Planetary Rotorcraft

Panel on Aeronautics for Space

Aeronautics and Space Engineering Board/Space Studies Board

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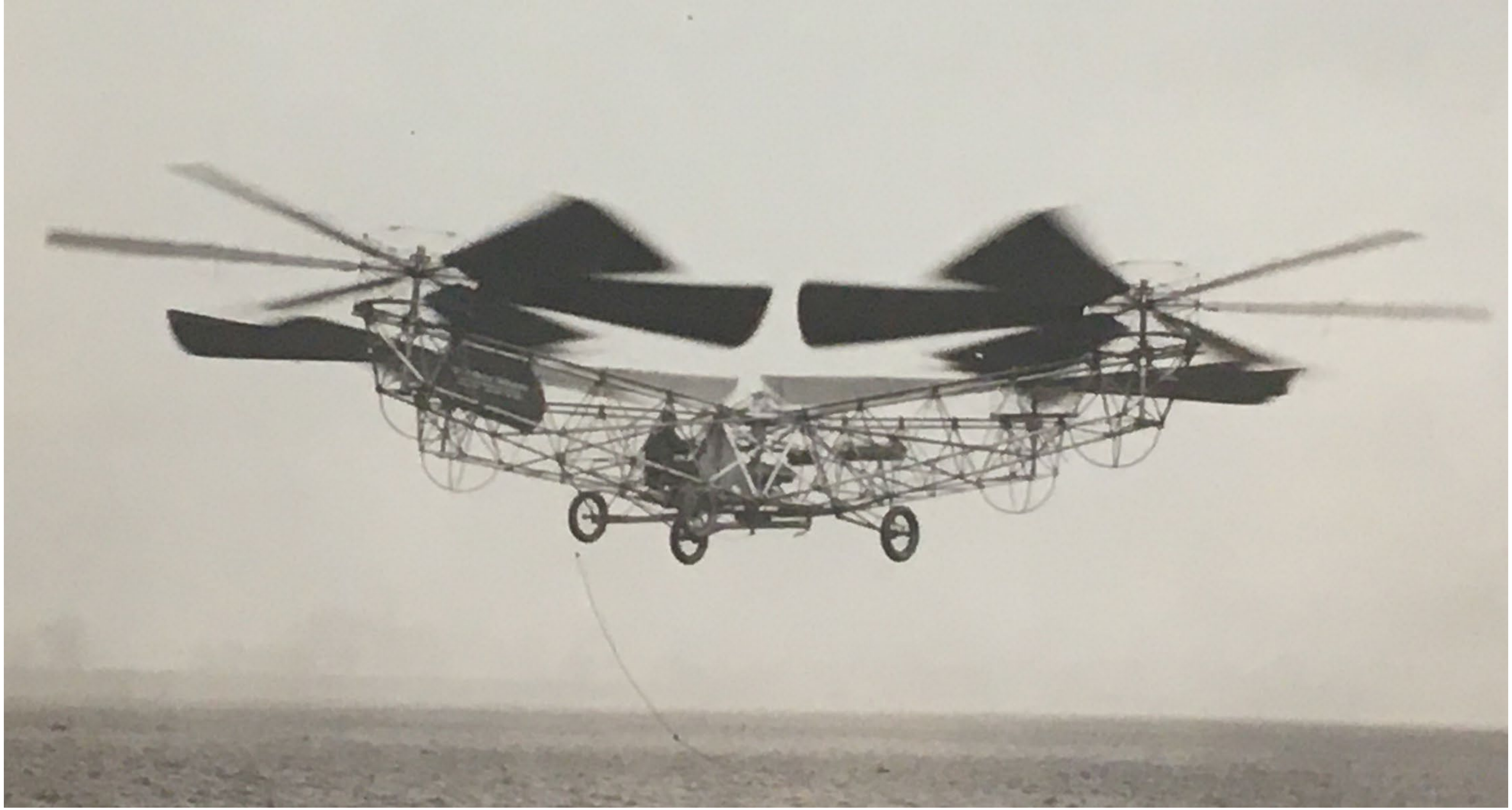
Early Rotorcraft, a century ago

De Bothezat
Flying Octopus
1922

Control via differential thrust (collective on each of 4 rotors)

Small fans for yaw control

Promising, but discontinued: pilot workload a notable issue

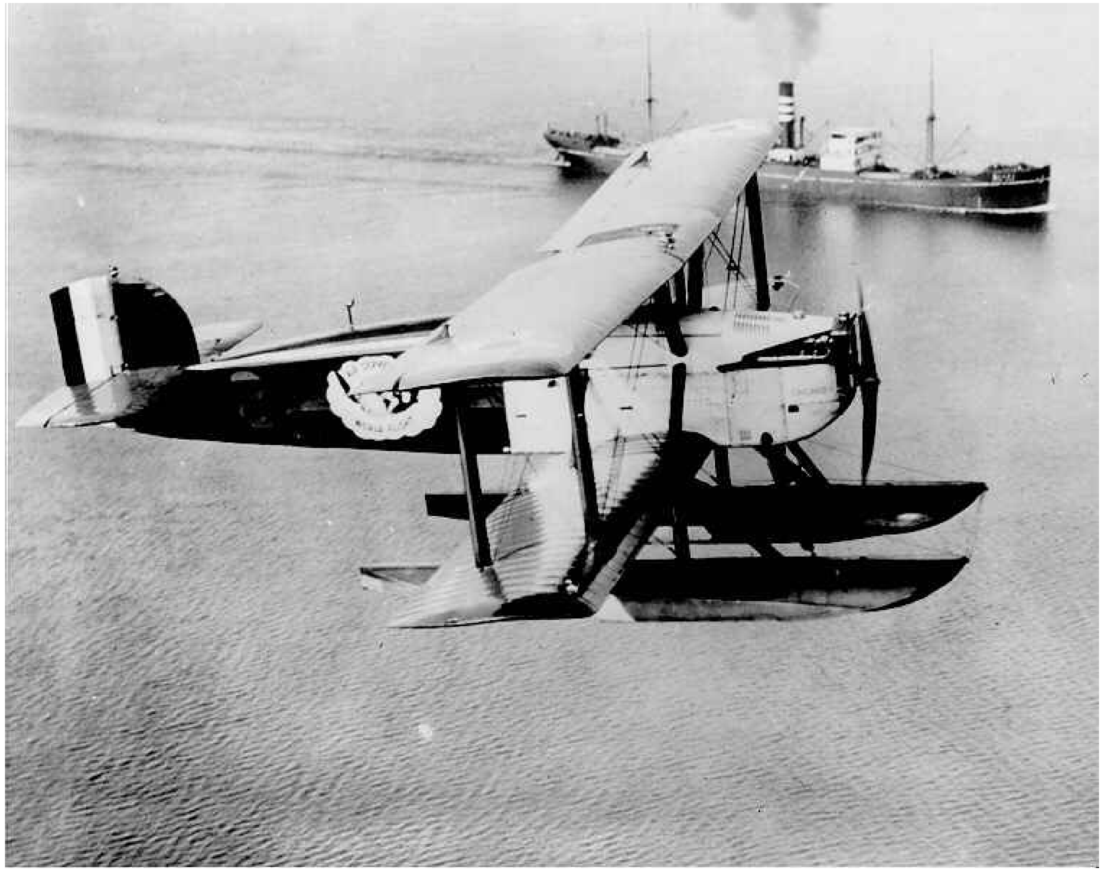


First Round the World Flight

1924 US Army Air Service
Douglas World Cruiser configured as floatplane
Fuel 144 → 644 gal (1x 340kW)
15m wingspan   2350kg empty weight
Crew : 2 (pilot + copilot/mechanic)
Max speed : 46 m/s
Range 2660 km

Round-the-world flight 175 days, by 4 planes, supported by multiple ships.
Engines changed 5 times at predetermined sites

4 planes launched from Seattle
1 reached Alaska
1 reached Faroe Islands
2 completed trip (all 8 crew survived)



Graf Zeppelin LZ-127

1929
236m long
5x 510 kW engines
Top airspeed 36 m/s
~36 crew 20 passengers
Range 10,000 km
21 day circumnavigation

The Lessons

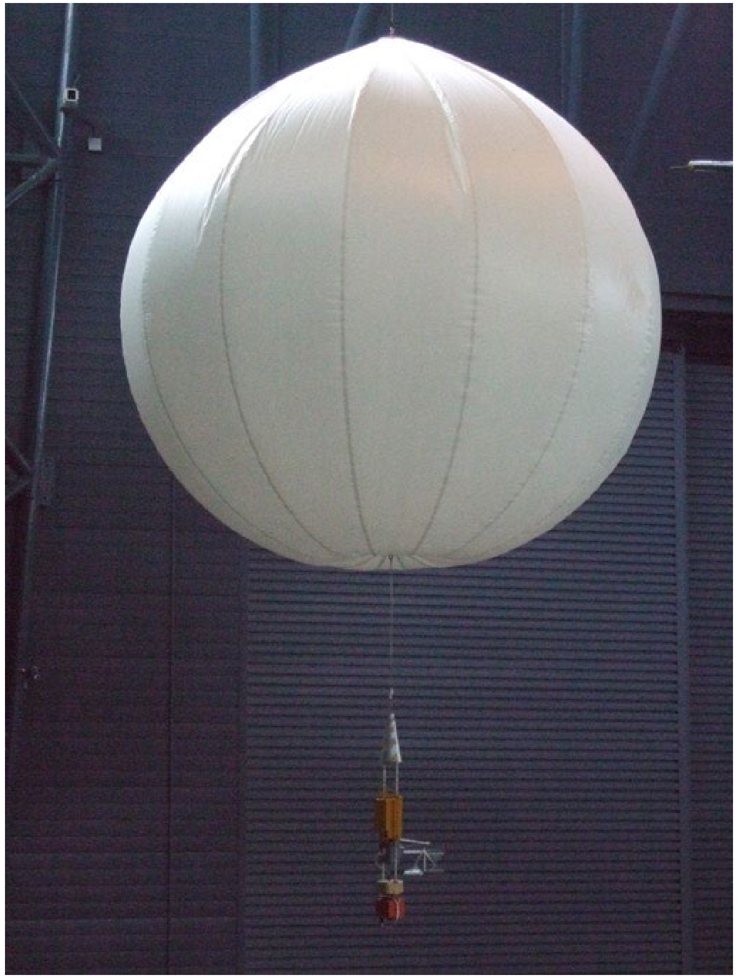
The right vehicle configuration answer may not be initially obvious (e.g. conventional helicopter layout not reached until 1940)

Interaction with the ground (takeoff / landing / sampling / seismology) and *sustained flight* are distinct problems with distinct optimal solutions. Ground handling of airships was a formidable difficulty.

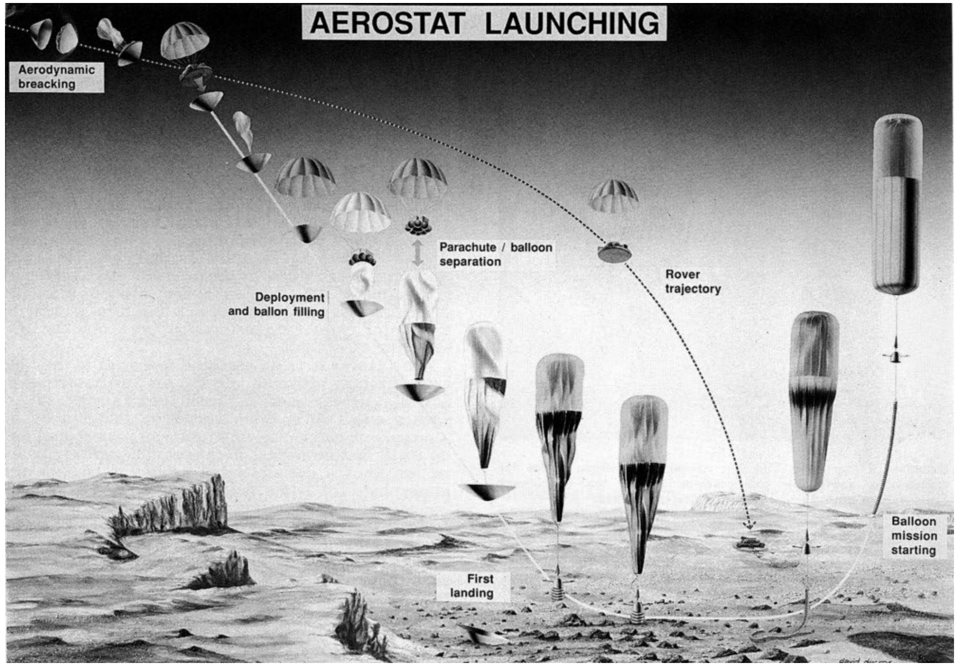
Lighter-than-air (LTA) solutions favored for large mass / low speed applications. Rotorcraft favored for applications needing hover or unprepared ground

System solutions may be coupled with wider infrastructure. Fixed wing aircraft are now able to dominate terrestrial air transport due to airports with long, perfect runways (i.e. vehicle-ground interaction challenge solved by engineering the ground more than the vehicle…)

Planetary Aeronautics – LTA (initially) to the fore



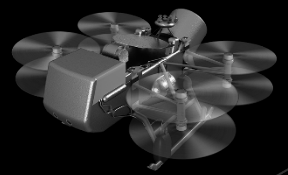
Soviet VEGA helium balloons flew at Venus in 1985



Mars-94 (-98) CNES Balloon Concept Guiderope ‘snake’ (Planetary Society) to provide passive ballasting overnight and ground radar sensing

NASA Titan Montgolfière (RTG heat) in 2007 Titan Explorer Flagship study (w/ lander and orbiter)

Titan Environment offers Transformative Aerial Mobility
Rotorcraft is a ‘relocatable lander’



4x Denser Atmosphere than Earth (good for heavier than air or lighter than air)
1/7th Gravity of Earth (especially good for heavier than air aviation.)

Rotorcraft advocated for Titan 1999-2001 by Lorenz*. Can hover with 38x less power than Earth !

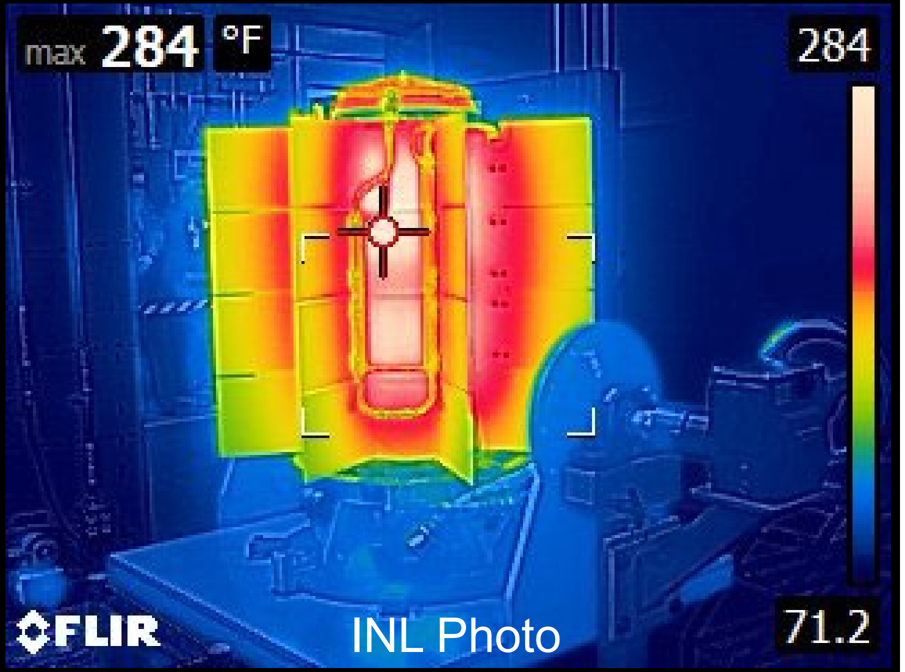
$$P_{Hover} = \frac{(mg)^{1.5}}{\sqrt{2\rho A}}$$

Low T gives lower viscosity (higher Reynolds number.) Rotor aerofoil section can be similar to terrestrial wind turbines

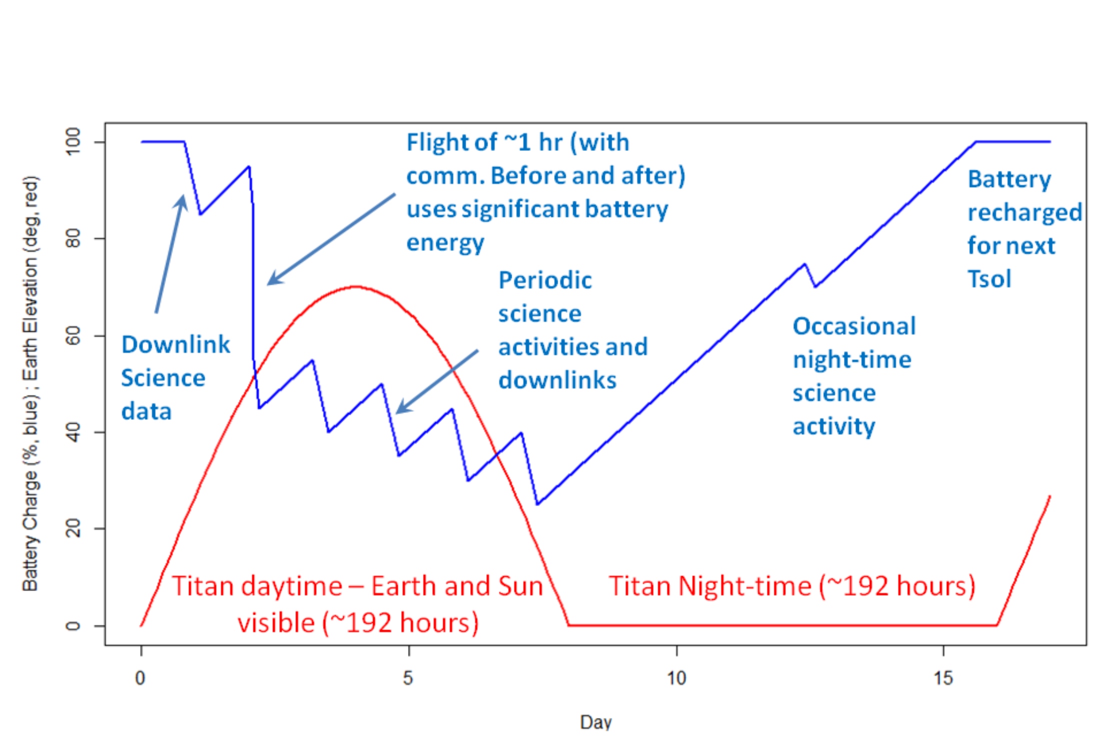
*and independently by L. Young (NASA)

Power and Heat at Titan. 94K atmosphere - heat loss challenges small platforms especially

Mission-enabling plutonium MMRTG (~40kg) provides nearly 2kW of essential heat, as well as 70-120W of electrical power



Heat is distributed around lander by fans and ductwork, retained by foam insulation layer around hull

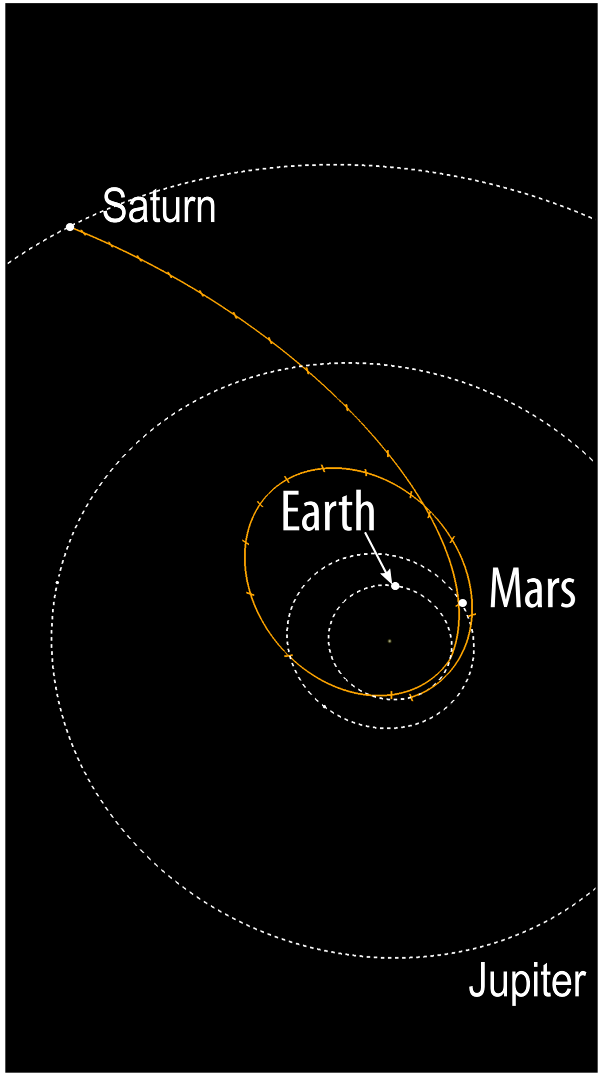


16-day diurnal cycle on Titan allows night-time recharge of large battery that permits ~10kW flight power for ~20 minute flights (few km)

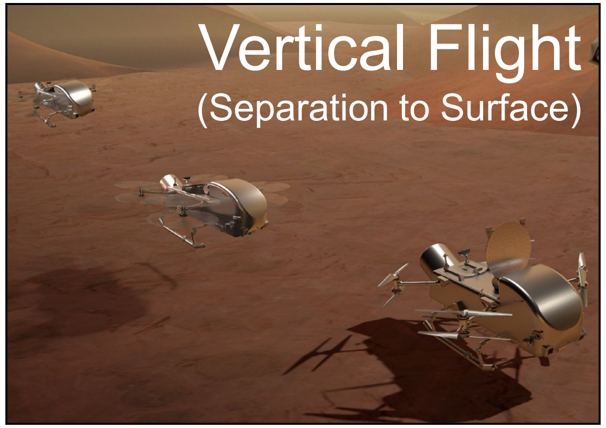
Dragonfly's Mission Phases

Launch

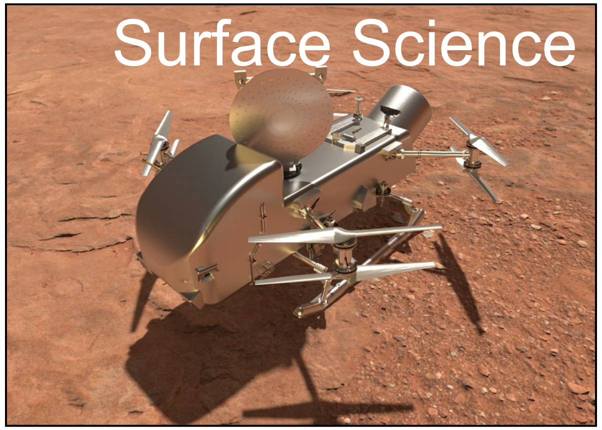
Cruise



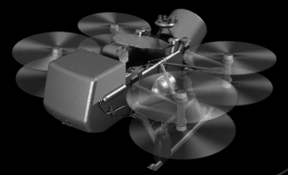
Arrival



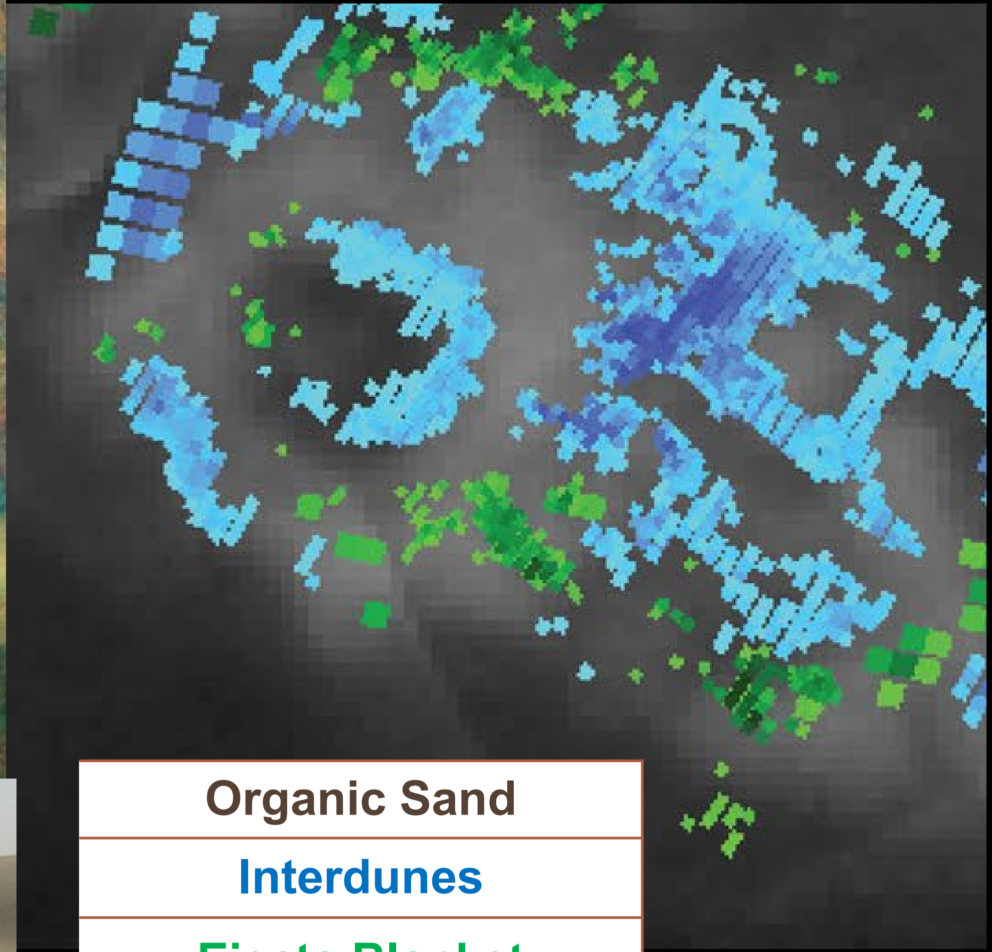
Surface



Mobility is science-enabling
Water-bearing material at Selk Crater



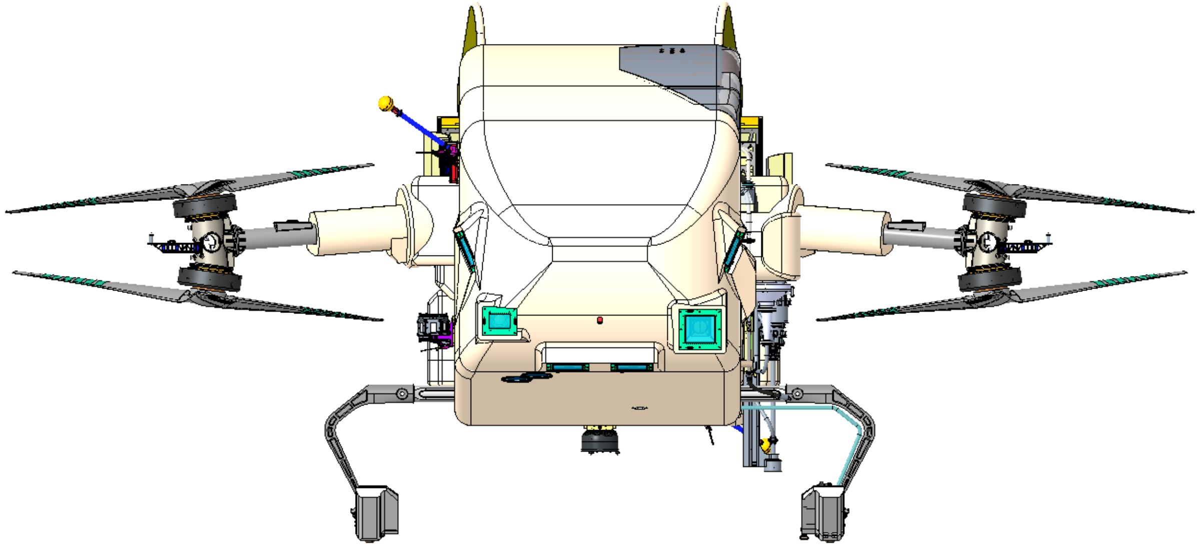
3.3 year nominal
surface mission



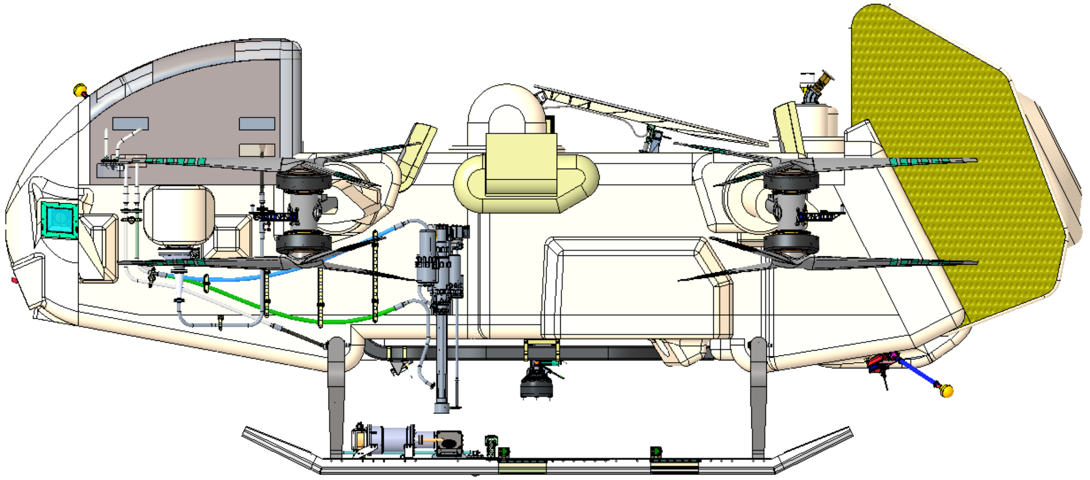
Organic Sand
Interdunes
Ejecta Blanket
Impact Melt

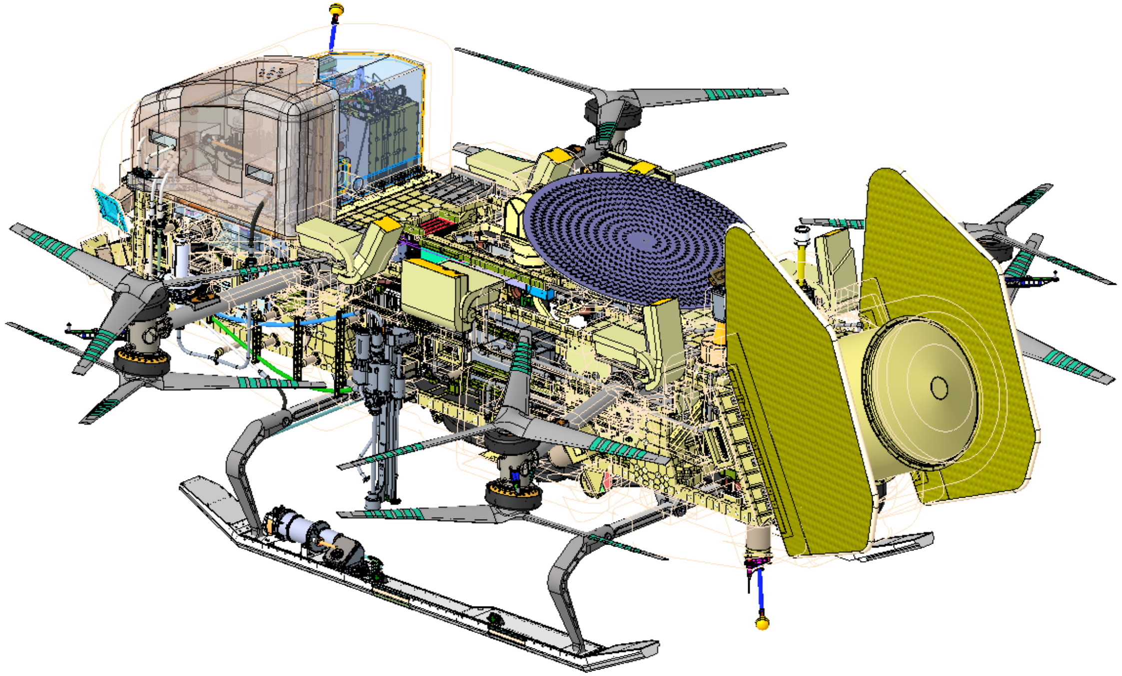
DRAGONFLY

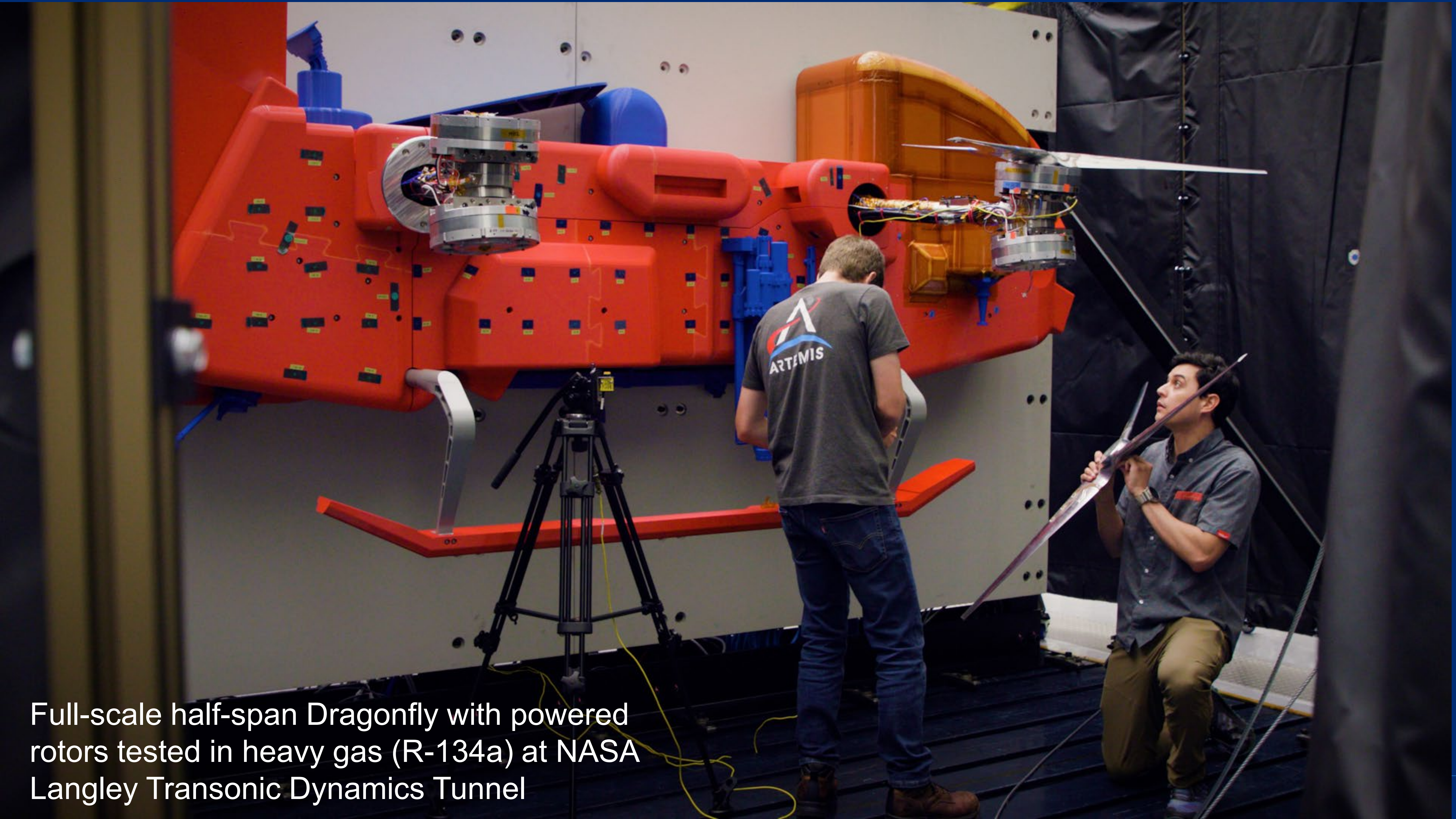
Lander Overview



- 995 kg MPV mass (current CBE of 920 kg)
  - Fuselage length (nose to end of fin): 4 m
  - 3-bladed rotor diameter 1.3 m

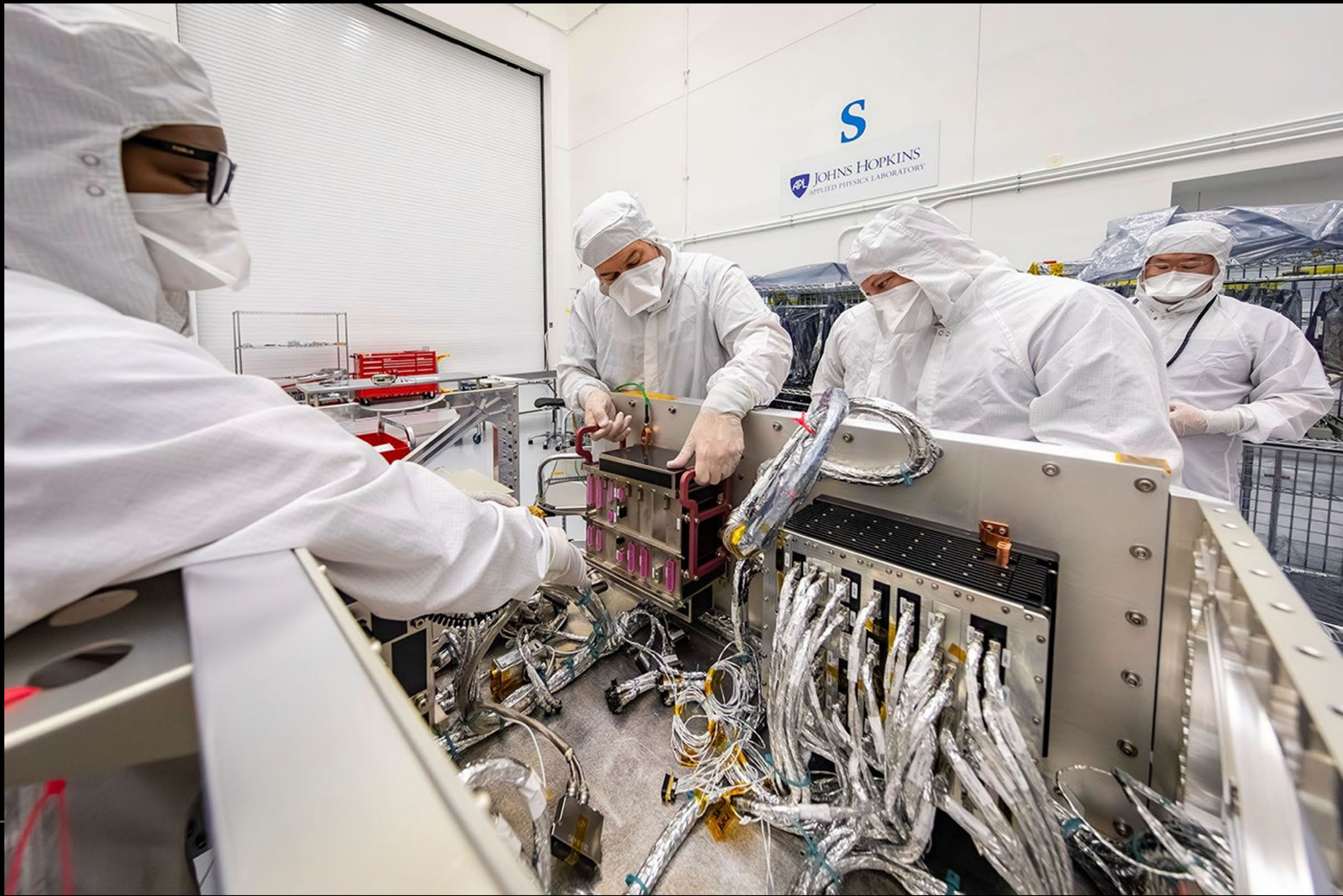




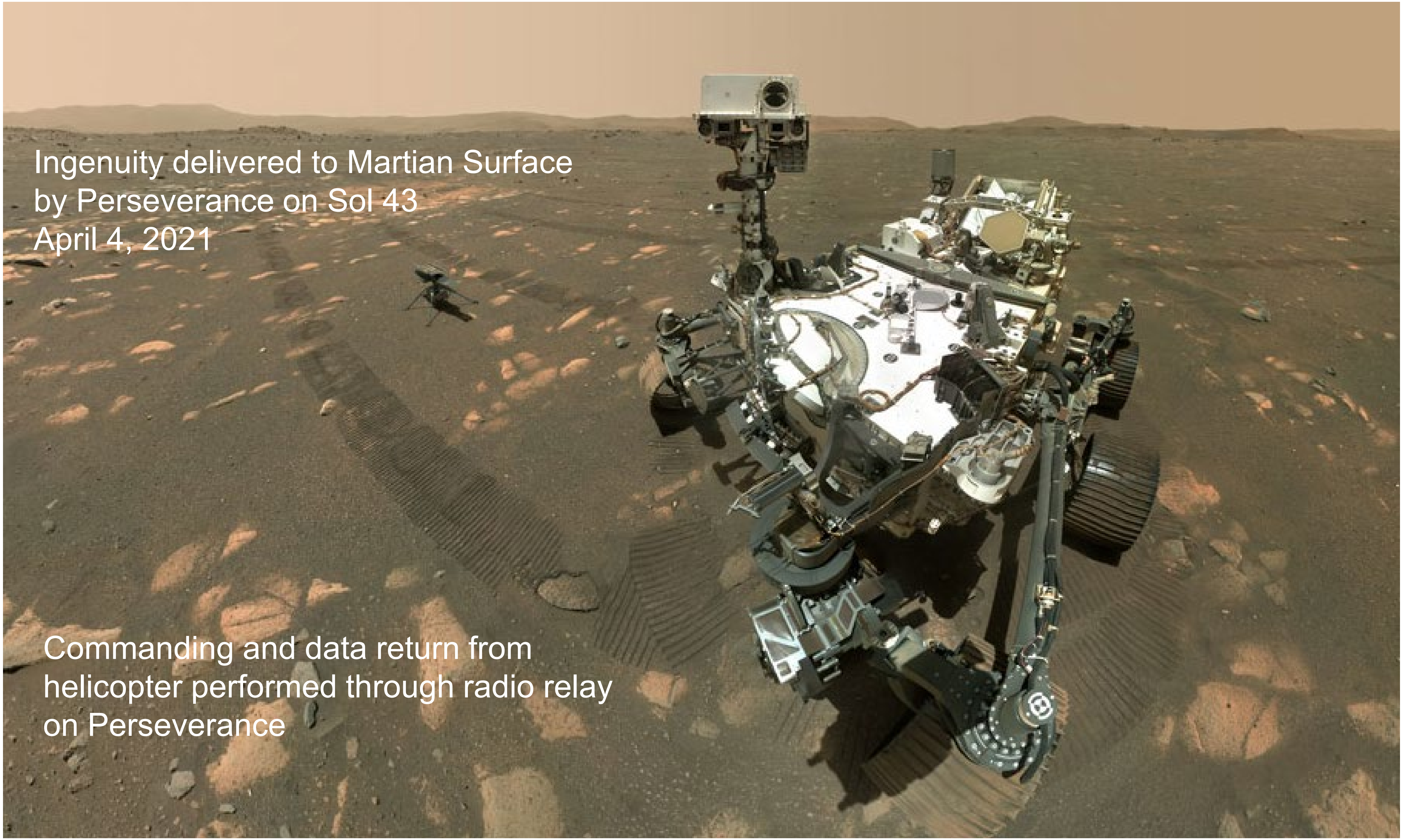


Full-scale half-span Dragonfly with powered rotors tested in heavy gas (R-134a) at NASA Langley Transonic Dynamics Tunnel

Lander integration has begun at APL, February 2026
Aeroshell and Cruise Stage build at Lockheed Martin




Initially proposed as payload for Mars 2020
Not selected
Re-emerged as a technology demonstration
2 kg
1.3m diameter rotors
Solar power / battery


Ingenuity delivered to Martian Surface
by Perseverance on Sol 43
April 4, 2021
Commanding and data return from
helicopter performed through radio relay
on Perseverance

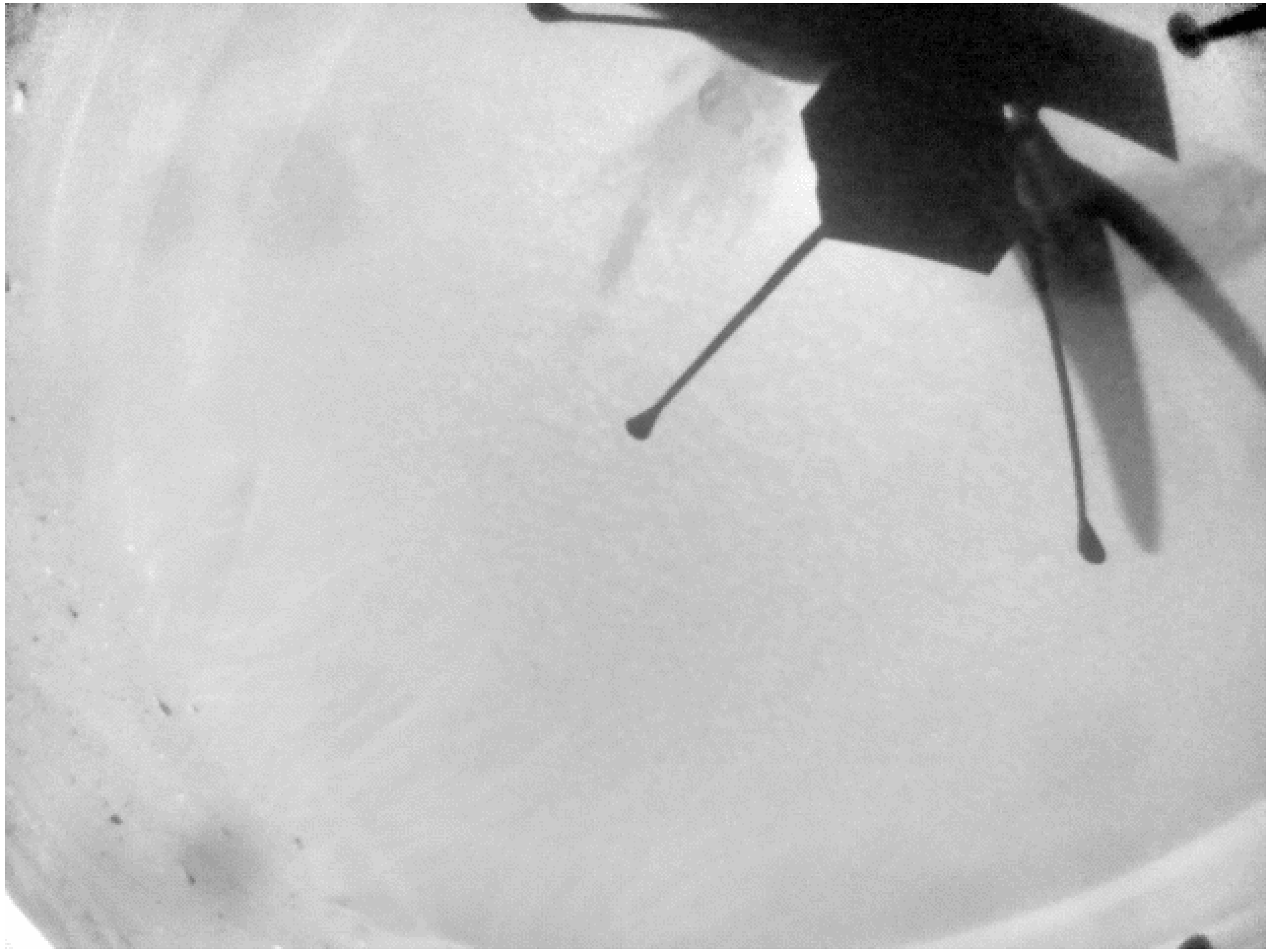
Mission far exceeded technology demonstration requirement of 5 flights !

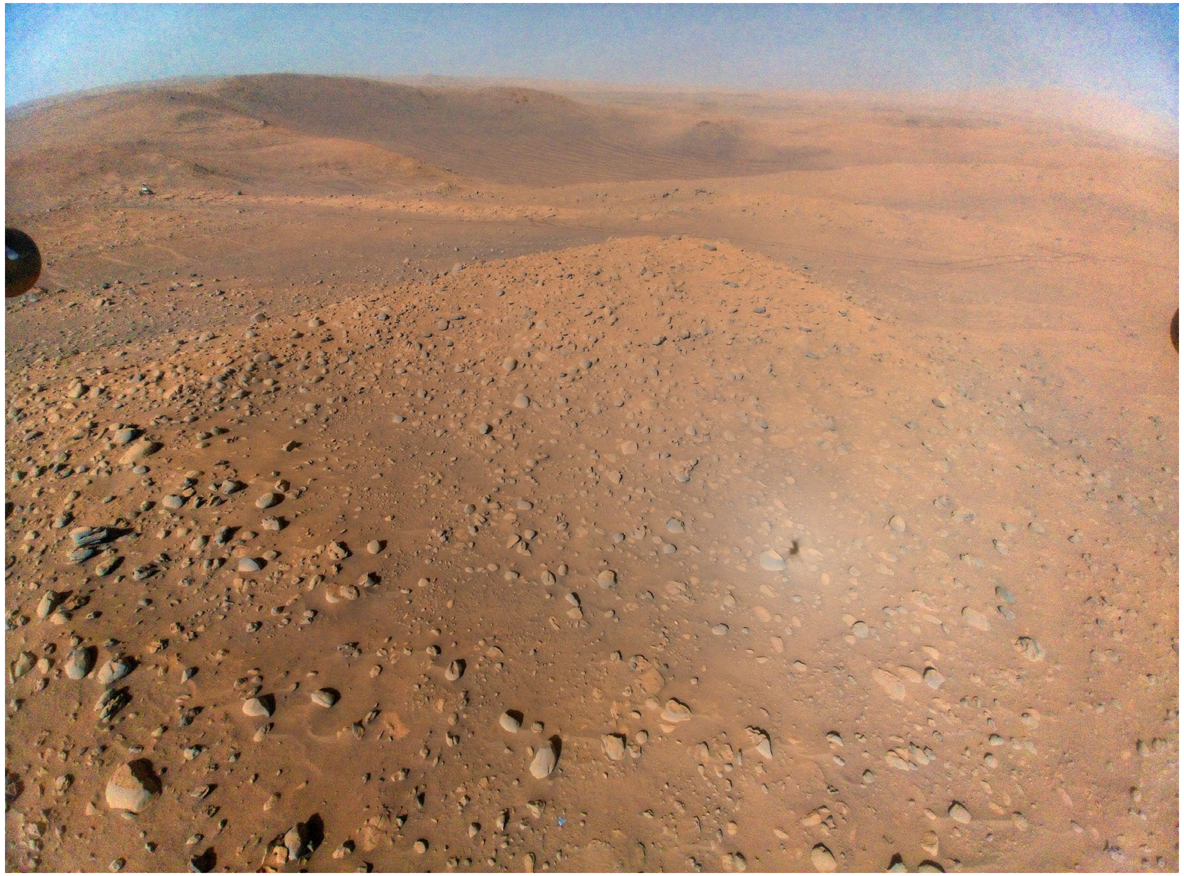
Image data were useful in rover planning. Some wind estimates derived from flight dynamics

Flight Log

By the Numbers

FLIGHTS	FLIGHT TIME	DISTANCE FLOWN	MAX. GROUND SPEED	HIGHEST ALTITUDE
72	~128.8 MINS	11 MILES (~17.0 km)	22.4 MPH 10 m/s	24 METERS (~79 ft)





Flight 6 anomaly caught horizon in frame

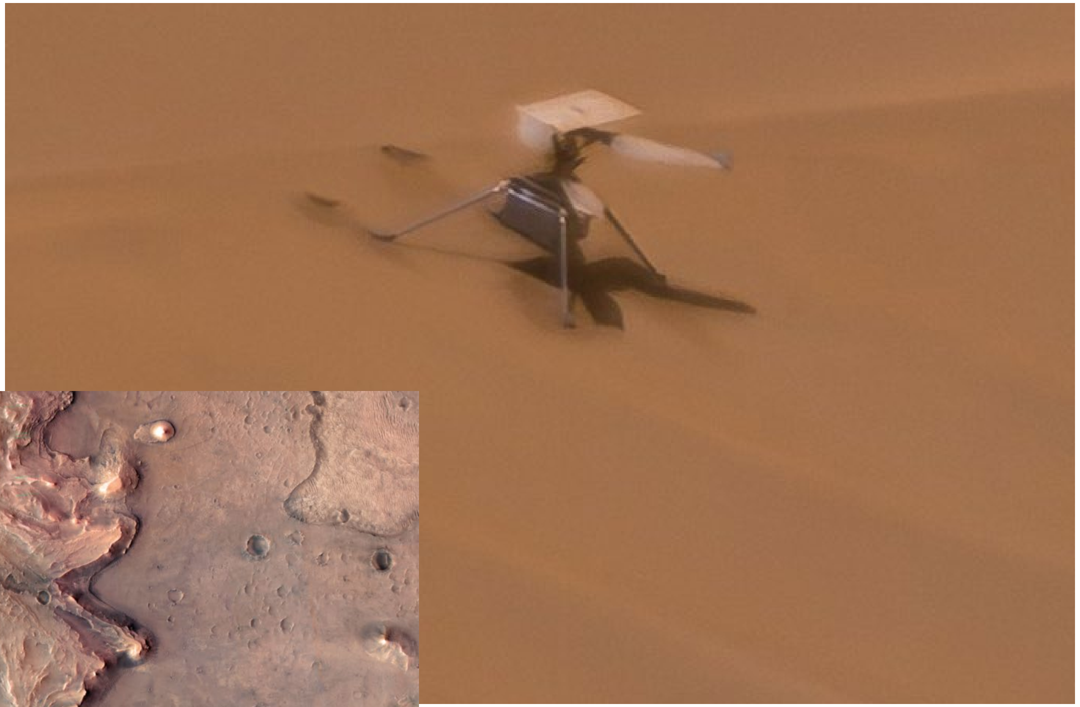
Flights limited to 2-3 minutes due to internal motor overheat (very limited cooling by thin Mars atmosphere)

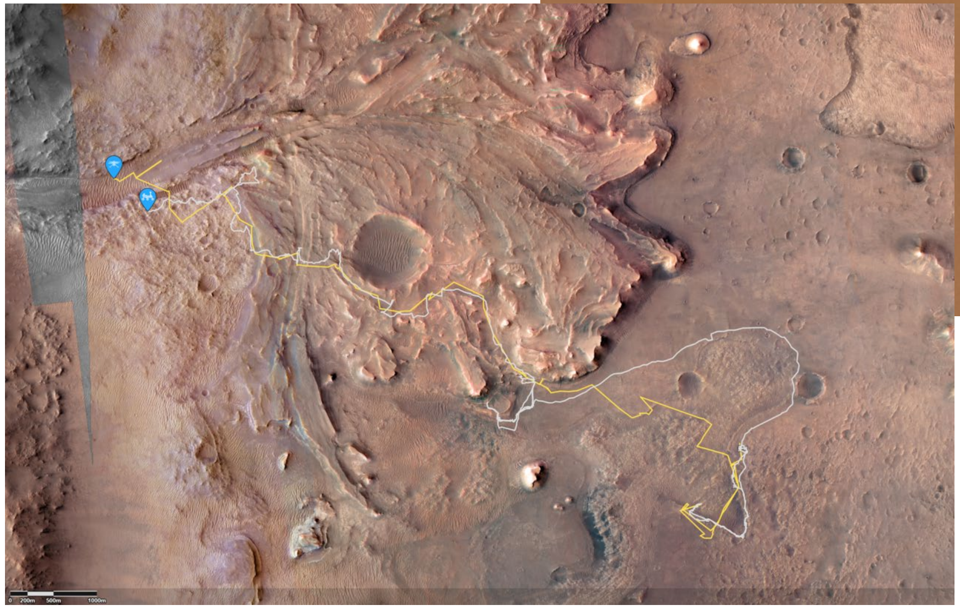
Flight capabilities enhanced throughout mission (e.g. capability added to tolerate uneven terrain)

Rotor rpm increased from 2400 to 2700 to allow operation in seasonally-thinner atmosphere

Mobility capabilities were lost on flight 72 (January 2024). Flying over low-contrast sandy area, navigation errors caused high horizontal velocity at landing, causing violent roll which snapped rotor blades.

Vehicle could still be commanded and data retrieved. Rover presently too far for contact.



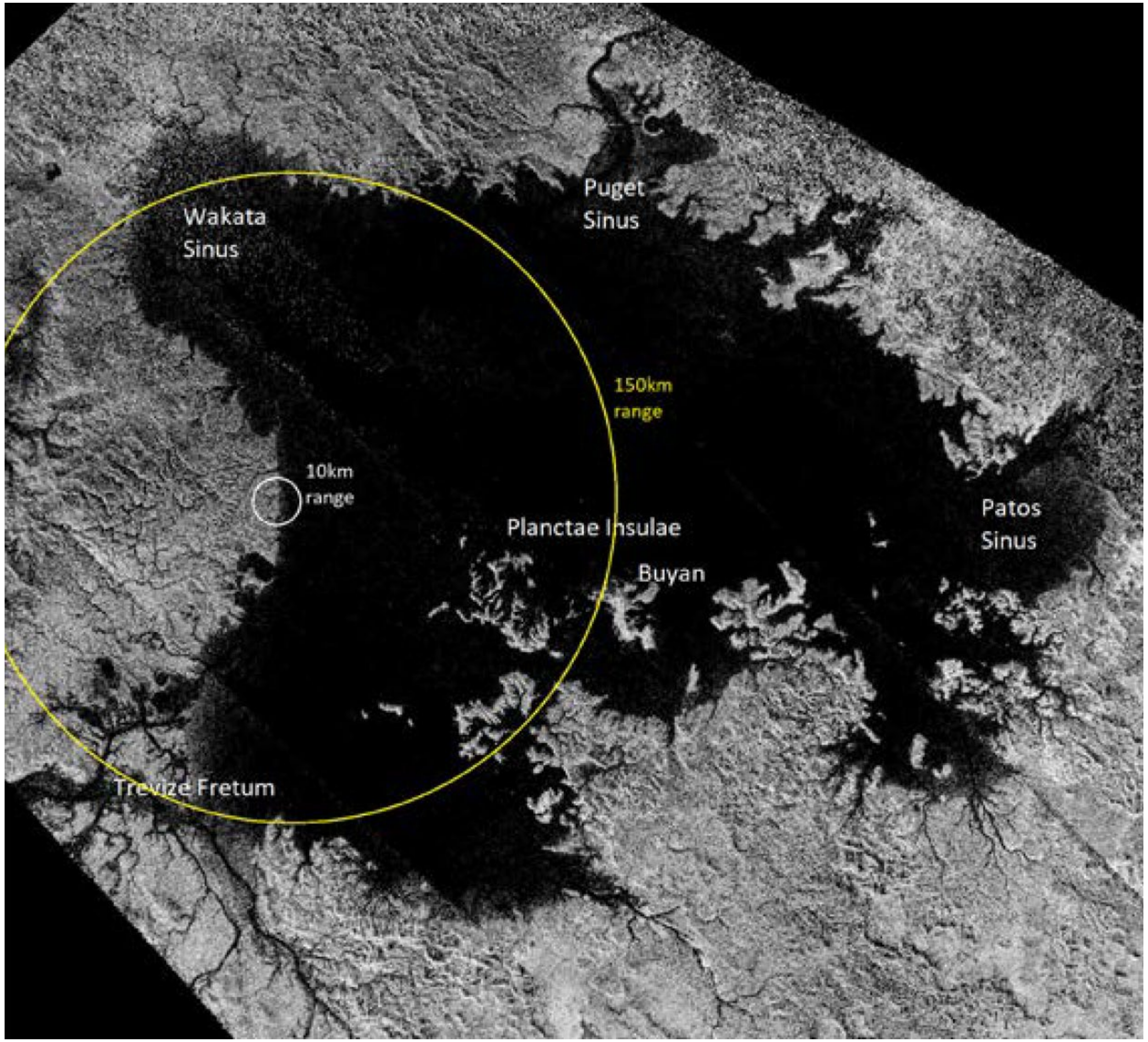


The Future of Planetary Rotorcraft

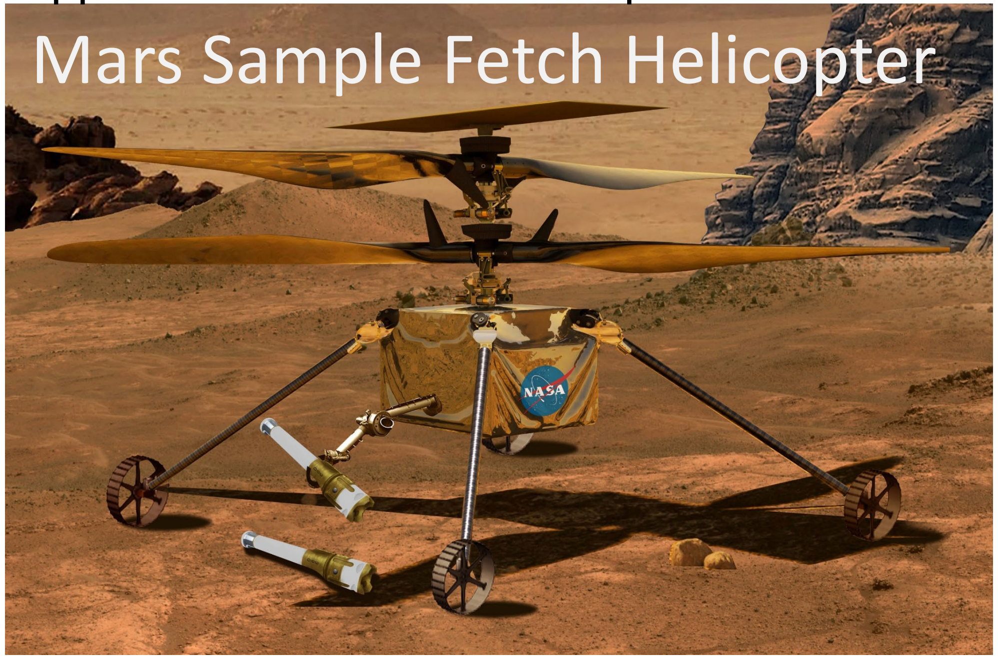
- Not obvious that a use case exists at giant planets or Venus, since no surface to land on or too hot. Without surface interaction, LTA or fixed-wing solutions are likely preferable

- Dragonfly rebuilds would be effective explorers at other Titan sites. Perhaps add floats, or a dipping sonar, to explore Titan's seas ? A relay orbiter would be a valuable augmentation. However, another Titan mission seems programmatically unlikely in the near term.

- Rotor-based 'zeroth' stage considered in a Titan sample return study by G. Landis et al. (gets rocket vehicle above the densest part of the atmosphere and thus reduces drag loss)

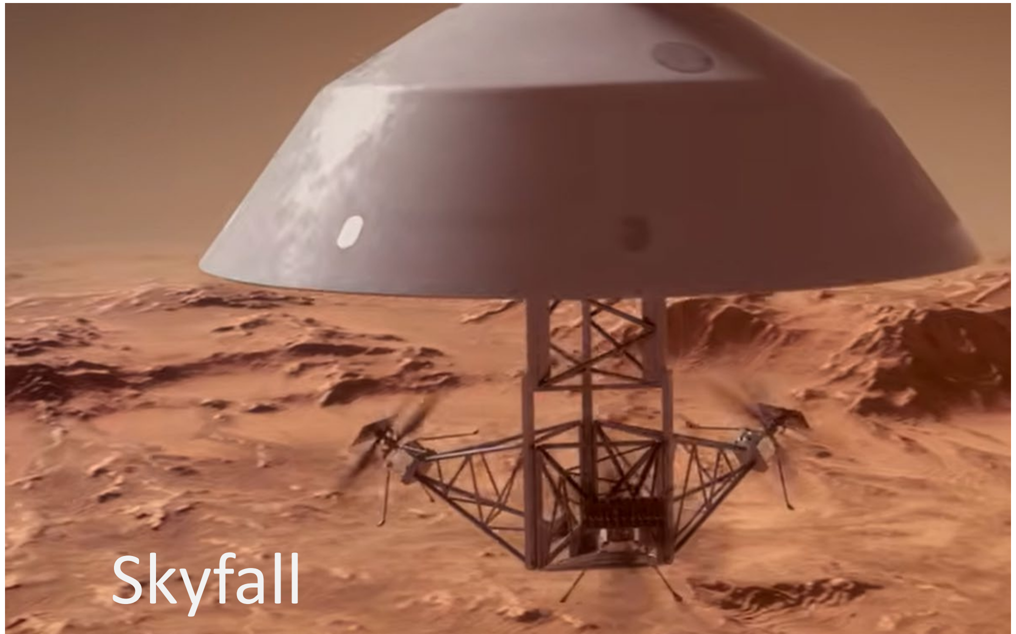


Difficult to scale up Mars helicopter substantially, but many applications of similar-sized platforms exist

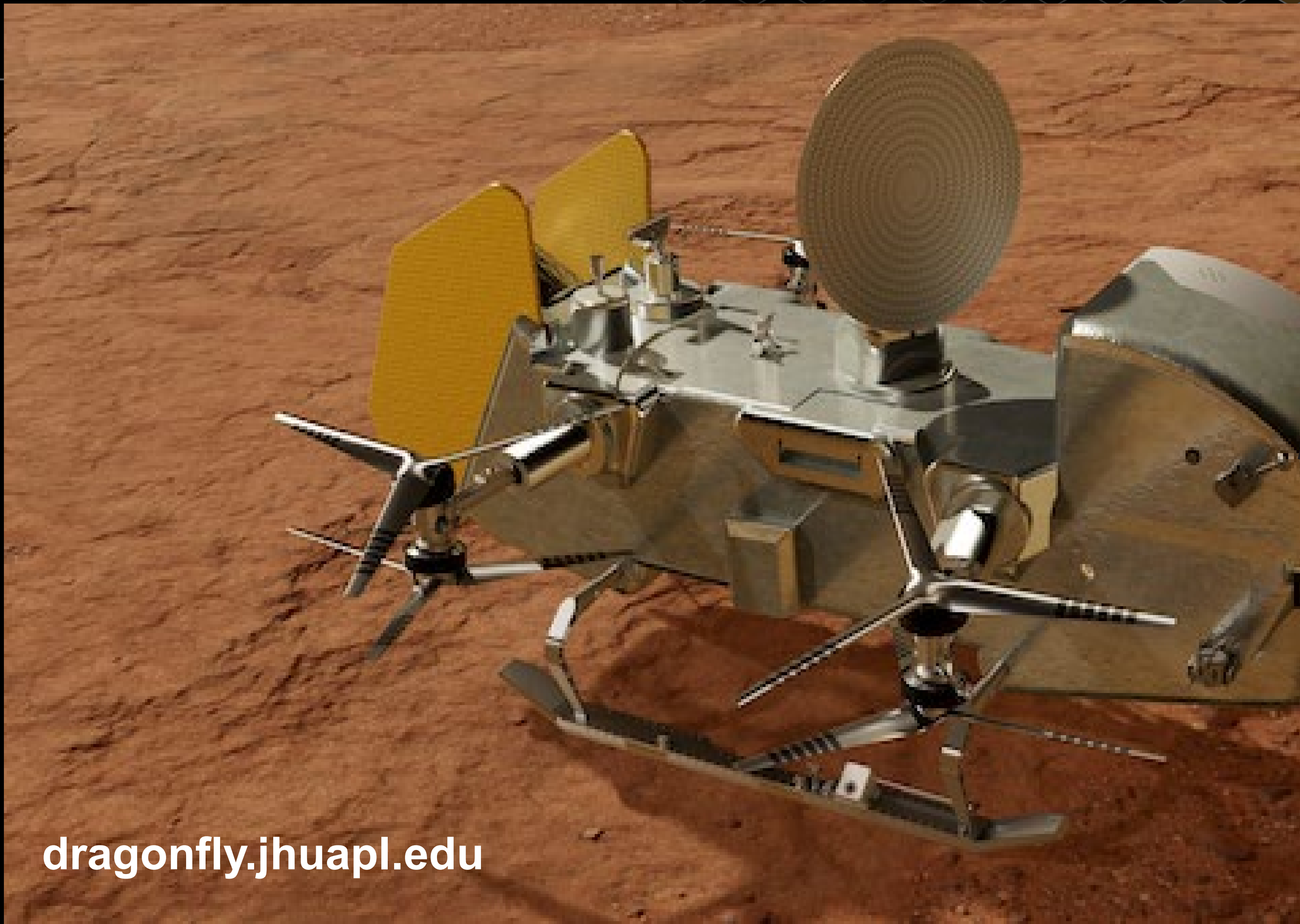


https://www.nasa.gov/solar-system/planets/mars/nasa-pushes-next-gen-mars-helicopter-rotor-blades-past-mach-1/

Mars surface cruise drone, Chinese Academy of Sciences



Dragonfly : Launch July 2028 !



dragonfly.jhuapl.edu