Vertical Lift Technology in Non-Earth Atmospheres

Aeronautics and Space Engineering Board Fall Meeting
20 October 2022

Haley Cummings – ROAMX Principal Investigator – NASA Ames

Outline

- Technology development through Rotor Optimization for the Advancement of Mars eXploration (ROAMX) project
- Future of extraterrestrial aeronautics

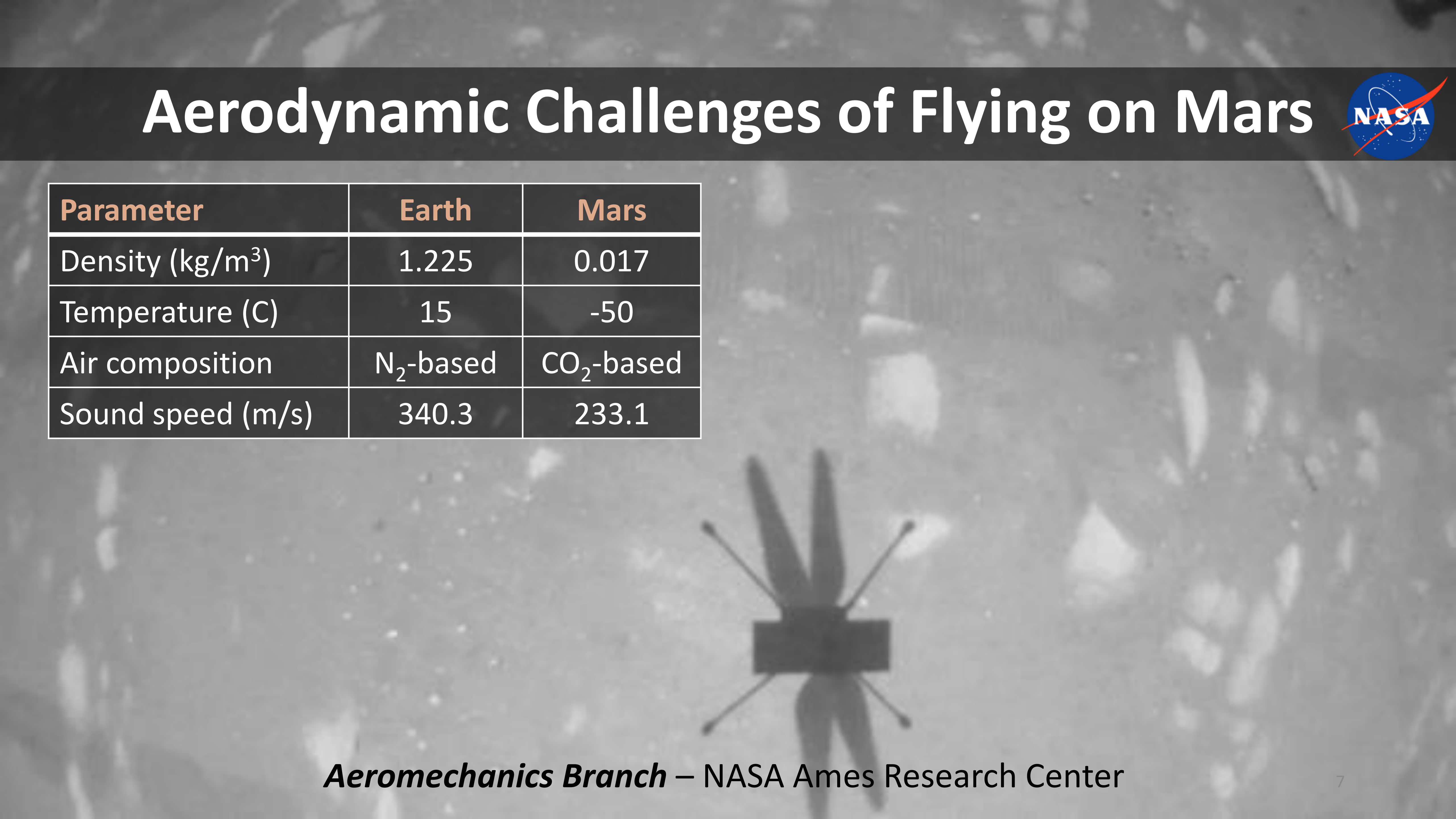
ROAMX Goal

Computational optimization and experimental validation of rotorcraft rotors for Mars.

What is the impact on science and exploration that can be achieved by investing in Vertical Lift Technology in Non-Earth Atmospheres?


Jezero Crater, image courtesy of JPL
Perseverance Rover Range: 0.3 km
Ingenuity Helicopter Range: 0.7 km
Future Generation Helicopter Range (with 1.3 kg science payload): 4+ km
Rotorcraft can access regions rovers cannot

Aerodynamic Challenges of Flying on Mars



Parameter	Earth	Mars
Density (kg/m^3)	1.225	0.017
Temperature (C)	15	-50
Air composition	N_2-based	CO_2-based
Sound speed (m/s)	340.3	233.1

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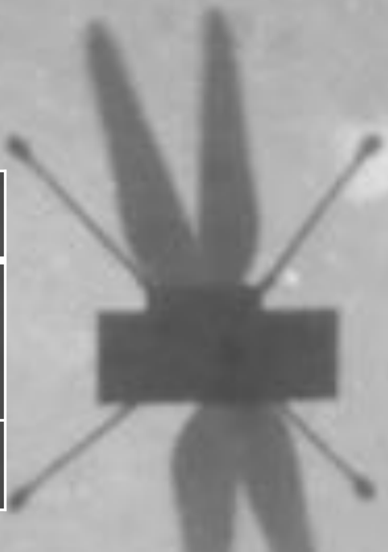
Parameter	Earth	Mars
Reynolds number (rotorcraft flight)	~10^6	~10^4
Tip Mach number	~0.6	0.7-0.95



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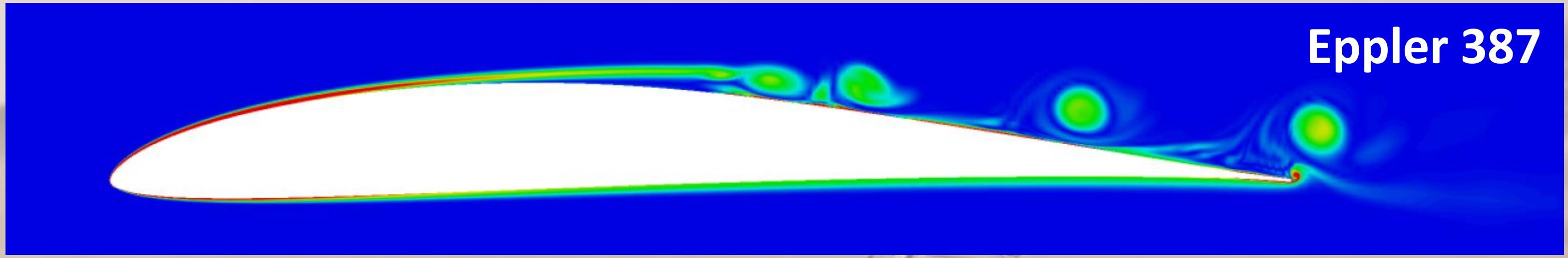
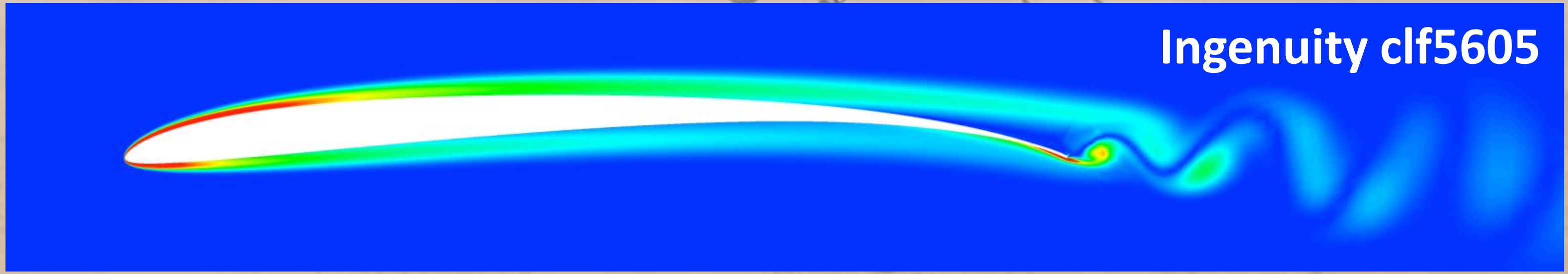
Computational Optimization

Computational Optimization



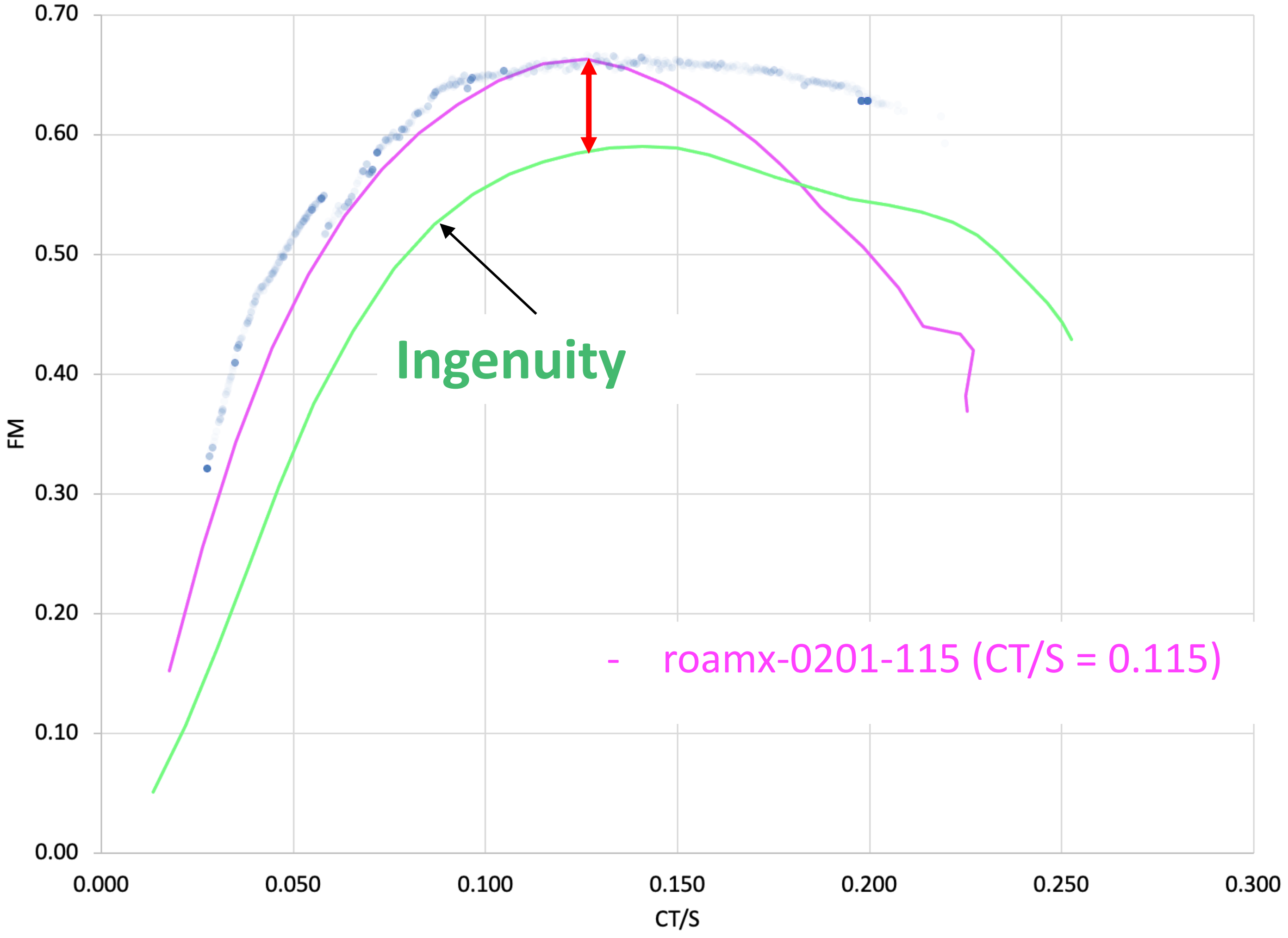


Taking advantage of flow field using ROAMX technology

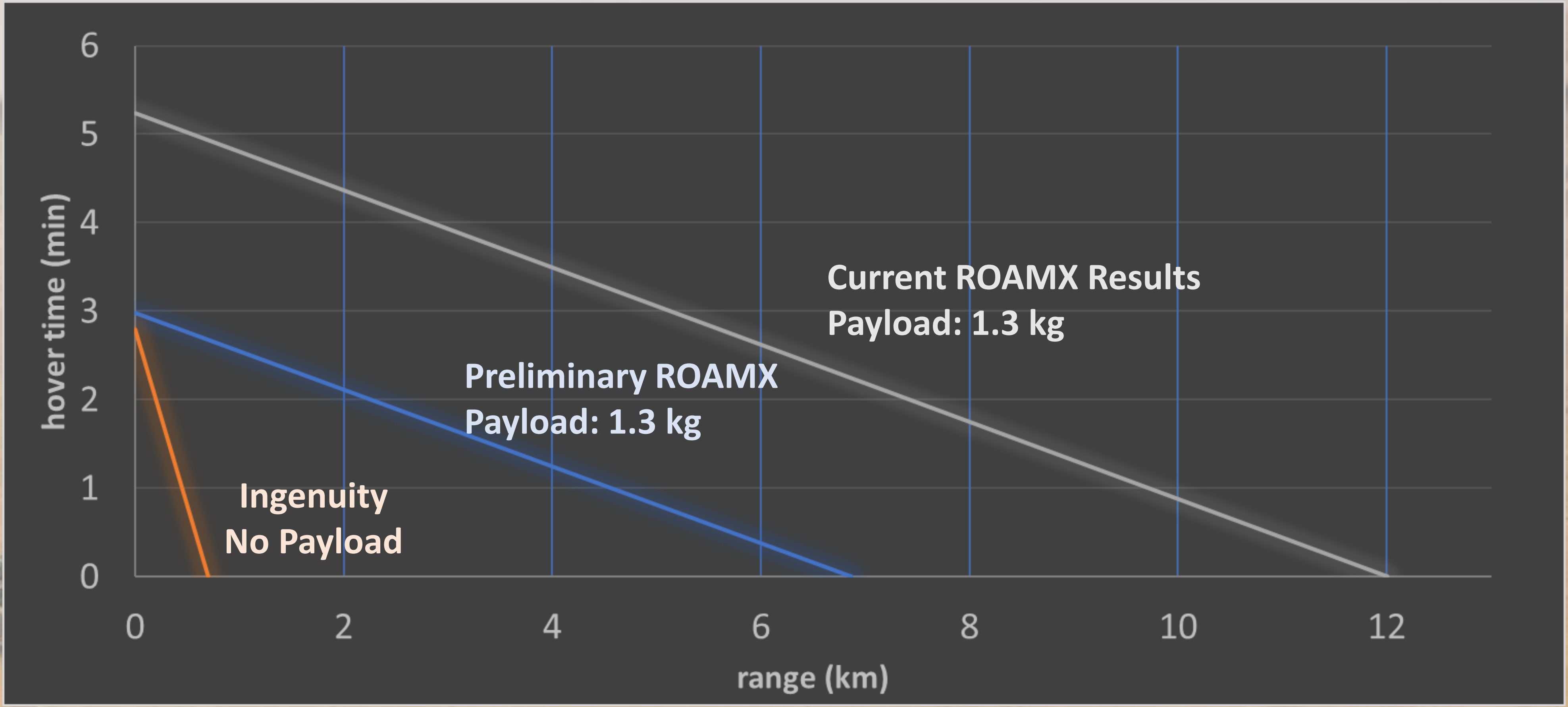
“On Improved Understanding of Airfoil Performance Evaluation Methods at Low Reynolds Numbers, ”Koning et al., Submitted to Journal of Aircraft.
"Improved Mars Helicopter Aerodynamic Rotor Model for Comprehensive Analyses,“ Koning, Johnson, and Grip, AIAA Journal, 2019.

Computational Rotor Optimization

Increased understanding of aerodynamics in this regime allows for significant advances in aerodynamic efficiency



Computational Rotor Optimization



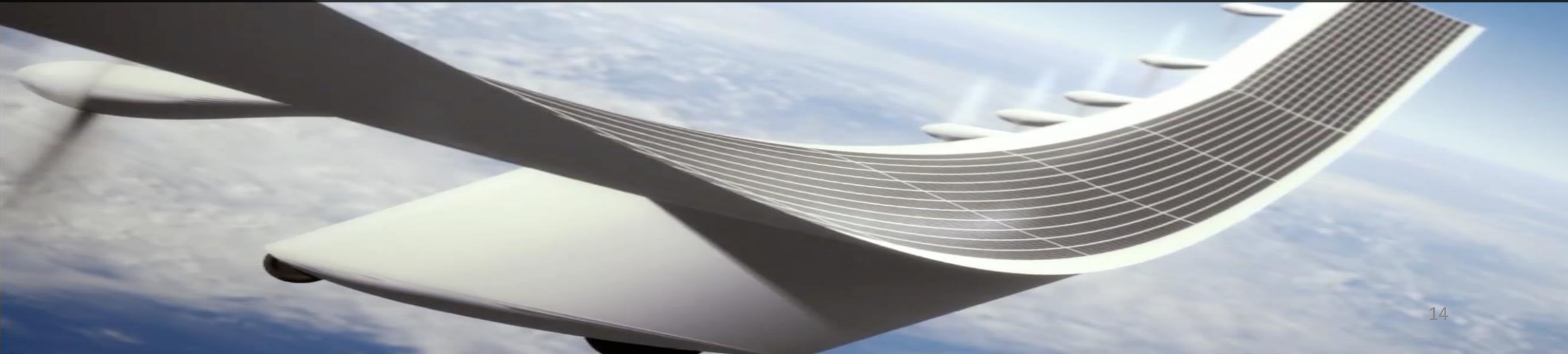
Experimental Validation

Planetary Aeolian Laboratory at NASA Ames Research center

- **Validate simulations through experimentation**
- **Simulate Mars flight conditions**
- **Match Re and M number seen on Mars**

- **Facilities capable of experimental validation are crucial**
- **Infrastructure refurbishment and updating was necessary**

Terrestrial Applications where Similar Aerodynamic Conditions Apply



Aerial Vehicles Throughout the Solar System

Planetary Bodies	Aerial Vehicle	Potential Science Missions
Mars, Titan, Venus, and Earth	Rotorcraft or vertical-lift aerial vehicles (e.g. ducted-fan, tiltrotors, tailsitters, etc.)	Atmosphere sciences; imagery on surface and in flight; geology and geochemistry; climatology; astrobiology; surface-interactive science
	Airplanes or gliders; rotary-wing decelerators	Atmospheric sciences; mid- to low-altitude imagery and remote sensing of surface; distribution of (finite) sensors and small robotic devices to selectively target high-priority sites on surface
	Balloons	Atmospheric sciences; mid-altitude imagery and remoting sensing of surface
Gas Giants	Airplane-like gliders (powered-, buoyancy-driven-, and dynamic-soaring)	Atmospheric sciences, especially atmospheric chemistry and implications for gas giant formation and evolution
	Parasite-drag-driven “drifting” (e.g. parachutes, ballutes, and dandelion-like) vehicles	Atmospheric sciences
"Airless" Planetary Bodies (Moon, asteroids, most Jovian/Saturnian moons)	Avionics, GNC software, electric propulsion, and electromechanical actuators developed for planetary aerial vehicles all potentially have cross-cutting technology synergy with small spacecraft explorers for airless planetary bodies	

Technology development via aeronautics can have far reaching impact for science and exploration

Table provided by Larry Young, NASA Ames Research Center

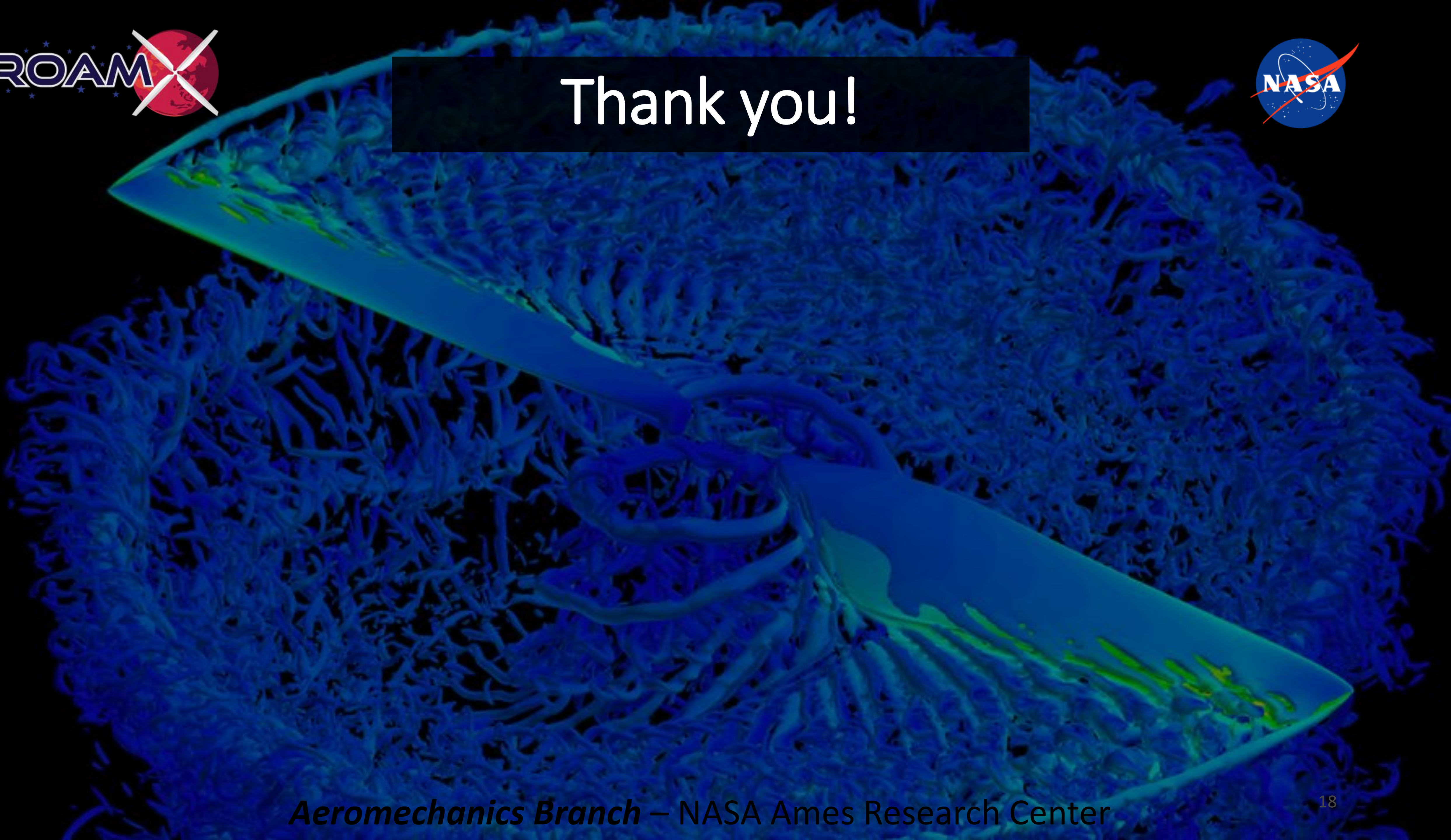
Key Takeaways for Technology Development

- It is important to have computational tools for future generation extraterrestrial rotorcraft
  - Understanding of the fundamentals leads to improved designs
- Important to ensure computational tools can be experimentally validated
- With ROAMX we are seeing what the potential is for aerodynamic research and development
- Ingenuity utilized collaboration between Mission Directorates; that collaboration should be continued and increased to benefit future extraterrestrial flight
- Beyond Mars and beyond rotorcraft

Potential for Substantial NASA Aeronautics Contributions

- Key investments for technical activities – utilizing current expertise and adding new dimensions (including facilities)
- Near-term program for enabling science and exploration
- ARMD should consider adding a new, 7^{th} Thrust
  - With an Agency-wide focus, leverage aeronautics technology for science and exploration
  - Will lead to expanded, valuable, and important interactions with SMD and STMD, benefiting every Mission Directorate portfolio

Thank you!



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