Considerations for Landing Accuracy and Landed Mass

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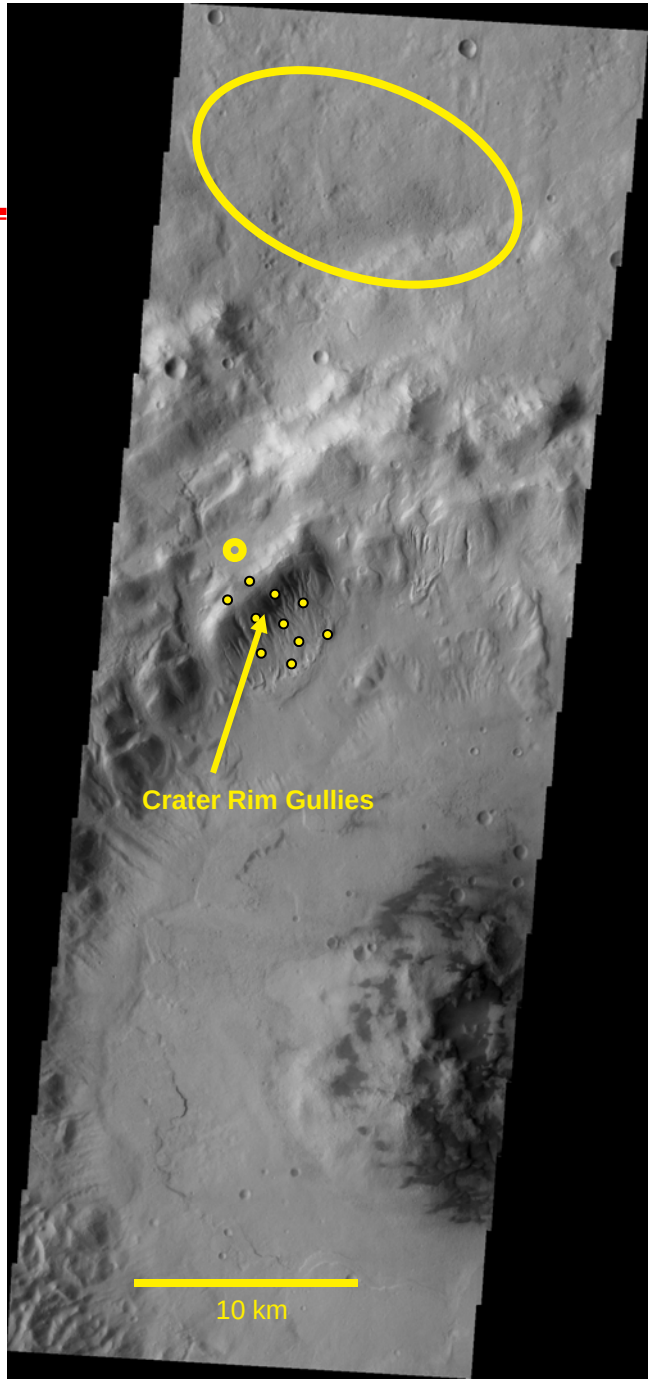
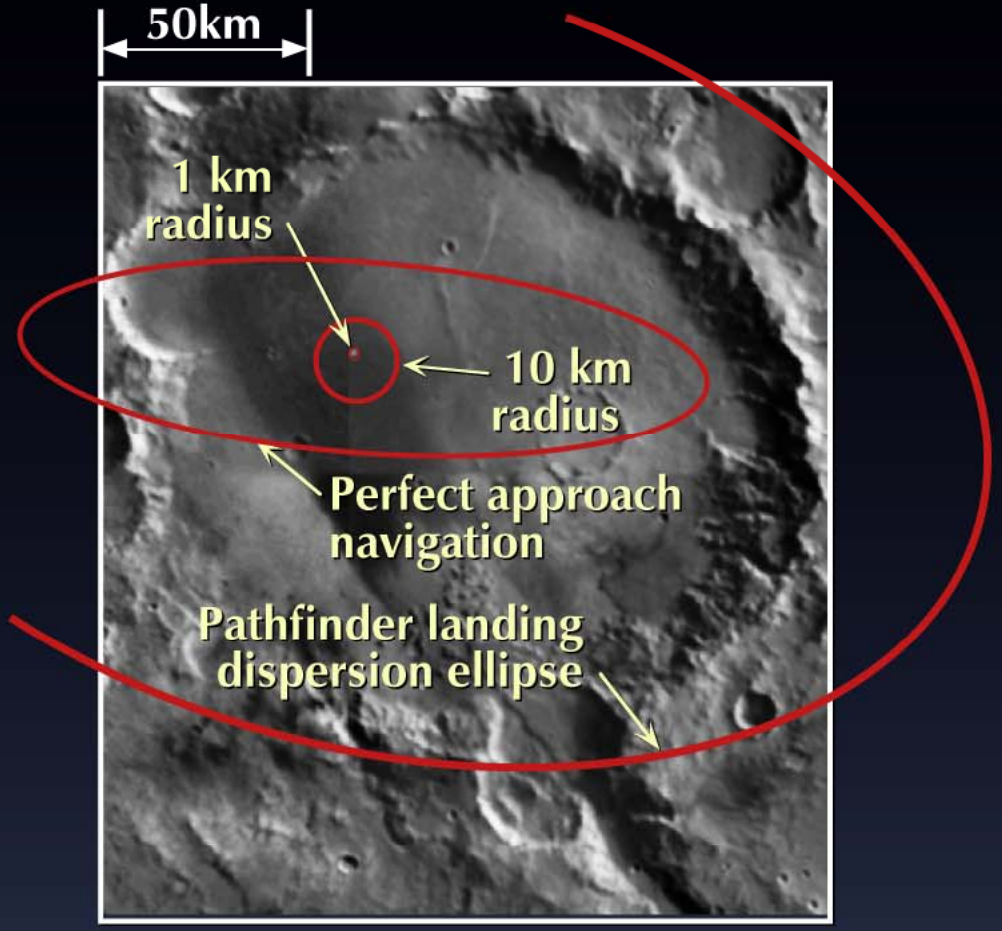
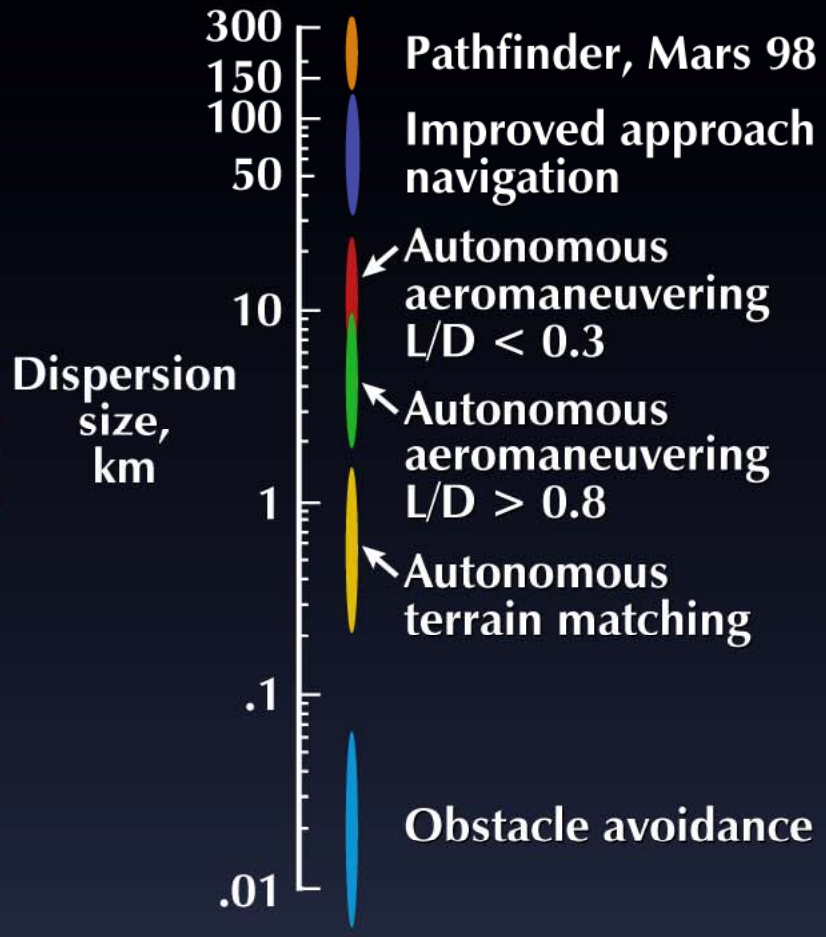
Approaches to Accessing High-Risk Terrain

- Precision landing (< 10 km, 3-sigma)
  - Target safe landing region within mobility range of landed asset
- Pinpoint landing (10s of meters, 3-sigma)
  - Allows landing in close proximity to desired surface feature
  - Target small “safe zone” within larger unit of hazardous terrain
- Shotgun approach
  - Multiple small penetrators blanket target feature
  - Reliance on statistics of large numbers to provide success probability



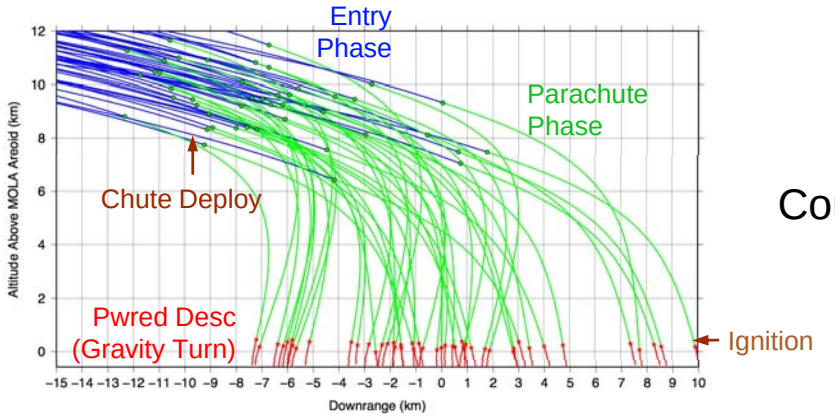
Landing Footpring Improvement Through Precision Landing Technology





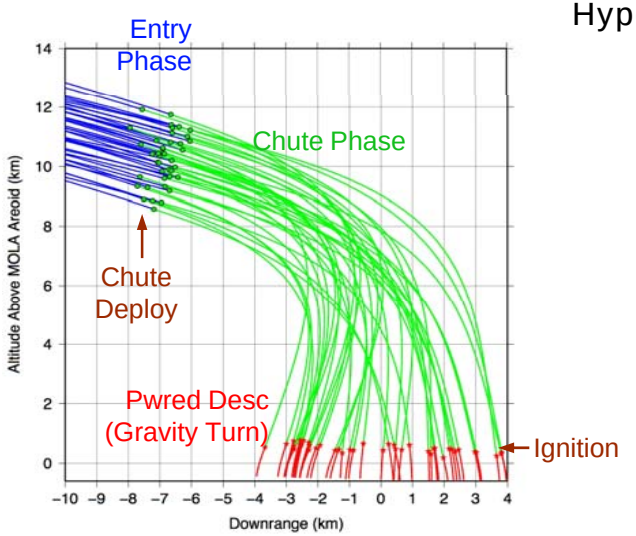
Courtesy Bobby Braun, GT

Strategies to Improve Landed Accuracy

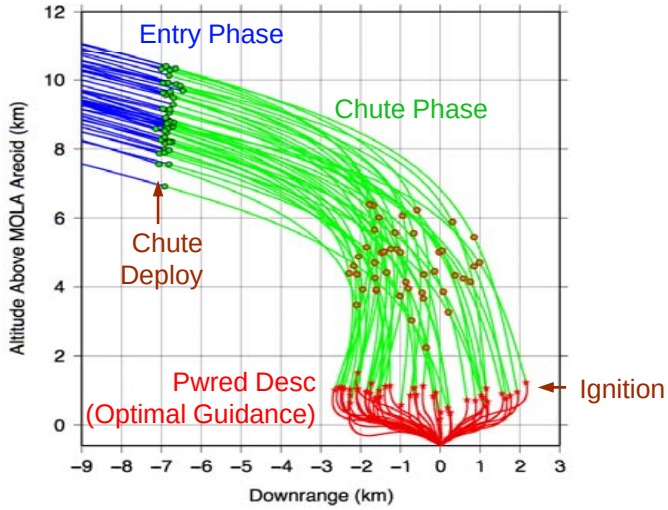


Courtesy Aron Wolf, JPL

MSL ~**10km** from target
Hypersonic Guidance



Improved chute deploy strategy + improved entry att. knowledge => **~3 - 4km** from target



Add terrain-relative nav + powered descent guidance => **≤~100m** from target

U.S. Mars Mission EDL Summary (Successful and Planned Missions)

Mission	***Viking***	***MPF***	***MER***	***Phoenix***	***MSL***
Entry from	Orbit	Direct	Direct	Direct	Direct
Inertial entry velocity, km/s	4.7	7.3	5.5	5.6	< 6.0
Inertial entry flight path angle, deg	-17	-14.1	-11.5	-13	-15.2
Ballistic coefficient, kg/m2	64	63	94	65	115
Entry mass, kg	992	584	830	600	2920
Hypersonic guidance	Unguided	Unguided	Unguided	Unguided	Guided
Lift-to-drag ratio	0.18	0.18	0	0	0.24
Parachute deploy altitude, km	5.8	9.4	7.4	9.8	6.5
Touchdown rock height capability, cm	20	50	50	30	100
Touchdown slope capability, deg	15	>30	>30	16	>15
Touchdown mass, kg	590	360	539	350	800
Landing ellipse major axis, km	280	200	80	100	20
Landing ellipse minor axis, km	100	100	12	21	20
Landing site elevation, km MOLA	-3.5	-2.5	-1.4	-4	2

Adapted from Braun & Manning, “Mars Exploration Entry, Descent and Landing Challenges”

Approximate Limits on Landed Mass Using Current Technologies

Assumptions

- MER packaging density within aeroshell assumed to be an upper limit
- 70 deg sphere-cone aeroshell configuration
- 6 km/s entry velocity
- Atmospheric opacity ~ 0.3
- 19.7 m parachute deployed at Mach 2.1
- Need 15 s timeline from Mach 0.8 to altitude of 1 km (start of propulsive descent)
- Lift-up L/D of 0.18 to maximize parachute deployment altitude

MOLA Surface Elevation (km)	Maximum Ballistic Coefficient (kg/m2)	Maximum Landed Mass for 2.65 m Diameter Aeroshell	Maximum Landed Mass for 4.5 m Diameter Aeroshell
-2	160	350	1000
0	135	300	850
2	115	250	750

Credit: Braun & Manning, “Mars Exploration Entry, Descent and Landing Challenges”