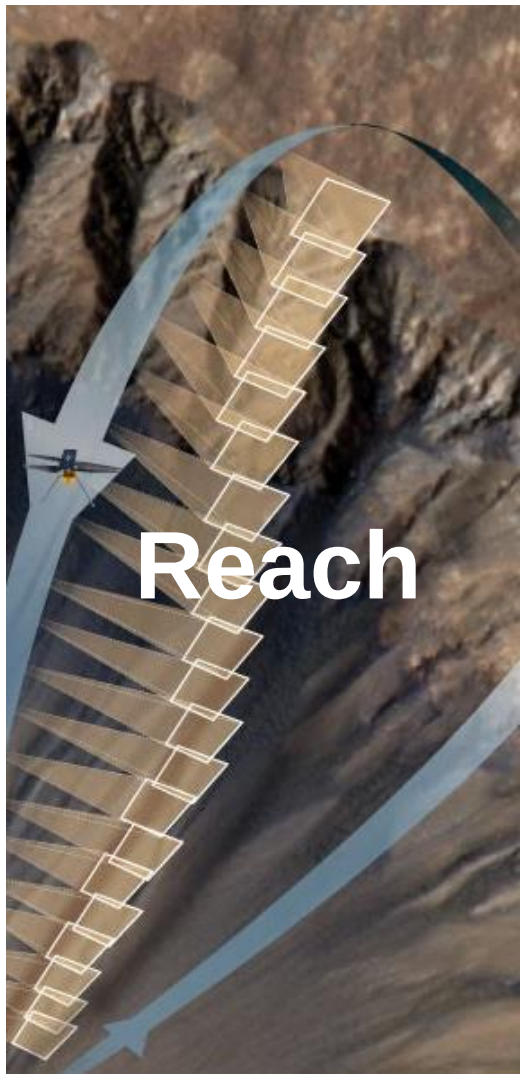
- NASA Science Mission Directorate – Mars Exploration Program
- NASA Aeronautics Mission Directorate – Revolutionary Vertical Lift Technology Program
- NASA Science Technology Mission Directorate

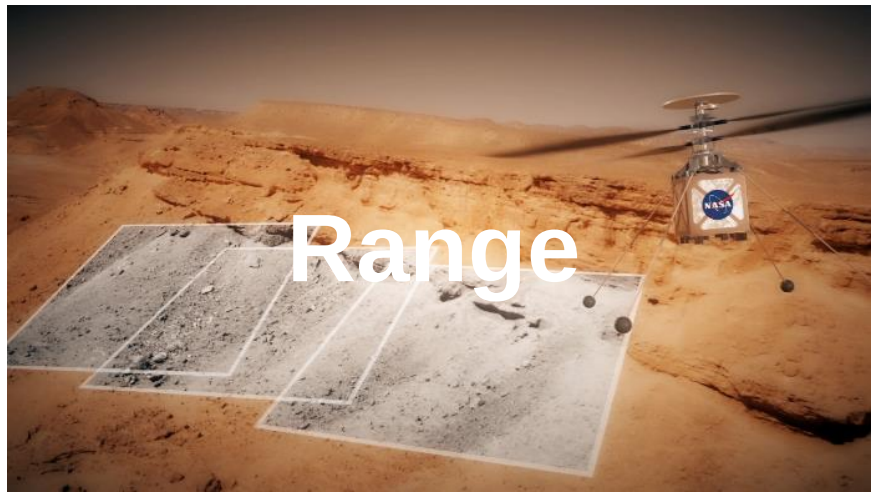
NASA Centers & Industry

- NASA JPL
- NASA Ames Research Center
- NASA Langley Research Center
- AeroVironment Inc.
- QualComm
- SolAero
- Others …

Mars Helicopter Team

Why helicopters ?





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What would they do on Mars ?

ROVER
SCOUT

LANDER
ASSISTANT

INDEPENDENT
EXPLORER

HUMAN
EXPLORATION

The Challenge

Mars has a very thin atmosphere …

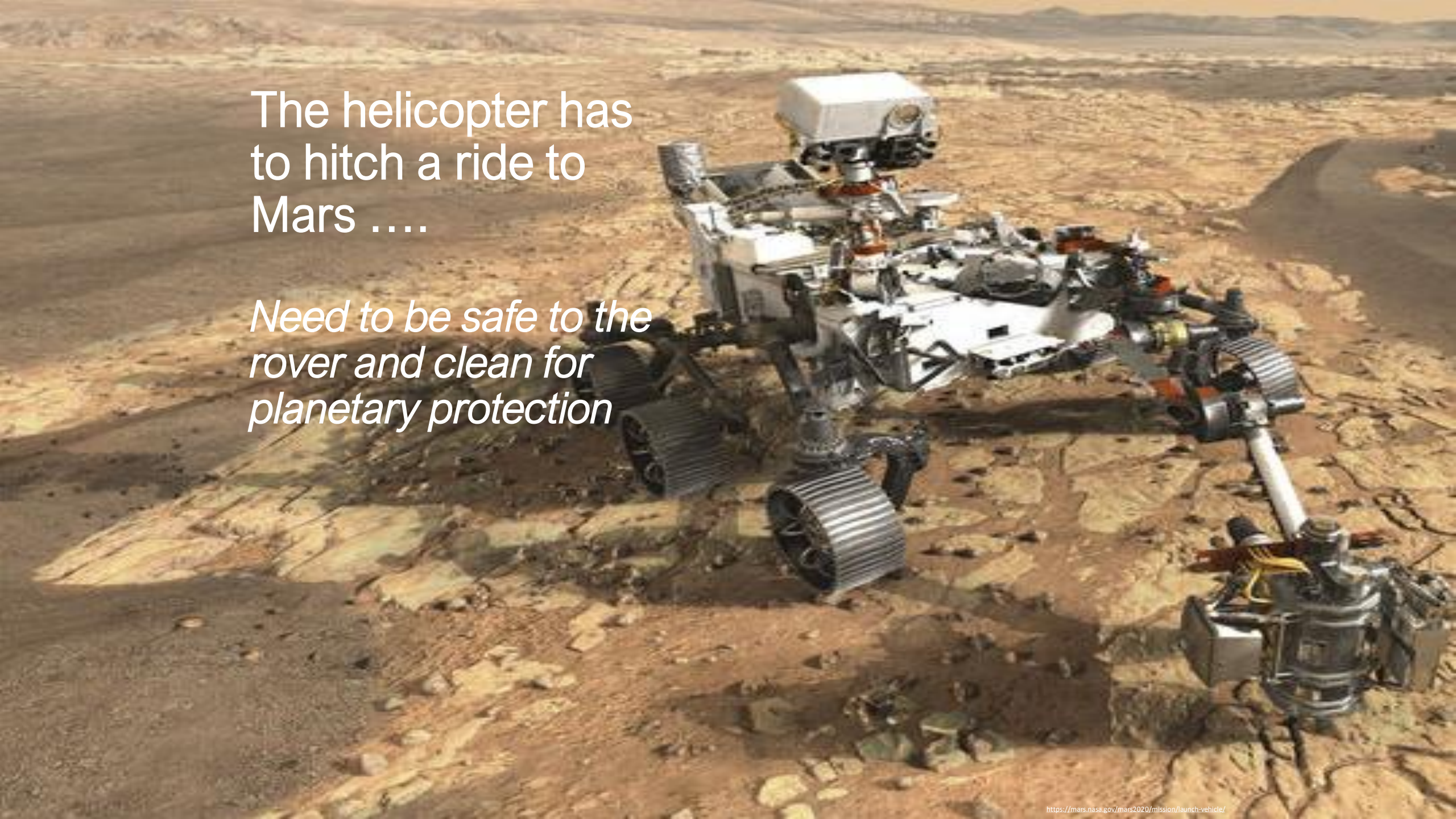
The density is 1% of that at Earth's surface - like being at a 100,000 feet above sea-level on Earth

Mars is very far from Earth 

It can take up to 20 minutes to get a radio signal transmitted to or from Mars

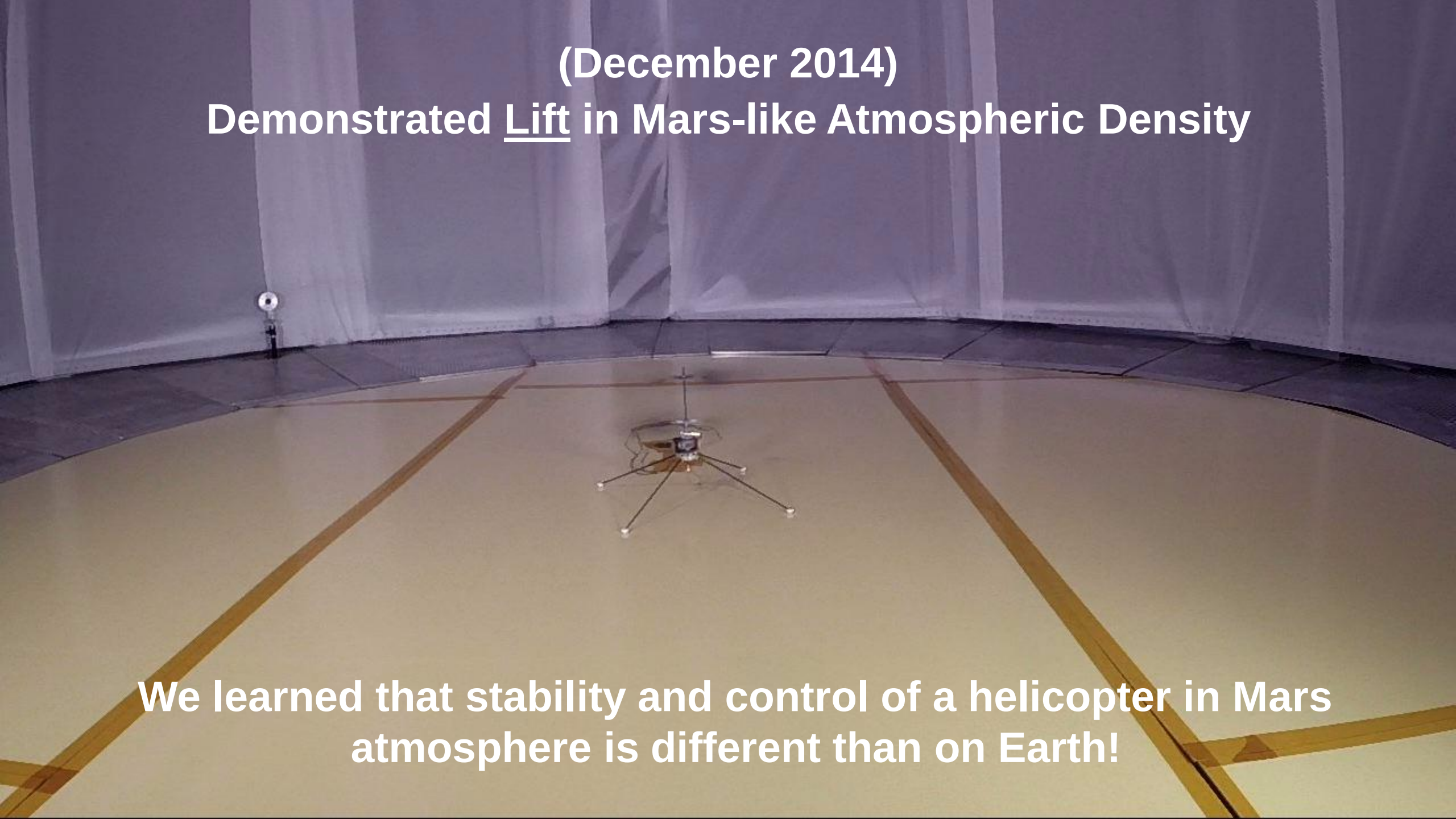

Mars can get very cold at night…
At -90C at night in the springtime that's as cold as the coldest recorded temperature in Antarctica
Courtesy: NASA/JPL/Texas A&M/Cornel


Need to be both an aircraft and a spacecraft ….
That means vibrations, g-forces, vacuum conditions and radiation not typically seen by an aircraft
https://mars.nasa.gov/mars2020/mission/launch-vehicle/


The helicopter has to hitch a ride to Mars ….
Need to be safe to the rover and clean for planetary protection
https://mars.nasa.gov/mars2020/mission/launch-vehicle/

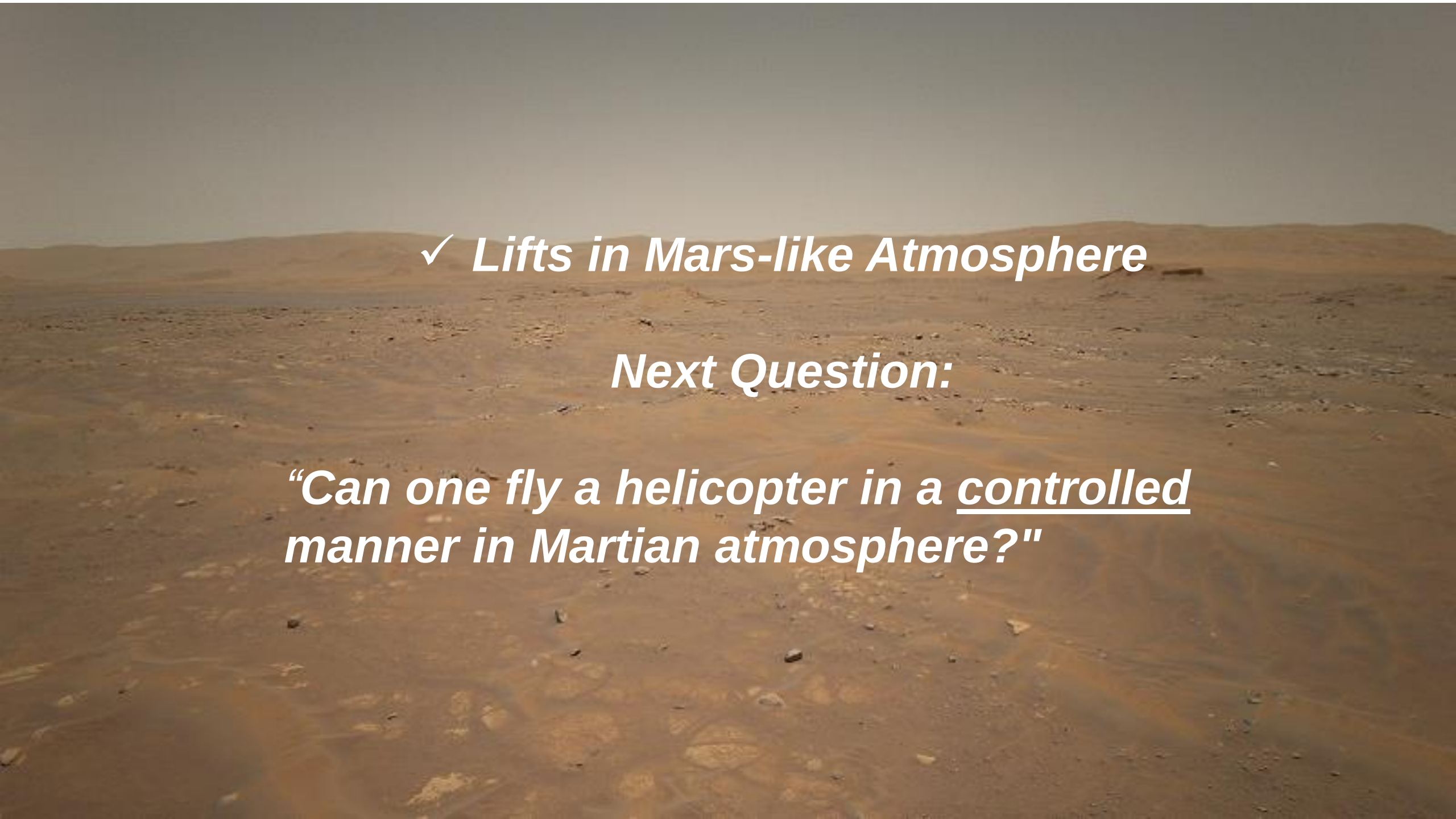
Ingenuity Technology Demonstrator

The Journey



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

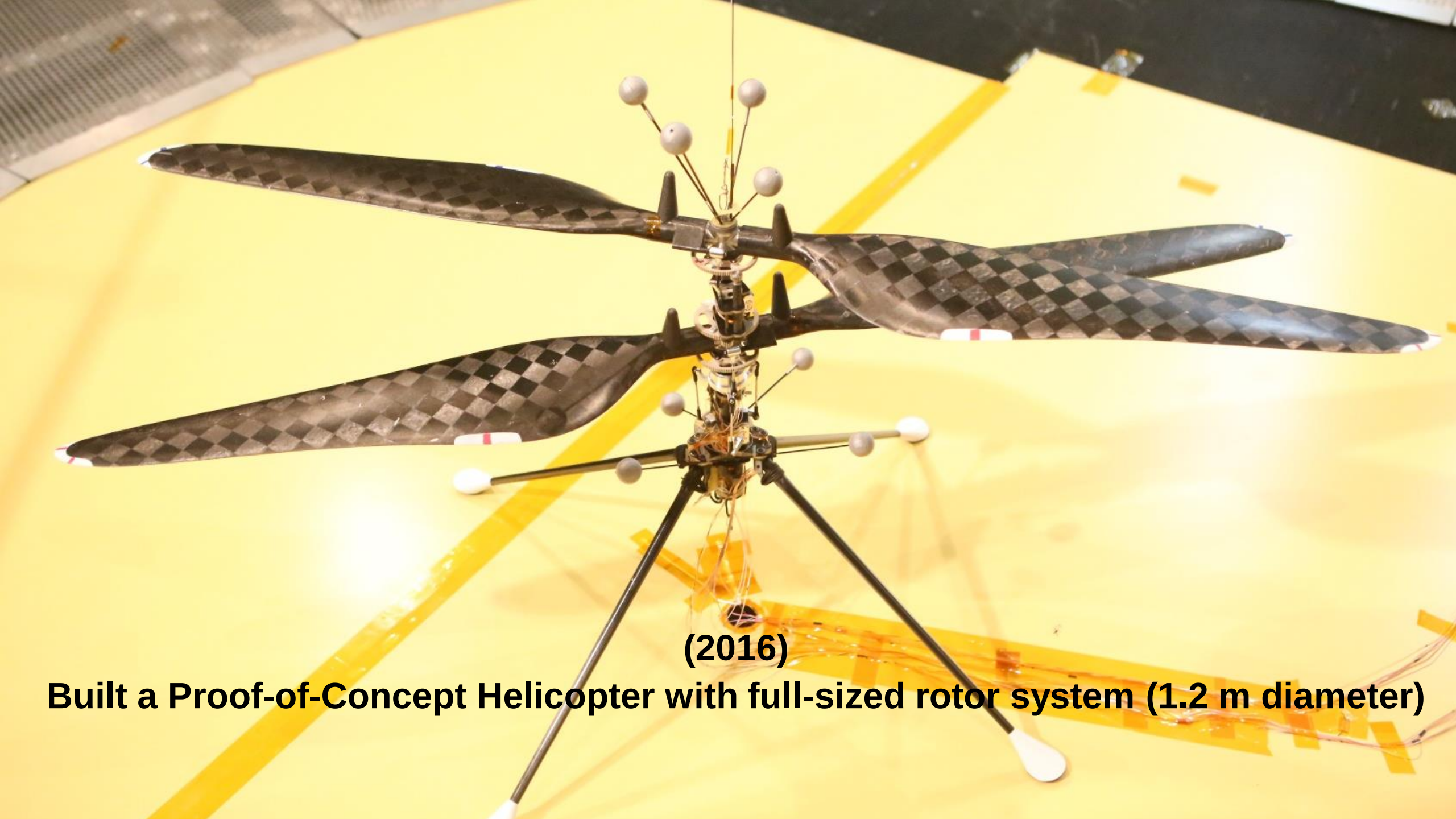
We learned that stability and control of a helicopter in Mars atmosphere is different than on Earth!



✓ *Lifts in Mars-like Atmosphere*

Next Question:

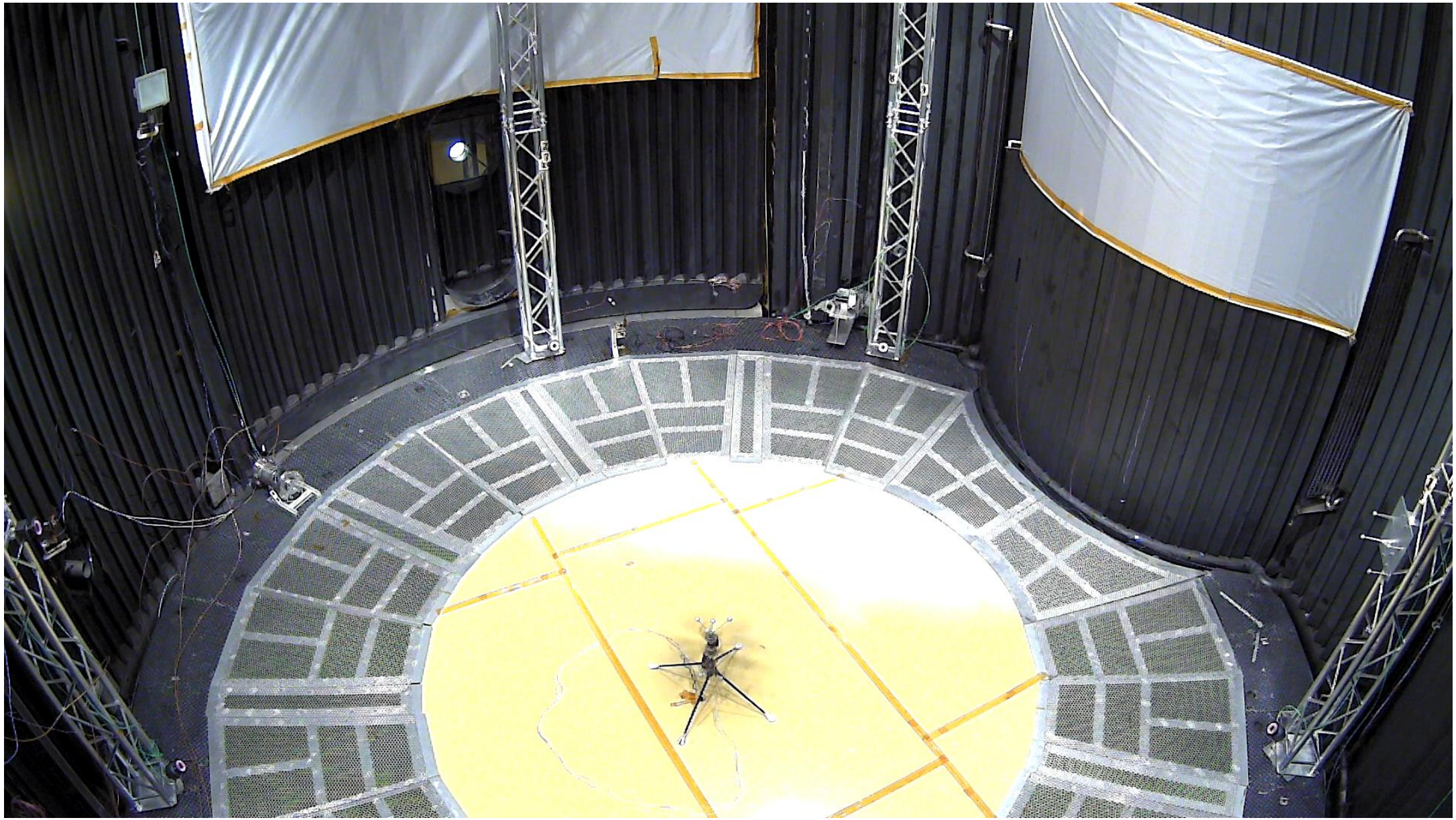
“Can one fly a helicopter in a controlled manner in Martian atmosphere?"



(2016)

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

First-Ever Autonomous Controlled in Mars-like Atmosphere



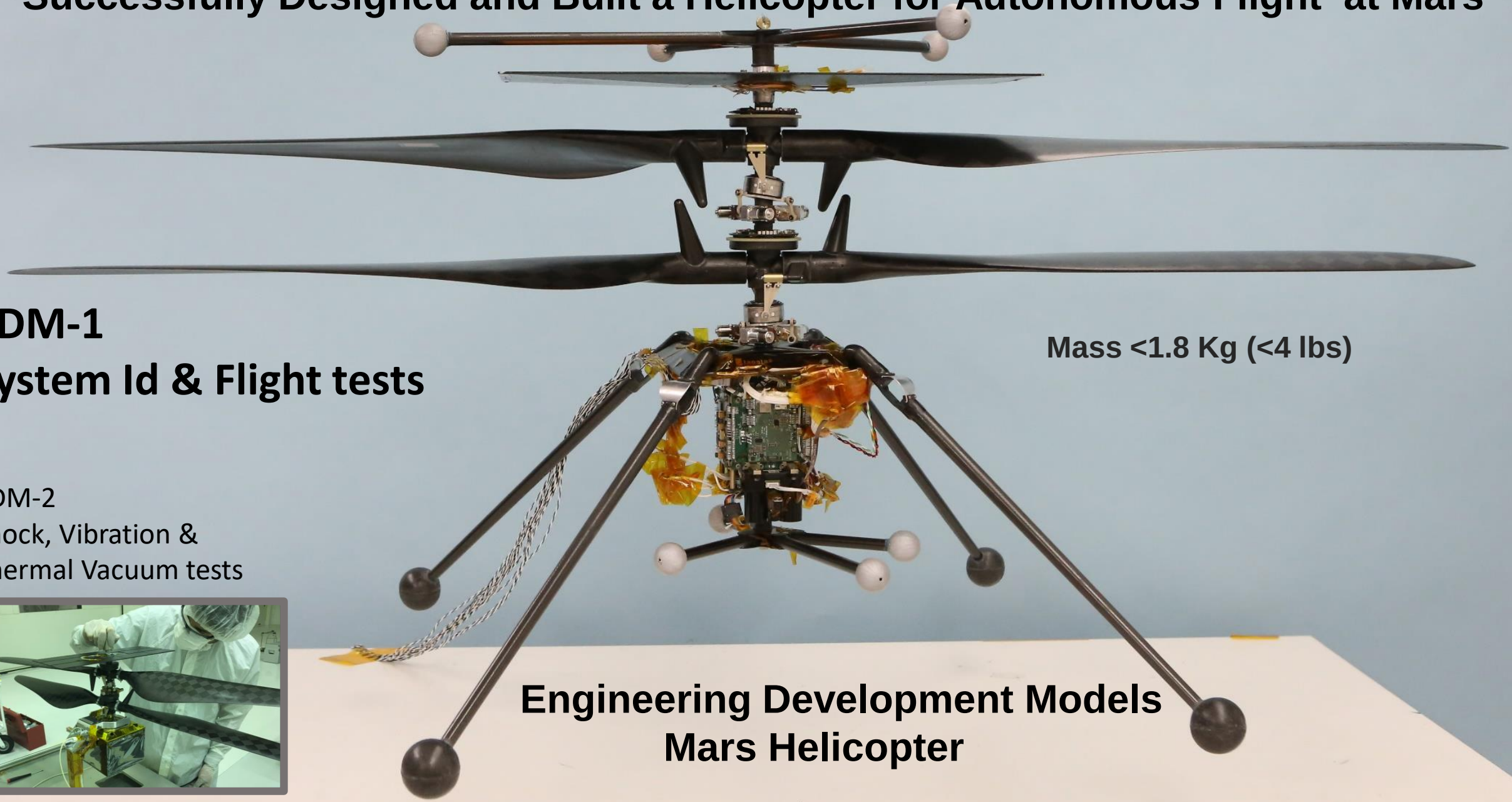
✓ *Lifts in Mars Atmosphere*
✓ *Achieves Controlled Flight*

Next Question:

“Can one build that helicopter to survive the environment and be operable on Mars?”

(2017)

Successfully Designed and Built a Helicopter for Autonomous Flight at Mars



EDM-1
System Id & Flight tests

Mass <1.8 Kg (<4 lbs)

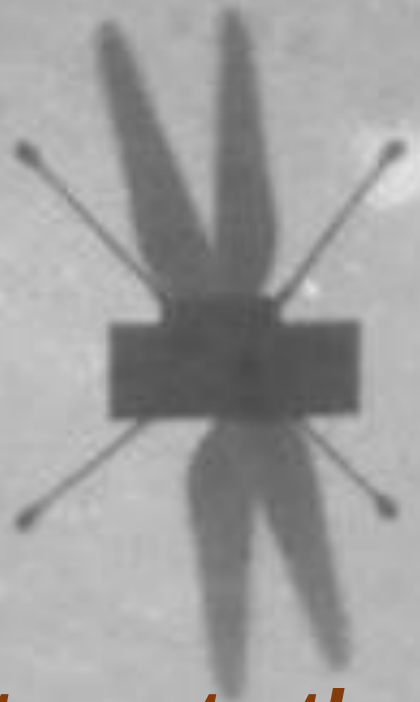
EDM-2
Shock, Vibration &
Thermal Vacuum tests

Engineering Development Models
Mars Helicopter

✓*Lifts in Mars-like atmosphere*

✓ *Achieves Controlled Flight*

✓ *Survives the Environment & Flies Autonomously*

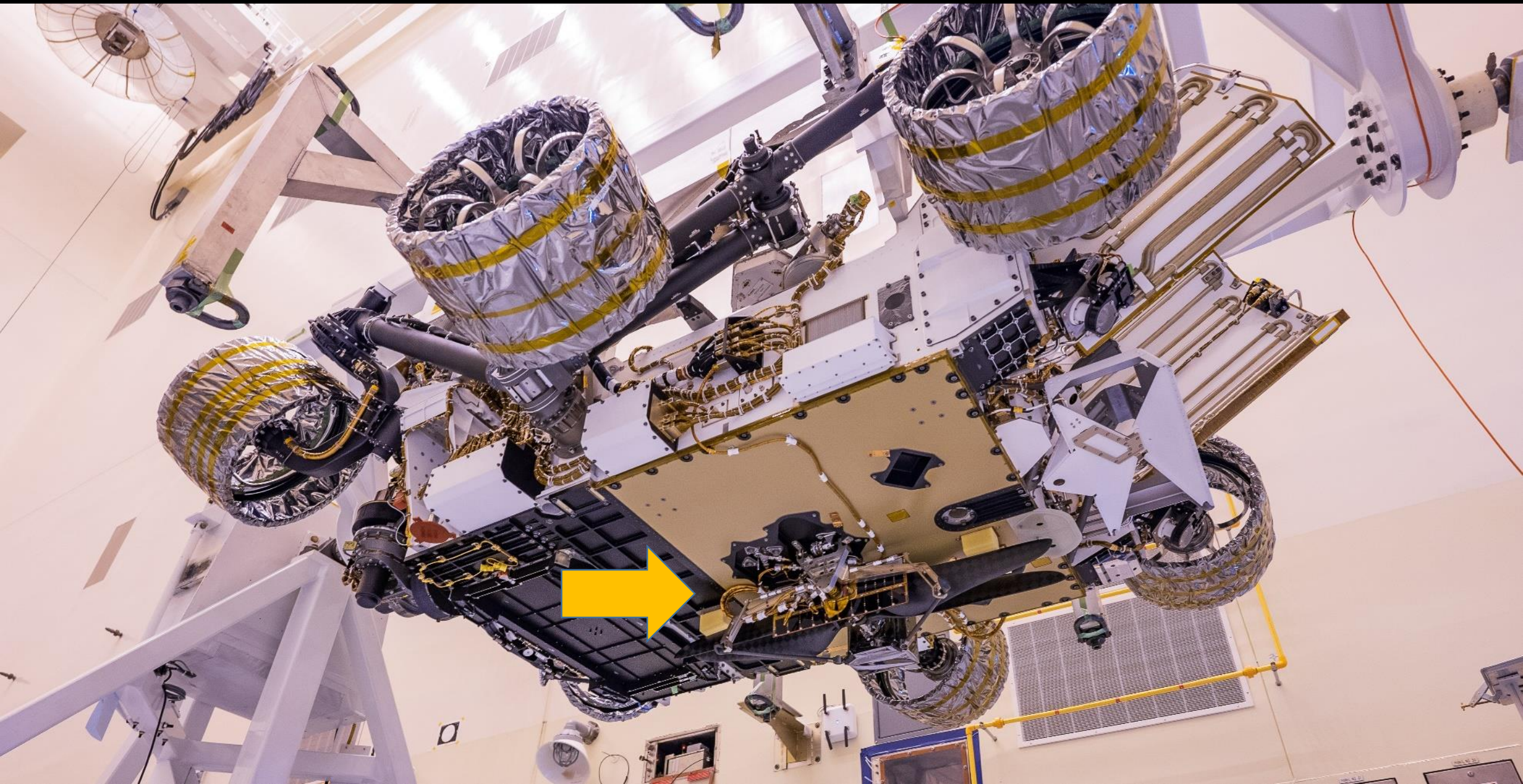


Build and Integrate the Flight Unit !

Mars Helicopter *Ingenuity* (2019)

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

Ingenuity Helicopter integrated on *Perseverance* Rover (2019)



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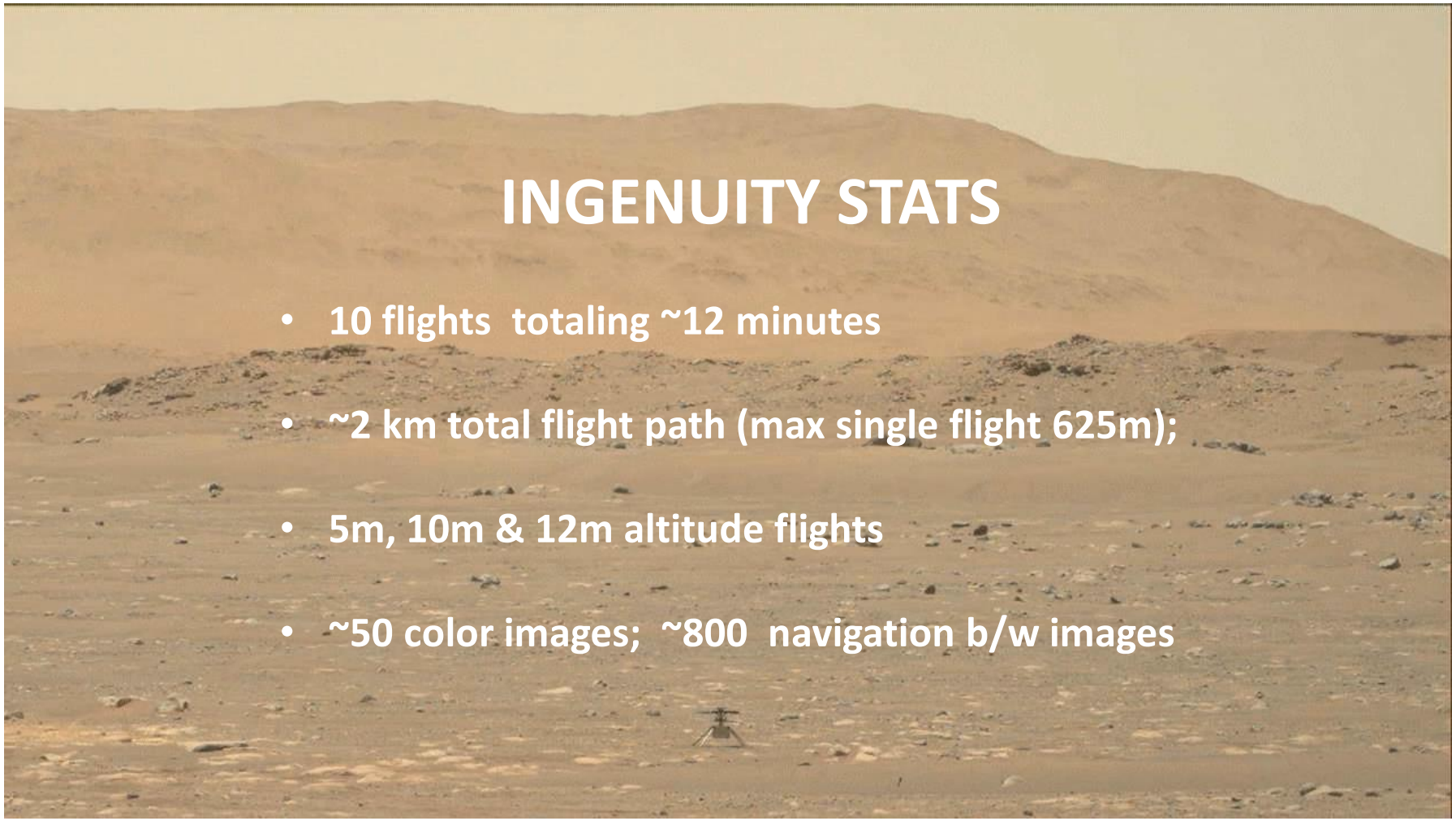
Ingenuity's First Flight at Mars



April 19th, 2021

Landing on Mars: *Feb 18, 2021*
Deployed from Rover: *April 3 2021*

The Design

Ingenuity Design Features

Built like a spacecraft – “Class A” interfaces to rover, spacecraft approved materials, parts radiation and temperature tested

Solar powered!

Special shaped blades for low density! Just 28 gm (1 oz) each

Ultra-safe battery pack – 500 Watts

High efficiency motors spinning at 2400 RPM

Super clean

Custom energy-absorbing coating to harvest the sun’s warmth

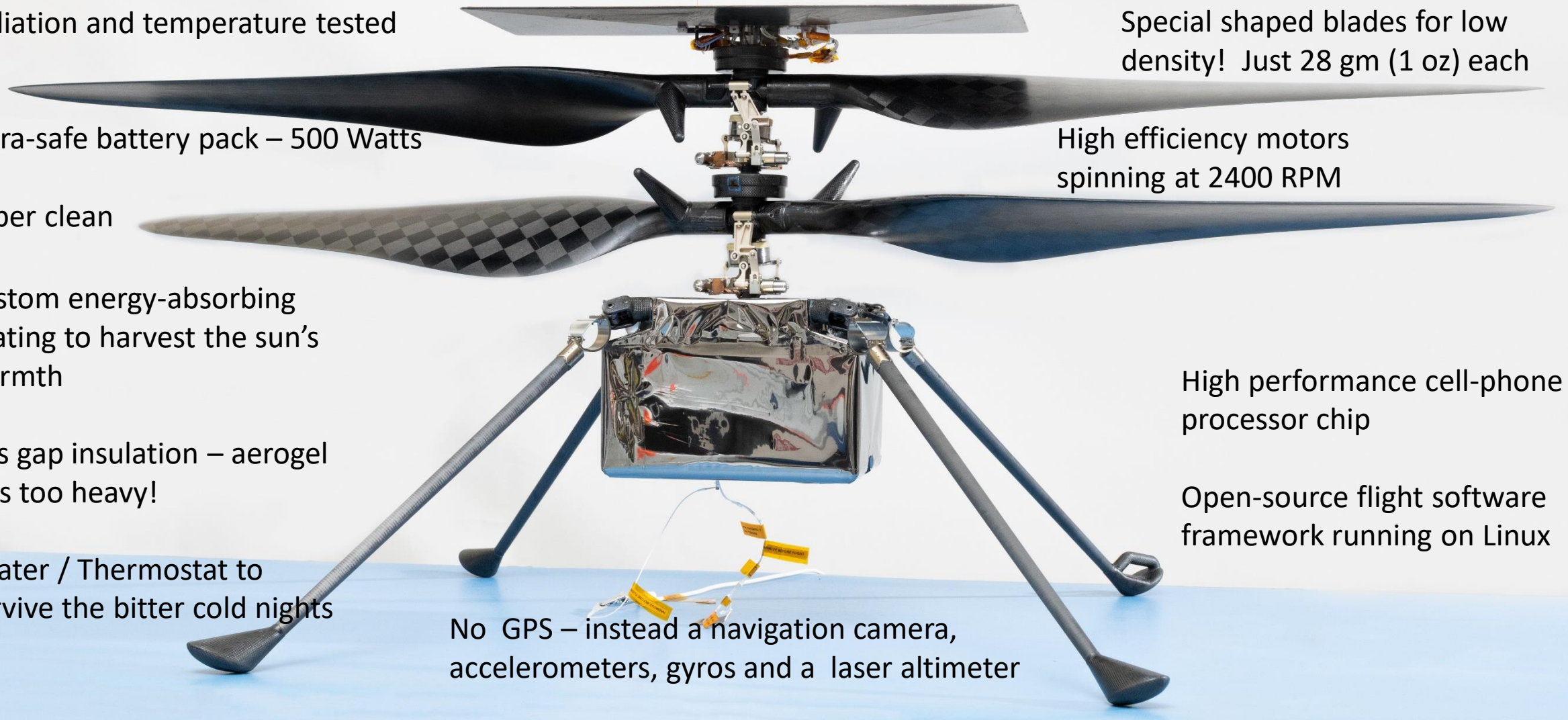
High performance cell-phone processor chip

Gas gap insulation – aerogel was too heavy!

Open-source flight software framework running on Linux

Heater / Thermostat to survive the bitter cold nights

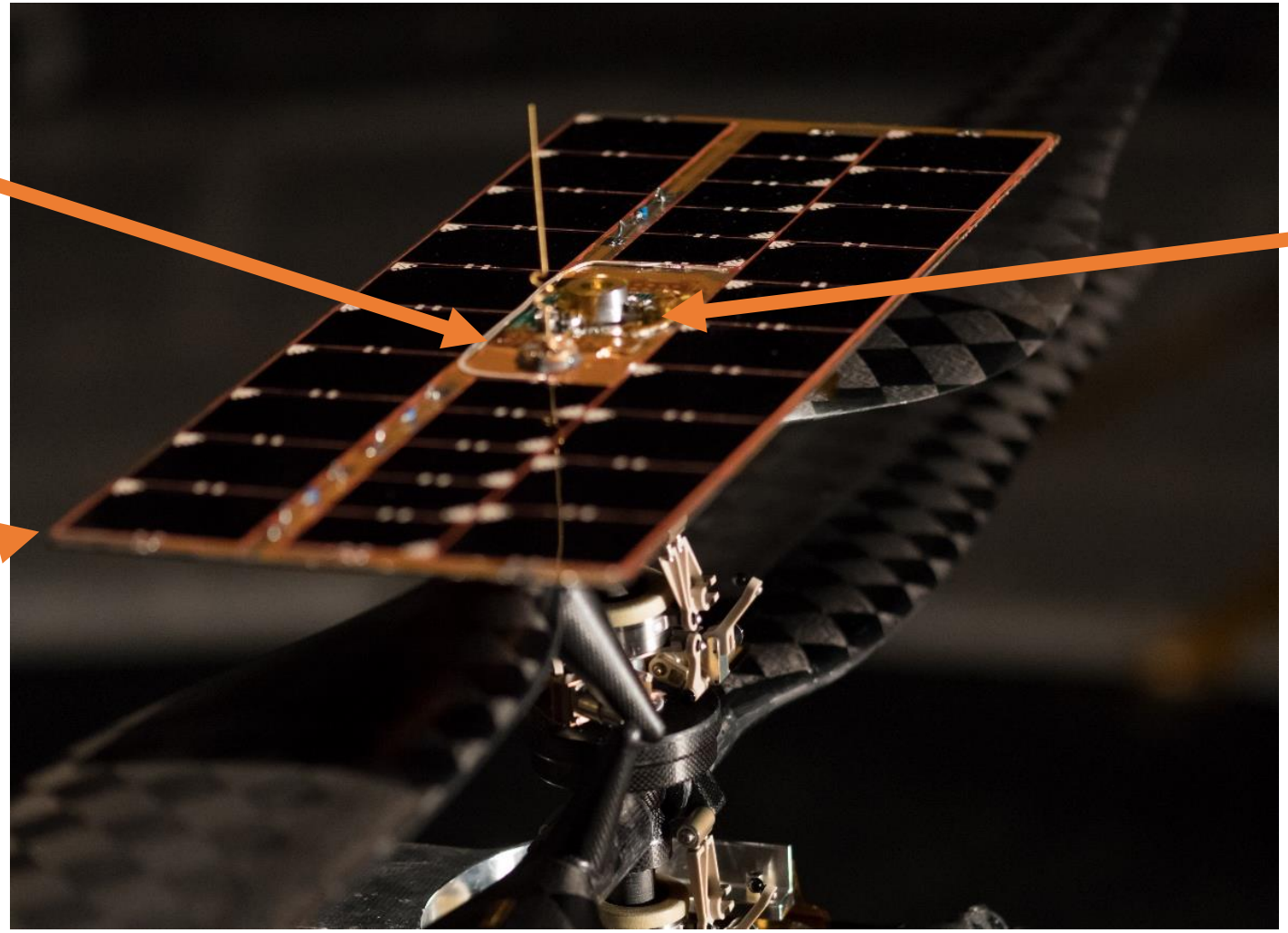
No GPS – instead a navigation camera, accelerometers, gyros and a laser altimeter



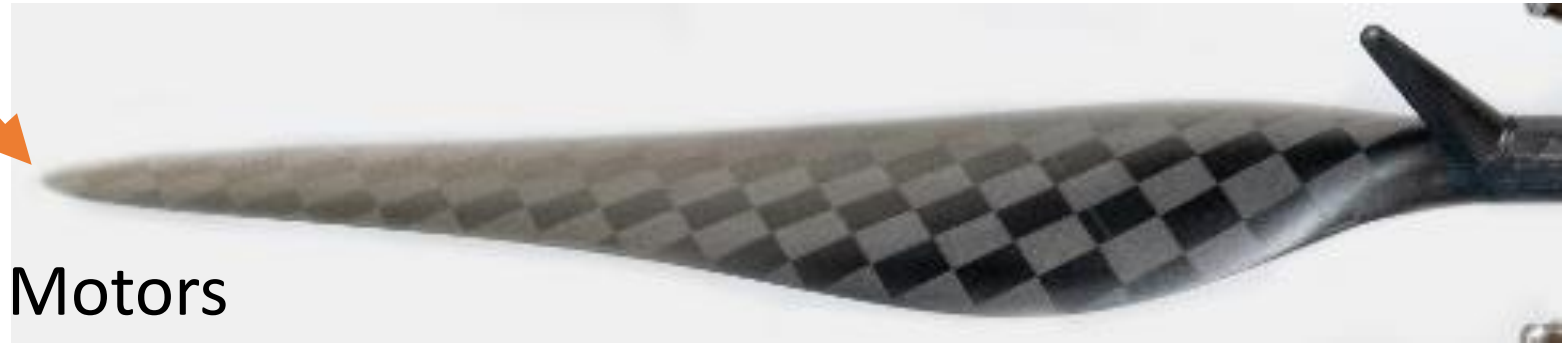
Antenna

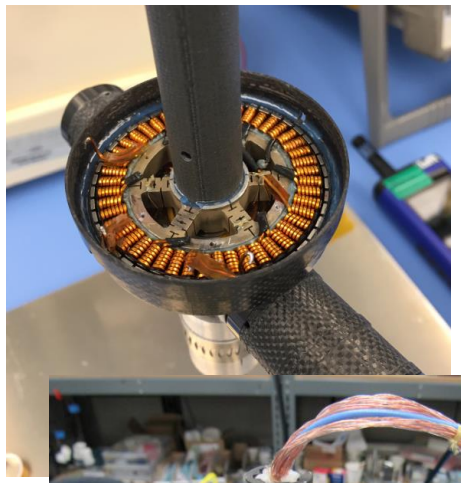
Rover Interface

Solar Array

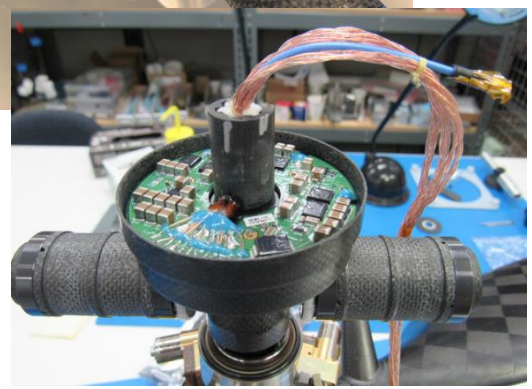


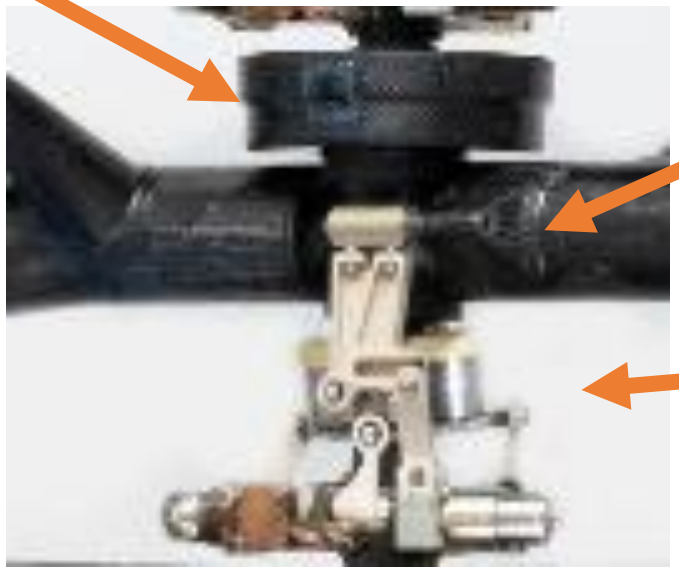
Blades
(40g/1.5oz each)





Propulsion Motors





Hubs

Swashplates

Spring & Damper
Hinge

Legs

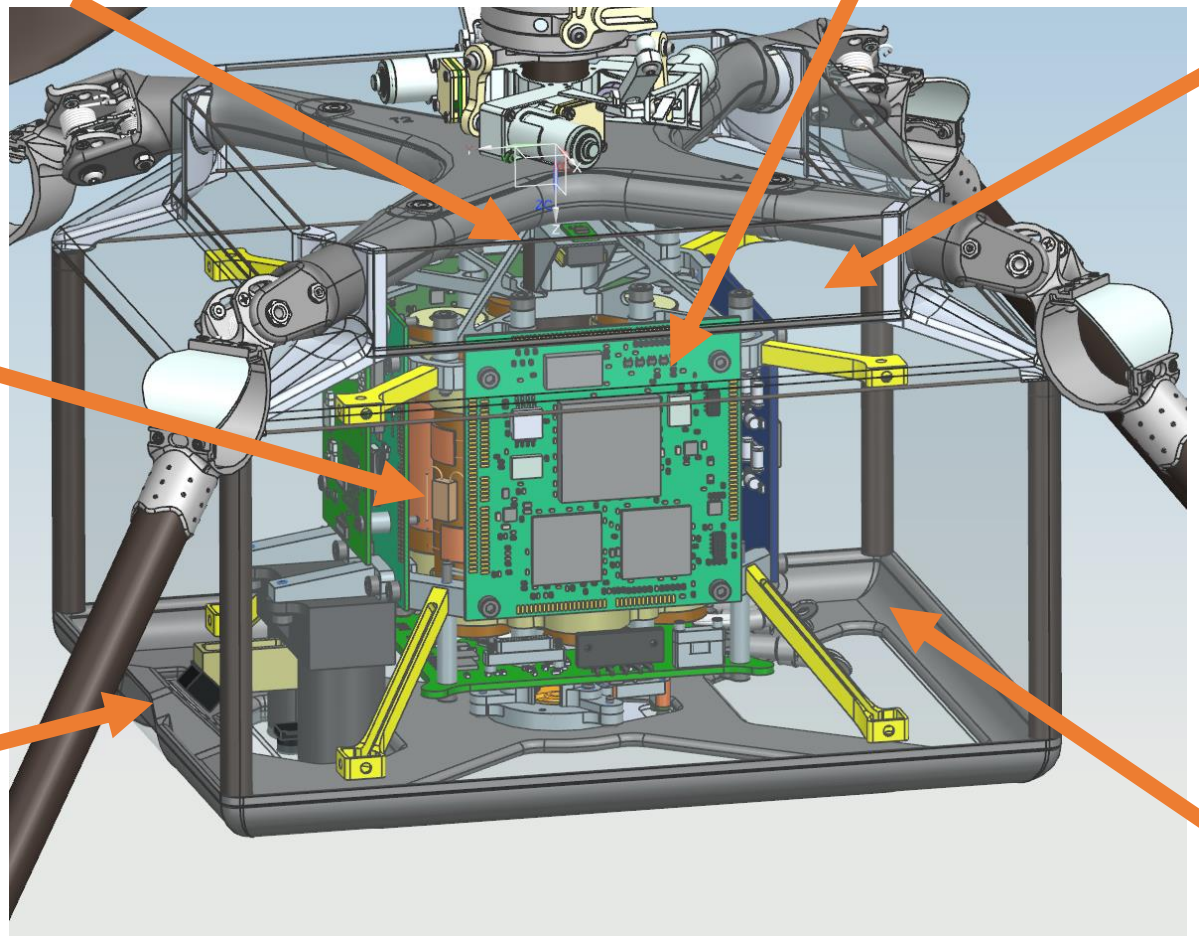
Feet

Mast
(w/ 70+ wires)

IMU + Inclinometer

Electronics

Wiring everywhere!

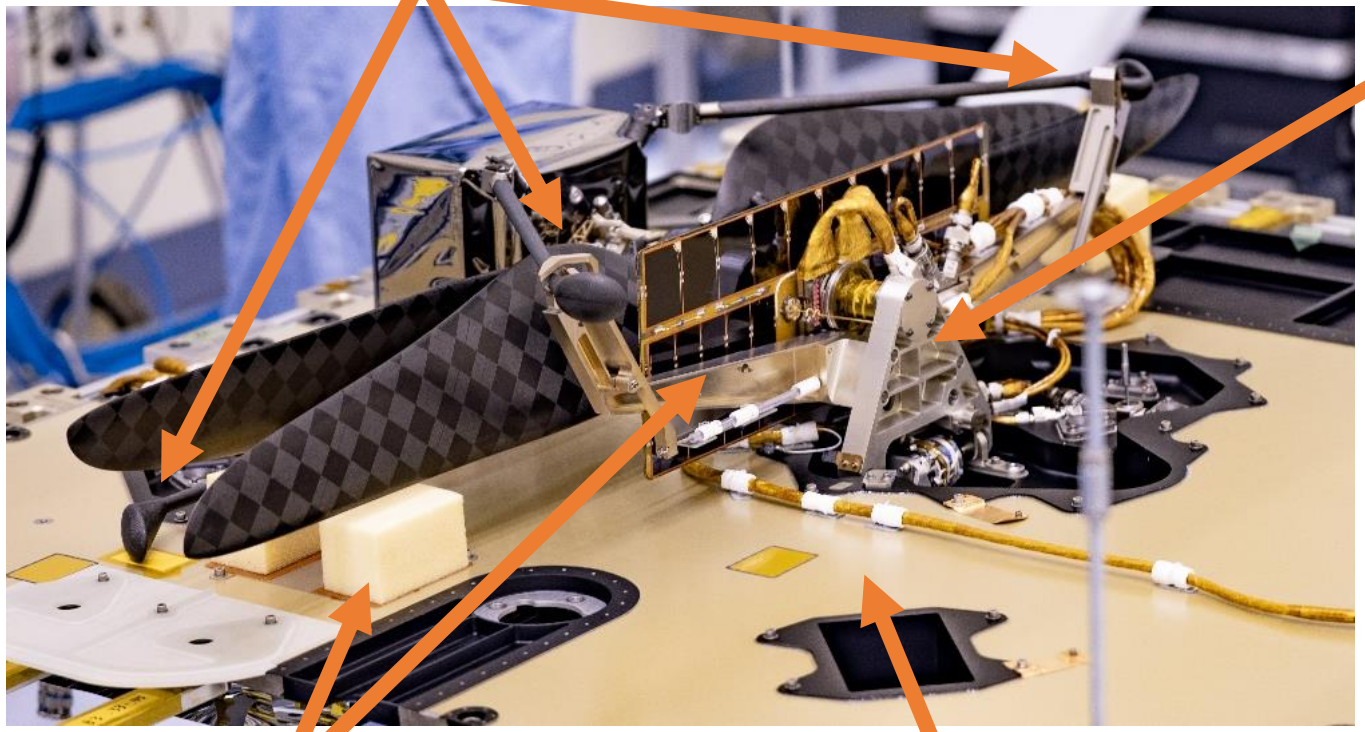


Battery Pack

Altimeter + Cameras

Nested Thermal Blankets

Leg Restraints



Separation Device and Egress Arm

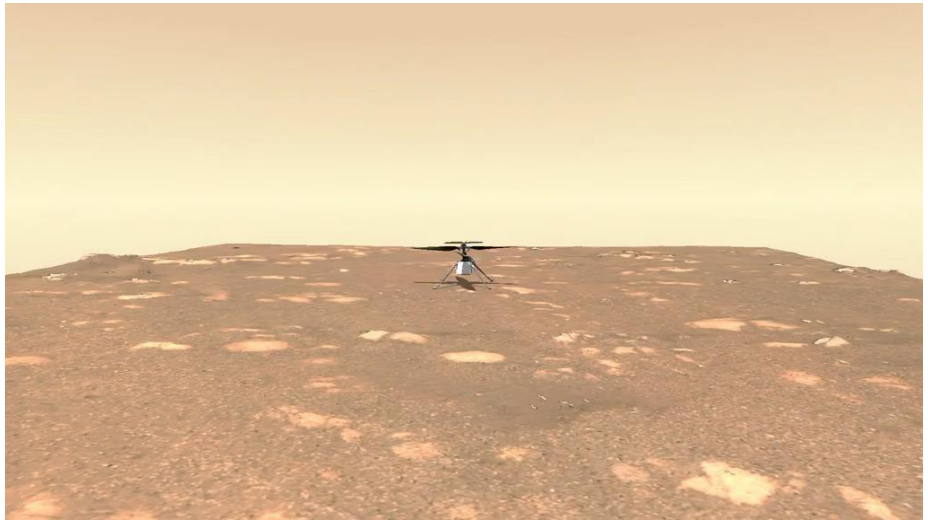
Blade Supports and Guards

Rover Belly Pan

The Tests

Learning to Fly

Computer simulation

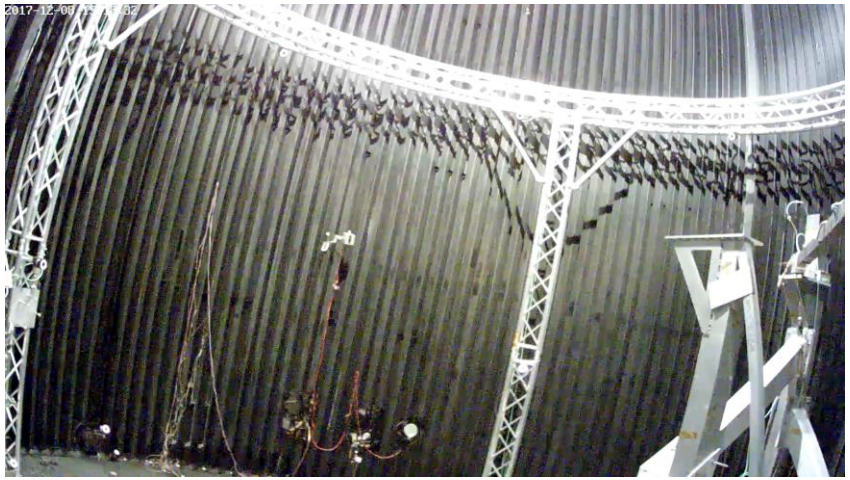


Aerodynamic experiments

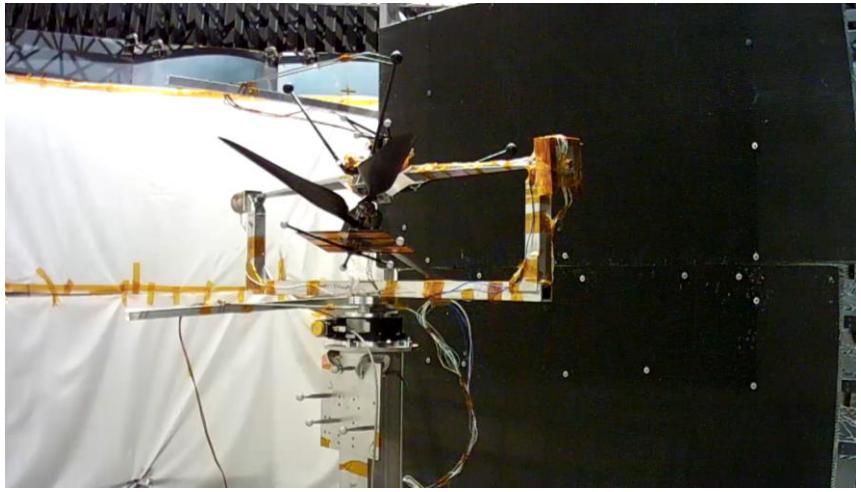
Flight testing

Some Creativity Required !

Generating airflow over rotor



“Wind wall” with 900 CPU fans



“Flying” the helicopter by hand

We had to suspend our helicopter using fishing wire

The Operations

Mars Helicopter System

Helicopter
Electronics

“Ginny”

Zigbee Radio

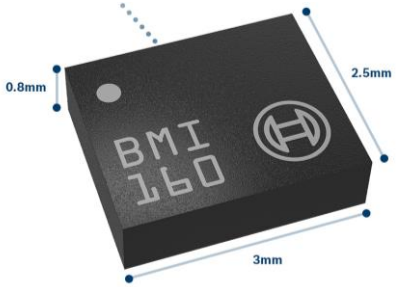
Base Station
Instrument Payload

“Percy”

F Prime Software: https://github.com/nasa/fprime.git

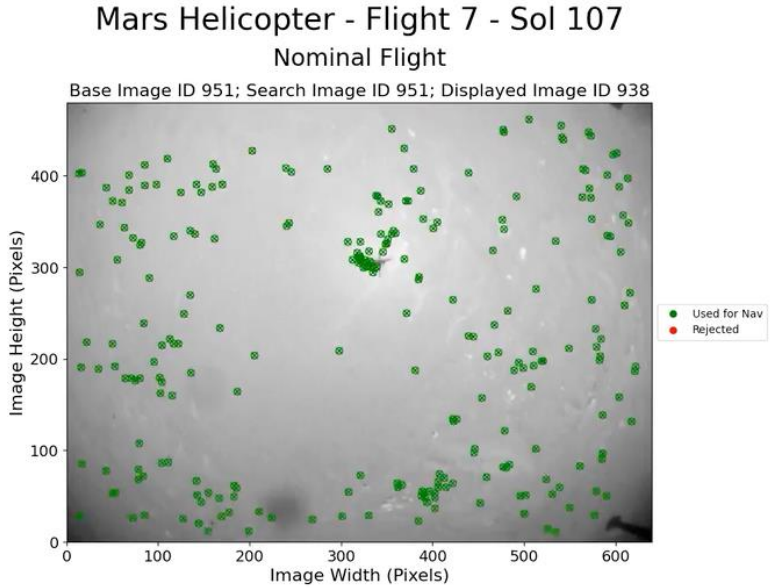
Navigating on Mars

Vision-based navigation system uses commonly available sensors

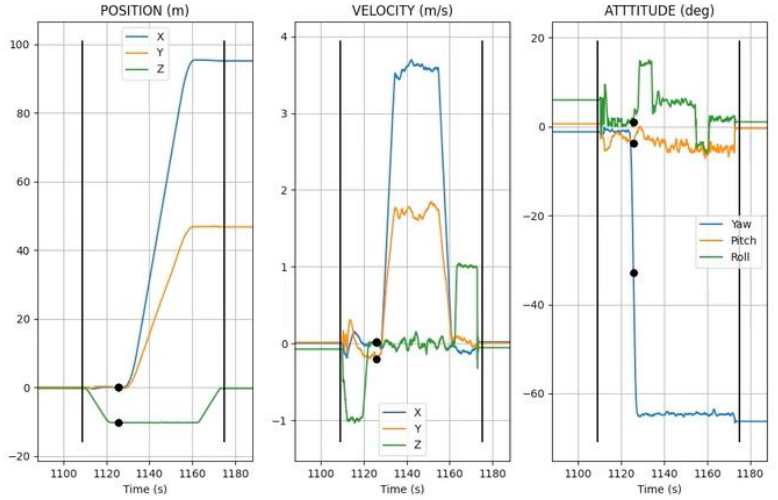


Bosch BMI160 IMU

Garmin Lidar-Lite-V3 Altimeter



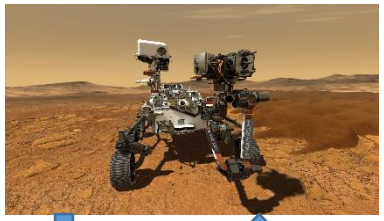
Navigation testing on Earth



Uplink & Downlink

Analyze data

Deep Space Network



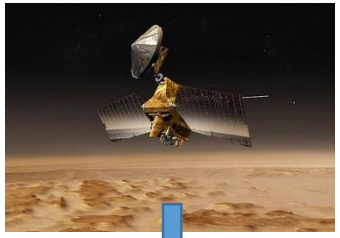
Write Commands

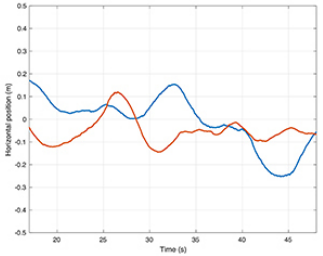
Send all Rover commands

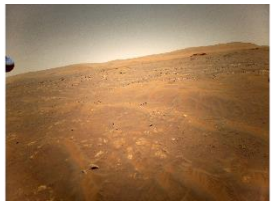
Heli commands

Heli data

Orbiter







Deliver to Perseverance Team

Ground system

Heli team

Martian Night

Martian Day

Martian Night