National Aeronautics and Space Administration

Human Mars Lander Design Drivers and Challenges

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AIAA Propulsion and Energy Forum

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Space Policy Directive-1

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities.

Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."

The Apollo Program

6 landings between 1969 and 1972

2 people

3 days on the surface

~2,000 m/s down, 8.4t propellant
~2,000 m/s up, 2.5t propellant

Pressure fed hypergolic propellants

Human Mars Mission

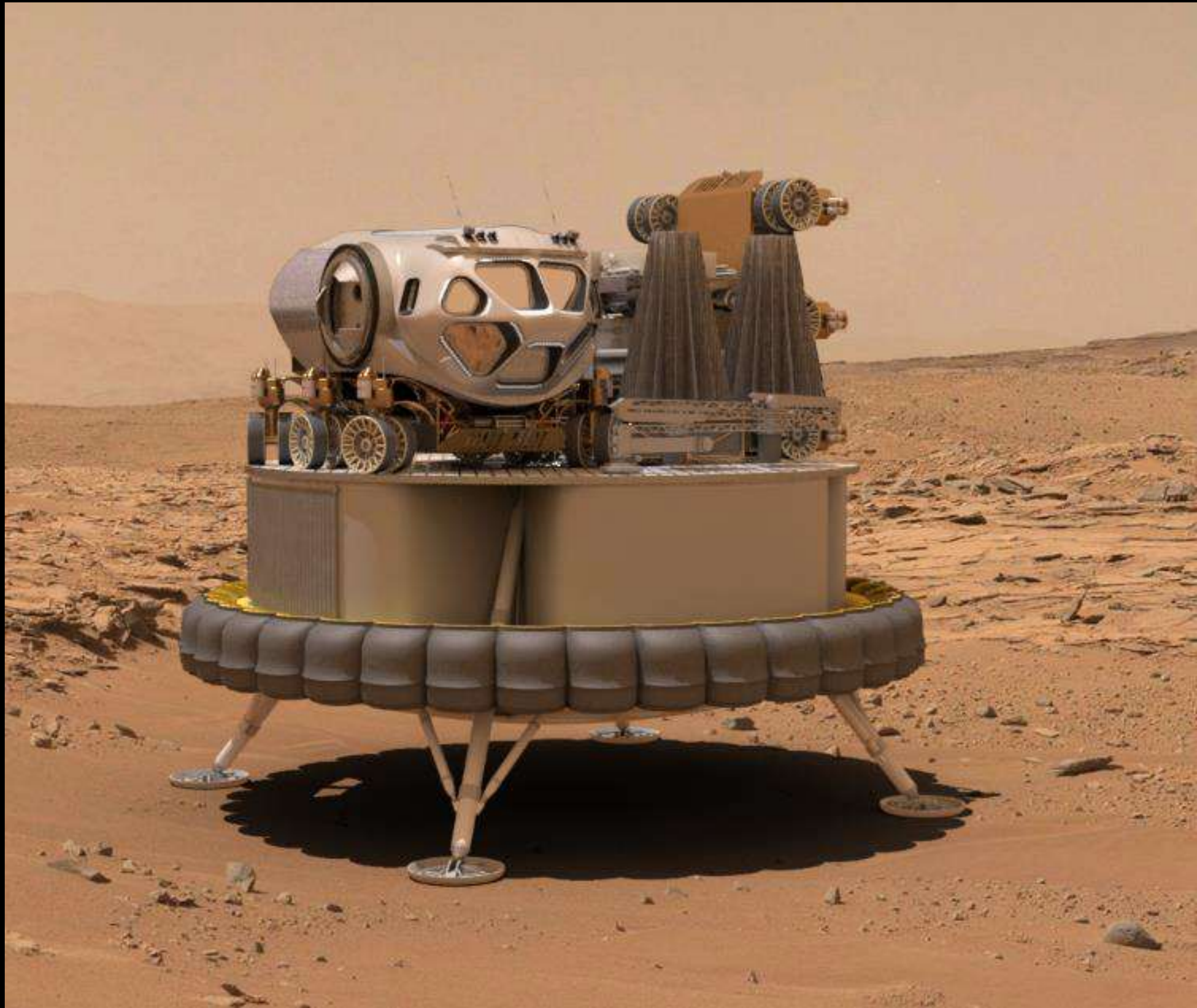
2-4 landers per mission

4+ people

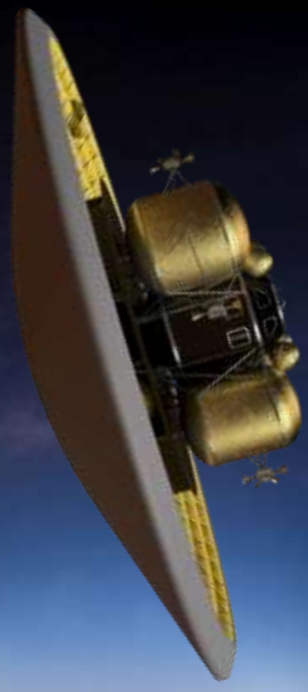
>1 year on the surface

~800 m/s down, 15t propellant
~5,300 m/s up, 36t propellant

Cryogenic ISRU-compatible propellants



	Viking 1 & 2	Pathfinder	MER A/B	Phoenix	MSL	Human Scale Lander (Projected)
Diameter, m	3.505	2.65	2.65	2.65	4.5	16-19
Entry Mass, kg	930	585	840	602	3151	47-62 t
Landed Mass, kg	603	360	539	364	1541	36-47 t
Landing Altitude, km	-3.5	-1.5	-1.3	-3.5	-4.4	+ 2
Peak Heat Rate, W/cm^2	24	106	48	56	~120	~120-350
Landing Ellipse, km	280x130	200x70	150x20	100x20	20x6.5	0.1x0.1

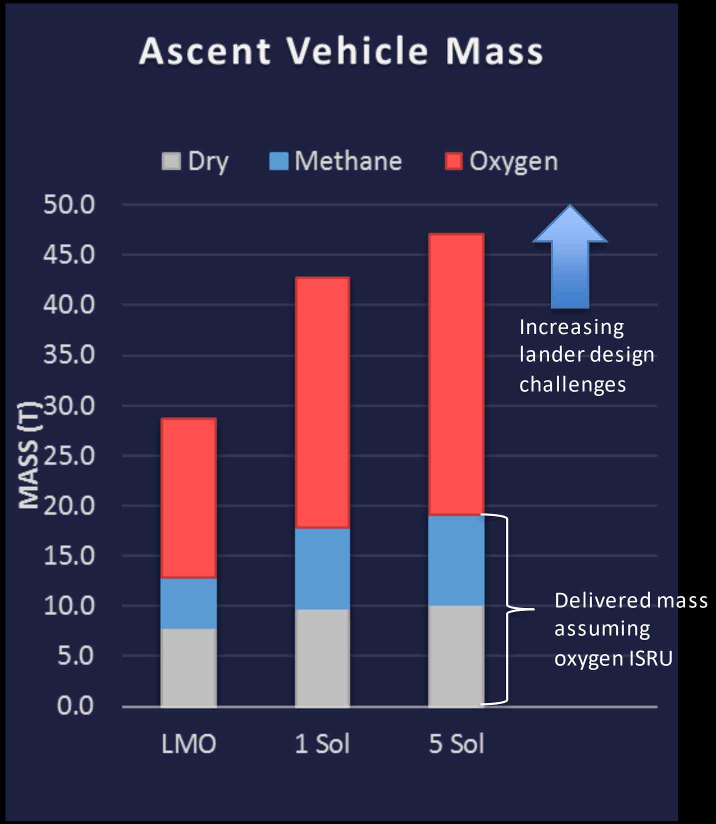


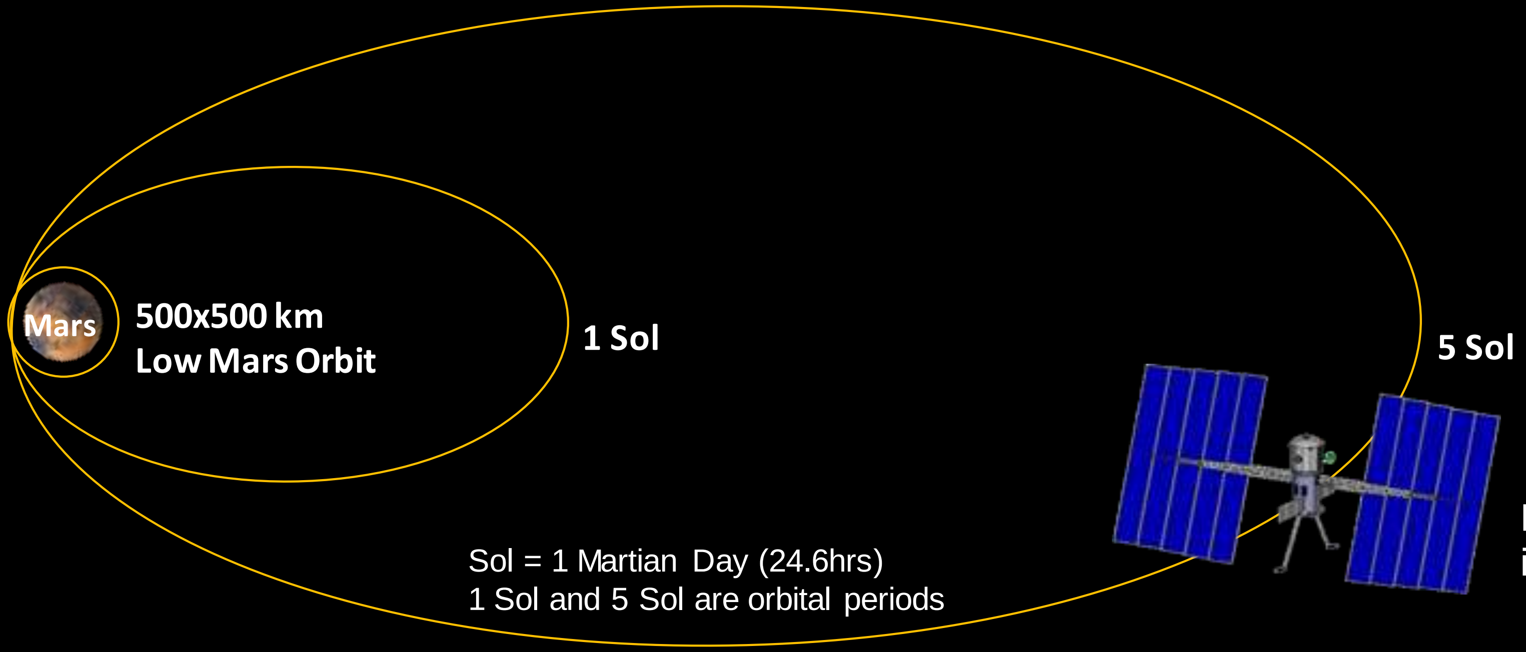
Steady progression of “in family” EDL

New Approach Needed for Human Class Landers

Mars Ascent Vehicle (MAV) Drives Lander Size

- The MAV is the largest indivisible payload that must be delivered
- MAV's to high orbits are > 40t at liftoff.
- Delivering 40t or more on a lander may be infeasible
- With ISRU generated propellants, MAV's can achieve high orbits with low delivered mass on the lander



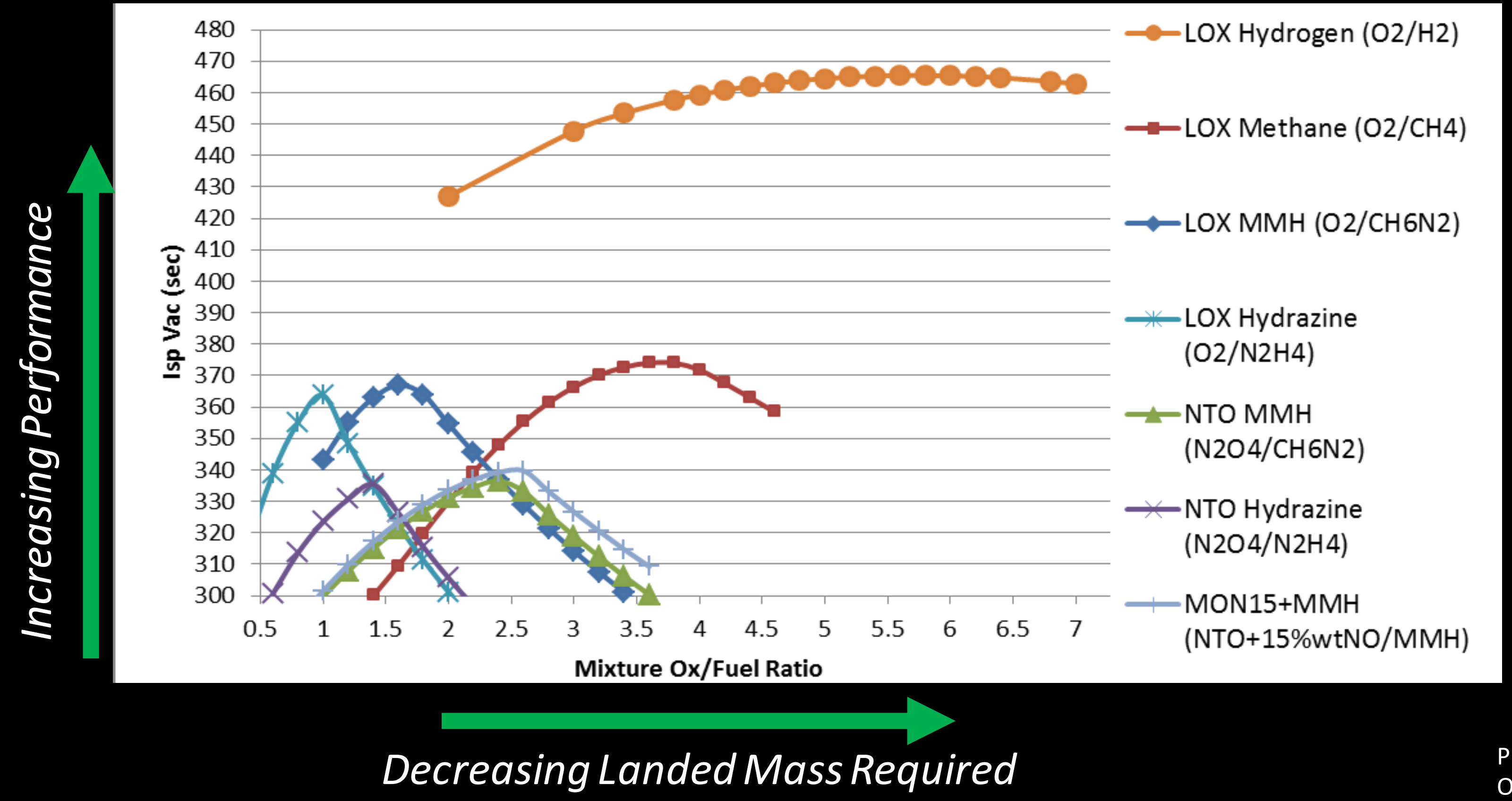


Sol = 1 Martian Day (24.6hrs)
1 Sol and 5 Sol are orbital periods

Earth Return Vehicle will be in a high orbit, 1 Sol to 5 Sol

Propellant Choice Drivers: Performance

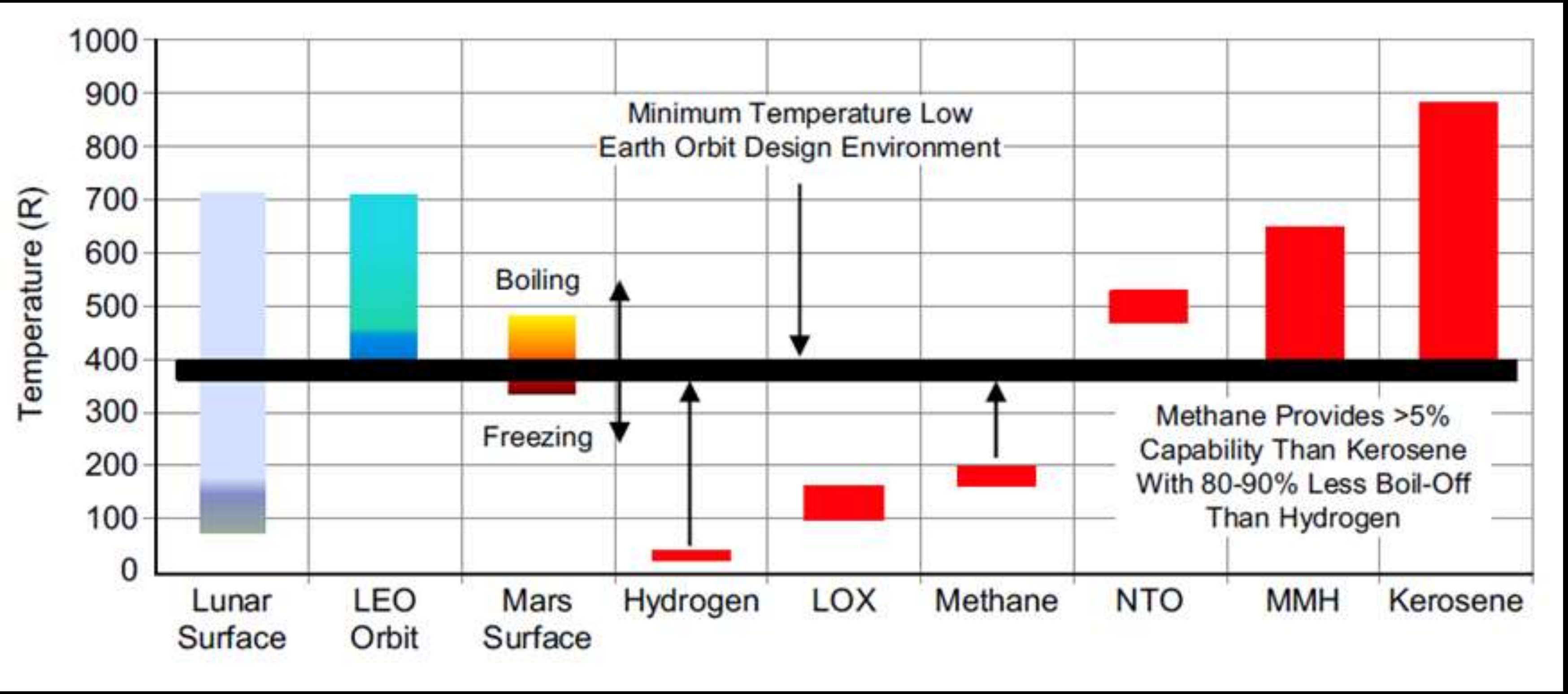
- **Ascent Performance**
  - Highly sensitive to Isp, impacts ripple through lander and transportation stages
  - Propellant combinations with higher mixture ratios favored to make greatest benefit of surface LOX



Pc 1,000 psia, Nozzle AR 250:1
Optimum Capability ISP Shown with ERE and Nozzle Efficiency Applied
Descent/Ascent Configurations Are Typically 10-15 Seconds Less Per Cycle & Installation

Propellant Choice Drivers: Thermal Management

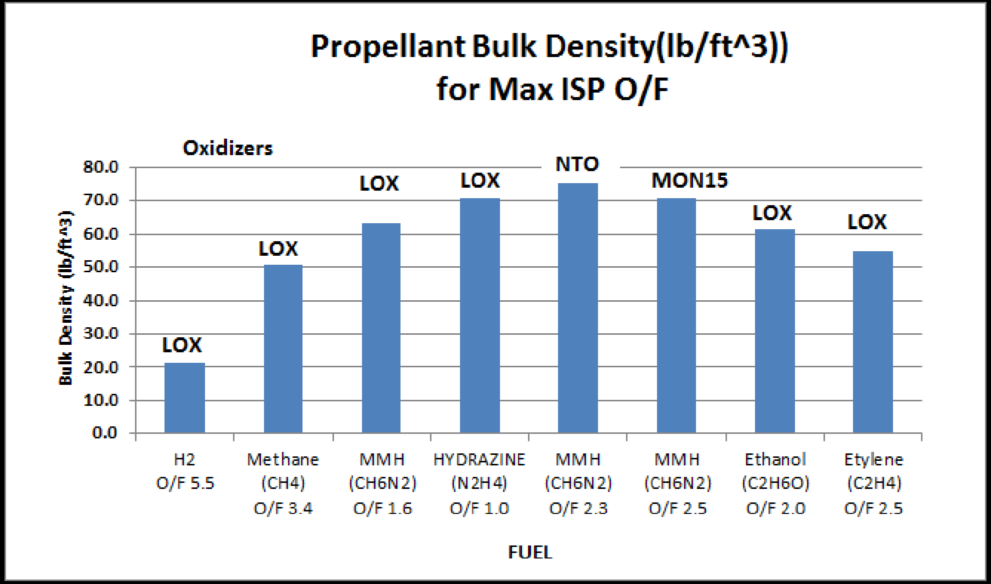
- **Long duration storage**
  - Fuel storage at similar temperature to LOX simplifies CFM design, and enables a nested tank option



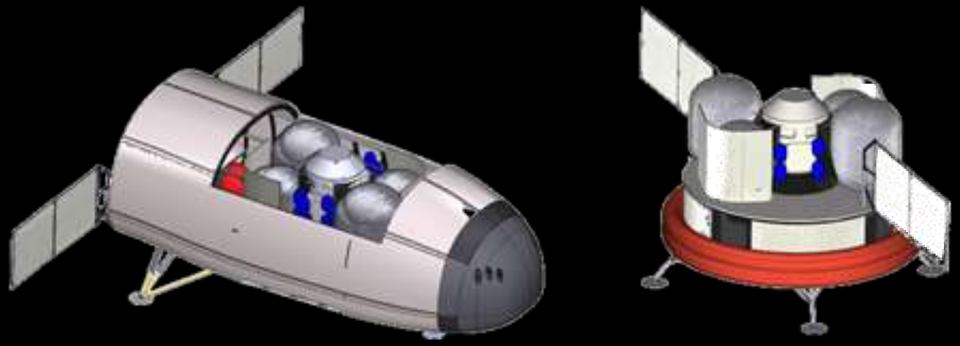
Thermal Environment Favors CH_4 (methane) as a Cryogenic Fuel for Mars due to Storage Temperature

Propellant Choice Drivers: Packaging

LOX/LH$_2$ LOX/CH$_4$ MMH/NTO
(must be landed fully fueled)



Variation in propellant volumes for 1 Sol MAV
- Radiators not shown
- No attempt was made to optimize the configuration

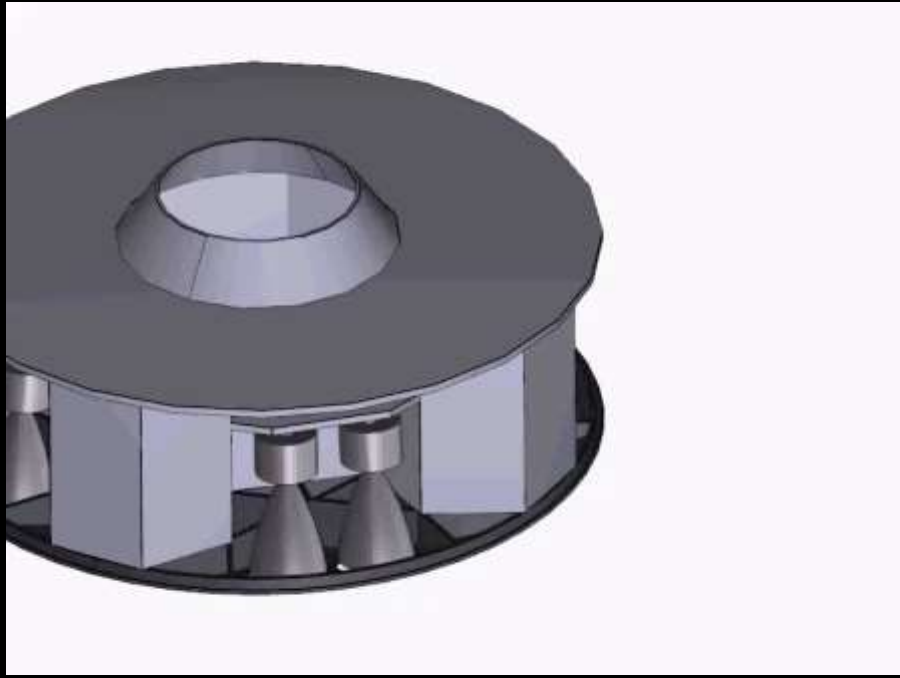


Lander Options & Packaging Challenges

Mars Descent Propulsion System

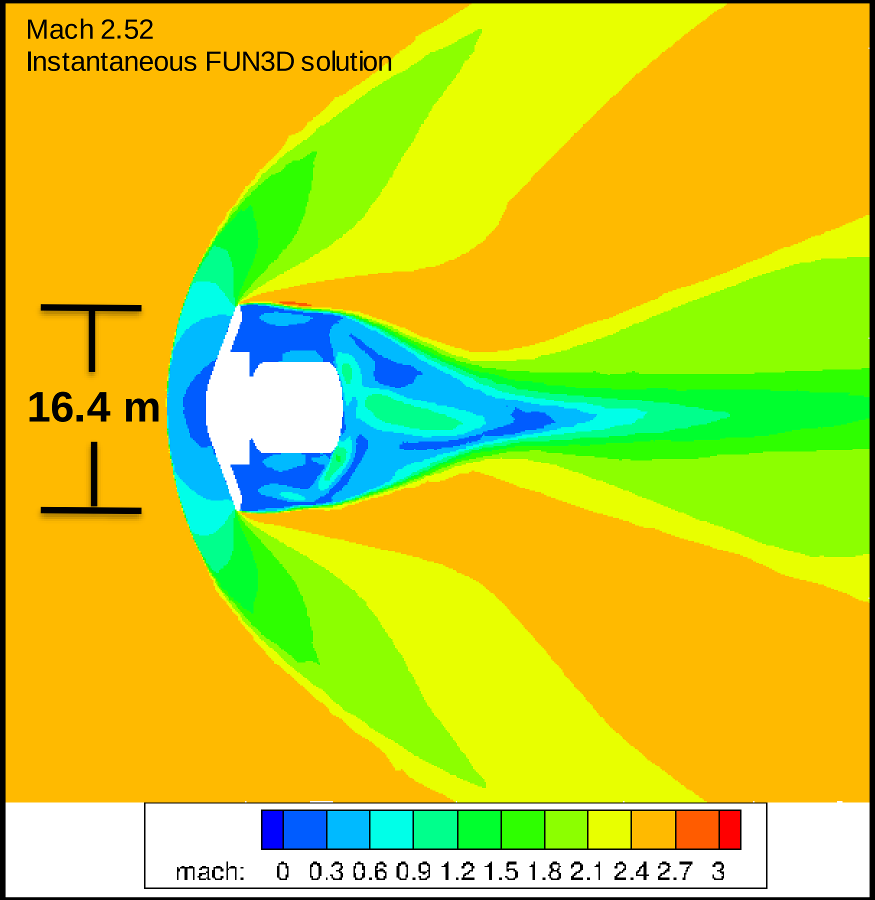
- **Commonality of propulsion components for descent and ascent can maximize the value of development investments**

  - We need main engines with throttle capability, thrust level, and Isp that balance descent and ascent performance needs
    - Common 22.5 klb_f O_2/CH_4 engine
    - 3+1 for Ascent, 8 for Descent
  - Active cryogenic fluid management with advanced insulation
  - Integrated reaction control systems
  - Capable of withstanding long duration dormancy with high reliability



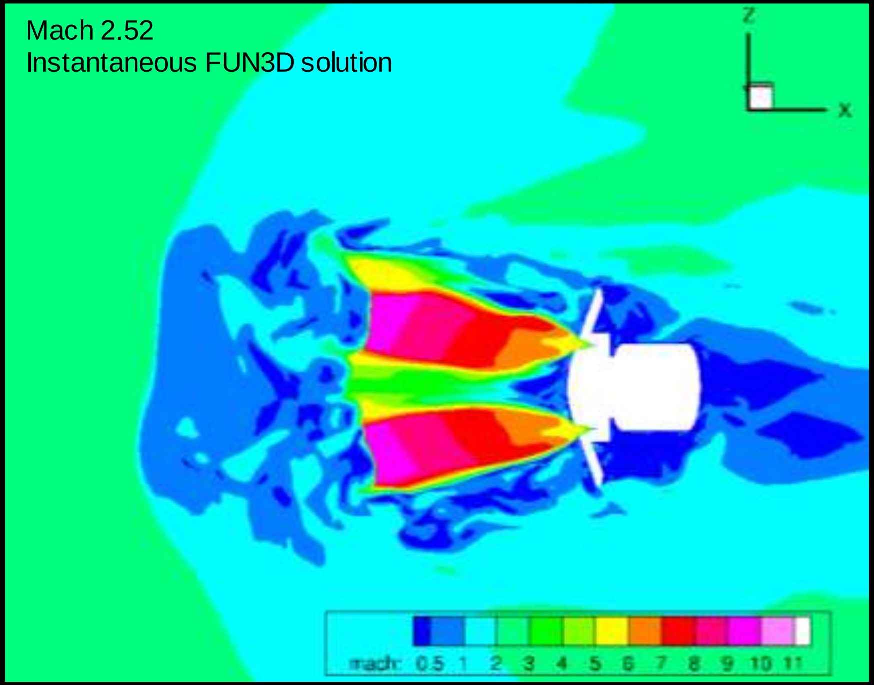
Propulsion Challenges: Powered Descent Initiation

Engines Off



- Strong, detached shock near vehicle
- Heatshield is the flow obstruction
- Dominant forces and moments are steady
- Well-defined scaling relationships

Engines On

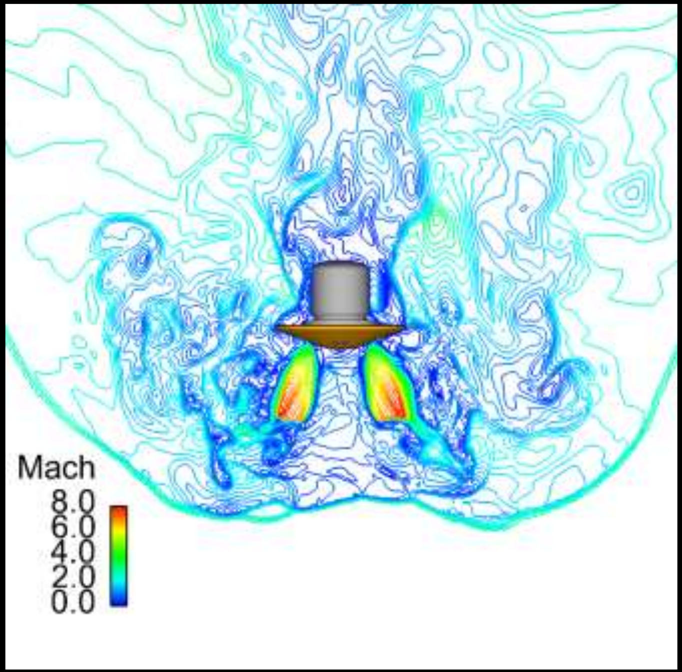


Source: A. Korzun (NASA LaRC), FUN3D solution, 2018.

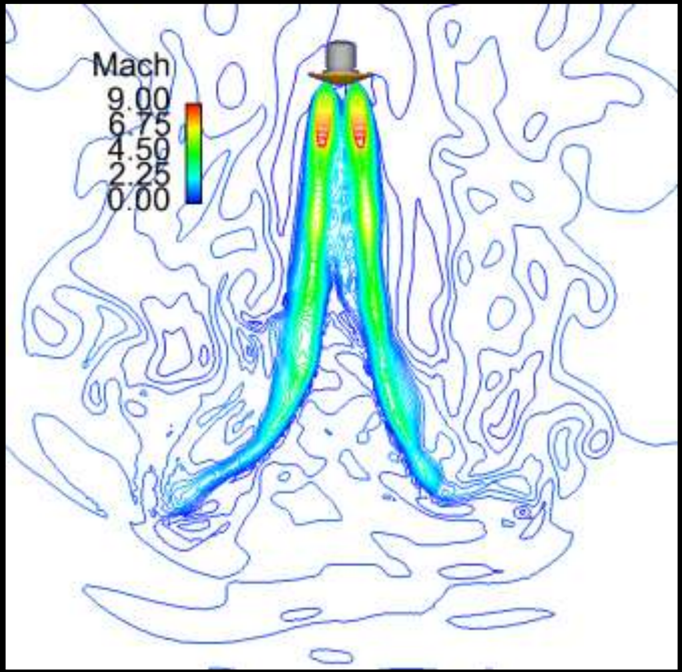
- Shock displaced far upstream
- Complex, unsteady plume structure is part of the flow obstruction
- Aerodynamic forces and moments can be unsteady
- Less confidence in scaling relationships

Propulsion Challenges: Plumes Near Landing

Mach 2.78



Mach 0.8



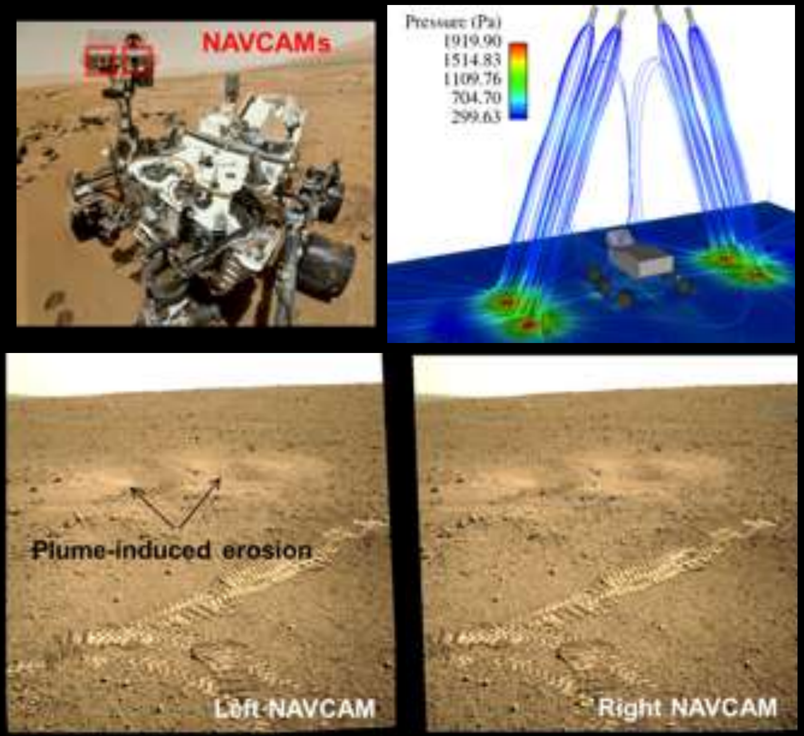
Source: F. Canabal (NASA MSFC), LociCHEM solutions, instantaneous Mach number contours, 2018.

At Mach = 0.8 (20t payload):
Altitude above surface: 975 m
Downrange to target: 1.04 km
Flight path angle: -35°
Plumes extend ~150 m in front of the vehicle!

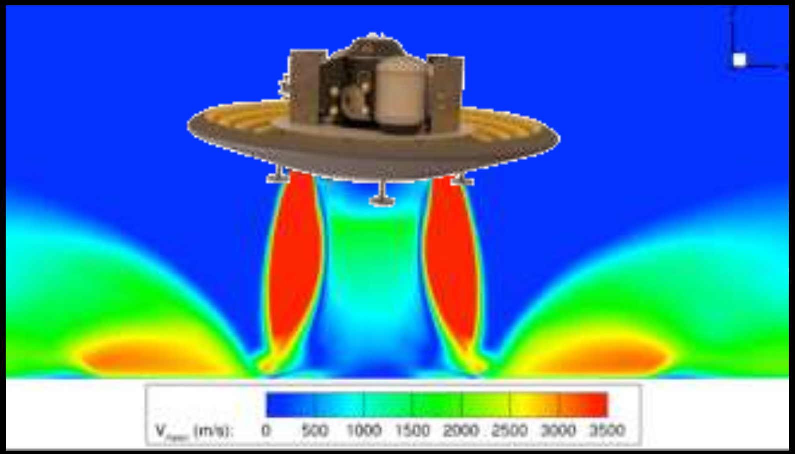
- **Unsteady aerodynamics in nominal operation**
- **Transitions through nozzle expansion conditions as the vehicle decelerates**
- **Throttling introduces asymmetry and can significantly alter the resulting aerodynamics**

Propulsion Challenges: Surface Plume Interaction

Mars Science Laboratory
5,600 → 700 lbf of thrust, 60+ft from surface
Damaged instrument



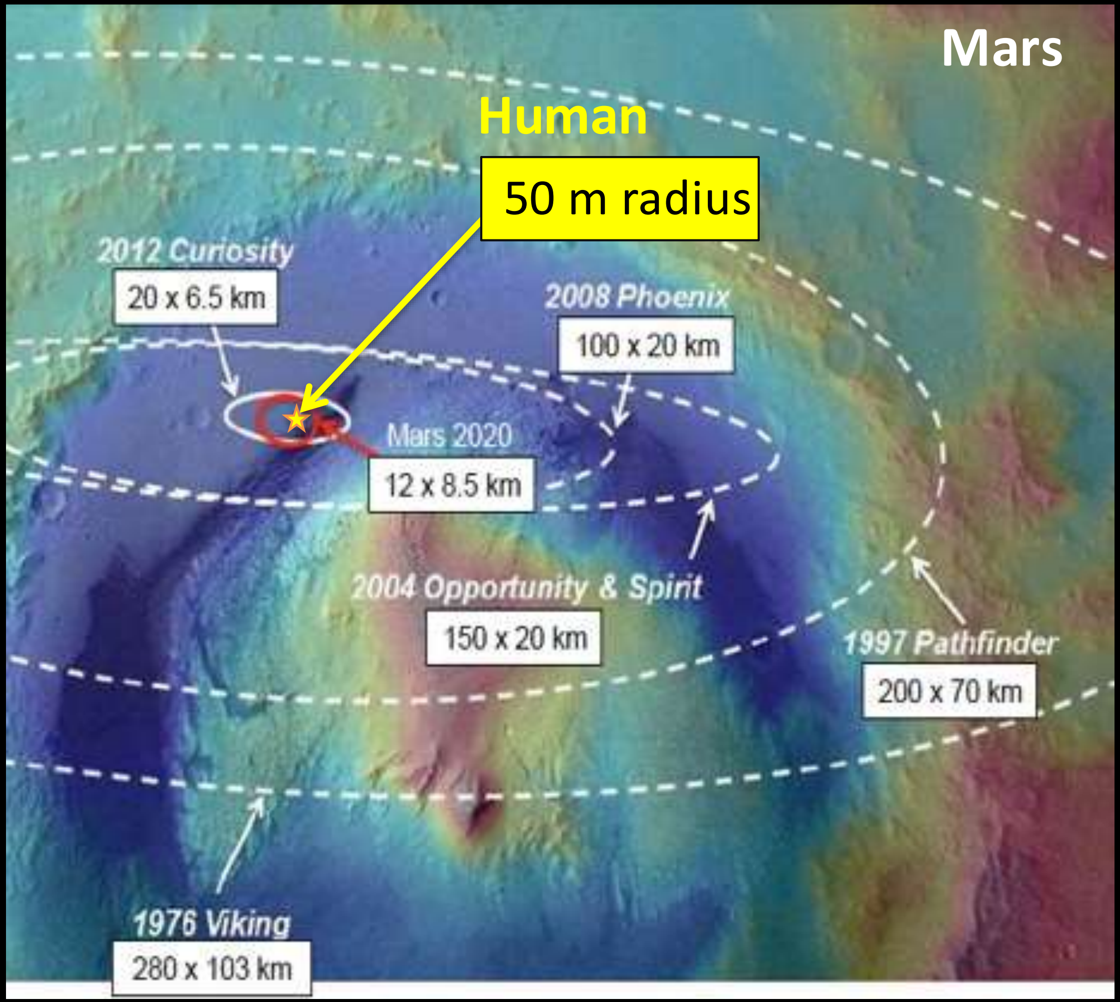
Human Mars Lander
180,000 lbf → 36,000 lbf of thrust,
10+ft from surface
in proximity to other assets

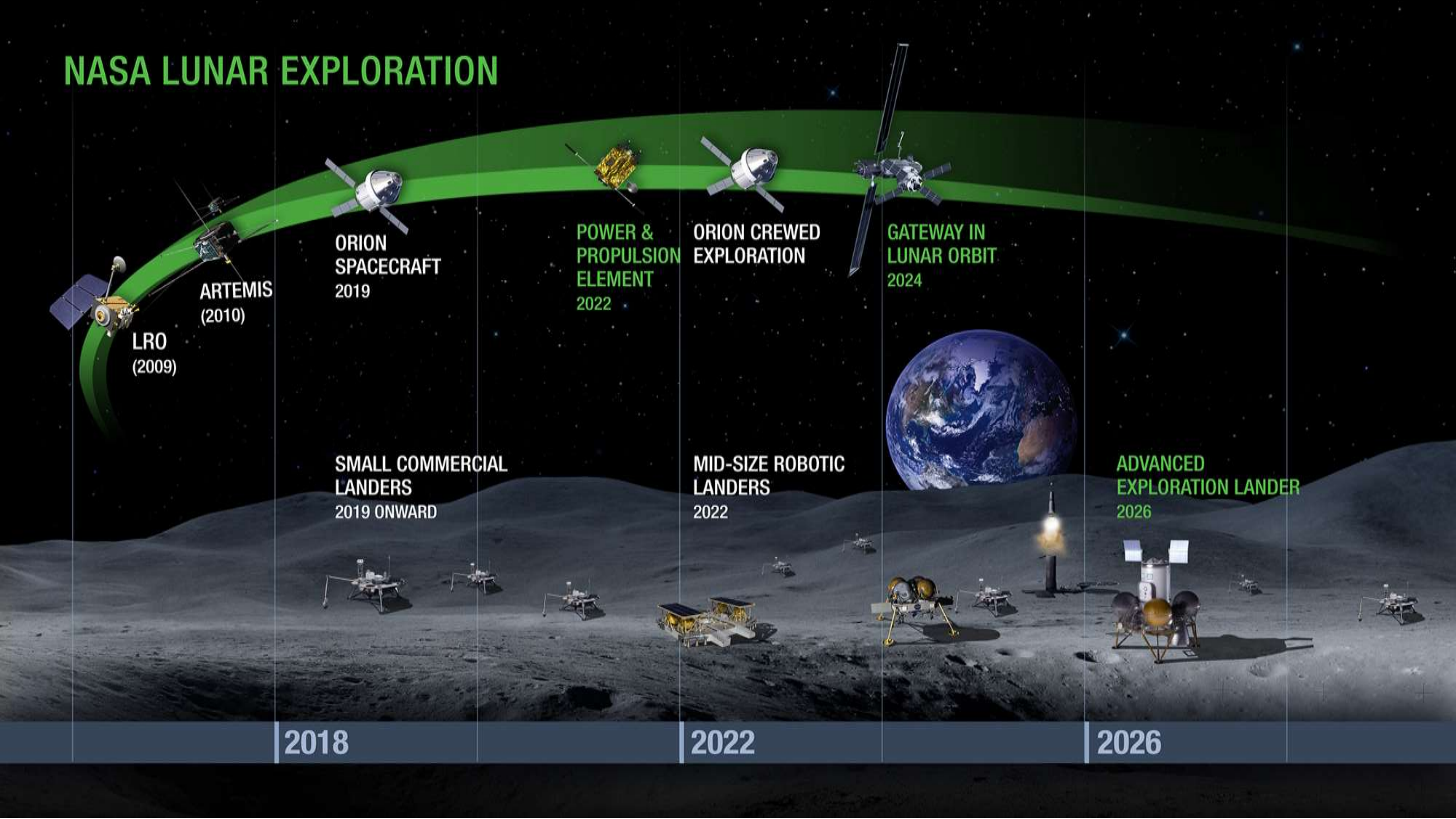


The total thrust at landing is 50 times more than Curiosity or InSight missions. Landing on bedrock is preferred, but even that may be altered.

Landing Precision

- **Landing precision is improving with each Mars mission**
- **To get to the current state of the art, system changes have been made, along the way:**
  - MSL had the first active hypersonic guidance
  - In addition, Mars 2020 employs a range trigger on the parachute, and uses Terrain Relative Navigation
- **Human missions will need integrated guidance, improved velocimetry, and hazard detection/ avoidance**



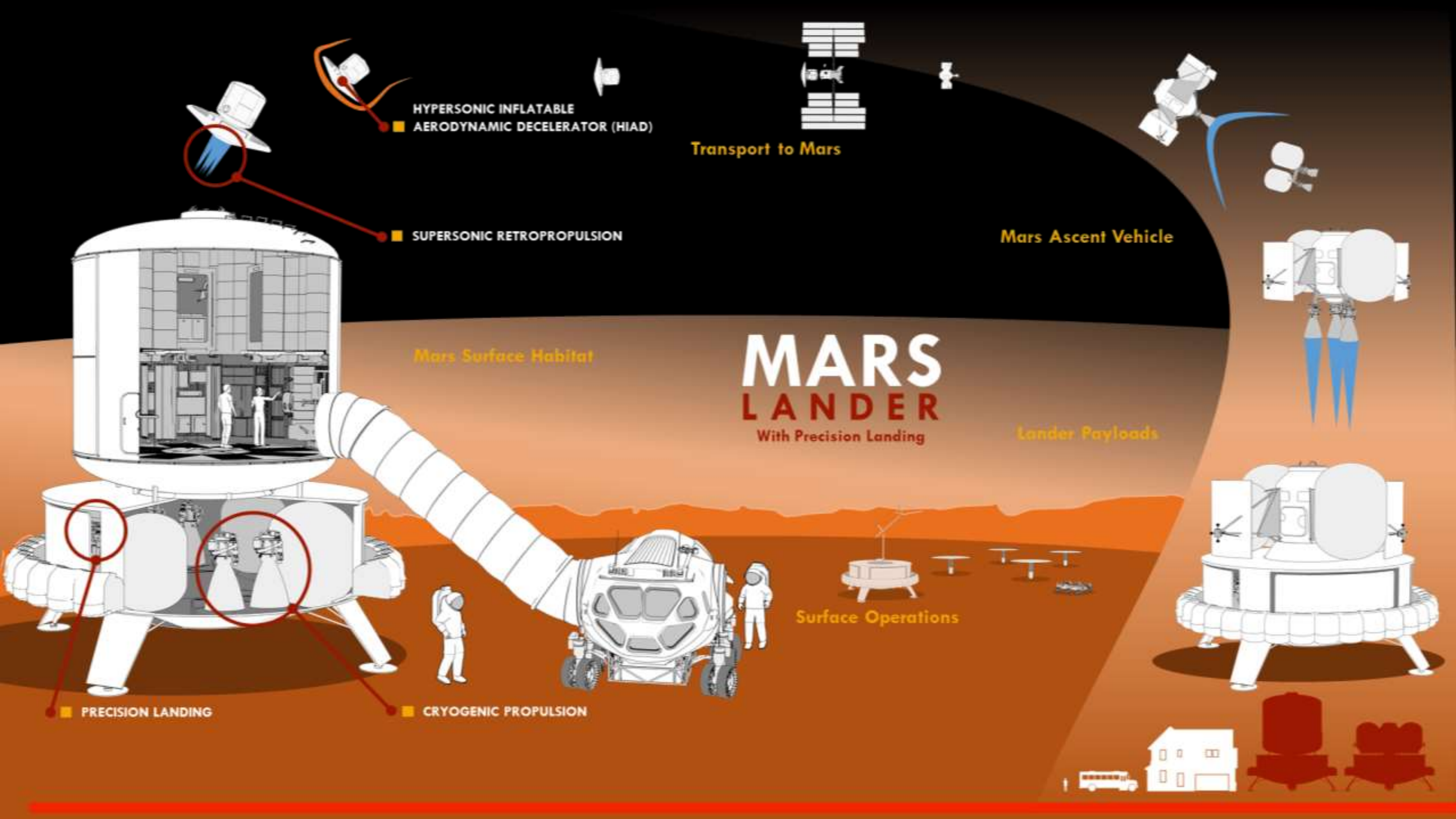

NASA LUNAR EXPLORATION
LRO
(2009)
ARTEMIS
(2010)
ORION
SPACECRAFT
2019
POWER &
PROPULSION
ELEMENT
2022
ORION CREWED
EXPLORATION
GATEWAY IN
LUNAR ORBIT
2024
SMALL COMMERCIAL
LANDERS
2019 ONWARD
MID-SIZE ROBOTIC
LANDERS
2022
ADVANCED
EXPLORATION LANDER
2026
2018
2022
2026

NASA

EDL Vehicle Designs: 20 t Payload Capability

Name	Shape	Vehicle Dimensions	Launch Mass	Entry Mass	Ballistic Number	L/D
Capsule		10 m (h) x 10 m (w)	68t	63t	500 kg/m^2	0.3
Mid L/D		22m (l) x 7.3m (h) x 8.8m (w)	66t	62t	380 kg/m^2	0.55
ADEPT		4.3m (h) x 18m diameter	60t	55t	155 kg/m^2	0.2
HIAD		4.3m (h) x 16m diameter	57t	49t	155 kg/m^2	0.2

ADEPT = Adaptable Deployable Entry & Placement Technology
HIAD = Hypersonic Inflatable Aerodynamic Decelerator
Mid-L/D = Has a lift-to-drag ratio (L/D) of about 0.55


HYPERSONIC INFLATABLE AERODYNAMIC DECELERATOR (HIAD)
Transport to Mars
SUPERSONIC RETROPROPULSION
Mars Ascent Vehicle
Mars Surface Habitat
MARS
LANDER
With Precision Landing
Lander Payloads
Surface Operations
PRECISION LANDING
CRYOGENIC PROPULSION