Dragonfly: Rotorcraft Landing on Titan

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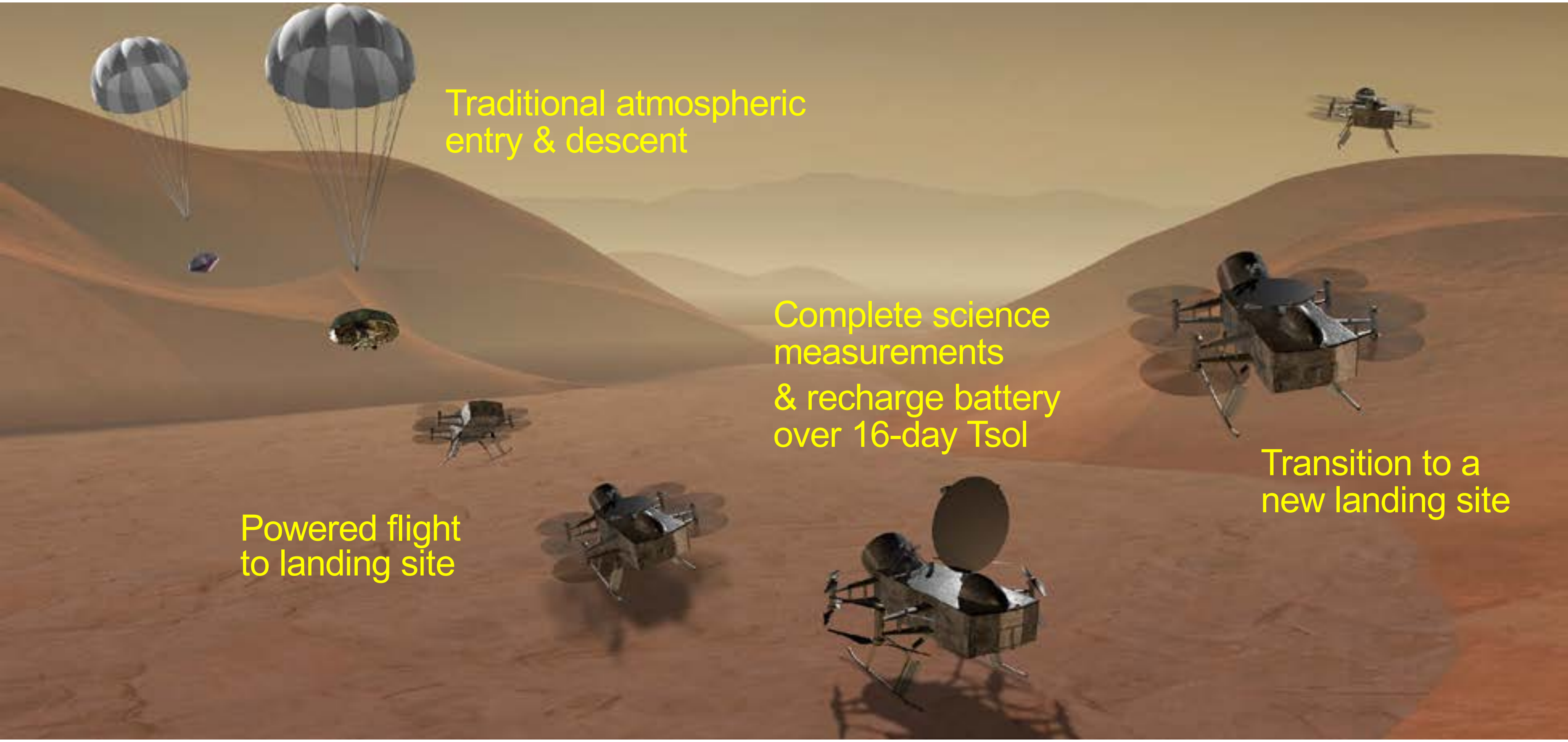
Conceptual Overview

- **Relocation of the Dragonfly lander and its suite of science instruments enables unprecedented long-range *in situ* exploration**



Powered Flight at Titan

DRAGONFLY

- Titan is more conducive to powered flight than any other body in the solar system, due to its dense atmosphere and low gravity
  - A person with artificial wings could flap their arms and fly
- Momentum theory can be used to estimate the power required for hover

$$P_{hover} = \frac{T^{3/2}}{\sqrt{2\rho A}} = \frac{(mg)^{3/2}}{\sqrt{2\rho 4 \cdot (\pi d^2/4)}} = \frac{(mg)^{3/2}}{d\sqrt{2\pi\rho}}$$

(four rotors used for illustration)

- For a fixed mass, the hover power at Titan relative to Earth is:

$$\left(\frac{P_{Titan}}{P_{Earth}}\right)_{hover} \propto \left(\frac{g}{g_e}\right)^{3/2}\left(\frac{\rho_e}{\rho}\right)^{1/2} = \left(\frac{1.352}{9.80665}\right)^{3/2}\left(\frac{1.225}{5.44}\right)^{1/2} = 0.0243$$

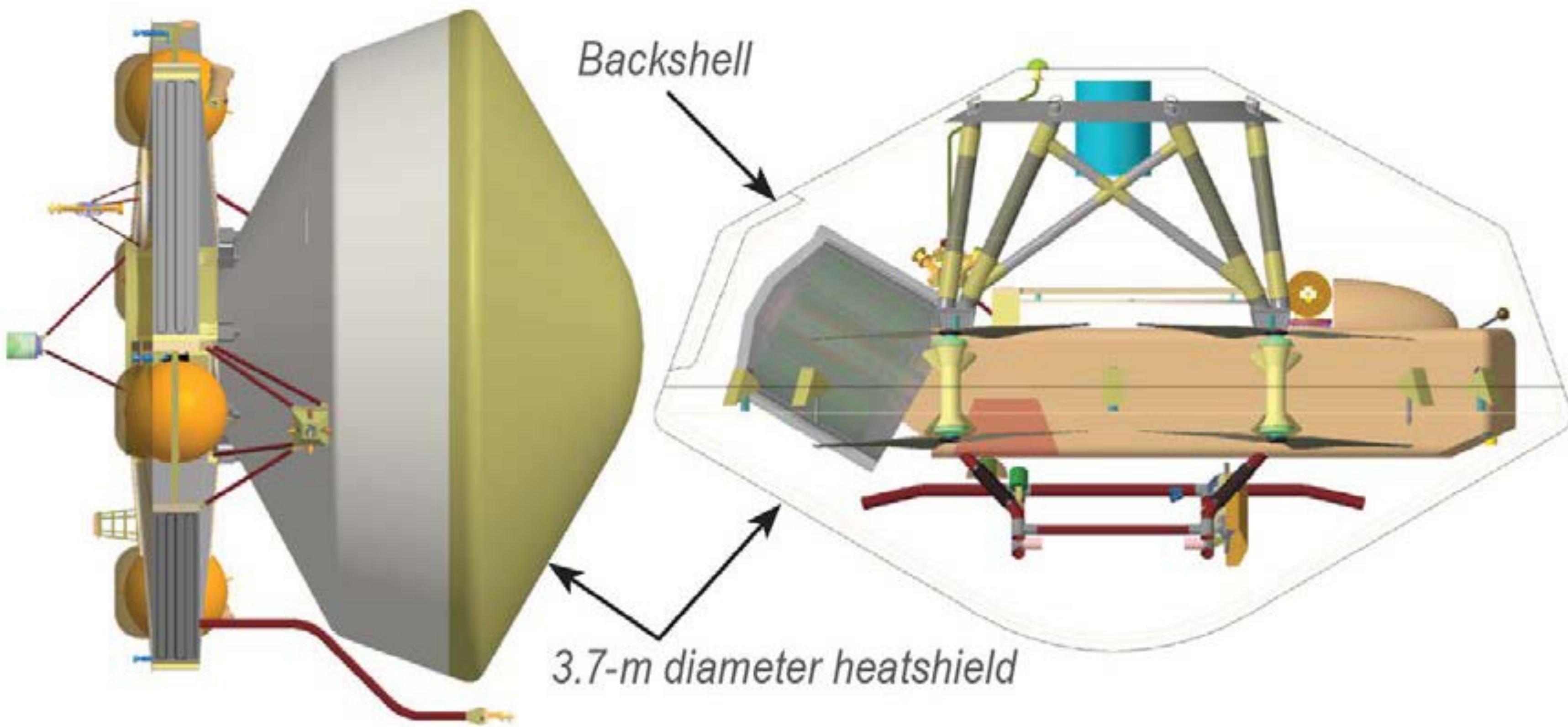
- Thus, hover at Titan requires only 2.4% of hover power at Earth, or the same power can lift ~12x the mass at Titan as on Earth

Lorenz, R. D., Scaling Laws for Flight Power of Airships, Airplanes and Helicopters : Application to Planetary Exploration, Journal of Aircraft, 38, 208-214 (2001)

Langelaan, J. W., Schmitz, S., Palacios, J., and Lorenz, R. D., "Energetics of Rotary-wing Exploration of Titan," 2017 IEEE Aerospace Conference, March 4-11, Big Sky, MT.

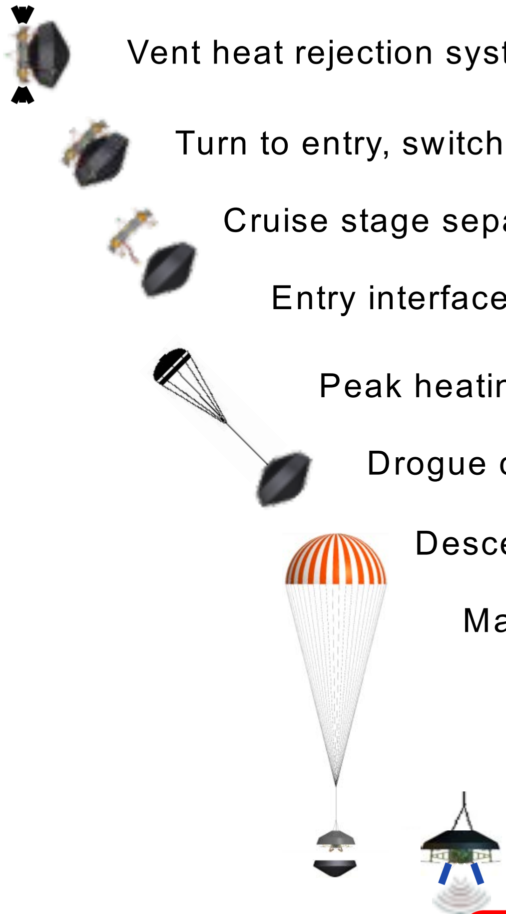
Cruise and Entry Configurations

- **Spin-stabilized during cruise and atmospheric entry**
  - **Enables low-power operation during interplanetary trajectory**



Cruise configuration (left) and lander packaged in EDL assembly (right)

Entry and Descent



Wake-up avionics, begin telemetry transmission, E-25 min

Vent heat rejection system, E-20 min

Turn to entry, switch to tone transmission, E-15 min

Cruise stage separation, E-10 min

Entry interface, h=1270 km, v=7.3 km/s, γ=-47.7°, E-0 min

Peak heating, h=254 km, v=5.9 km/s, a=7.8 g's, E+4 min

Drogue chute deploy, h=154 km, supersonic, E+6 min

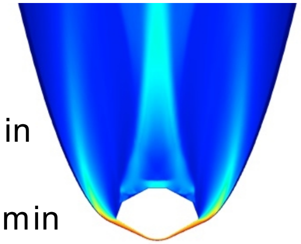
Descent on drogue

Main chute pilot deployed in lower atmosphere

Heatshield separation

Landing skid deployment

Radar and lidar active



Entry Preparation

Ballistic Entry

Parachute Phase

Lander release → *Powered Flight*

Dragonfly will arrive ~6 Saturn days after Huygens

For reference, Huygens took 152.5 min from entry to the surface. Dragonfly's descent is a bit shorter by design.

Transition to Powered Flight (TPF)

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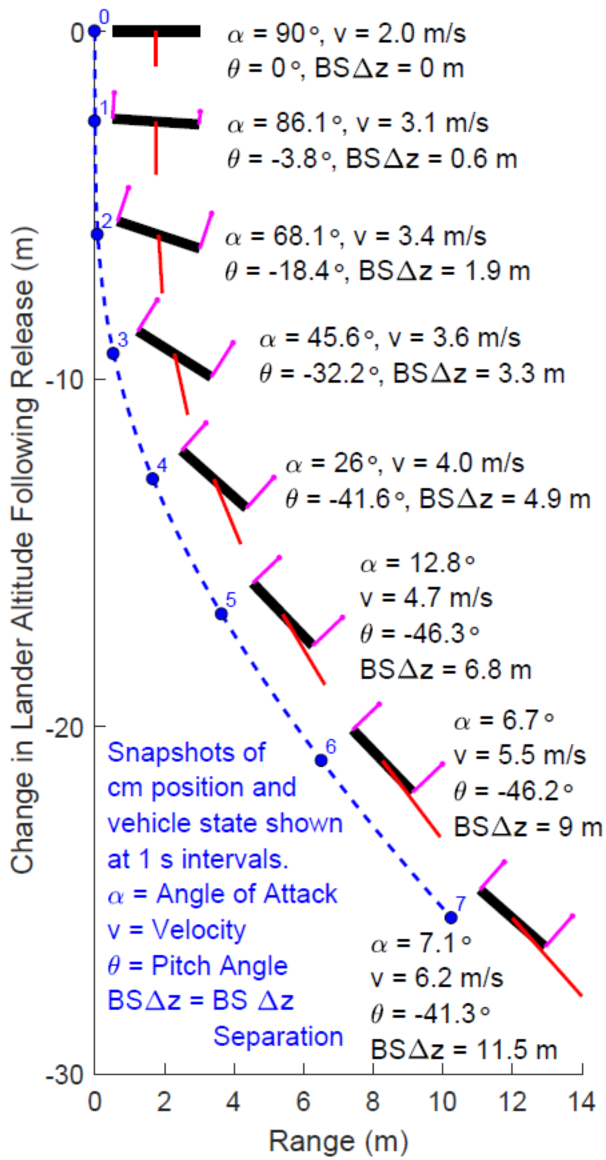

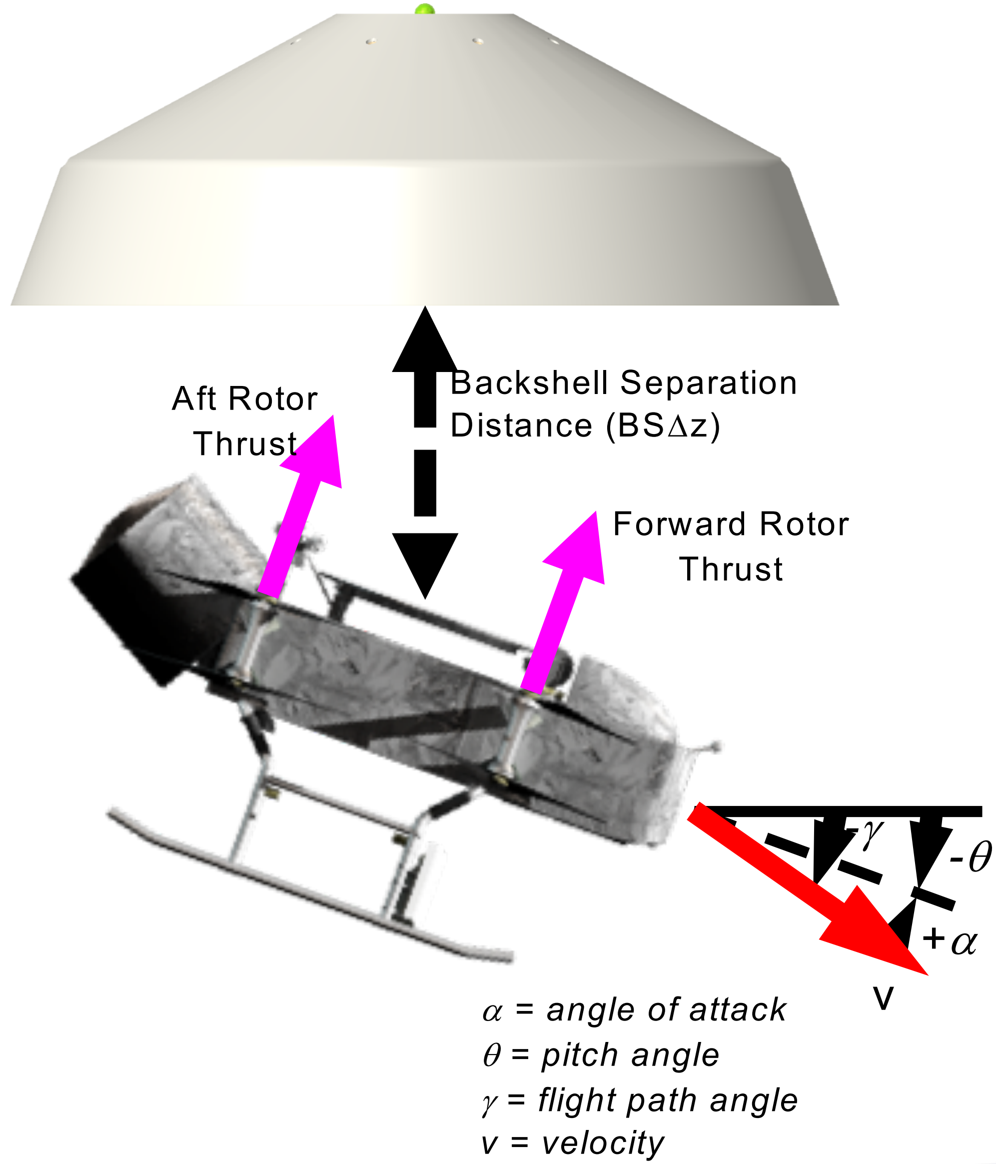

"Drag Turn" to Forward Flight

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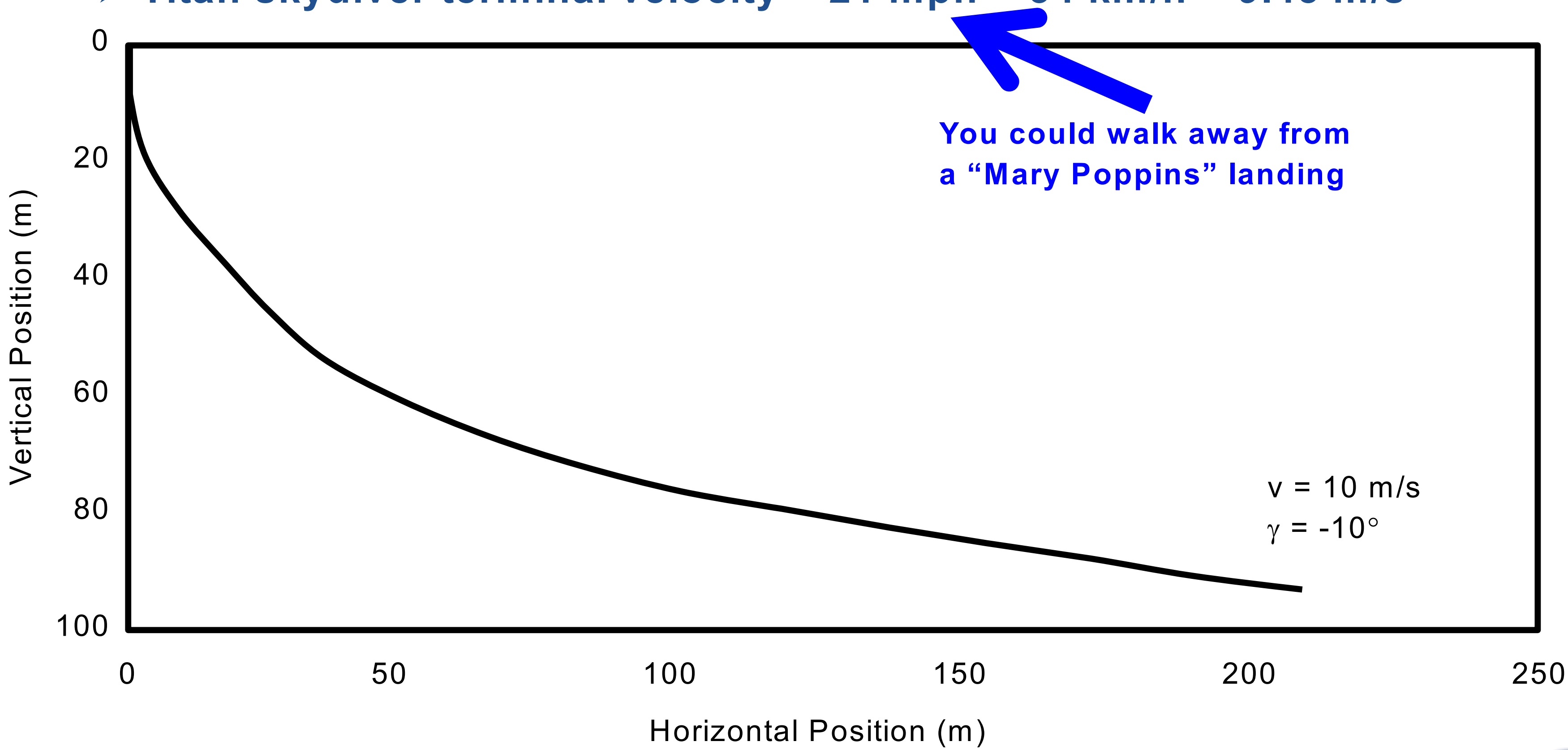
- The transition to powered flight takes advantage of the drag from the high atmospheric density in combination with the low gravity, which results in a gentle "drag turn" to forward flight
  - Earth skydiver terminal velocity = 120 mph = 193 km/h = 53.6 m/s
  - Titan skydiver terminal velocity = 21 mph = 34 km/h = 9.45 m/s



Interdune Initial Landing

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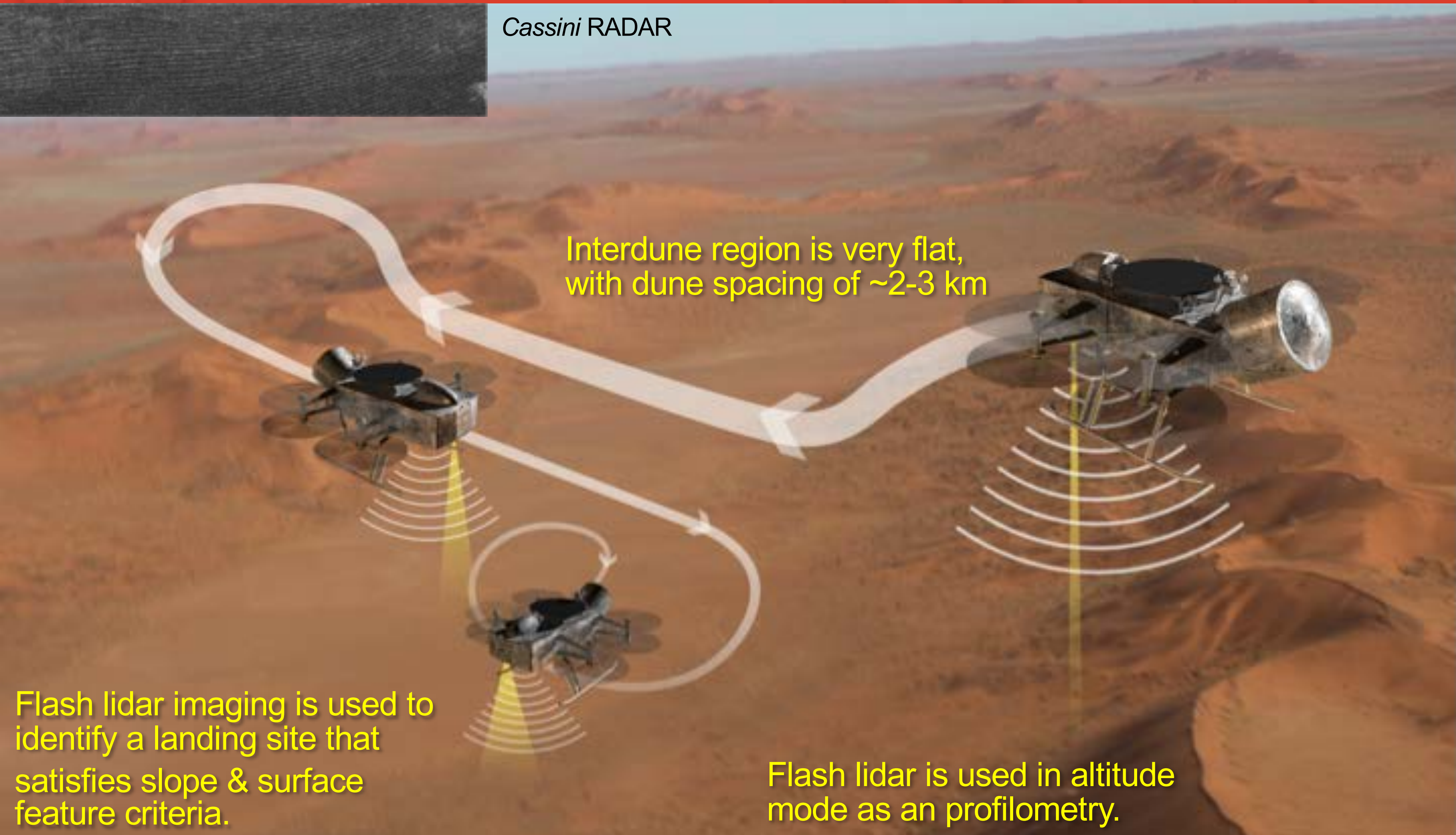
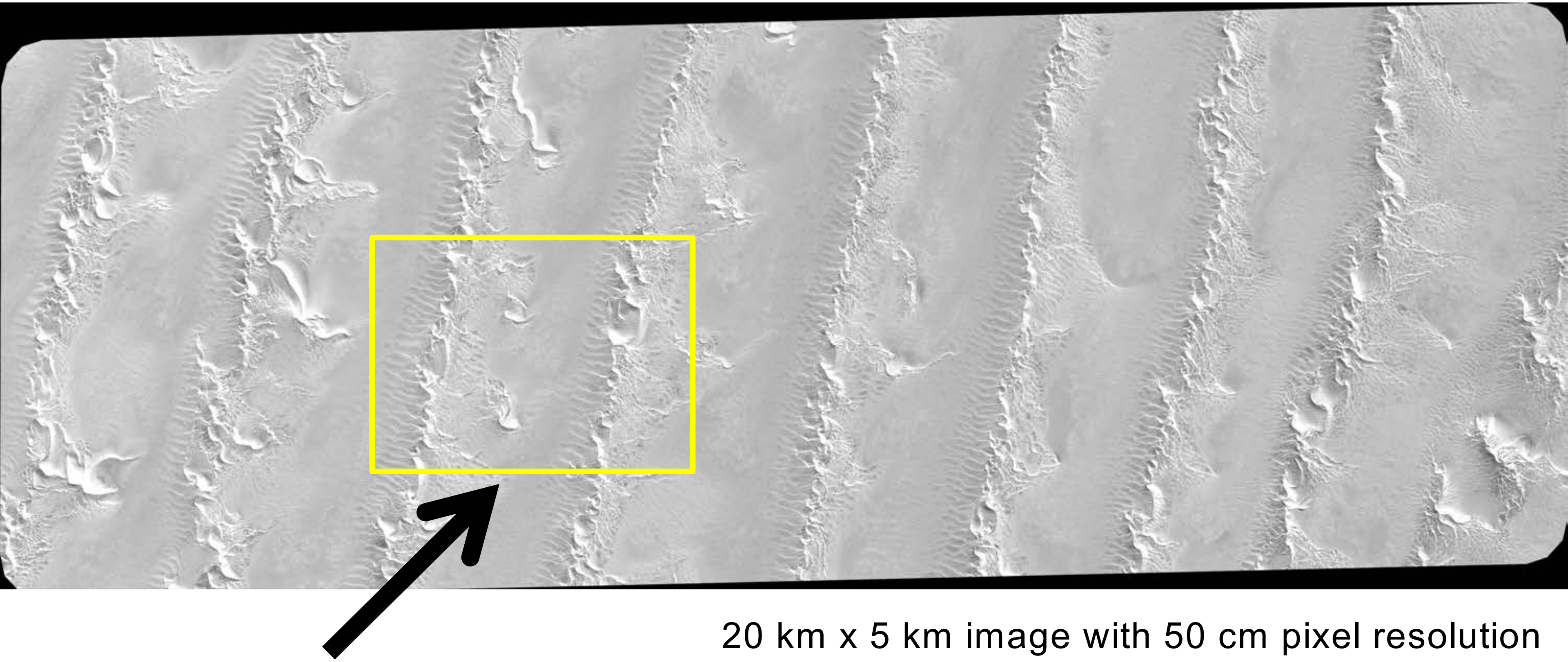


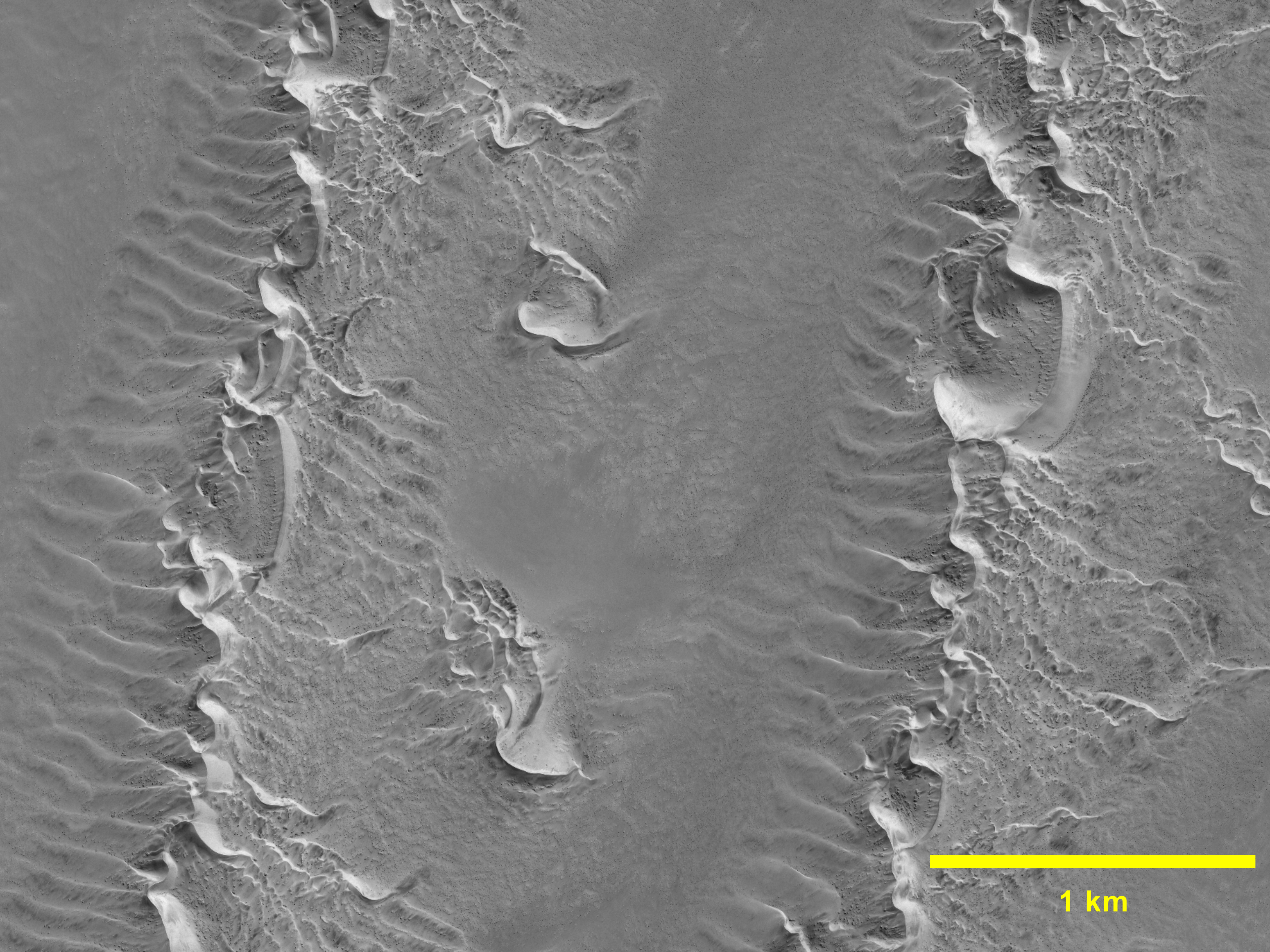
Earth analog from the Namib Desert. Note that the dunes are populated with plants, not rocks as it might at first appear in this image.

Namib Optical Imagery (Stereo Pair)

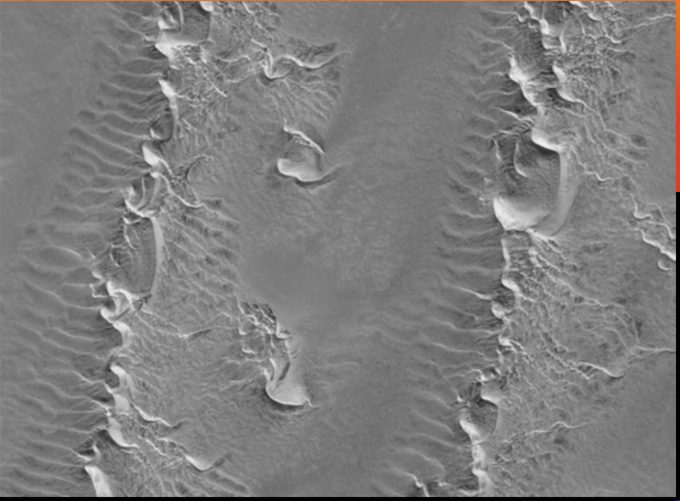
- **Dune spacing ~2.5 km**
- **Dune heights ~150 m**

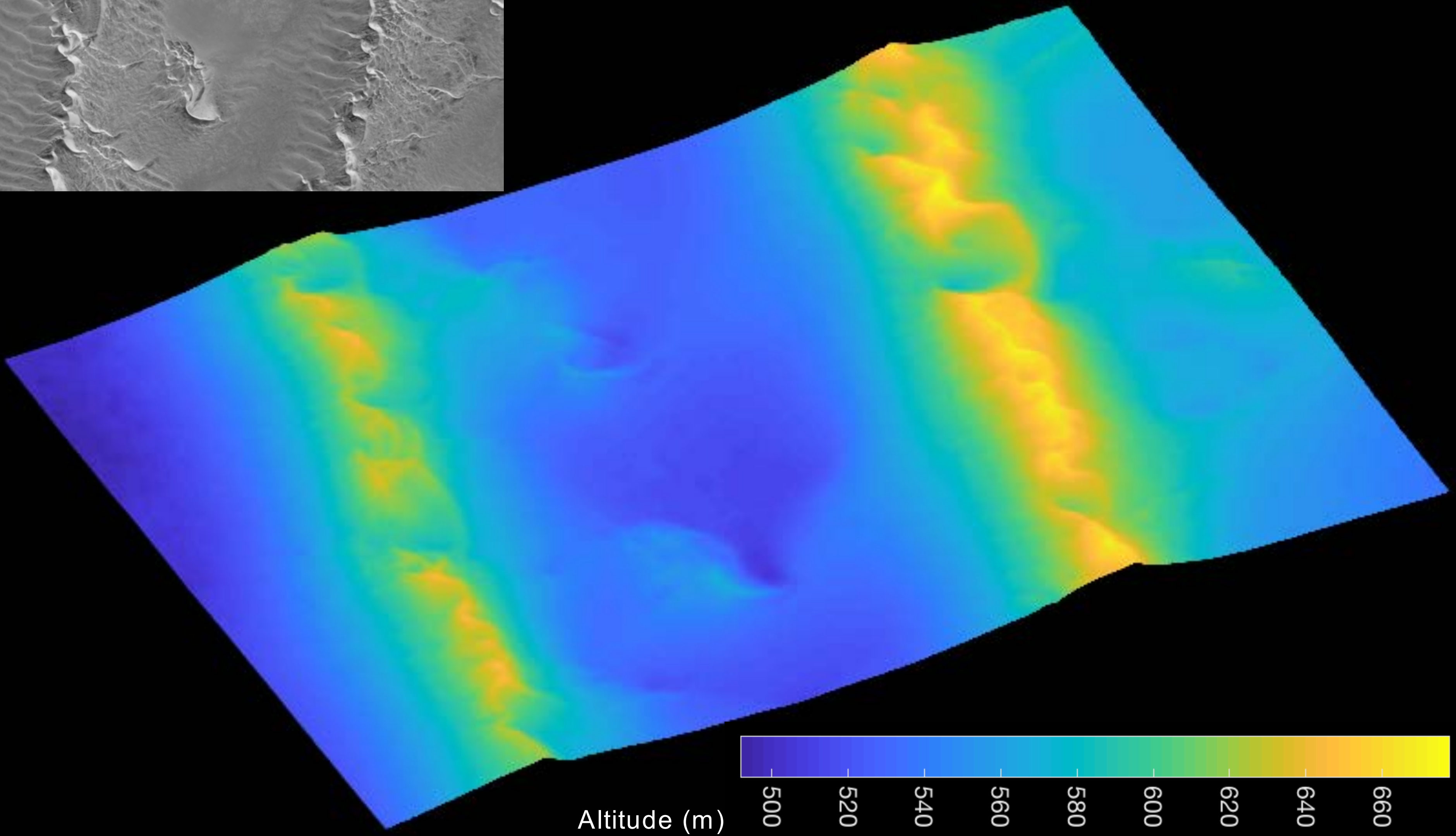


20 km x 5 km image with 50 cm pixel resolution


1 km

Namib Digital Terrain Map (4 km x 3 km)





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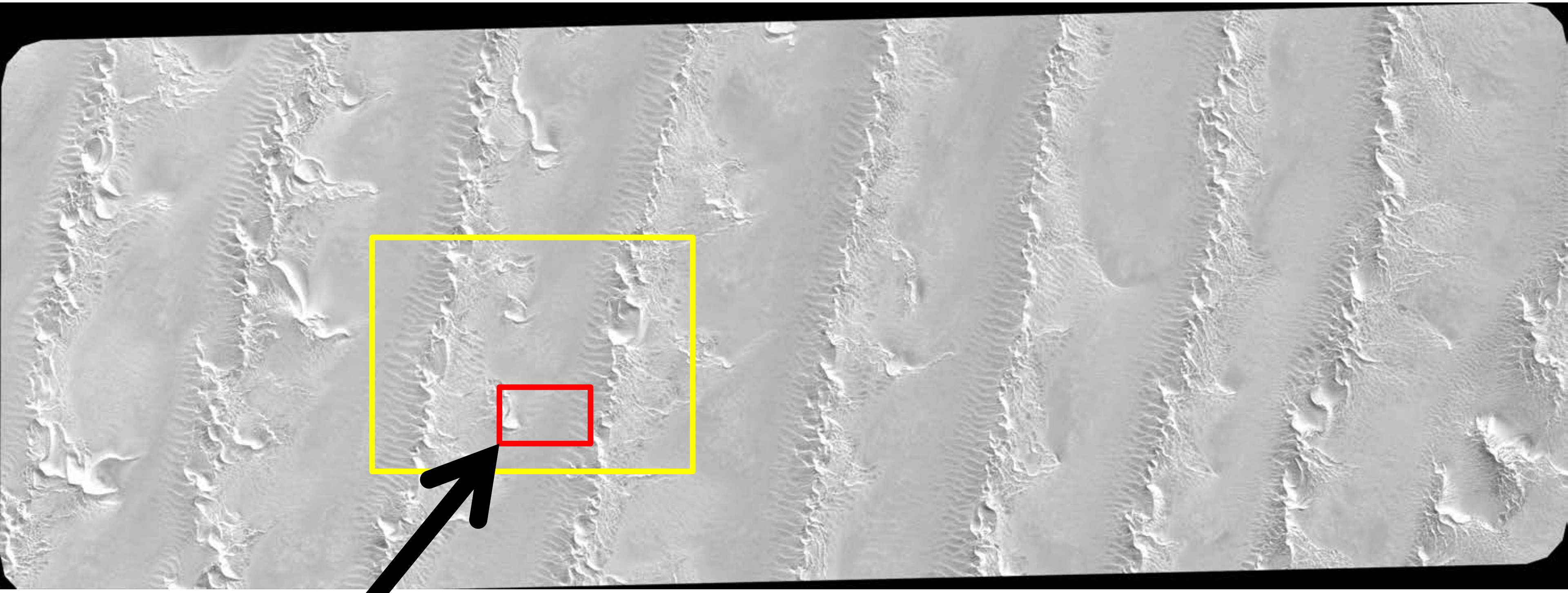
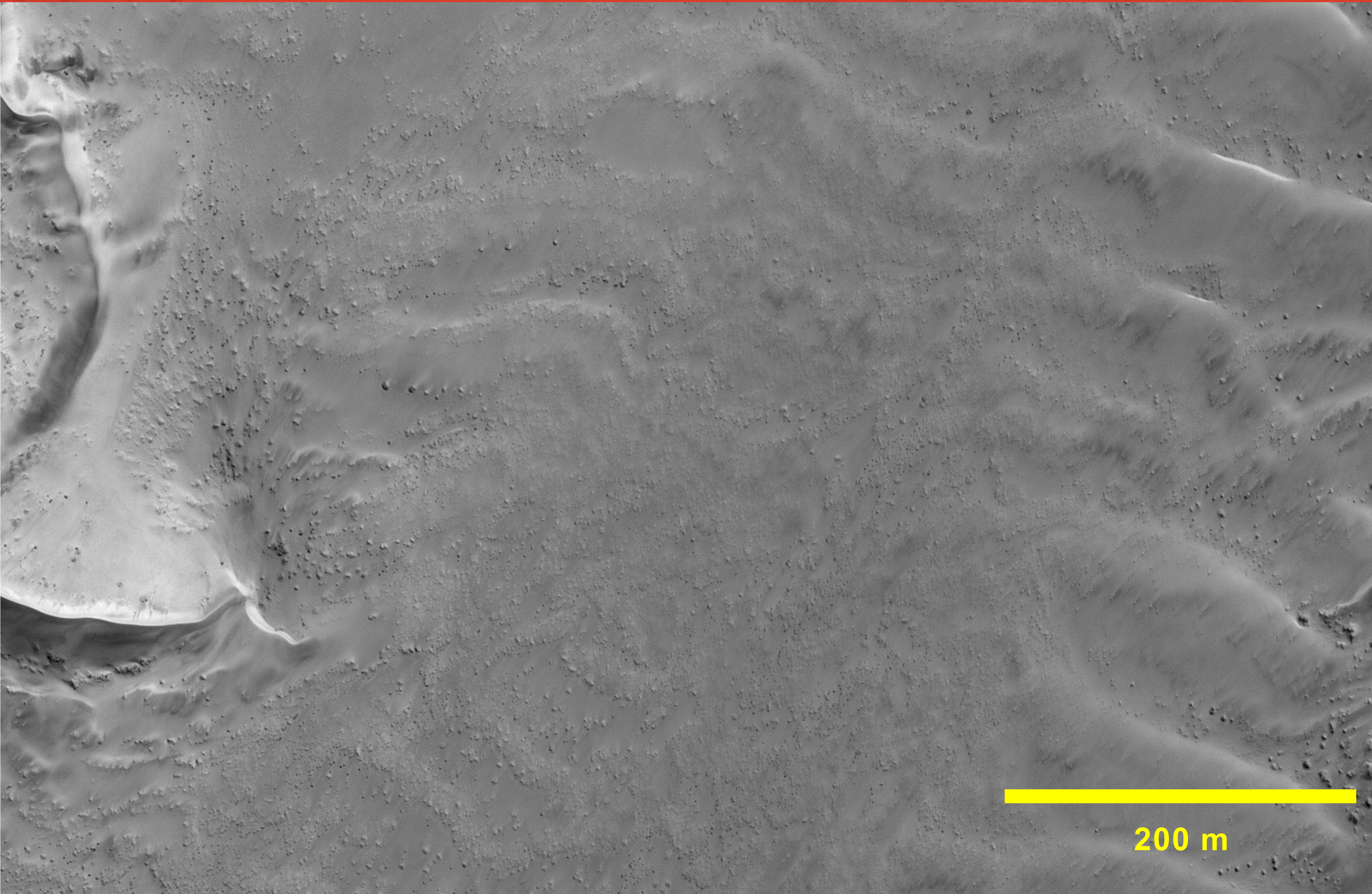


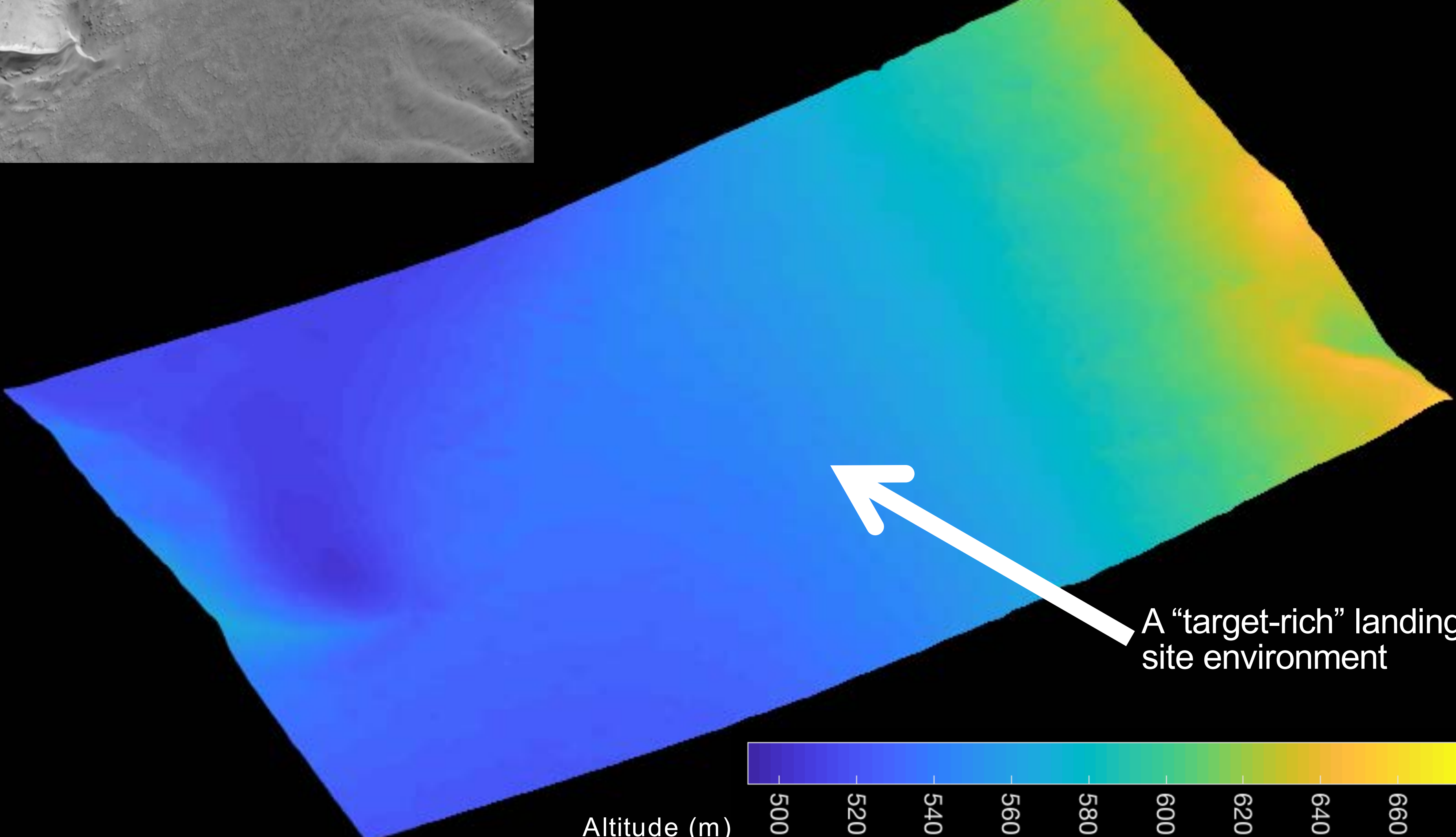
20 km x 5 km image with 50 cm pixel resolution

1 km x 0.75 km

Namib Interdune Region

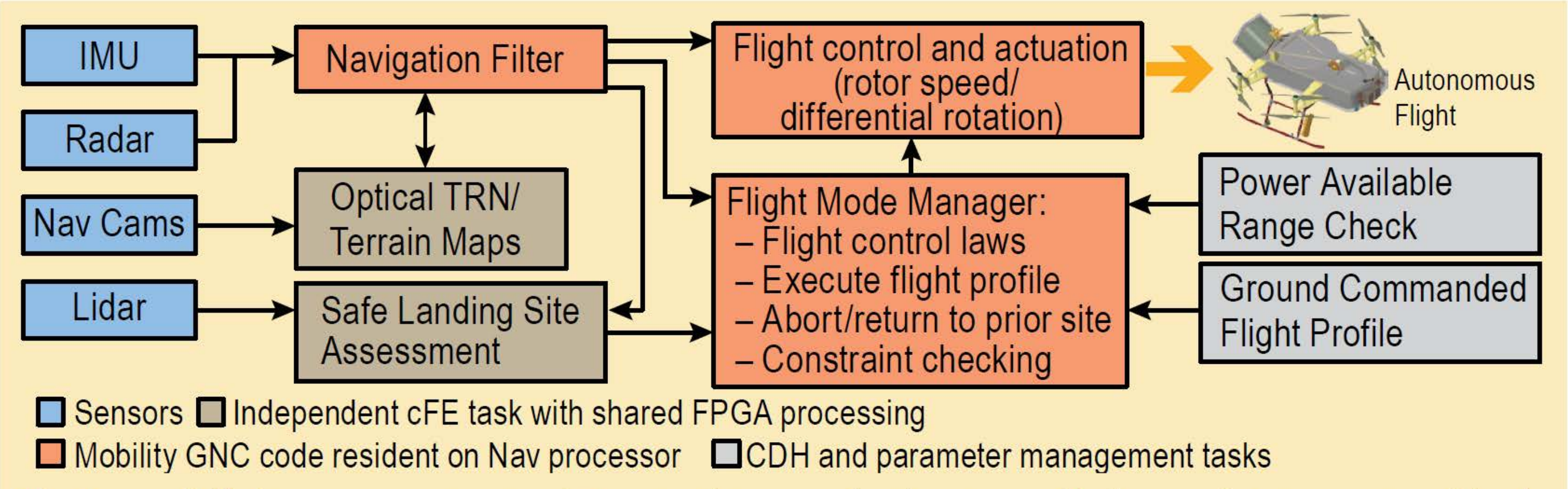


Namib Digital Terrain Map (1 km x 0.75 km)



Flight Management System

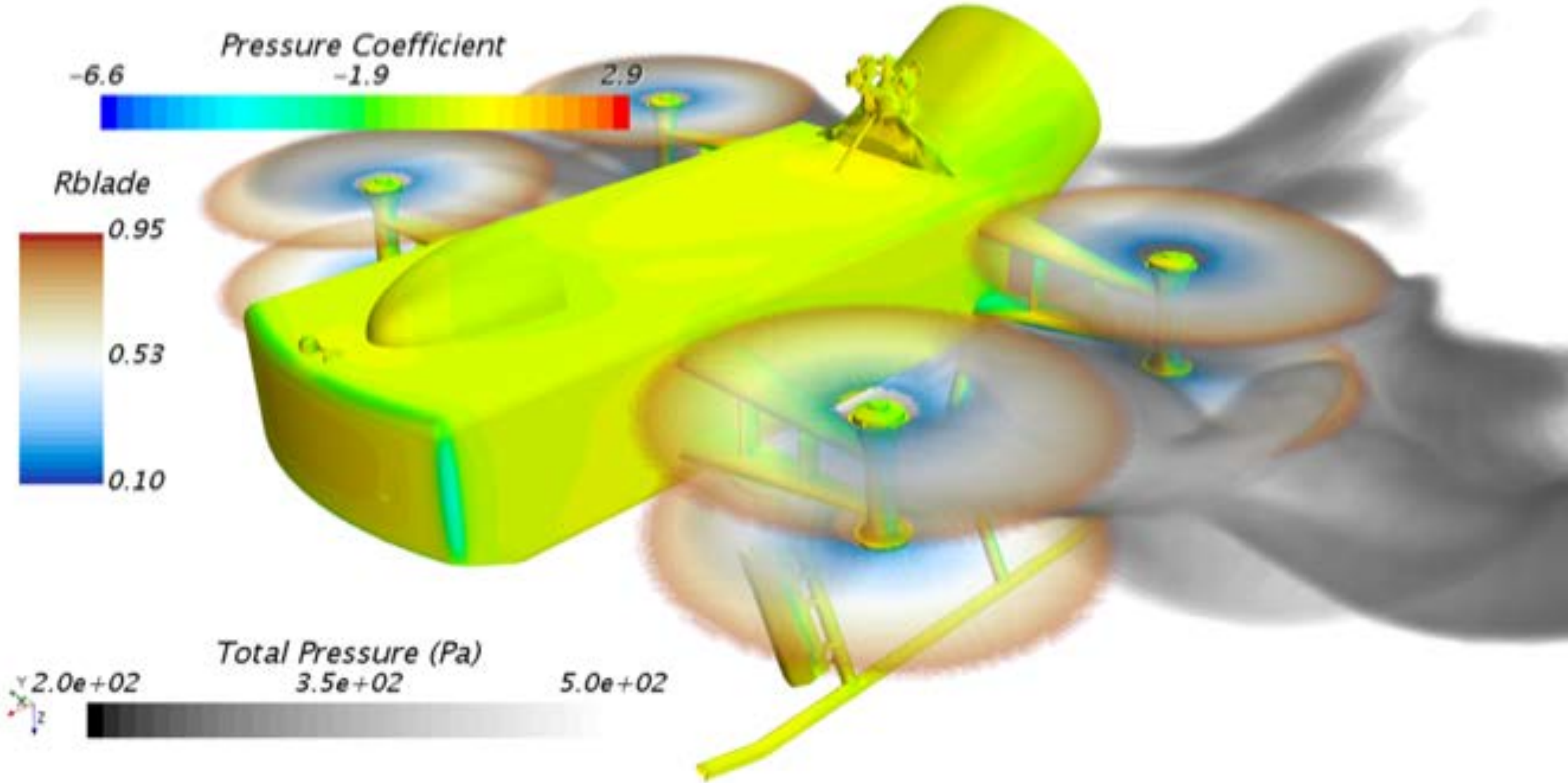
- The Dragonfly flight management system integrates data from redundant high-heritage sensors to ensure safe and accurate flight at Titan.
- The flight computer overlays these data with flight control laws and constraints, and commands the flight system accordingly.
- Dragonfly executes a flight profile uploaded each Tsol (every 16 Earth days), autonomously navigating to specified waypoints to scout and land.
- Preloaded and adjustable parameters define safe landing zones; Dragonfly always has the capability to return to a known safe landing site if necessary.



Mcgee, T. G., et al., AIAA 2018-1330

Early CFD Results

- CFD is being used to help optimize flight performance
  - Augmented with some wind tunnel testing



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NASA's Langley Research Center

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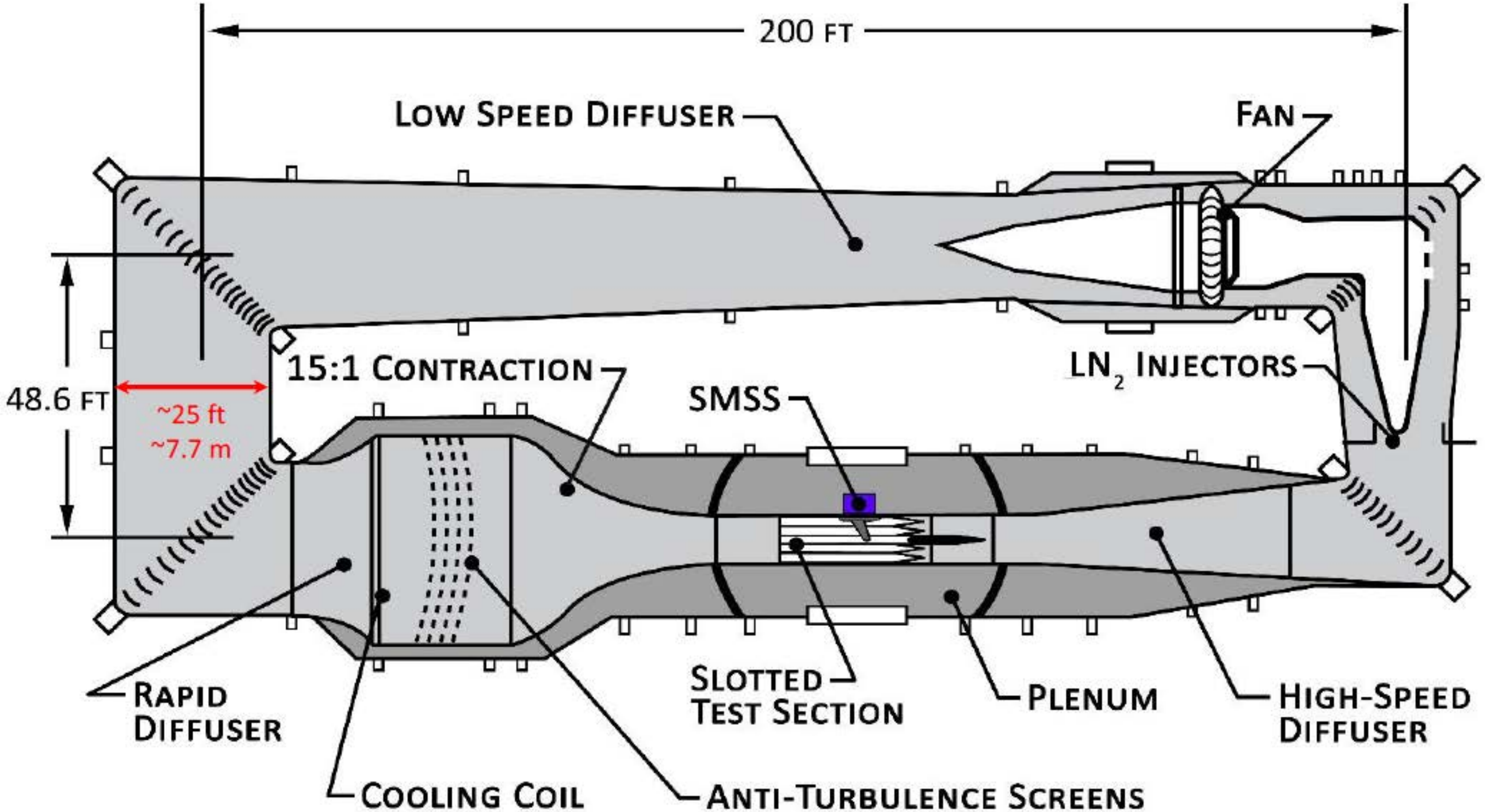


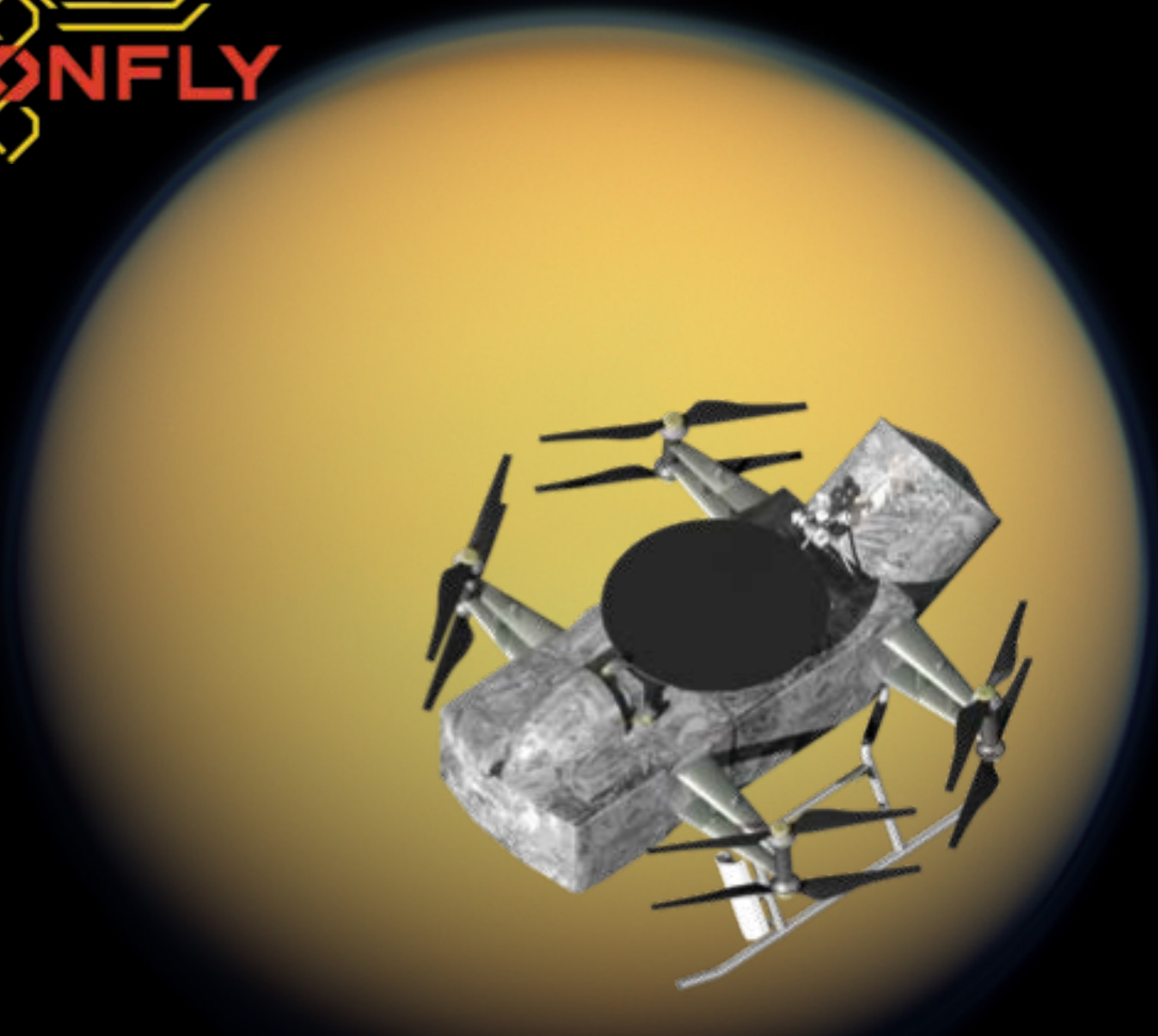
OPERATING PARAMETERS

Mach Number:	**0.1 to 1.2**	*Test Gas:*	**Air, Nitrogen, Mix**
Test Temperature:	**-250°F to 120°F** (116 K to 322 K)	*Reynolds Number:*	**146×10^6 per foot (max)**
Total Pressure:	**15 psia to 120 psia** (1 atm to 8.2 atm)	*Fan Power:*	**101 MW**

Summary

- The Dragonfly transition to powered flight is benign due to the special conditions present on Titan
- The equatorial dune fields, onboard instrumentation suite, and endurance of flight, permit robust autonomous selection of the first landing site
- The mobility GNC sensor suite and algorithms can readily be tested in a cost-effective manner using terrestrial drones and validated early in the development cycle
- Key behaviors of atmospheric flight can be tested under Titan-like conditions using existing wind tunnel facilities to both validate CFD solutions and quantify performance parameters

DRAGONFLY



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