The Challenge of Mars EDL (Entry, Descent, and Landing)

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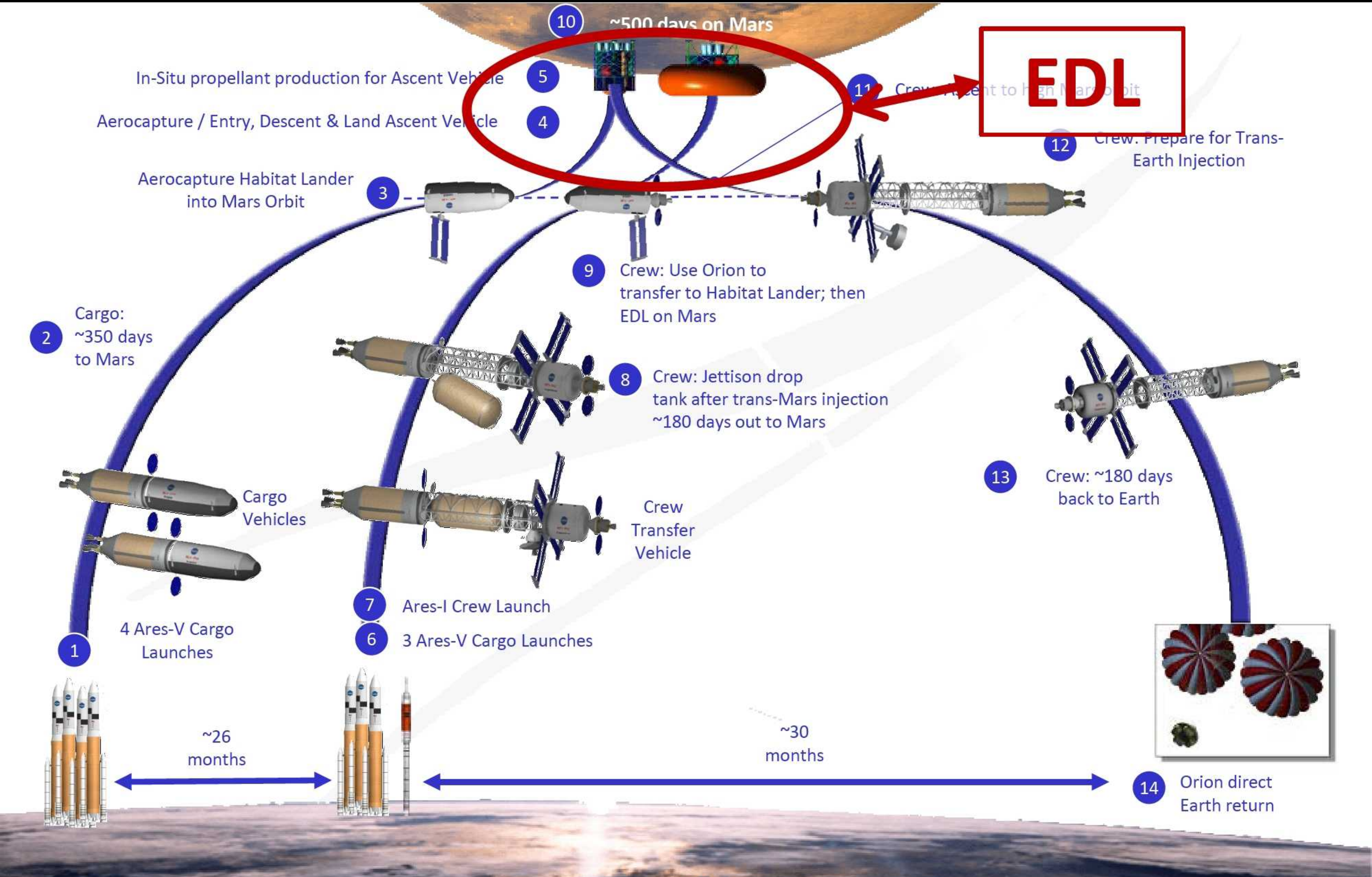
April 2010

Acknowledgements

- The information contained in this presentation reflects the collective wisdom and experience of a large number of individuals across the EDL community. It would be very difficult to attempt to list them all individually without missing a major contributor.
- However, I would like to acknowledge Carlos Westhelle of NASA who directly provided much of the data shown here.

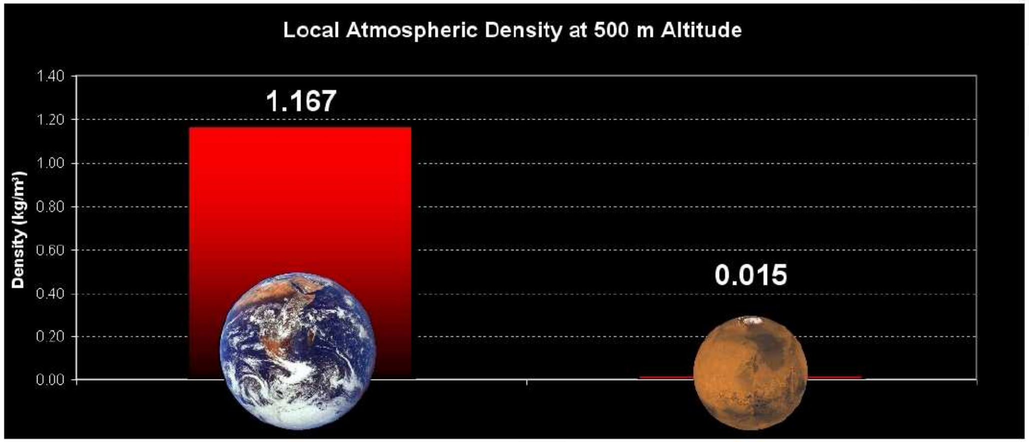
Mars Design Reference Architecture 5.0 Mission

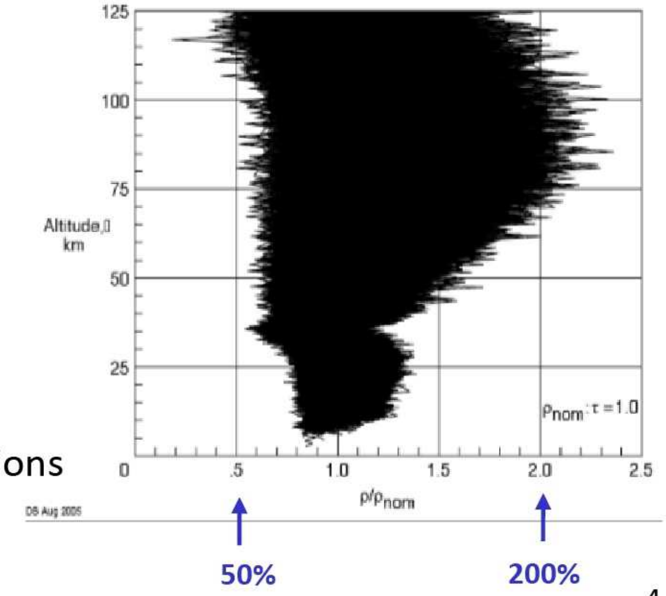


Why is Mars EDL so difficult?

ATMOSPHERE:

- Thin Martian atmosphere (surface density equivalent to Earth's at 30 km)
- Too little atmosphere to decelerate and land like we do at Earth
- Atmosphere is thick enough to create significant heating during entry





- Lack of understanding of the atmosphere:
  - Aerodynamics, aeroheating, winds, and density variations

Mars Entry Descent and Landing Challenge

GEAR RATIOS:

- All Propulsive: 1 metric ton (MT) on surface of Mars requires 20 MT in Low Earth Orbit (LEO). This would lead to unreasonably large masses in LEO.
- Using the Atmosphere allows a significant reduction in the gear ratio
  - 1 MT on surface of Mars requires 5-6 MT in LEO

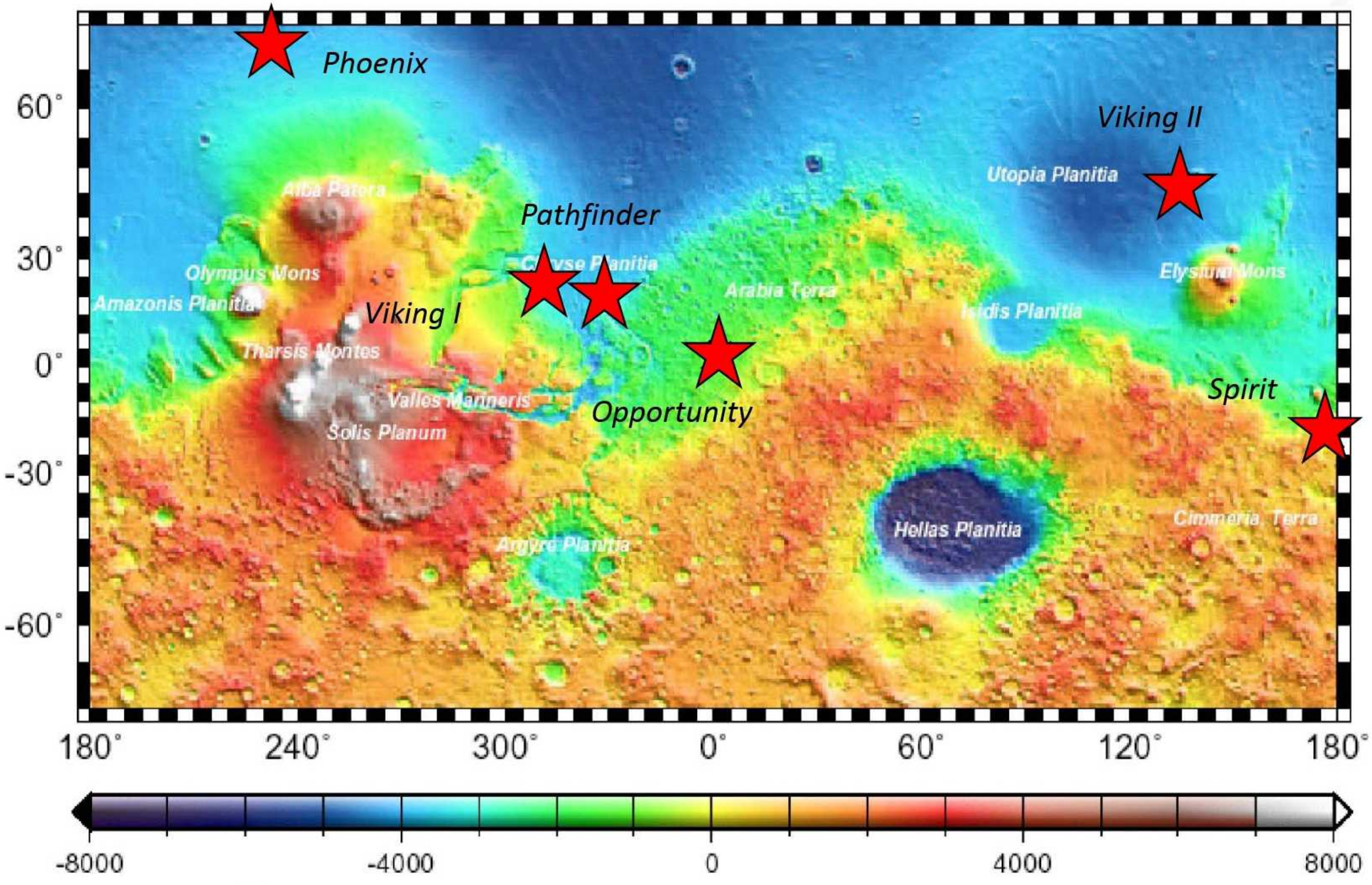
WILL IT WORK?

So far all potentially feasible human-scale Mars EDL architectures require the successful development of SEVERAL low TRL elements.

There are many promising ideas that need assessment and testing. These include:

- Large rigid heat shields (10m diameter by 30m length)
- Inflatable heat shields (20 to 25 m diameter)
- Inflatable aerodynamic decelerators
- Supersonic retro-propulsion
- Precision landing

6 U.S. Mars Entry, Descent, and Landing Successes



Mars EDL History

All six of the successful U.S. Mars EDL systems had:

- Low Landing Site: elevation sites below –1 km MOLA ← that's Mars Sea Level
- Low Mass: Had landed masses of less than 0.6 MT
- UNGUIDED: Had large uncertainty in targeted landing location (300 km for Mars Pathfinder, 80 km for MER)

Mars Science Laboratory (MSL) '11 EDL Architecture:

- Low Landing Site: Landed elevation requirement for sites below 0 km MOLA
- Low Mass: Has landed mass of 0.9 MT
- GUIDED: Has uncertainty in targeted landing location of 10km

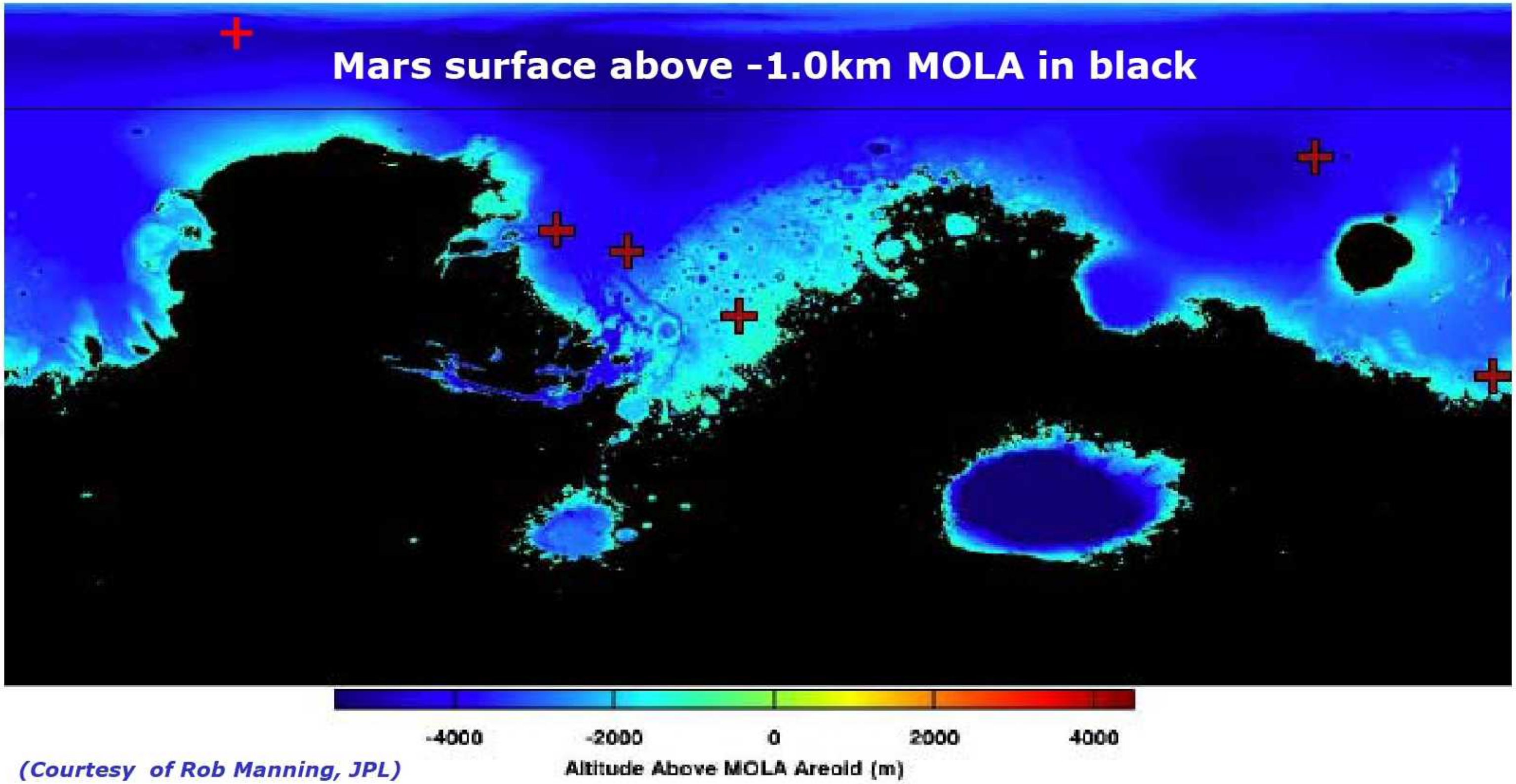
HUMANS need more capability:

- All of the current Mars missions have relied on large technology investments made in the late 1960s and early 1970's as part of the Viking Program (heatshield shape, thermal protection material, and parachute)
- Large Mass (Entry Mass of ~100 – 150 MT)
- Higher elevations – interesting science
- Precision Landing

Current Mars Accessibility

Previous Viking derived EDL systems and the thin Martian atmosphere and small scale height have limited accessible landing sites to those below -1.0km MOLA

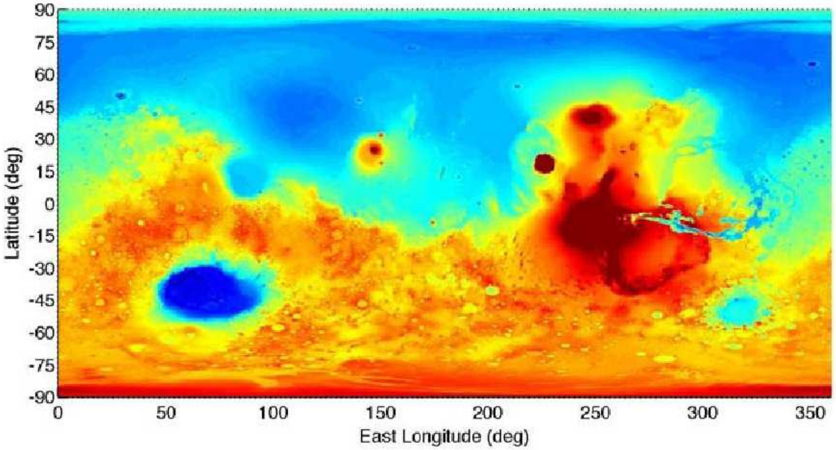
To date the southern hemisphere has been largely out of reach (**approximately 50% of the planet surface remains inaccessible with current EDL technologies**)



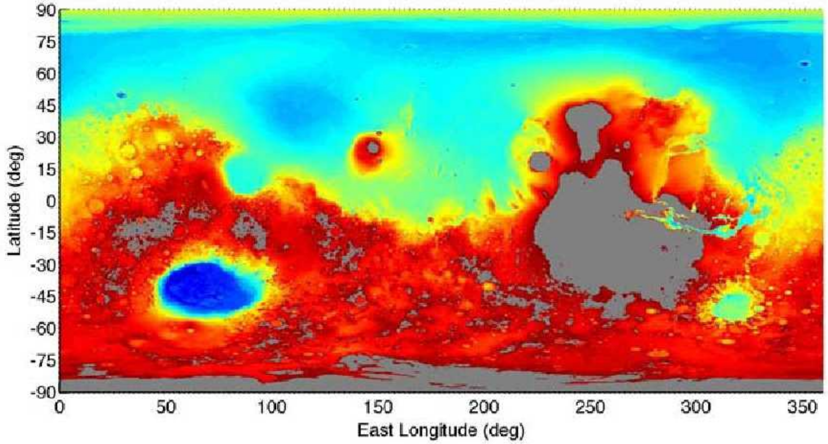
(Courtesy of Rob Manning, JPL)

Landing Site Elevation / Accessibility

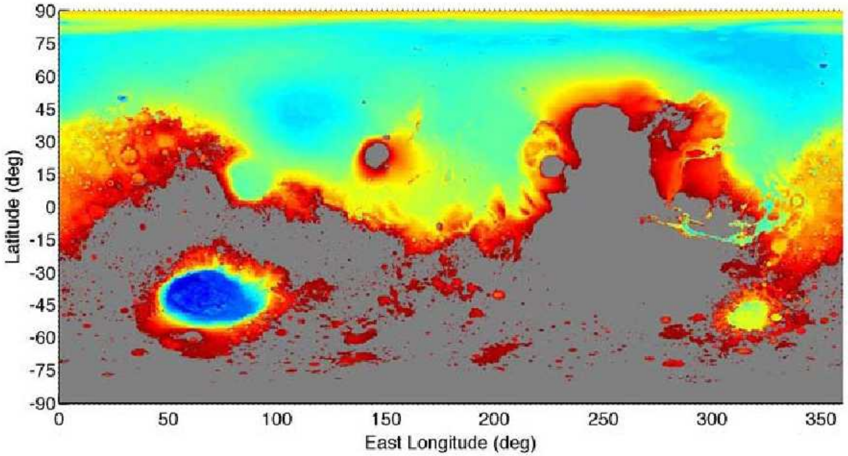
MOLA 1/4° Topographic Data



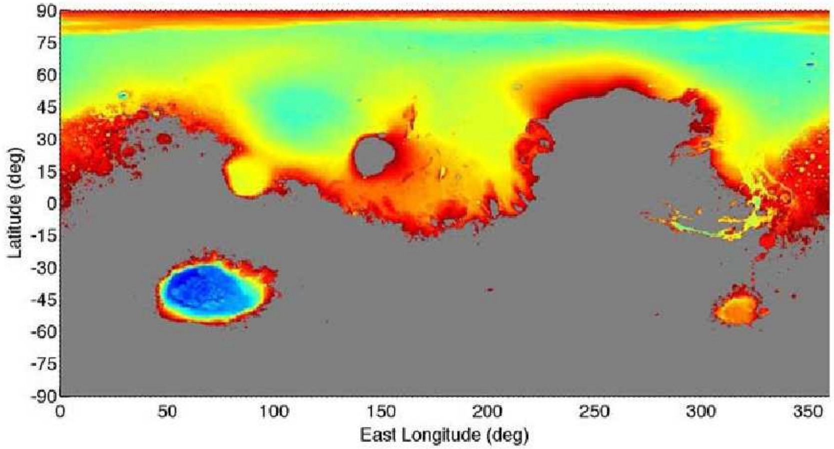
< 2.5 km (90% of Surface)



< 1.0 km (65% of Surface)

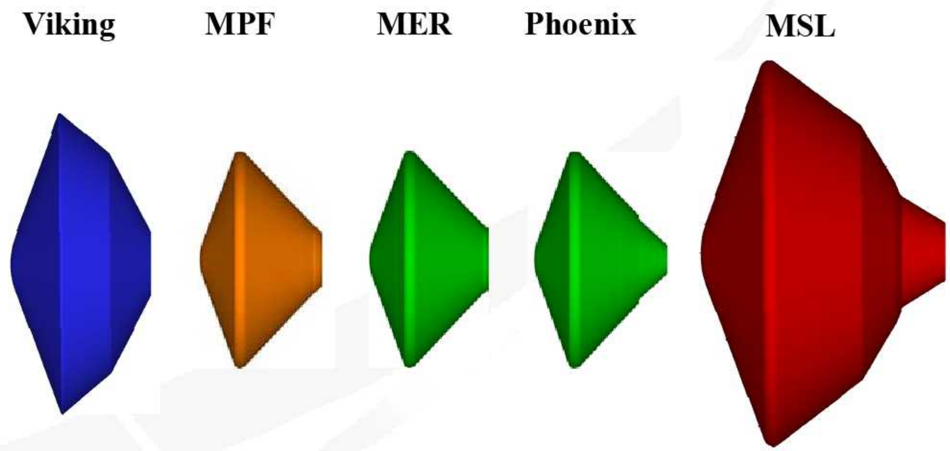


< -1.0 km (45% of Surface)



Mars Heritage Aeroshell - Mission Comparisons

Core Viking Technologies:
70° sphere-cone aeroshell



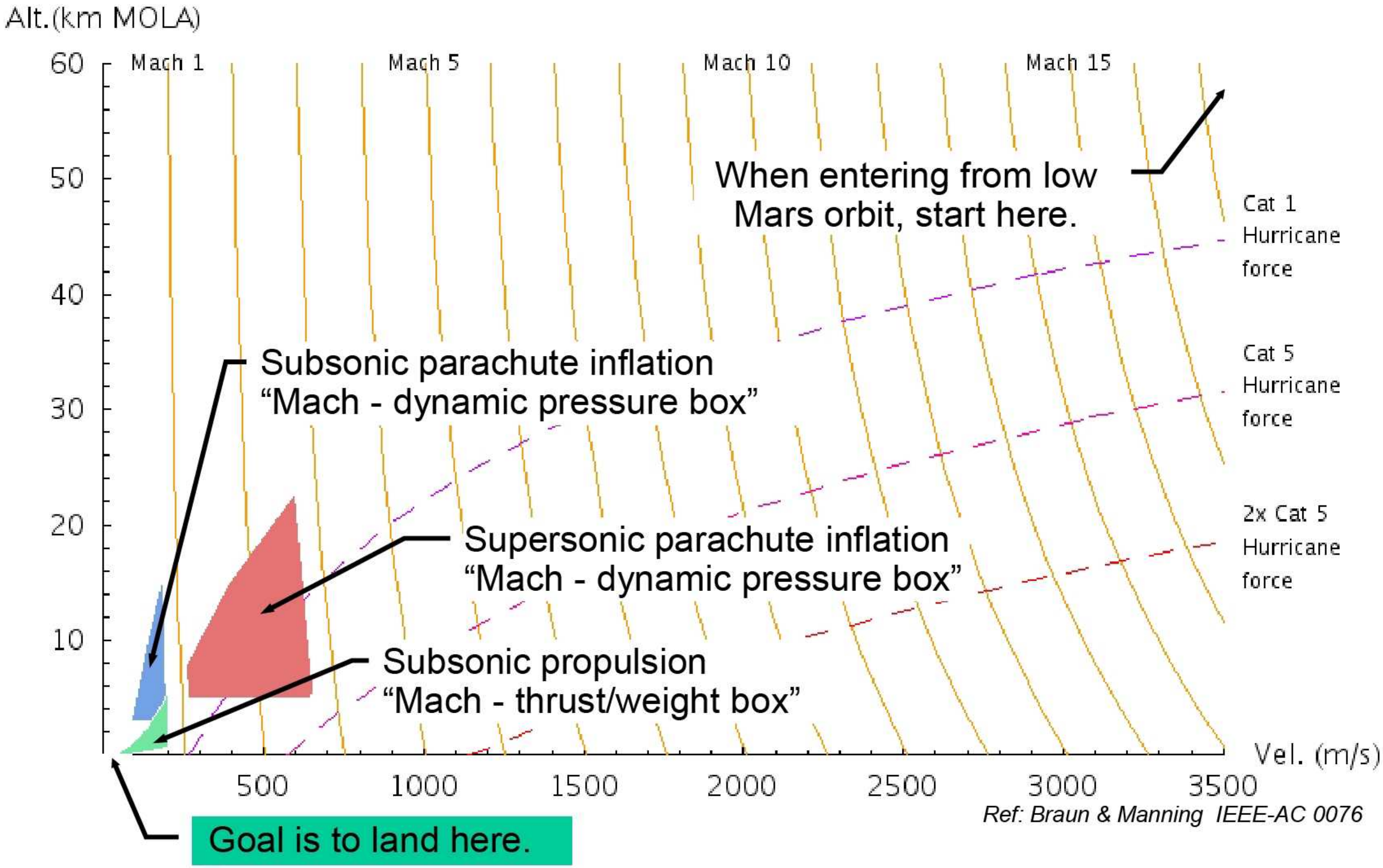
Parameter	Viking	MPF	MER	Phoenix	MSL
Entry Mass (kg) / Ballistic Coeff. (kg/m²)	**980 / 66**	**585 / 63**	**836 / 90**	**603 / 65**	**3257 / 140**
Lander/Rover Mass (kg)	**612**	**11**	**173**	**64**	**850**
Aeroshell Diameter (m)	**3.5**	**2.65**	**2.65**	**2.65**	**4.5**
Angle-of-Attack (deg) / L/D	**11.1° / 0.18**	**0° / 0.0**	**0° / 0.0**	**0° / 0.0**	**-15.5° / 0.24**
Peak Heatrate (W/cm²)	**21**	**106**	**44**	**59**	**<210**
Parachute Diameter (m)	**16.15**	**12.4**	**14.1**	**11.5**	**19.7**
Landing Site Elevation (km)	**-3.5**	**-1.5**	**-1.3**	**-3.5**	**0.0**

Comparison with Previous Missions

Core Viking Techn[illegible]
70° sphere-cone a[illegible]
SLA-561V TPS
Supersonic DBG parac[illegible]

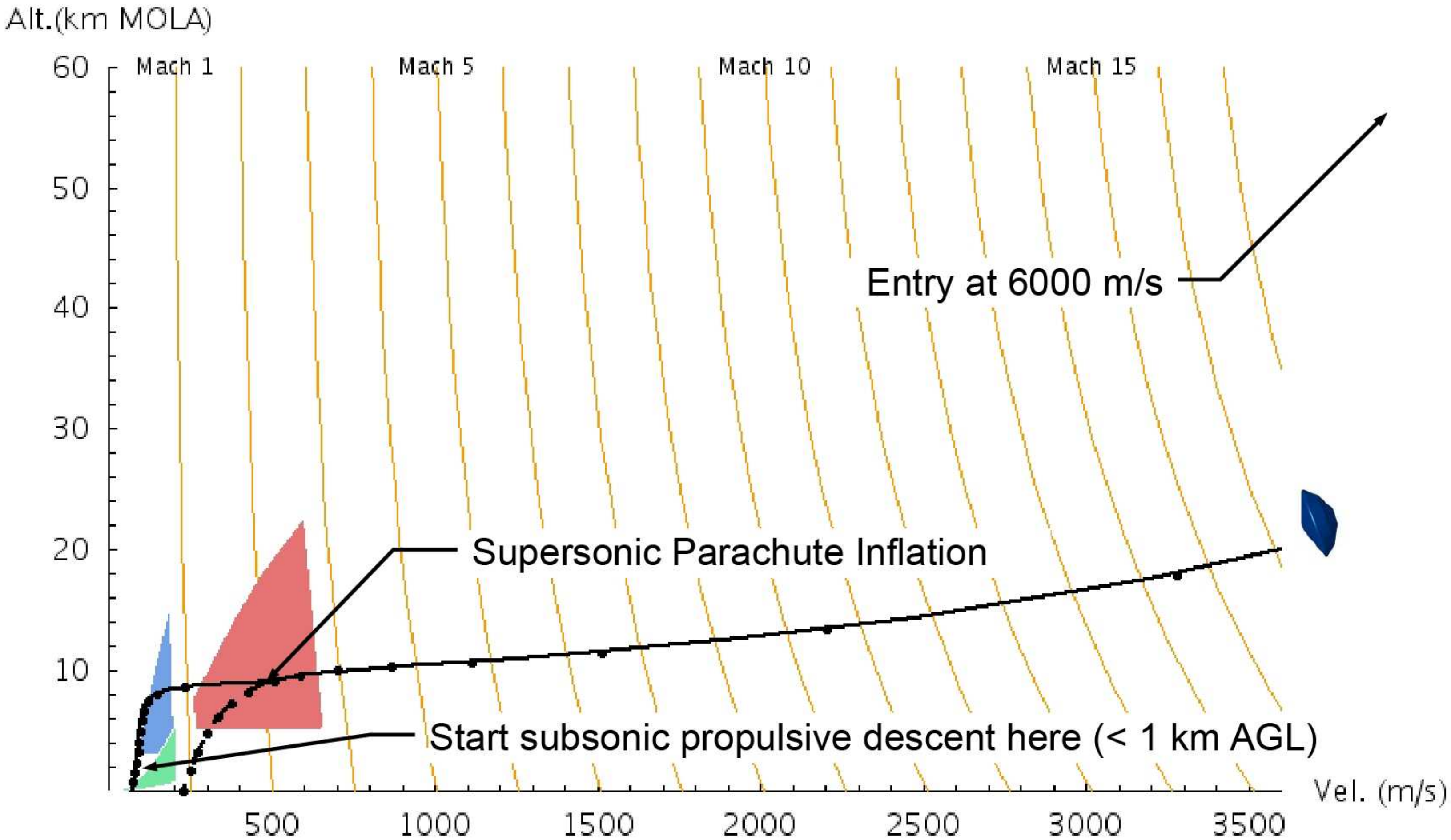
Parameter	[illegible]	[illegible]	[illegible]	[illegible]	Human
Entry Mass (kg) / Ballistic Coeff. (kg/m^2)	[illegible]	[illegible]	[illegible]	[illegible]	100-150 MT/ 150-600 kg/m2
Lander/Rover Mass (kg)	612	[illegible]	[illegible]	[illegible]	40-50 MT
Aeroshell Diameter (m)	3.5	[illegible]	[illegible]	[illegible]	[illegible]
Angle-of-Attack (deg) / L/D	11.1° / 0.18	[illegible]	[illegible]	[illegible]	[illegible]
Peak Heatrate (W/cm^2)	21	106	[illegible]	[illegible]	[illegible]
Parachute Diameter (m)	16.15	12.4	[illegible]	[illegible]	[illegible]
Landing Site Elevation (km)	-3.5	-1.5	[illegible]	[illegible]	[illegible]

EDL Phase Plot – A Handy Way to Visualize EDL

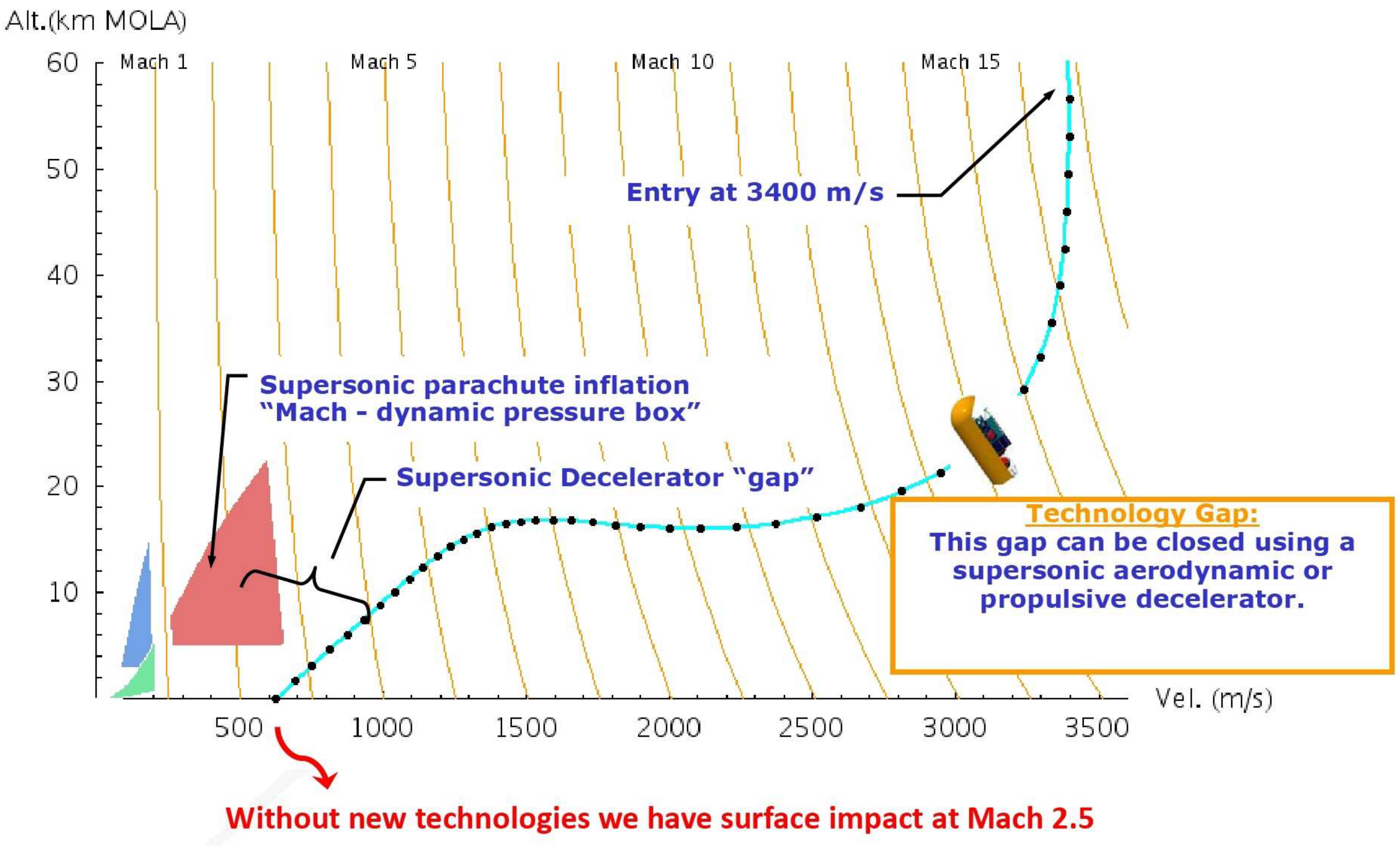


Ref: Braun & Manning IEEE-AC 0076

Robotic program: No gap so far ….



How would Humans Land?



EDL Technology Development

- **Technologies that can help close the “gap”**
  - Rigid Aeroshell
  - Inflatable Aerodynamic Decelerator (IAD)
  - Supersonic Retro-Propulsion
- **Other technologies of interest**
  - Aerocapture
  - Precision Landing
  - Hazard Detection and Avoidance

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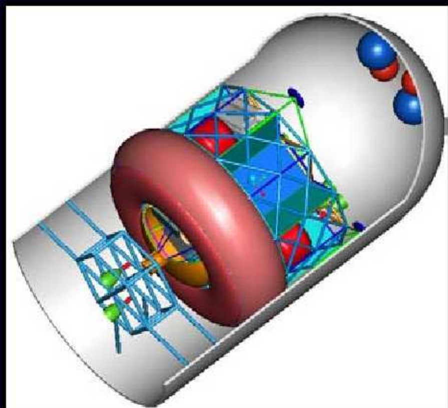
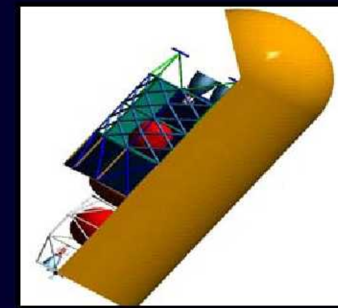
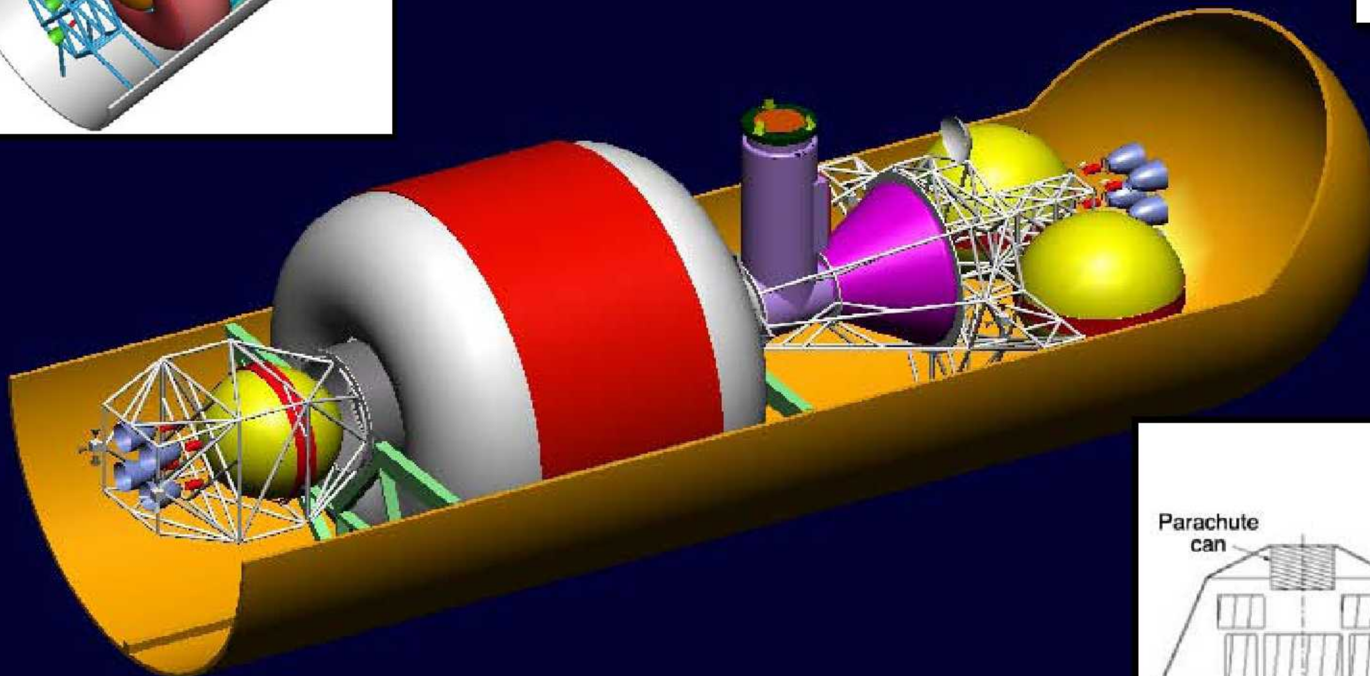
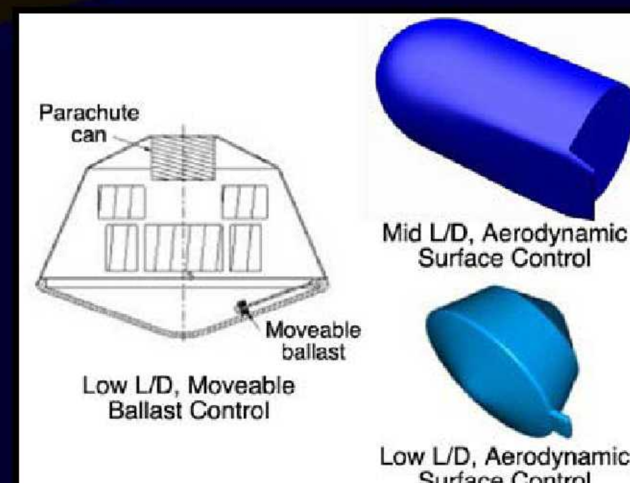
Rigid Aeroshells

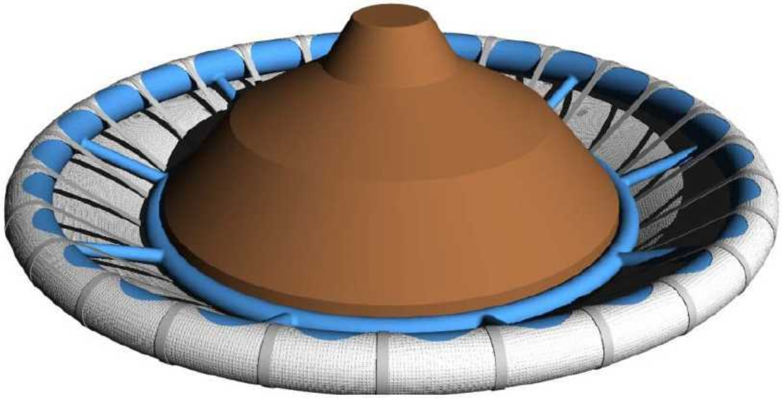


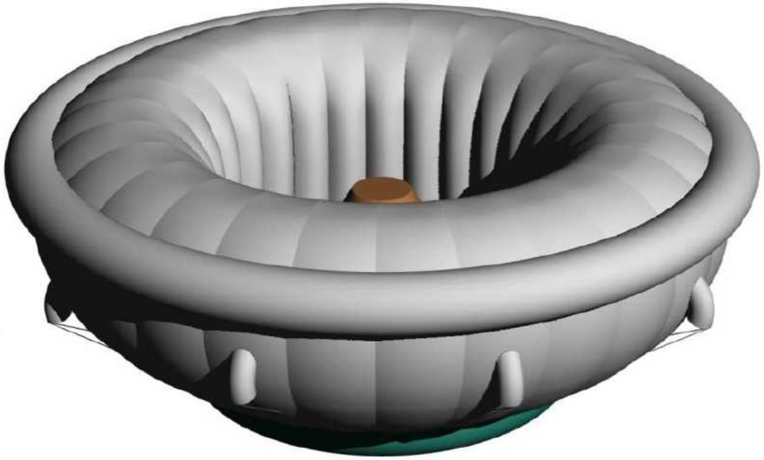




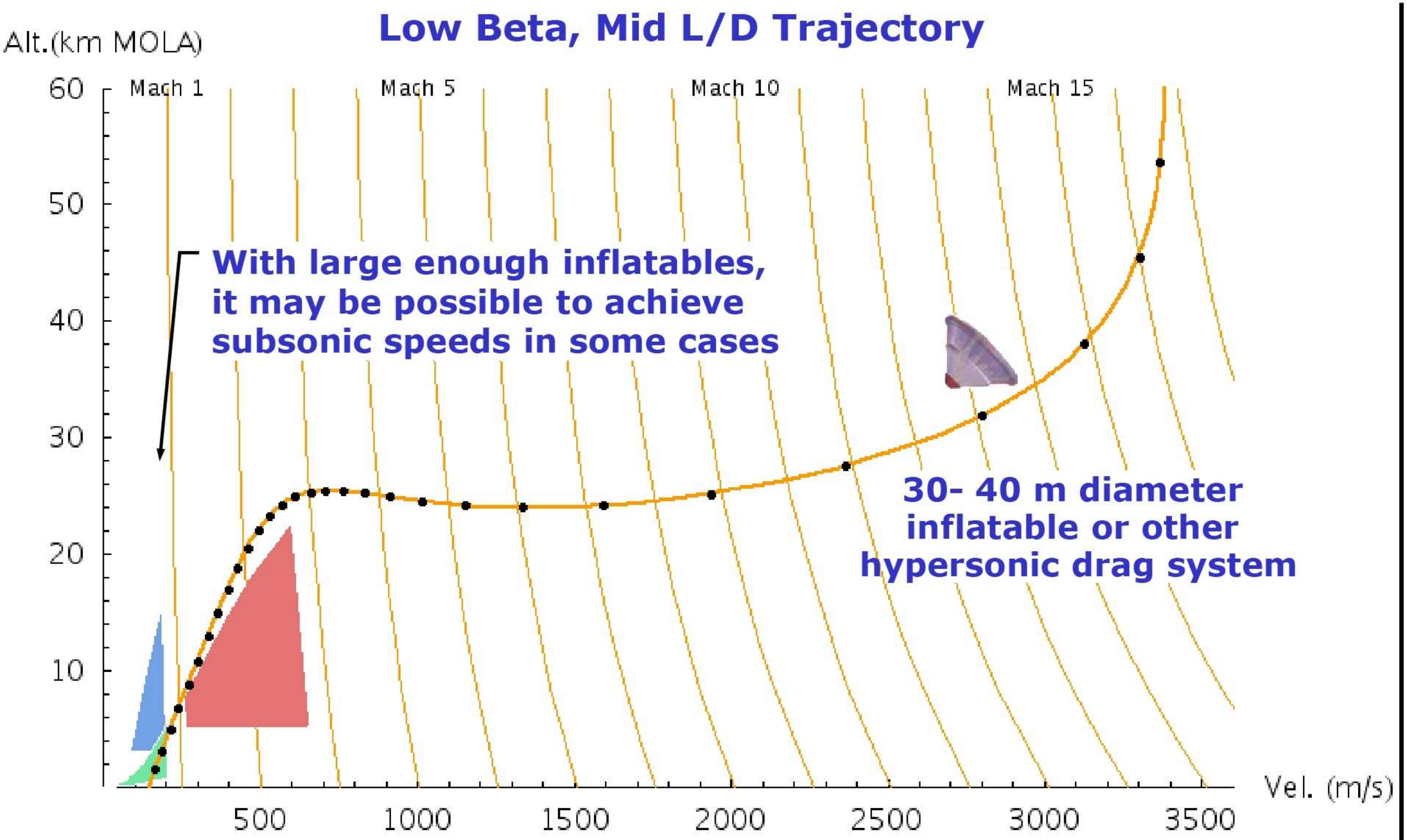


Inflatable Aerodynamic Decelerators





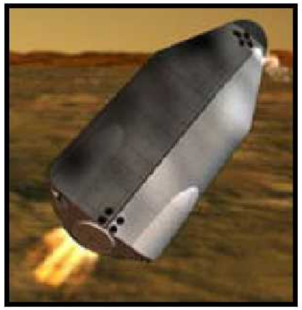
What about Large Inflatable Entry Vehicles? (ballistic coefficient = 50 kg/m² & L/D = 0.3)



Supersonic Retro-Propulsion

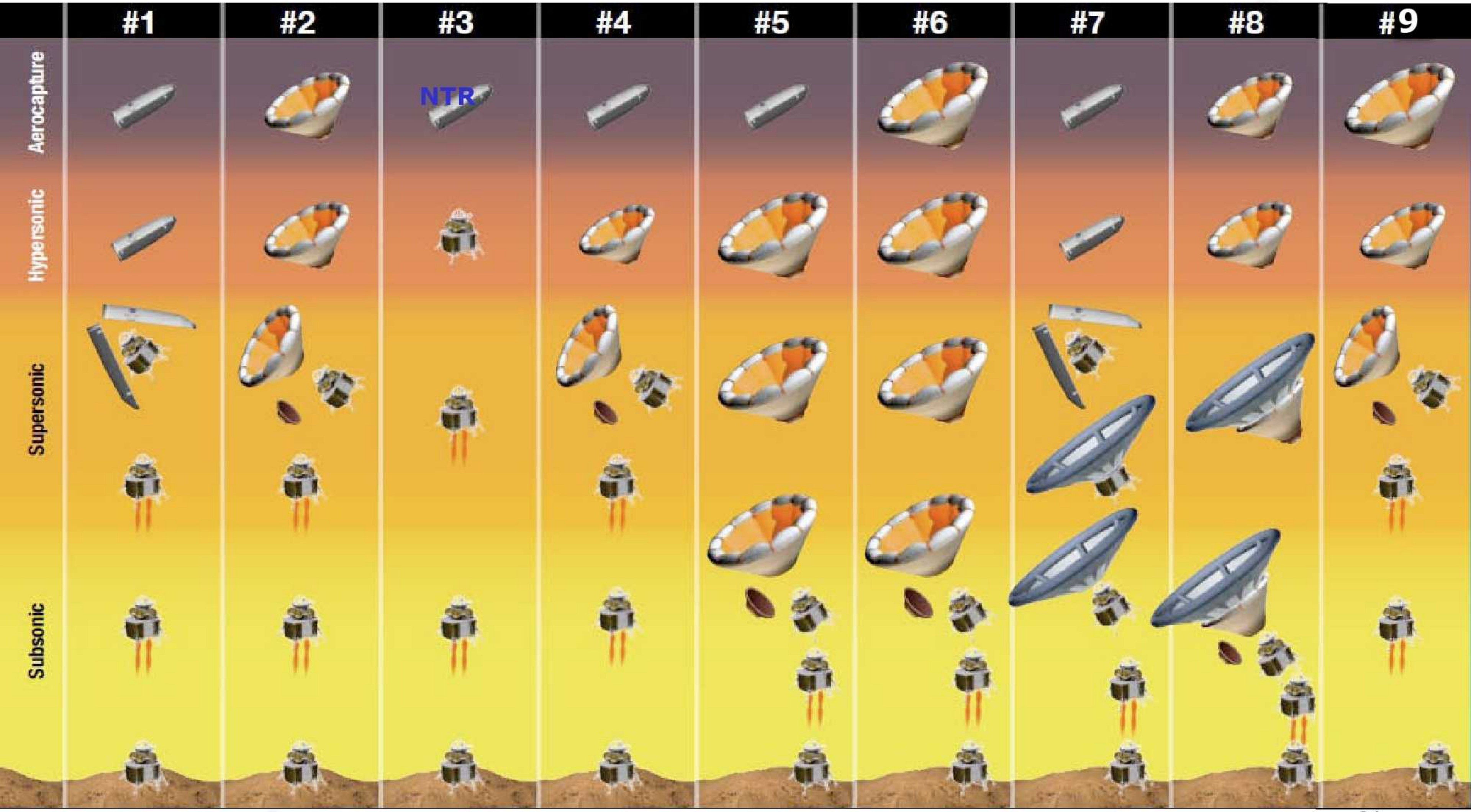
- **Advantages:**
  - More precise landing – aerodynamics / winds now secondary effect
  - Control authority and altitude from Mach > 3 to the ground
  - Fewer complex systems (e.g.parachutes, deployable systems)

- **Disadvantages:**
  - Large propellant mass fractions
  - Aerodynamic stability of the vehicle plume and flow impingements
  - RCS / flow interactions
    - Aerodynamic / propulsion flow interactions
    - Plume / flow aeroheating
  - Surface contamination issues



Potential Exploration Architectures

Some possible combinations…

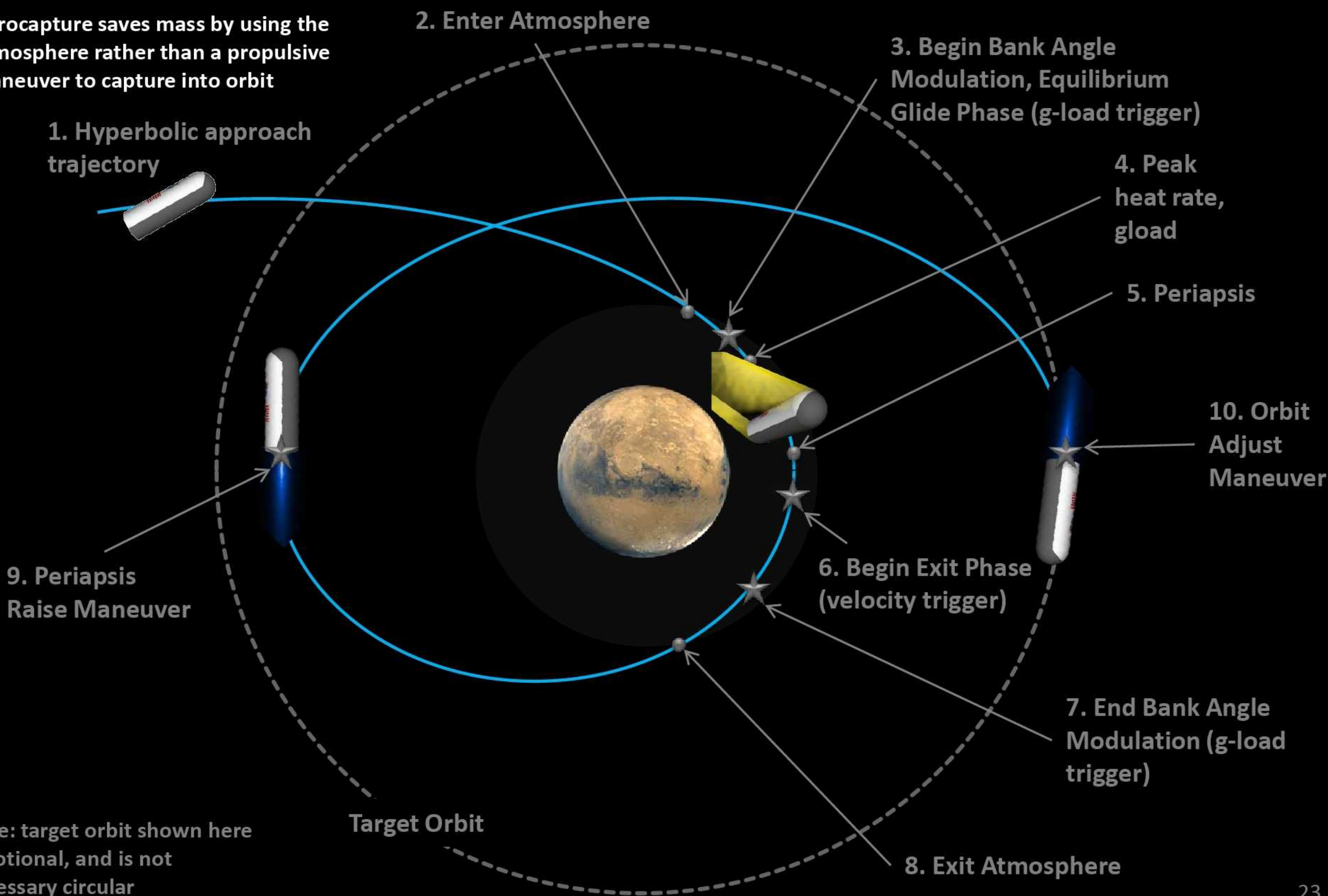


EDL Technology Development

- **Technologies that can help close the "gap"**
  - Rigid Aeroshell
  - Hypersonic Inflatable Aerodynamic Deceleration (HIAD)
  - Supersonic Retro-Propulsion
- **Enabling technology**
  - Aerocapture
- **Risk reduction and performance enhancement**
  - Precision Landing
  - Hazard Detection and Avoidance

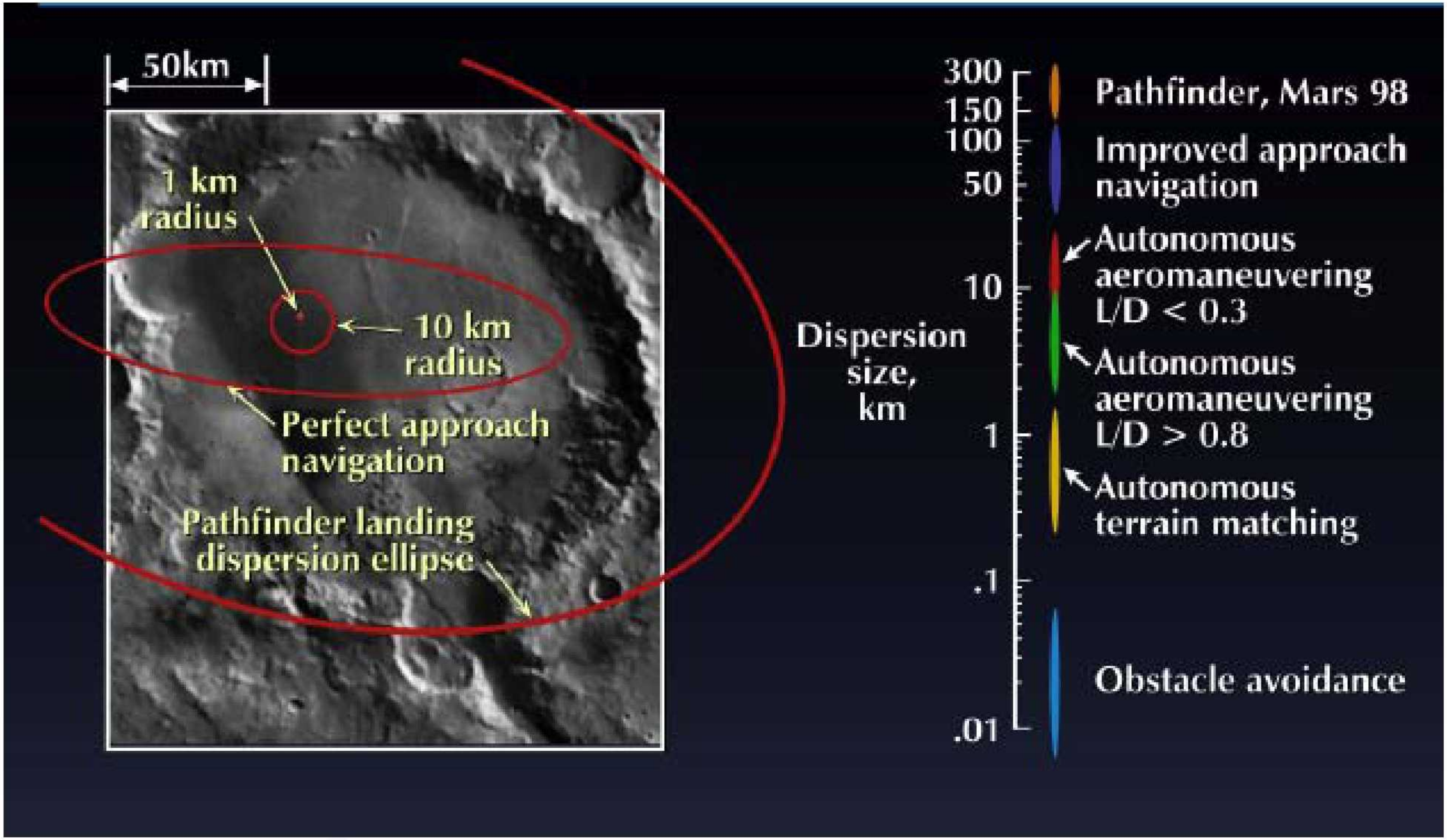
Aerocapture

Aerocapture saves mass by using the atmosphere rather than a propulsive maneuver to capture into orbit



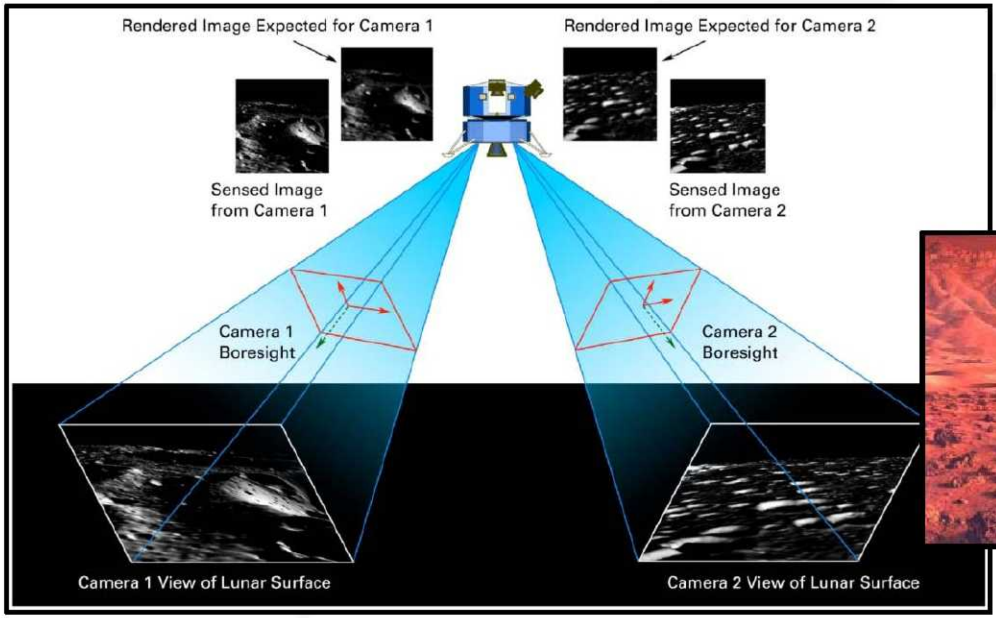
Note: target orbit shown here is notional, and is not necessary circular

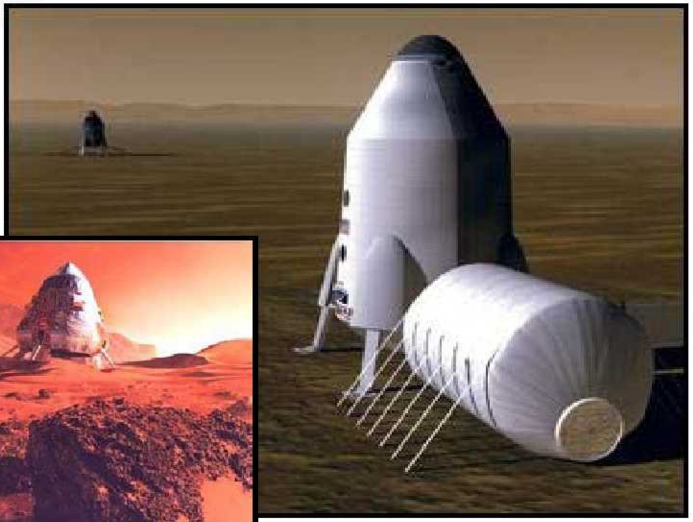
The Case for Precision Landing, Hazard Avoidance, and Pinpoint Landing



Precision Landing

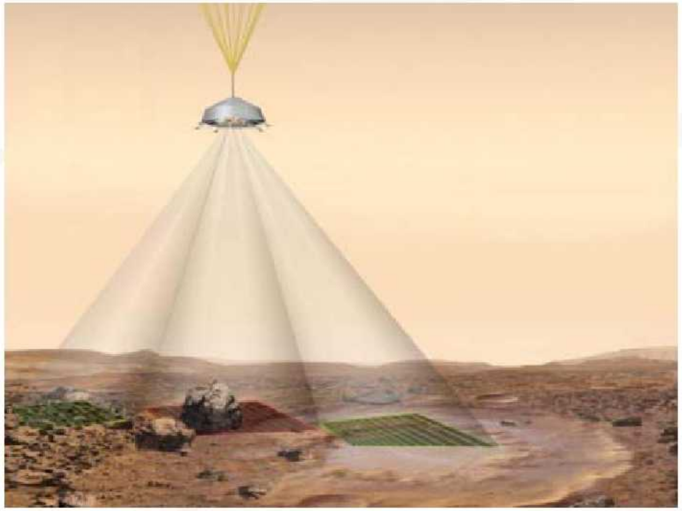
- Precision landing is the capability to land very accurately
- Requires very good knowledge of the vehicle state (navigation) at the right time, in addition to the ability to correct for state errors (guidance and control)
- A combination of sensors including star tracker, inertial measurement unit (IMU), altimeter, and velocimeter are used for state estimation
- Terrain Relative Navigation is a technology being developed for the Moon and Mars which may enable a precision landing level of performance

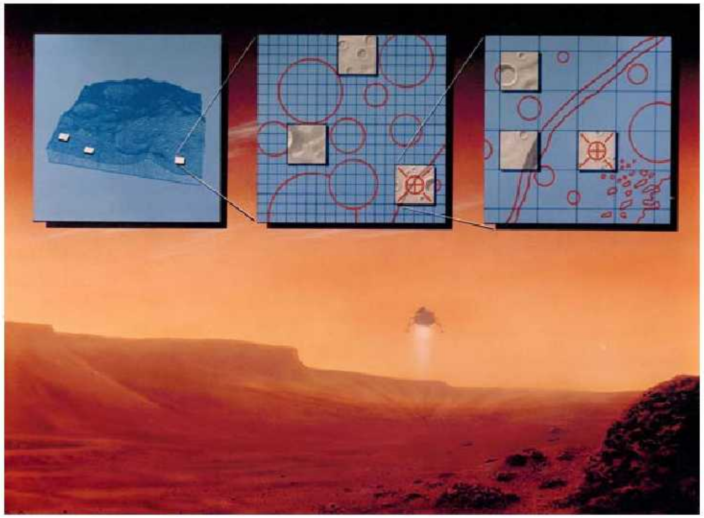




Hazard Detection and Avoidance (HDA)

- HDA is the capability to detect and avoid hazards during the landing
- An onboard hazard map is developed real time during the descent using flash LIDAR
- The flash LIDAR returns a 3-D image of the landing area which contains higher resolution information of the landing area than currently possible using orbit reconnaissance
- An updated landing point is then selected (either automatically or via crew intervention) and the vehicle re-targets to the new landing point



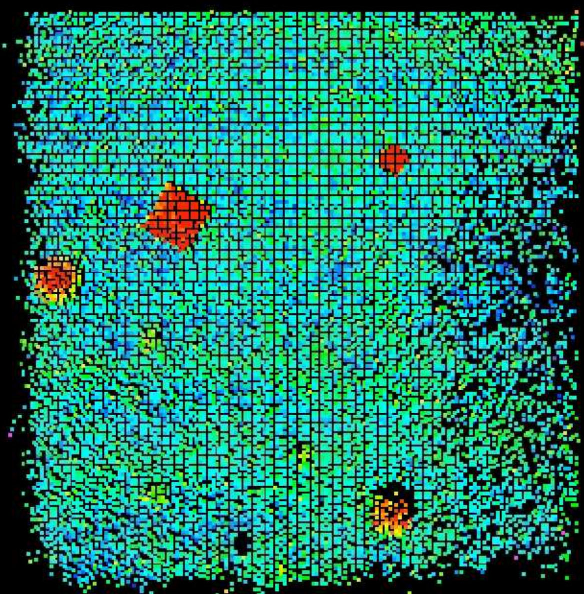


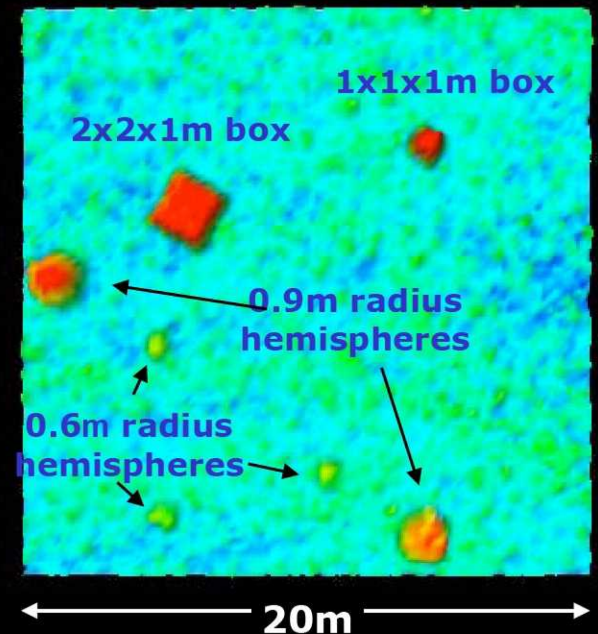
Example Flash Lidar Image

128x128 pixels
430m Range
7˚ Off Nadir

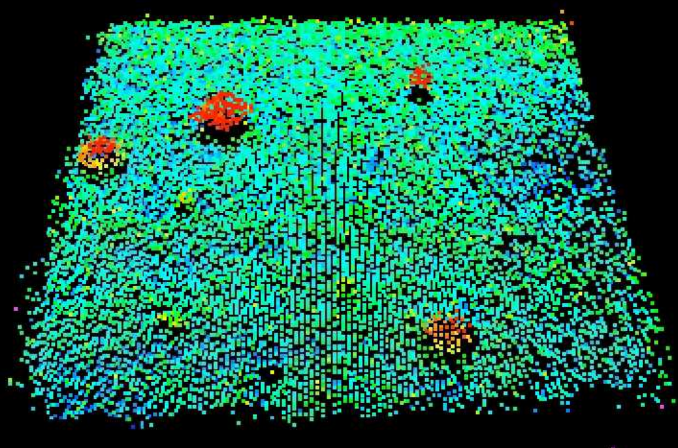
3D Points | **Elevation Map**

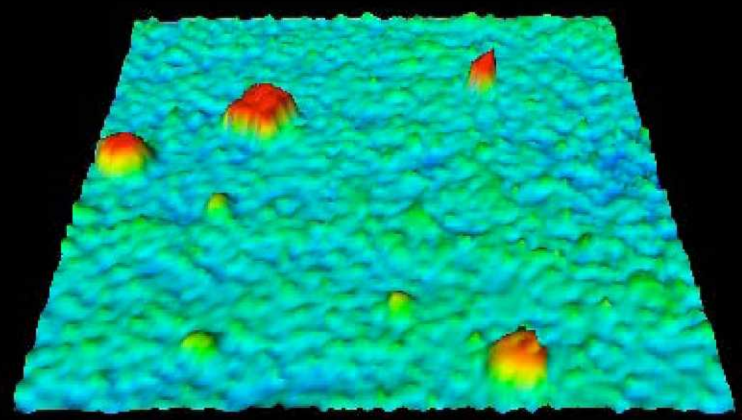
Top View



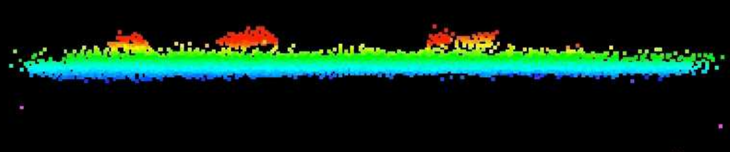


Oblique View





Side View



Conclusion

- **Current state of the art has a gap for large robotic (> 1 MT) and human Mars EDL**
- **NASA is developing a number of promising technologies that may eliminate the gap and enable future missions to Mars**
- **In addition, a general planetary capability for Safe and Precise Landing is being developed under the ALHAT (Autonomous Landing and Hazard Avoidance Technology) project**

BACKUP

Low Ballistic Coefficient Hypersonic Decelerator Development Challenges

- **For 50-100 MT entry masses we need a 20-40 m diameter aeroshell.**
- **Large uncertainties (unknown-unknowns):**
  - Lift control (how to modulate drag) with large density uncertainties
  - Dynamic stability issues at supersonic and transonic conditions
  - Subsonic position correction
  - Subsonic separation mechanism

  Specifically for an Inflatable Hypersonic Decelerator:
  - Lift control
  - RCS
  - Fluid structures interactions
  - Light weight flexible TPS with large radiative heating

  Specifically for a Rigid On-orbit-deployed Hypersonic Decelerator:
  - Mass fraction of Aeroshell & deployment device

- **Again, there are NO Earth analog for these systems.**
  - NASA, Russia and ESA have tested very small scale inflatable Earth entry systems (IRVE, IRDT)