MARS SCIENCE LABORATORY

MSL EDL Performance and Environments

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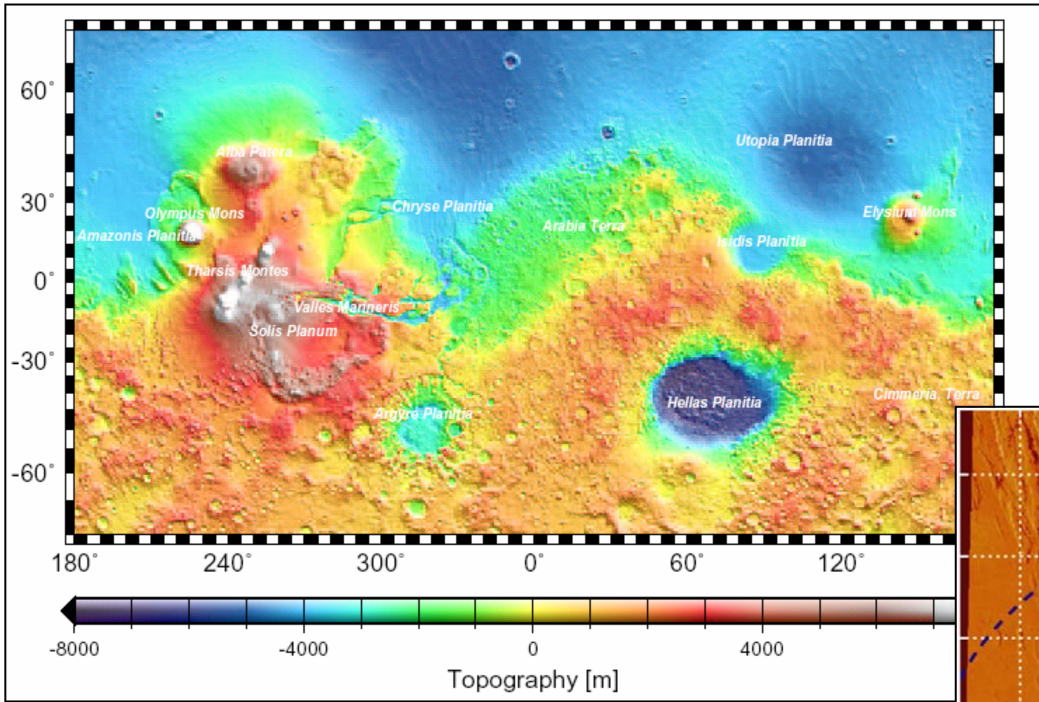
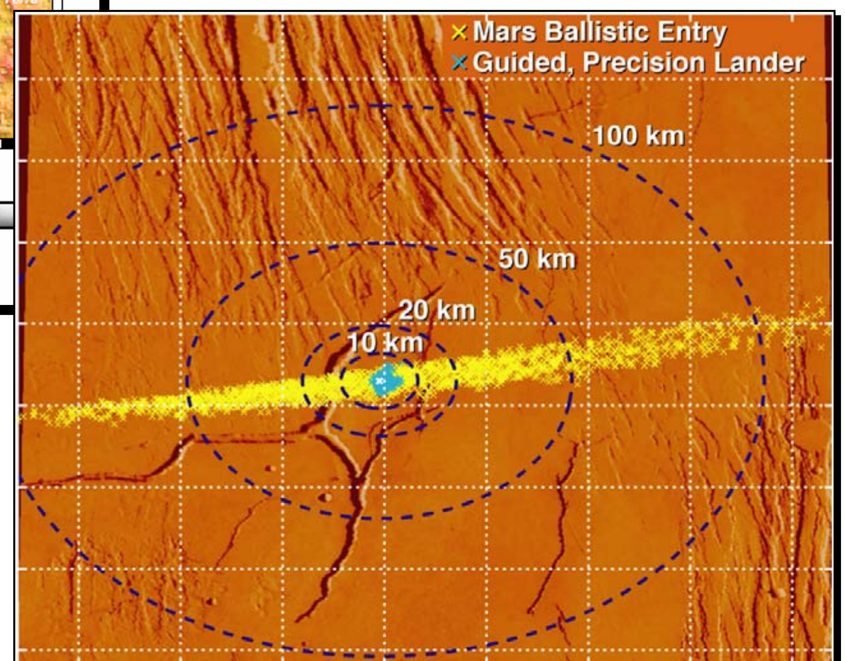
High Altitude and Precision Landing



~51% of Mars is below 0 km
~90% of Mars is below 2.5 km

All Mars landers to date have landed at altitudes below 0 km

- Number of possible landing sites – Scales with ellipse size
  - 200 km – <10 Sites
  - 100 km – ~200 Sites
  - 10 km – >>1000 Sites
- Precision landing – 1st step toward pinpoint landing



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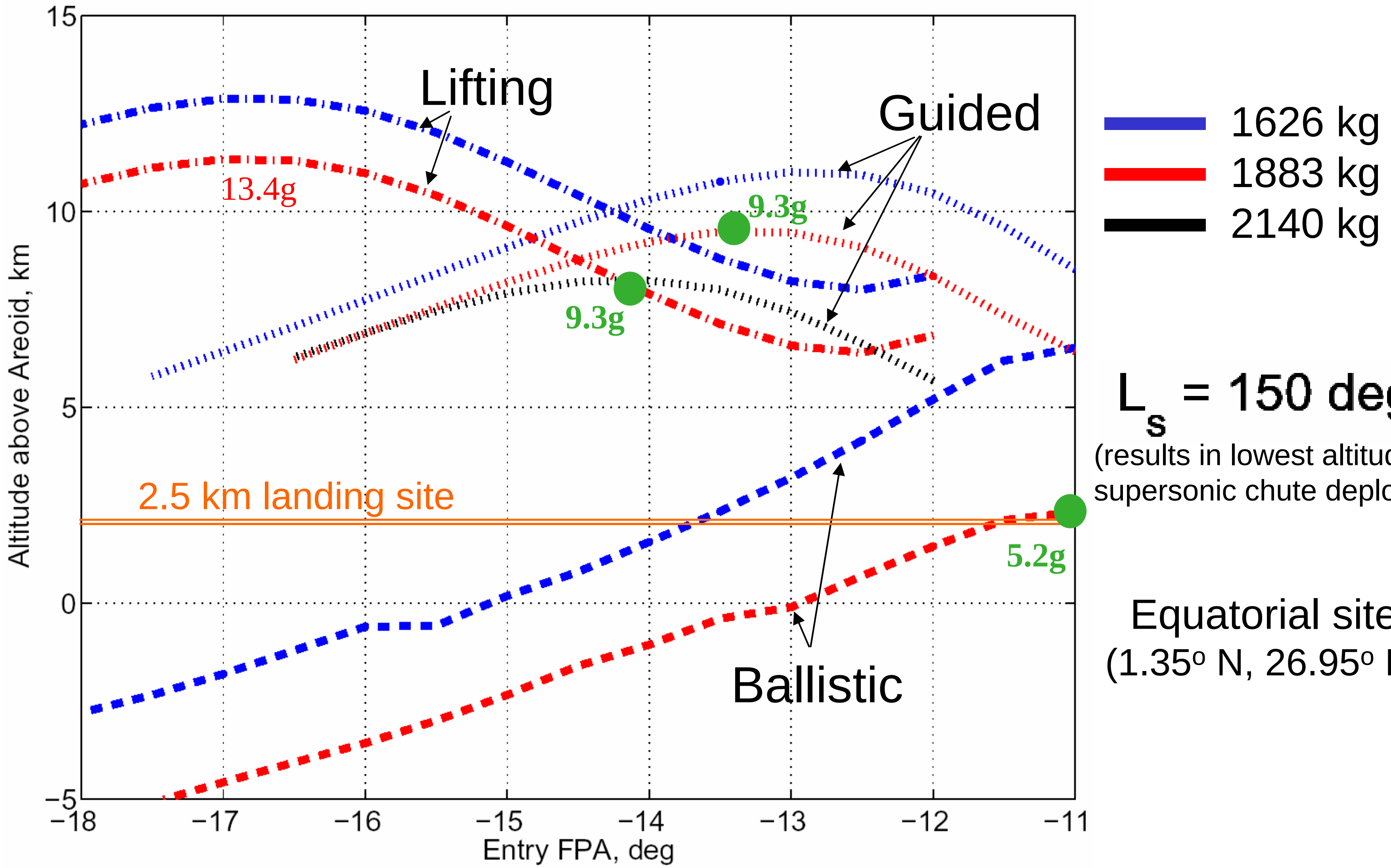
Guided, Lifting, Ballistic Trade

Supersonic Chute Deploy Altitude
Ballistic, Lifting, Guided Comparison



L_s = 150 deg
(results in lowest altitude at supersonic chute deploy)

Equatorial site
(1.35° N, 26.95° E)

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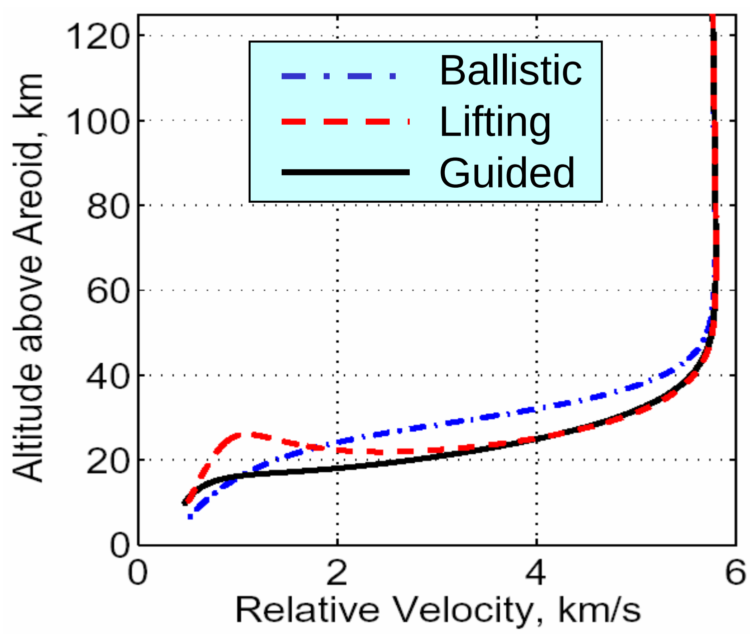
Guided, Lifting, Ballistic Landing Footprint Video

Transition Indicator at Peak Heating Point on Trajectory



Entry velocity = 6 km/sec

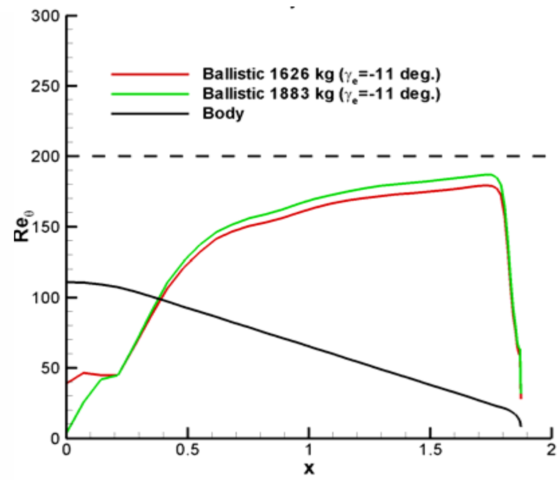
Mass = 1883 kg

Ls = 150 deg

Ballistic entry FPA = -11 deg

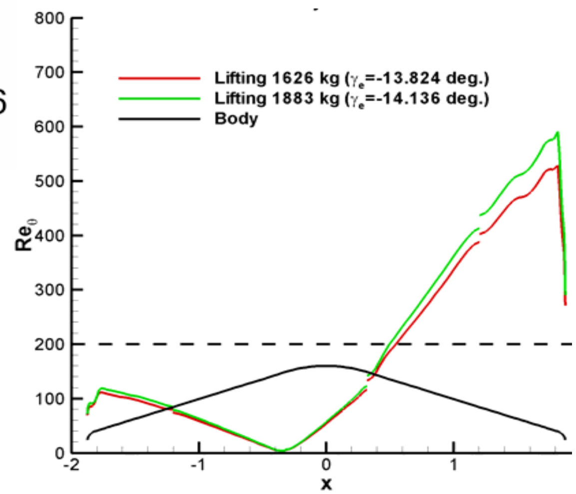
Lifting entry FPA = -14.136 deg

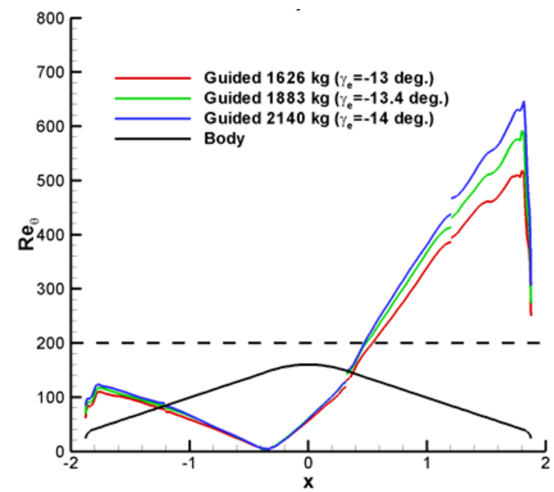
Guided entry FPA = -13.4 deg



Ballistic

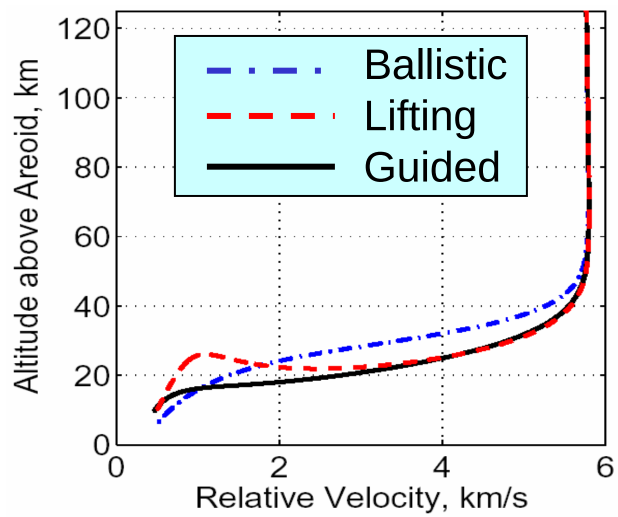
- No natural transition at pk heating.
- Transition soon after pk heating & trans due to roughness would need to be assessed

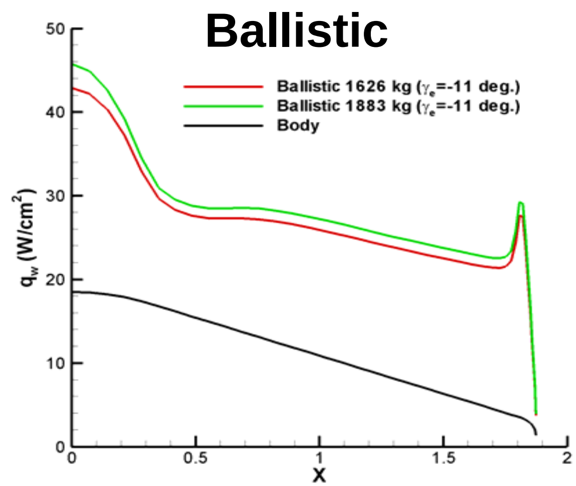




Lifting, Guided: Turbulent heating prior to peak heating point on trajectory is predicted for each case

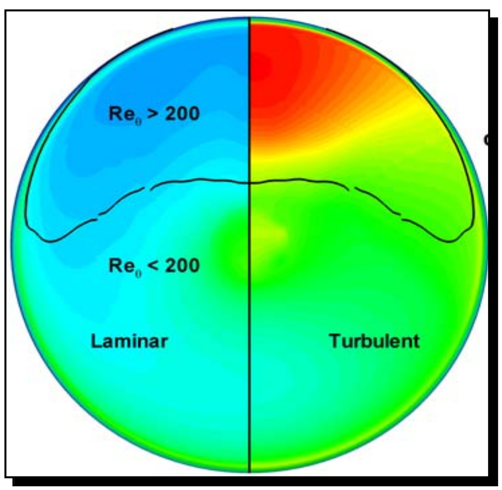
Aeroheating at Peak Heating Point on Trajectory Nominal, No Uncertainty Included

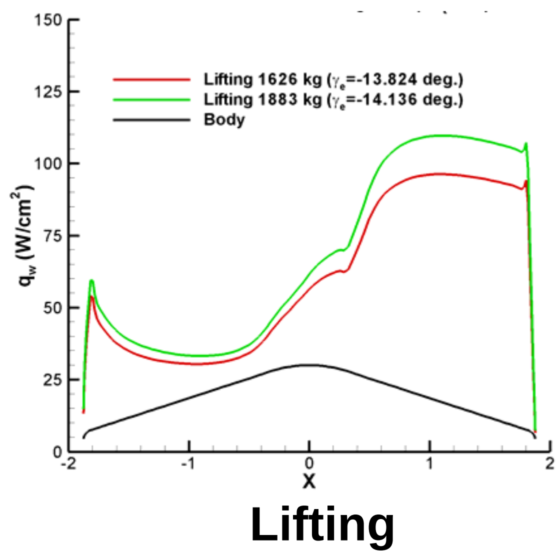


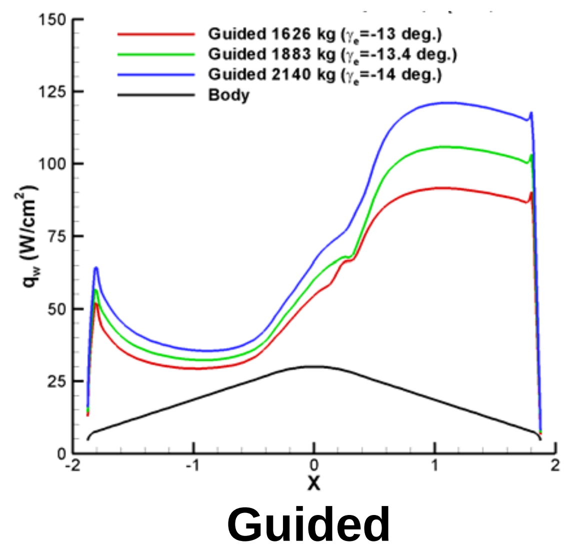


Ballistic – stagnation point heating; lower uncertainties

Lifting, Guided – lee side transition on heatshield; increased uncertainties







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Comparison to Previous Missions

MSL aeroheating analysis is challenging compared to Viking, MPF, and MER

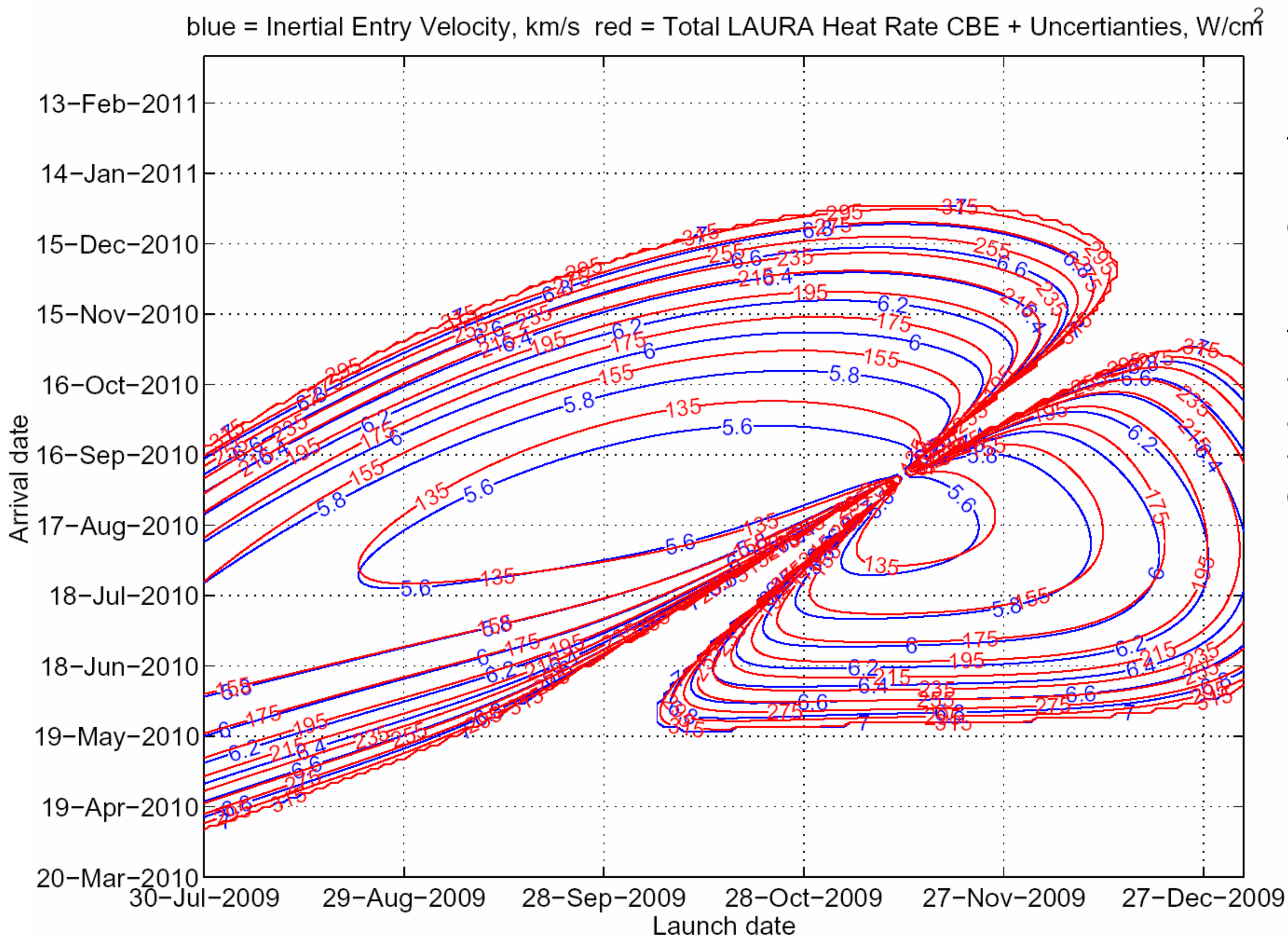
- Combination of ballistic coefficient (110 kg/m^2), angle-of-attack (11 deg.), larger aeroshell (3.75 m) promotes turbulent transition prior to peak heating that was not predicted or observed in previous missions
- Previous Mars missions did not experience turbulent transition before peak heating, and thus environments were defined by well-known stagnation point heating levels

Vehicle	Entry Velocity (km/sec)	Aeroshell Diameter (m)	Angle of Attack (deg)	Ballistic Coefficient (kg/m^2)	Heat Rate w/o Uncertainty (W/cm^2)	Location of Peak Heating	Turbulent Transition Before Peak Heating
Viking	4.5	3.5	11	63.7	24	Nose	No
MPF	7.5	2.65	0	62.3	118	Nose	No
MER	5.5	2.65	0	89.8	50	Nose	No
MSL	5.5-6.0	3.75	11	110	95	Flank	Yes

Pork Chop Plots
- EDL Performance for Mission Design

Max Heat Rate Est (CBE+Uncert) W/cm2

1883 kg Guided Entry, Equatorial Site (1.35° N, 26.95° E)



Turbulent aeroheating indicator plotted with entry velocity in mission design space

Turbulent aeroheating
- increases approximately with V^4
- only very weakly dependent on density

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Nominal Super Chute Deploy Alt Above MOLA (km)

1883 kg Guided Entry, Equatorial Site (1.35° N, 26.95° E)

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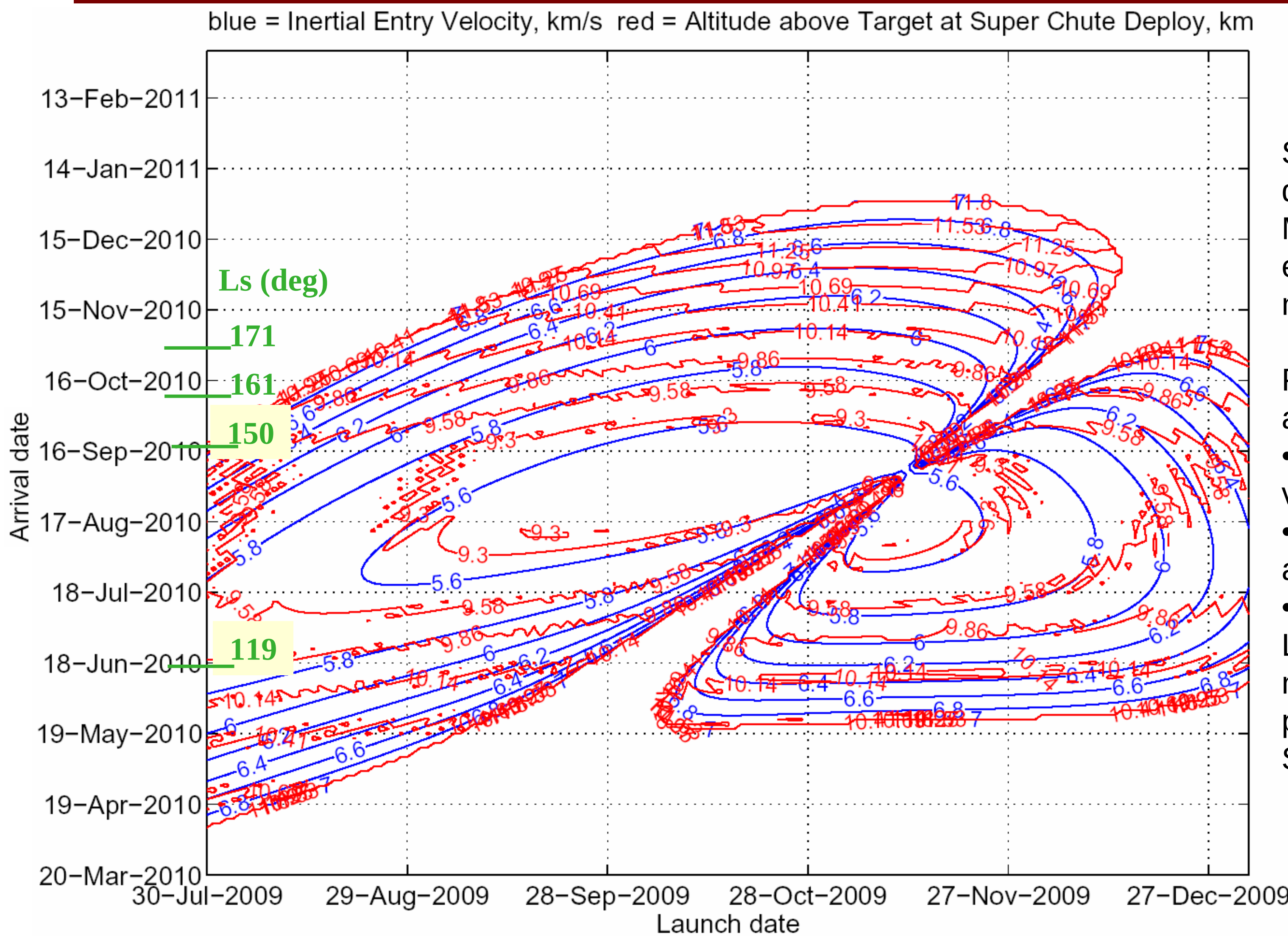

Supersonic parachute deploy altitude above MOLA plotted with entry velocity in mission design space

Parachute deploy altitude

- increases with velocity
- increases with atmospheric density
- is a minimum near Ls = 150 deg (near minimum of Mars pressure cycle in South)

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Monte Carlo

MSL Option M2 Entry, Descent and Landing

Nominal Timeline (Configuration 04-07 1883 kg, October 27, 2010 Entry)

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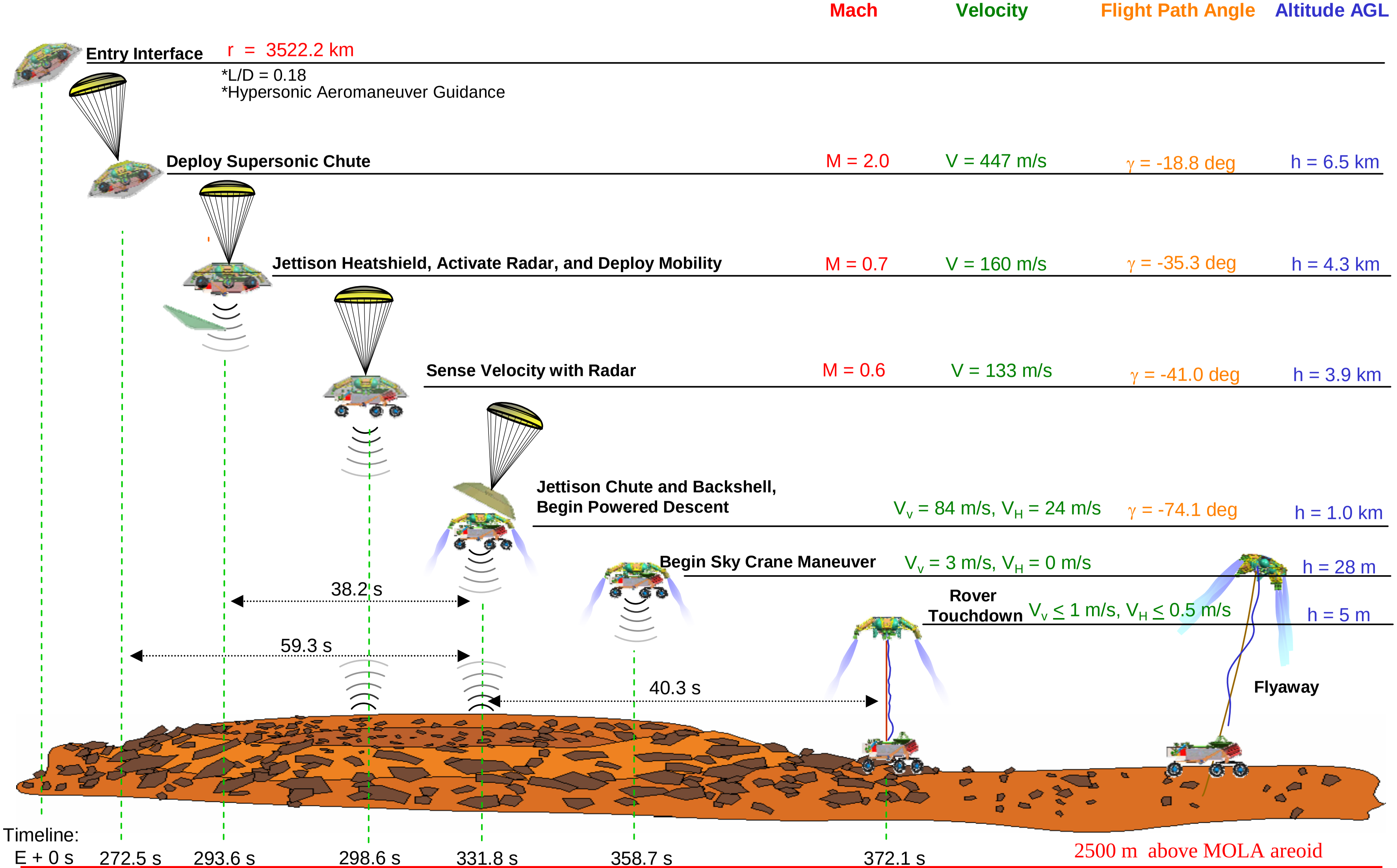

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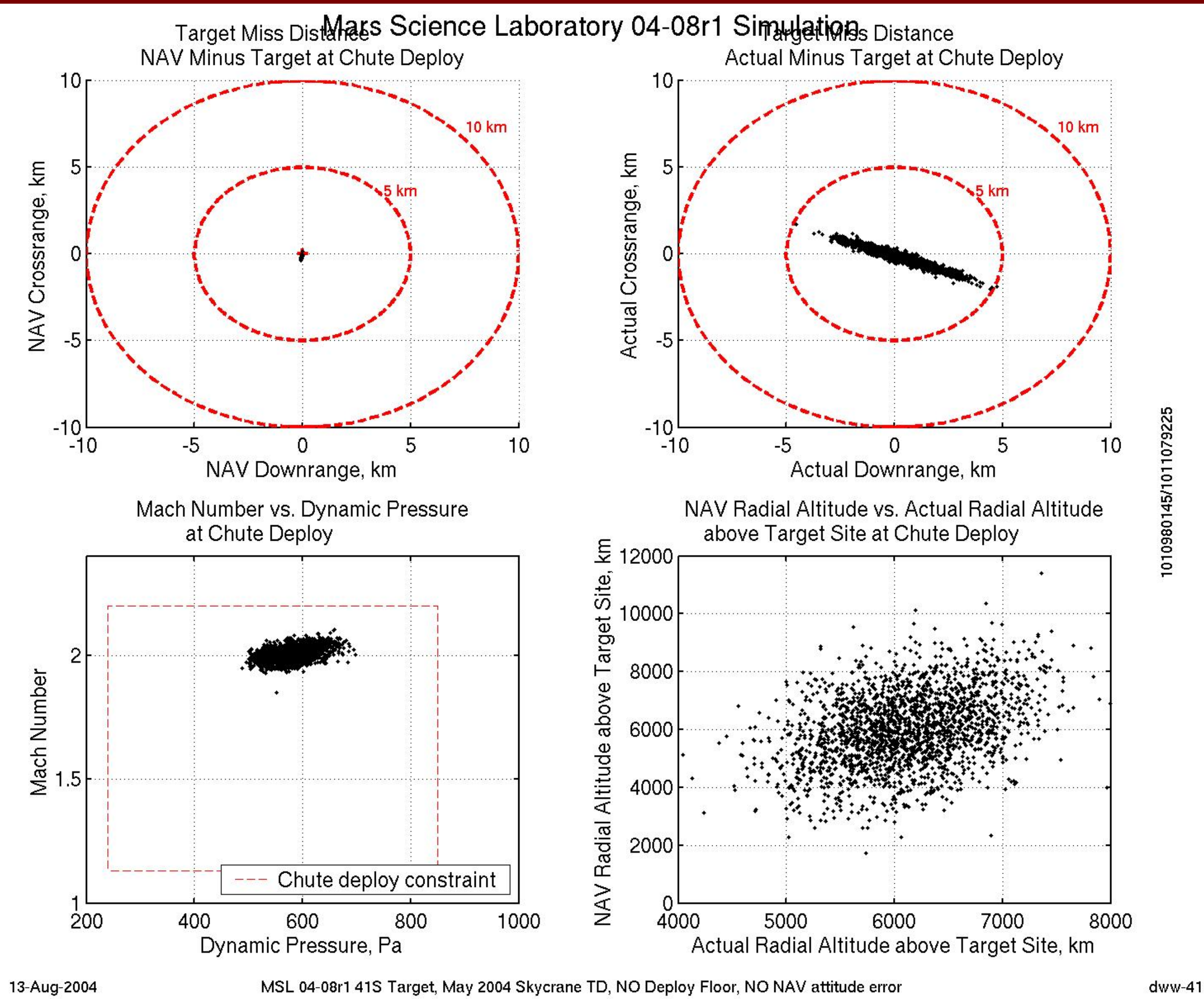
S. Striepe - NASA LaRC

Entry Performance

04-08rev1, zero initial attitude knowledge errors



Nav range at supersonic chute deploy = .34 km 99.87%

Actual range at supersonic chute deploy = 4.9 km 99.87%

100% of cases meet parachute deploy constraints

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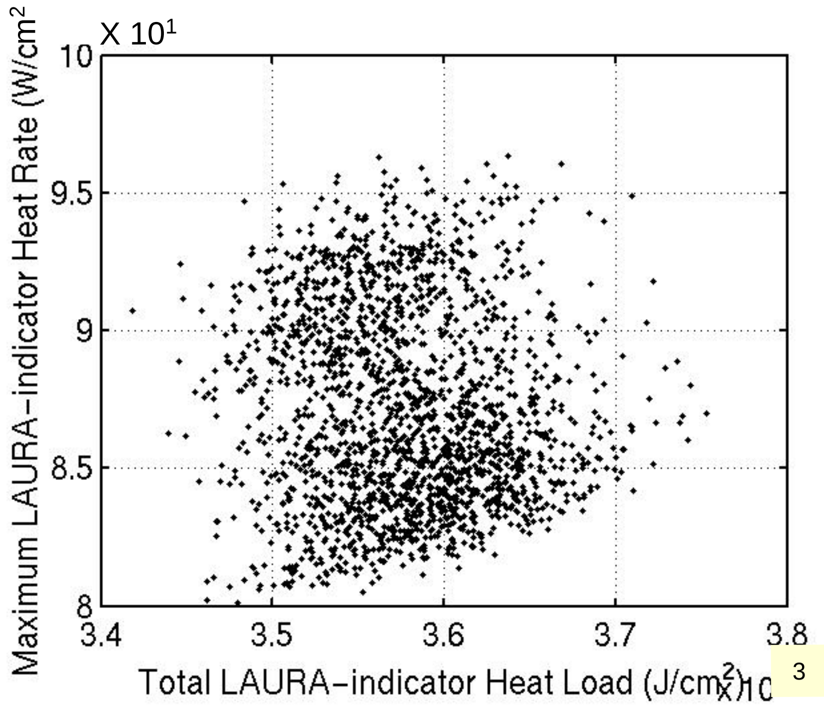
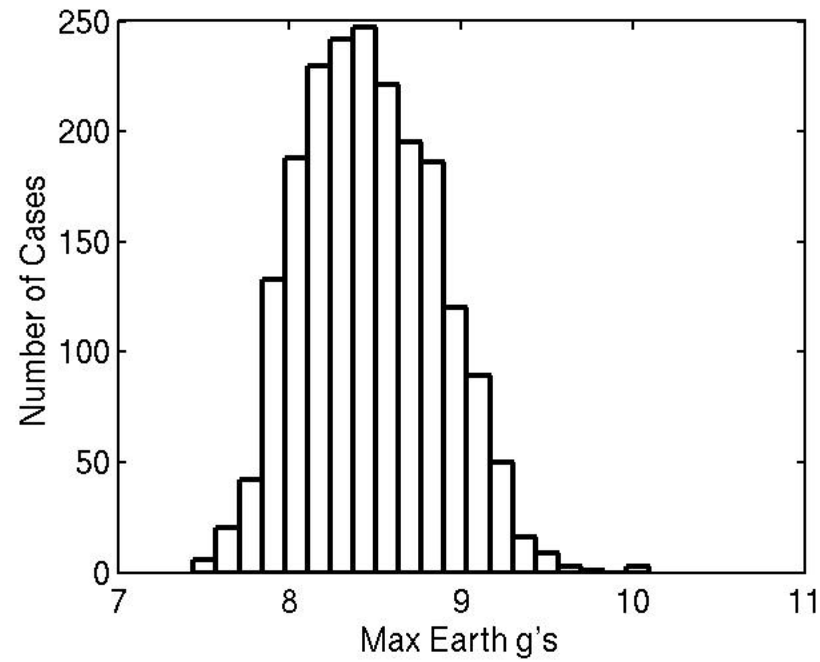
Entry Aeroheating and Entry g's

04-08rev1, zero initial attitude knowledge errors





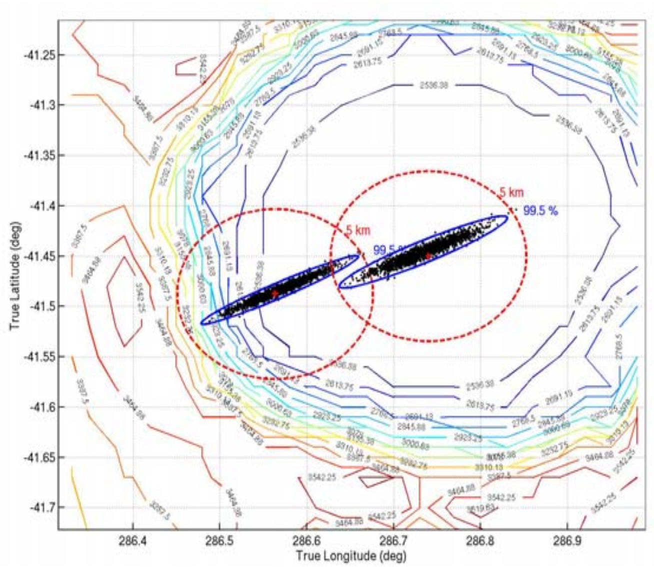
- **Heat rates and loads are CBE's. Add 50% uncertainty.**
- **Note: Aeroheating and entry g's may increase for alternate entry states, Ls, landing sites, for increased timeline margin, etc.**

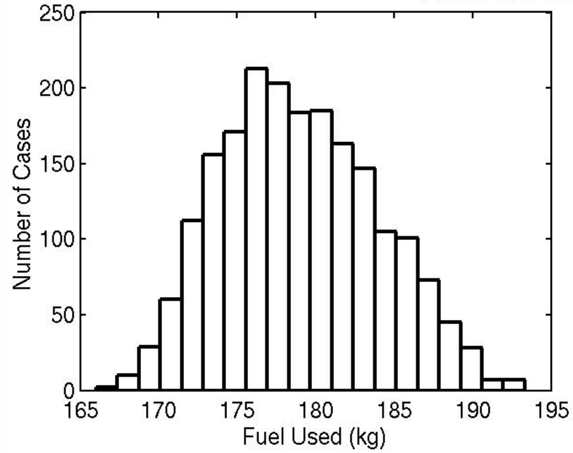
Terminal Descent

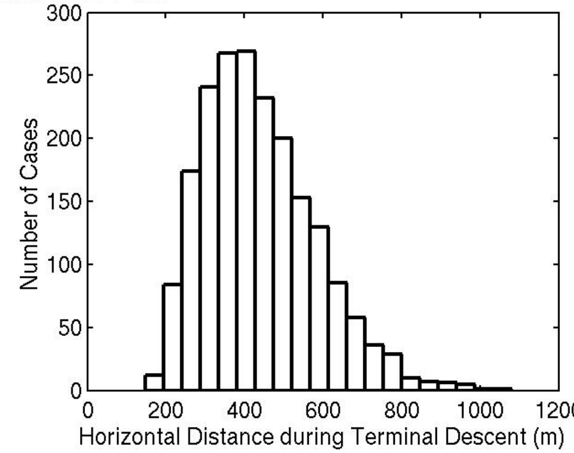
04-08rev1, zero initial attitude knowledge errors

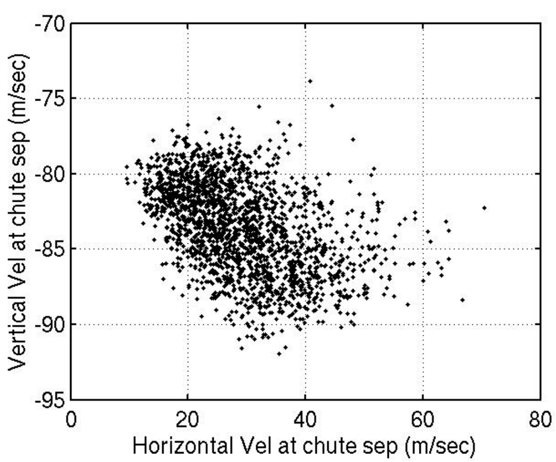
100% touch down successfully with vertical vel < .75 m/s

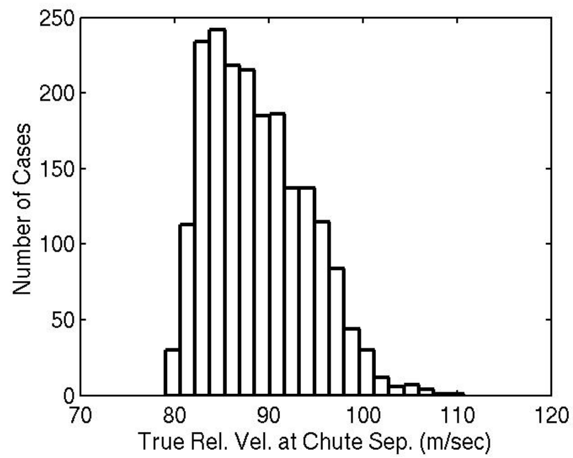
Fuel use less than 219 kg powered descent allocation

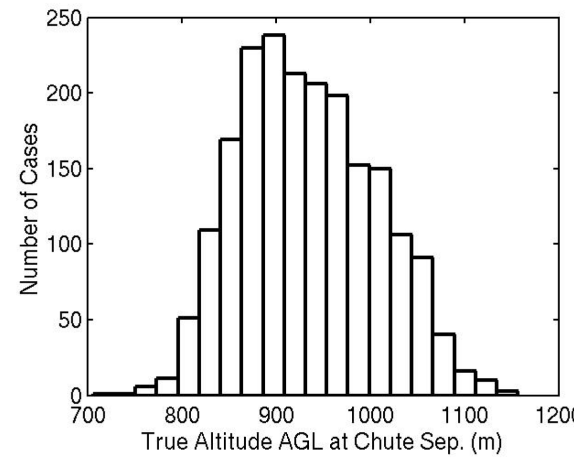












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Summary

- **Guided entry results in significant reduction in range to target errors at touchdown, with range errors at parachute deploy <10km.**
  - With adequate control authority, guidance can converge all known errors.
  - Remaining range errors at parachute deploy result from entry knowledge error.
- **Guided entry results in increased landing altitude capability compared to ballistic entry for equivalent mass, configuration, and arrival conditions**
- **Lifting or guided MSL trajectories result in transition to turbulence prior to peak heating.**
  - Ballistic entry trajectory for same mass, configuration, entry conditions, does not result in smooth body transition to turbulence prior to peak heating.
- **Entry velocities < 6km/sec are selected for MSL to reduce aeroheating**
- **Mission design EDL performance indicates region of launch arrival space for achieving parachute deploy altitudes and reducing aeroheating rates, using rapid trajectory analysis and aeroheating indicator approach**
- **Monte Carlo analysis for specific design demonstrates 100% successful landing for 2000 cases, with range error at touchdown <10km**

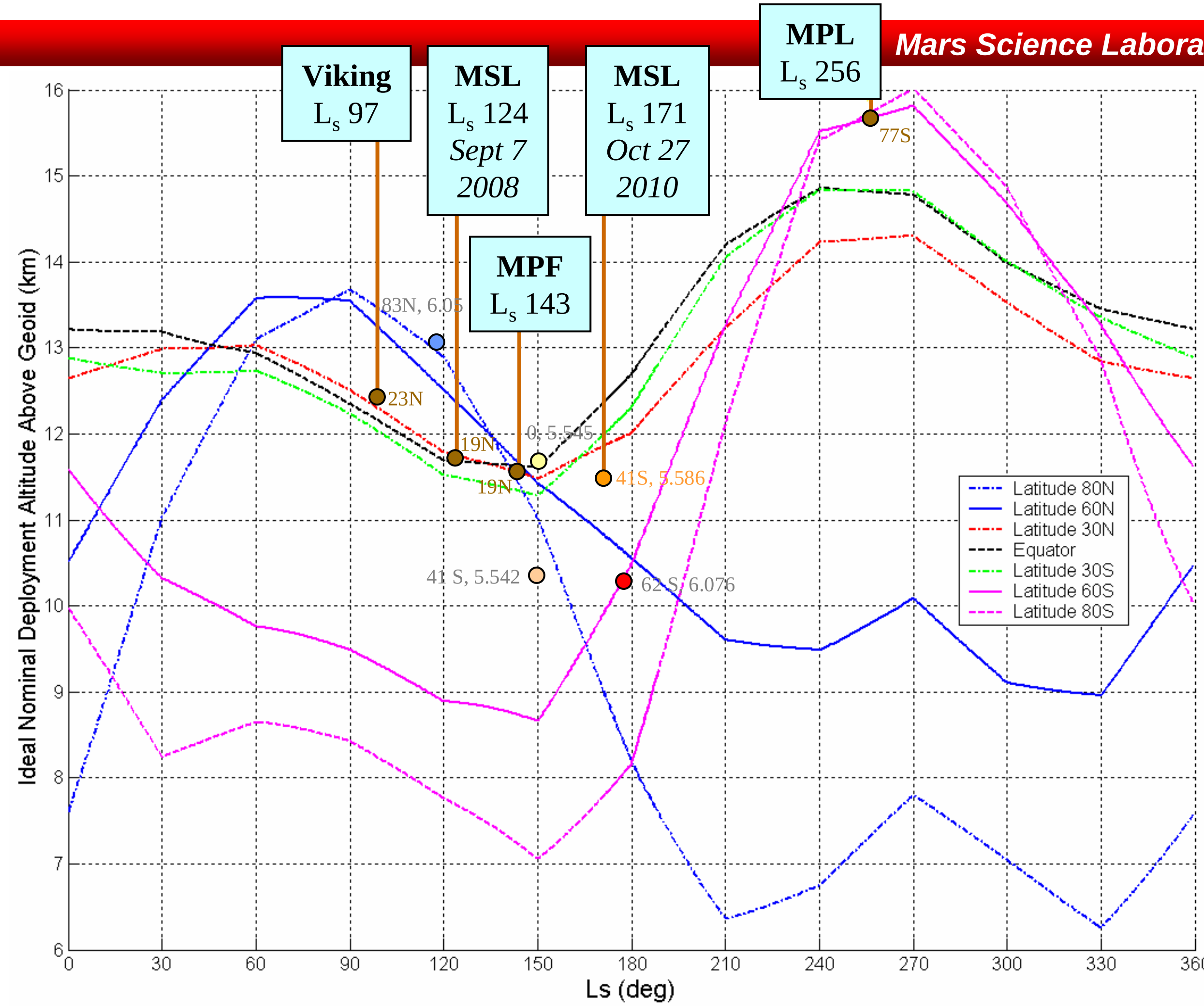
BACKUP

How An Ideal Chute Deployment Altitude Varies with Time of Year and Latitude (JSC Chart)

- Altitude in nominal atmosphere where Q-bar of 450 Pa occurs at Mach 2.0

- Maximizes altitude within standard Viking chute constraints with margin for expected dispersions

- Ability of lander to deploy at these conditions depends on:
  1. entry conditions
  2. ballistic coefficient
  3. lift/drag ratio
  4. entry guidance



Northern	Spring	Summer	Autumn	Winter
Southern	Autumn	Winter	Spring	Summer

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