

**MARS SCIENCE LABORATORY**

# **MSL EDL Performance and Environments**

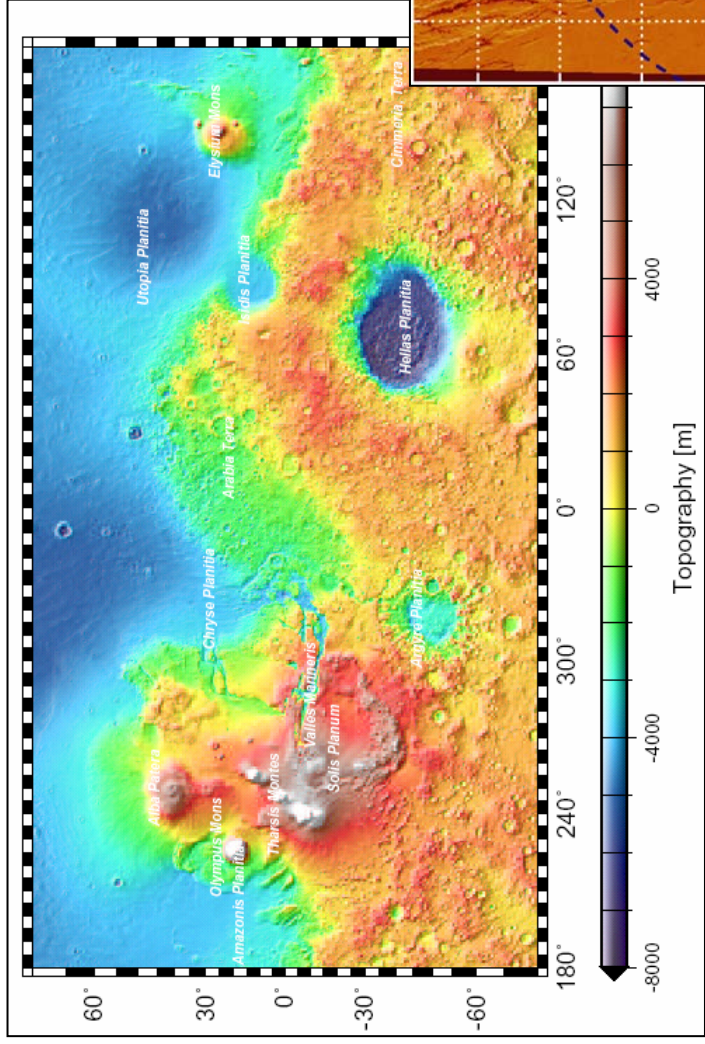
**Mary Kae Lockwood**

**Alicia Dwyer-Cianciola, Artem Dyakonov, Karl Edquist,  
Dick Powell, Scott Striepe, David Way, LaRC**

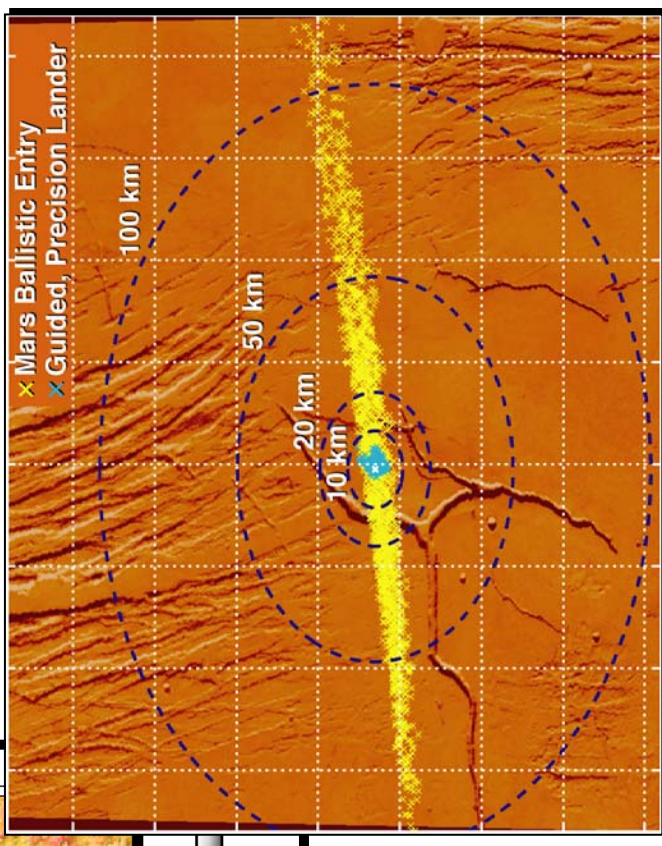
**Claude Graves, Gil Carman, Ron Sostaric, JSC**



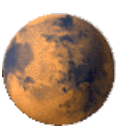
# High Altitude and Precision Landing



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



# **Guided, Lifting, Ballistic Trade**



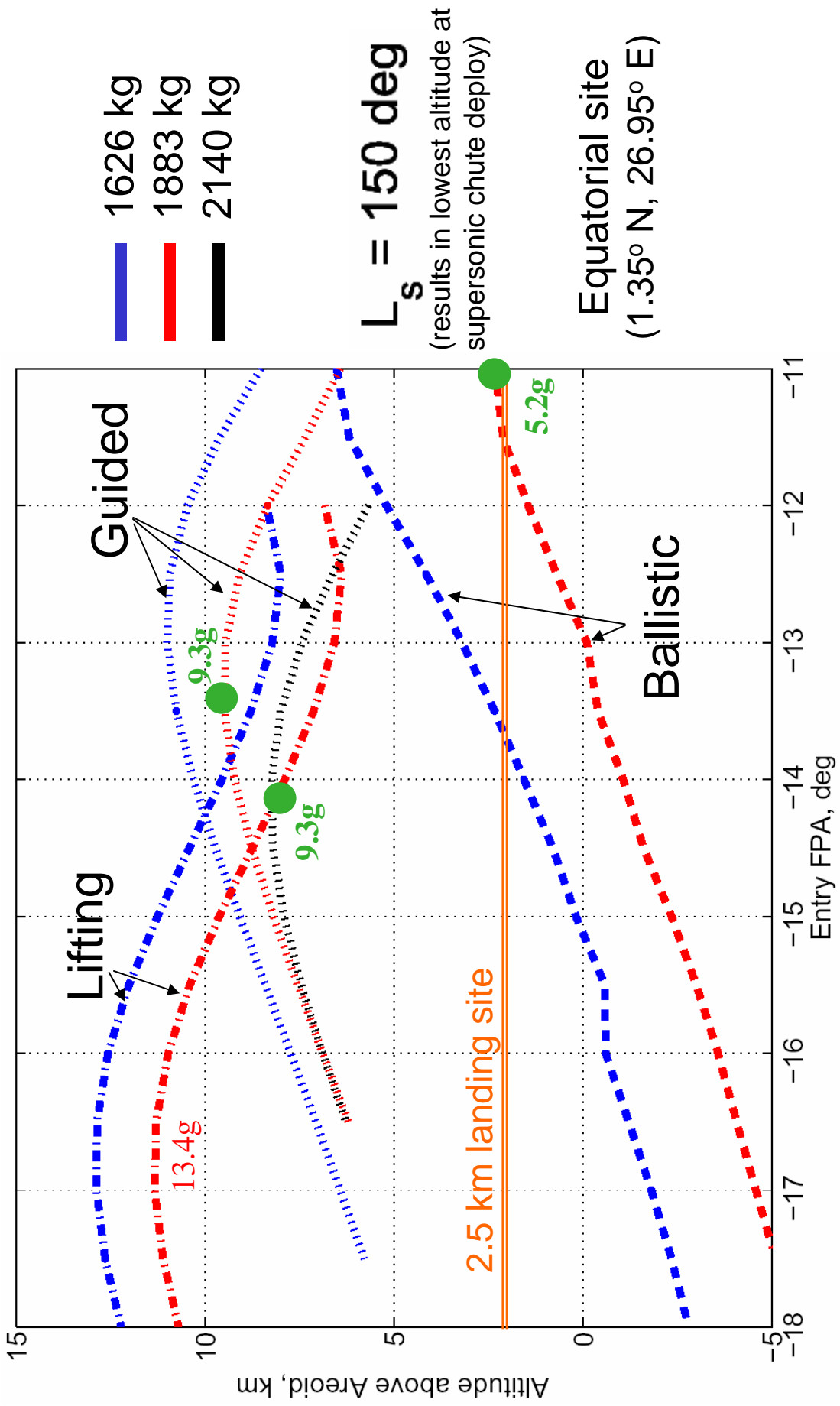


# Supersonic Chute Deploy Altitude

## Ballistic, Lifting, Guided Comparison



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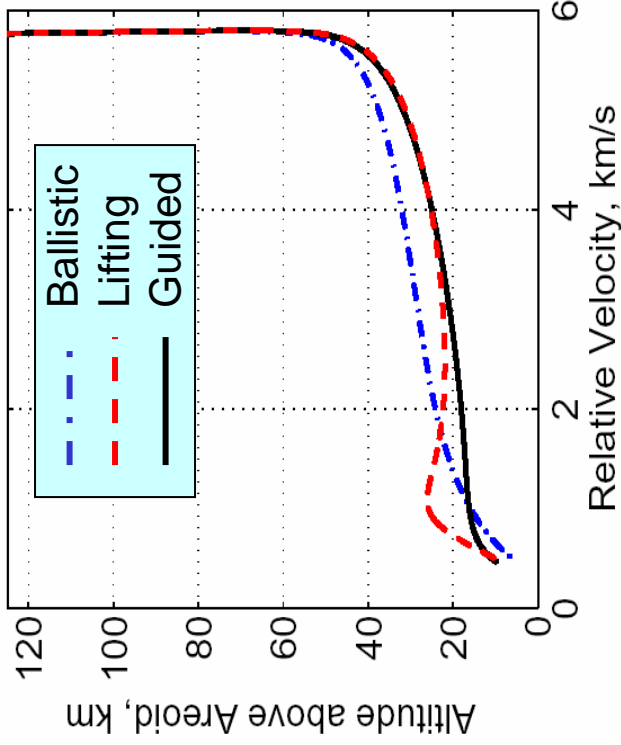




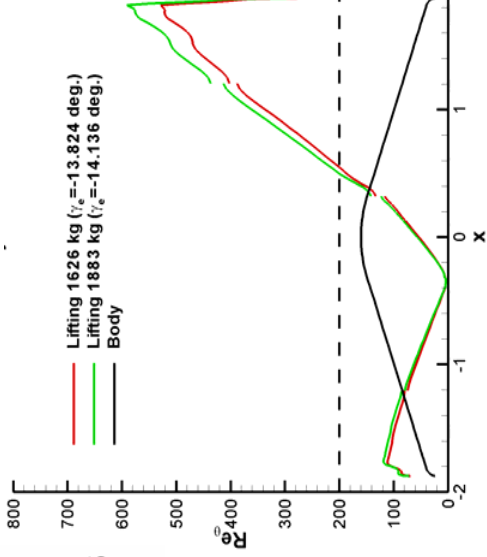
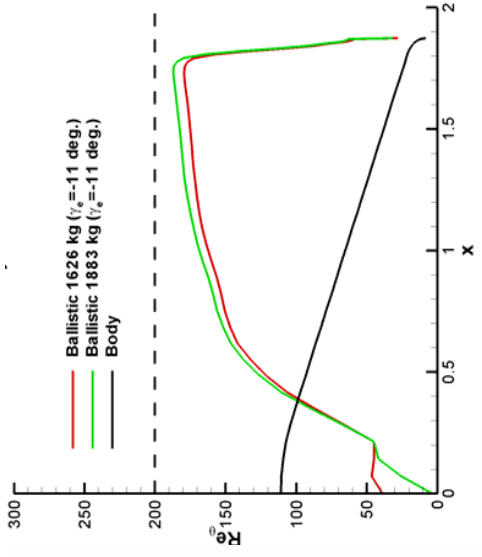
# **Guided, Lifting, Ballistic Landing Footprint Video**



# Transition Indicator at Peak Heating Point on Trajectory

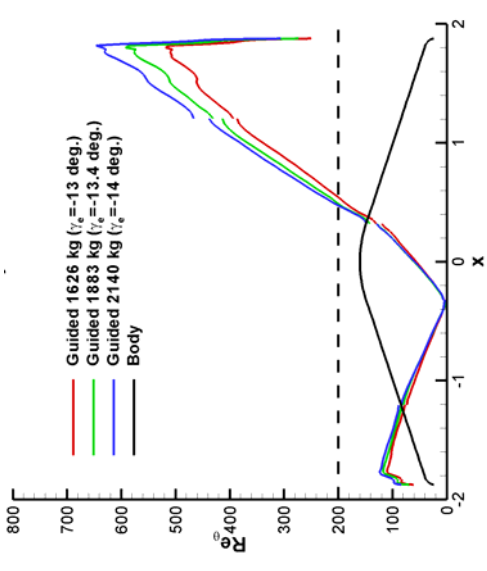


- Entry velocity = 6 km/sec
- Mass = 1883 kg
- Ls = 150 deg
- Ballistic entry FPA = -11 deg
- Lifting entry FPA = -14.136 deg
- Guided entry FPA = -13.4 deg



## 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

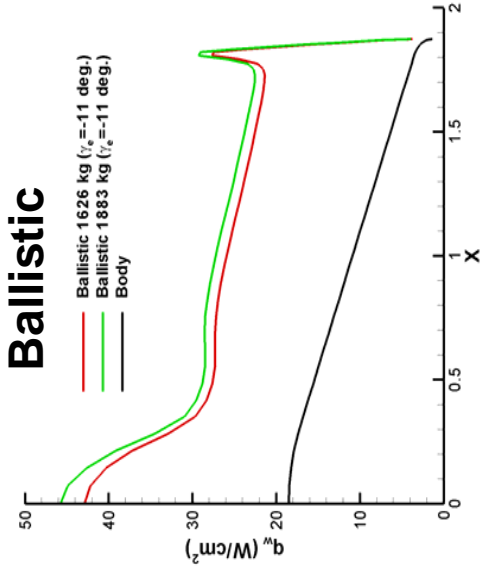
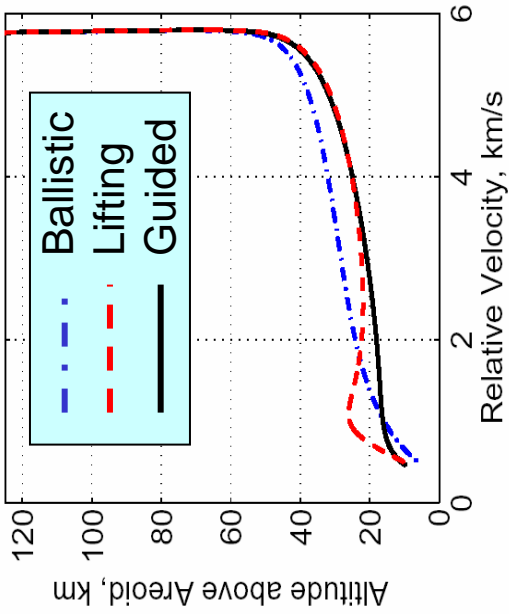


# Aeroheating at Peak Heating Point on Trajectory



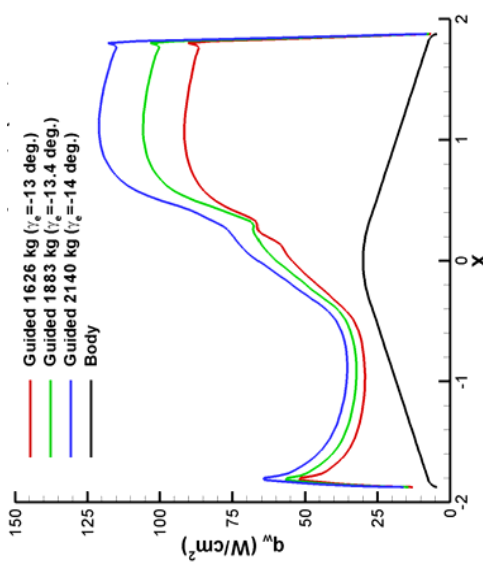
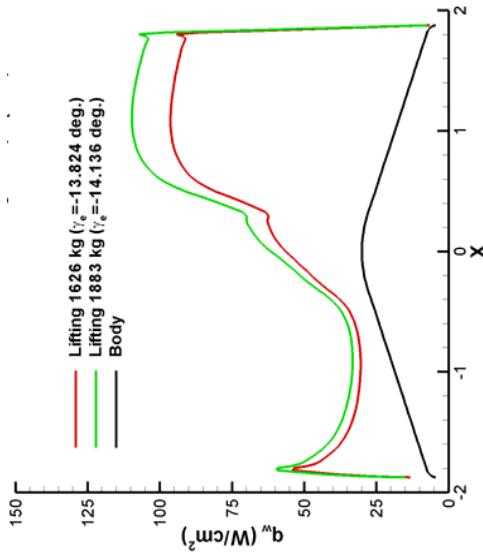
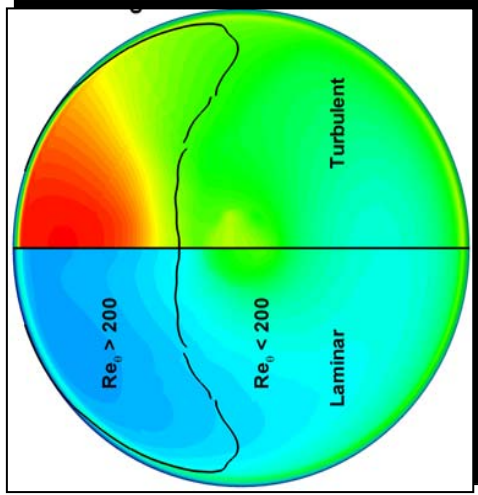
## Nominal, No Uncertainty Included

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**Ballistic** – stagnation point heating; lower uncertainties

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



Lifting

Guided

MKL - 7



# Comparison to Previous Missions

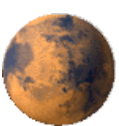


## MSL aeroheating analysis is challenging compared to Viking, MPF, and MER

- Combination of ballistic coefficient (110 kg/m<sup>2</sup>), 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 <sup>2</sup> )	Heat Rate w/o Uncertainty (W/cm <sup>2</sup> )	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**



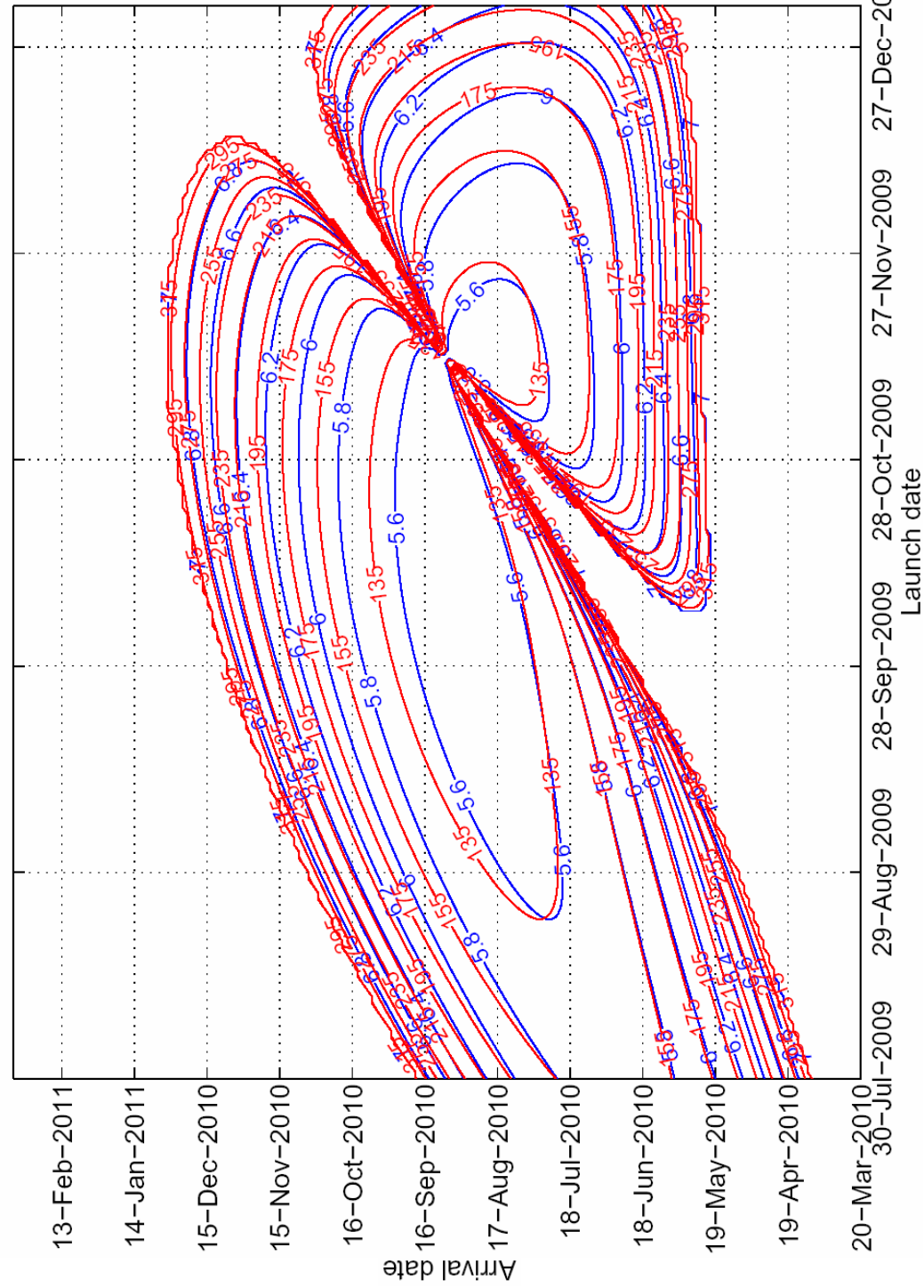
# Max Heat Rate Est (CBE+Uncert) W/cm<sup>2</sup>

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



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blue = Inertial Entry Velocity, km/s red = Total LAURA Heat Rate CBE + Uncertainties, W/cm<sup>2</sup>



- Turbulent aeroheating indicator plotted with entry velocity in mission design space
- Turbulent aeroheating
- increases approximately with V<sup>4</sup>
  - only very weakly dependent on density

PRE-DECISIONAL DRAFT; For planning and discussion purposes only



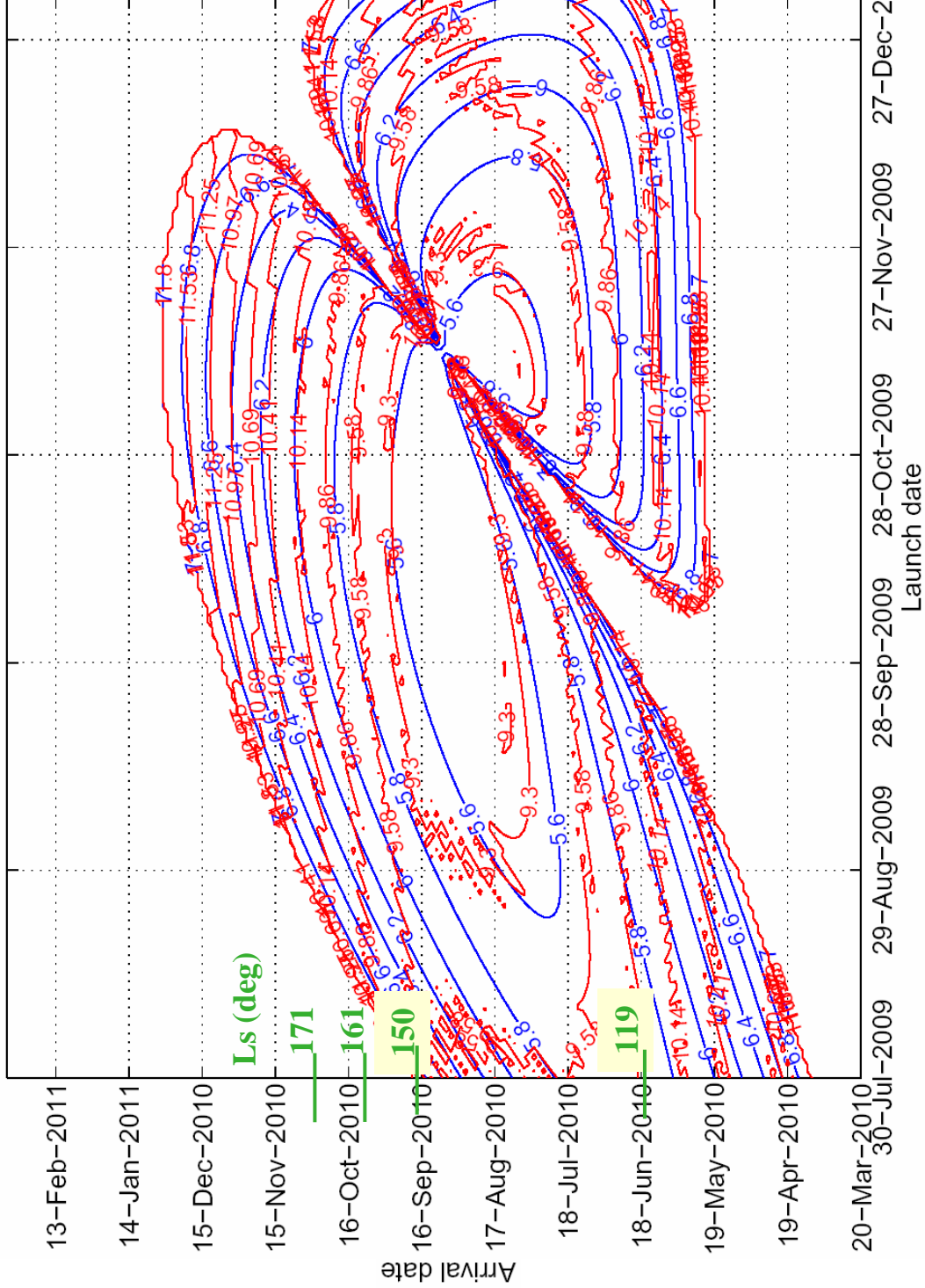
# Nominal Super Chute Deploy Alt Above MOLA (km)

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



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blue = Inertial Entry Velocity, km/s red = Altitude above Target at Super Chute Deploy, km



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)

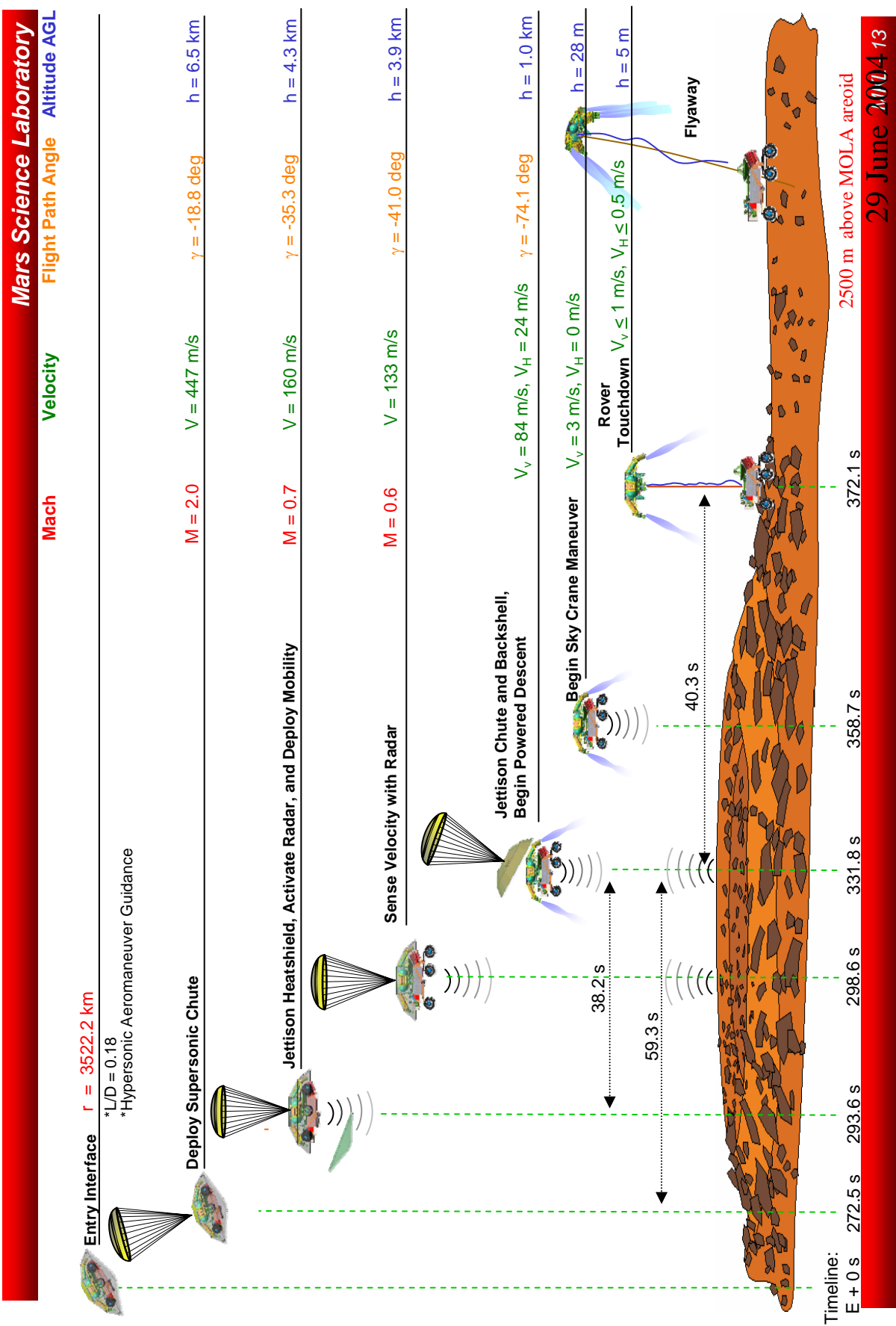


# Monte Carlo



# MSL Option M2 Entry, Descent and Landing

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



29 June 2004.13

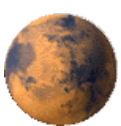
S. Strieppe - NASA LaRC

PRE-DECISIONAL DRAFT; For planning and discussion purposes only



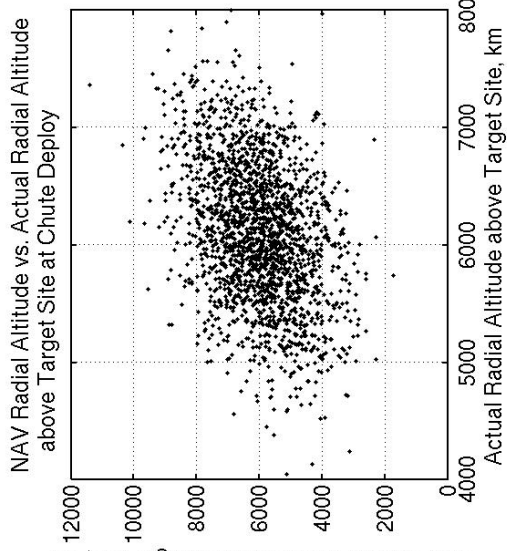
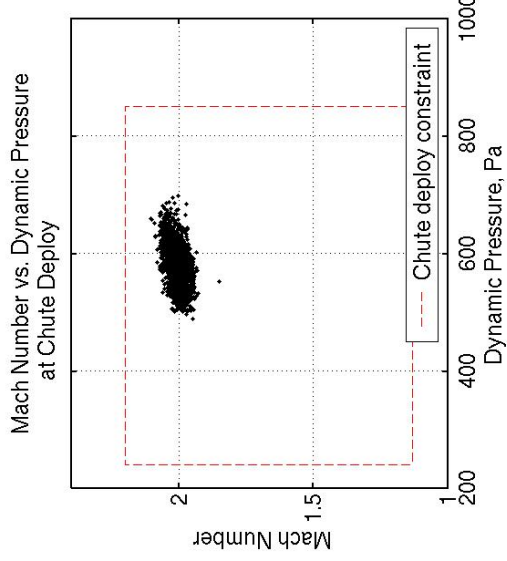
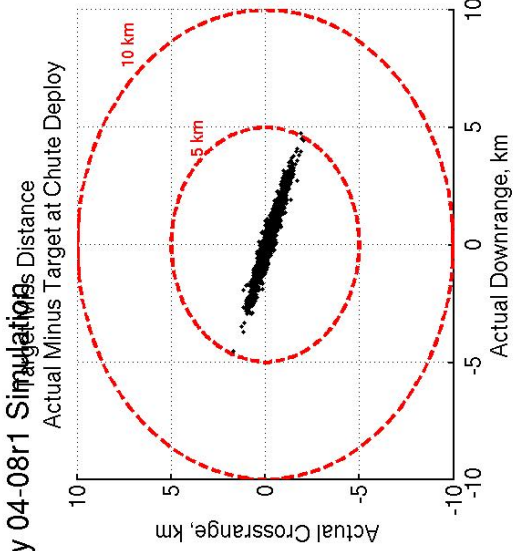
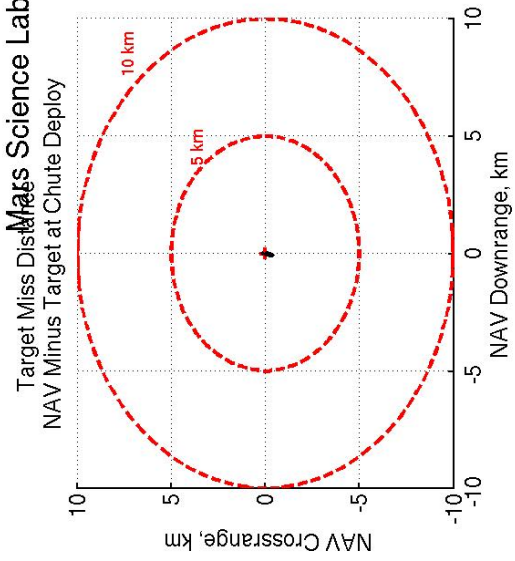


# Entry Performance



## 04-08rev1, zero initial attitude knowledge errors

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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

1010980145/1011079225

13-Aug-2004

MSL 04-08r1 41S Target, May 2004 Skycrane TD, NO Deploy Floor, NO NAV attitude error

dww-41

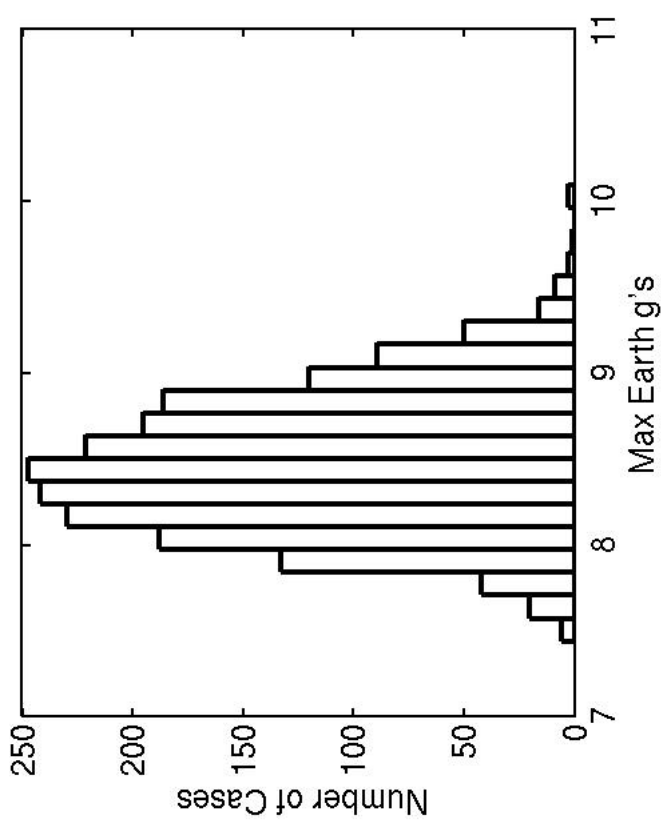
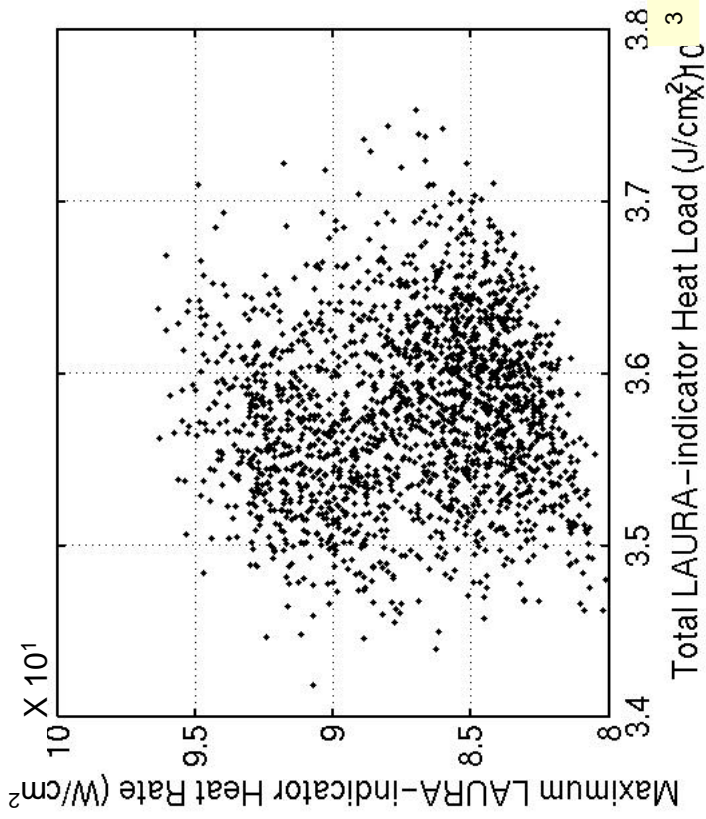


# Entry Aeroheating and Entry g's



04-08rev1, zero initial attitude knowledge errors

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- 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.

MKL - 15



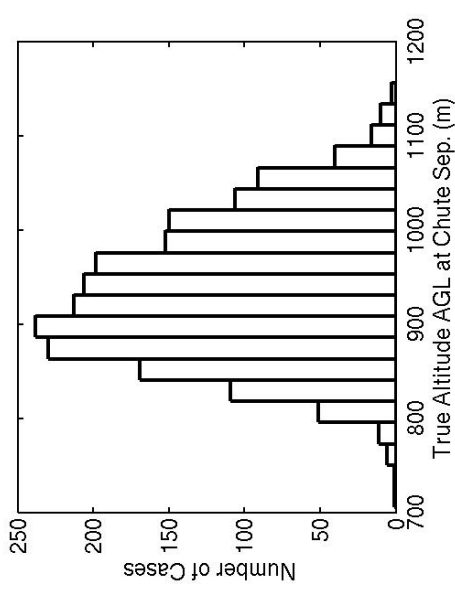
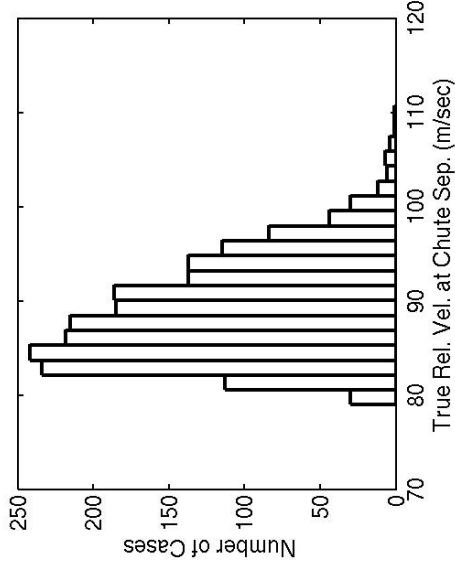
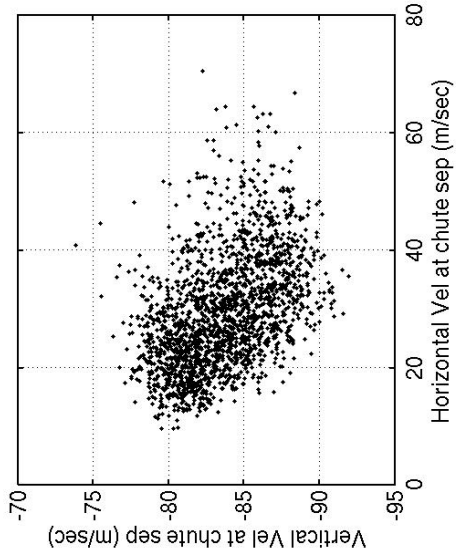
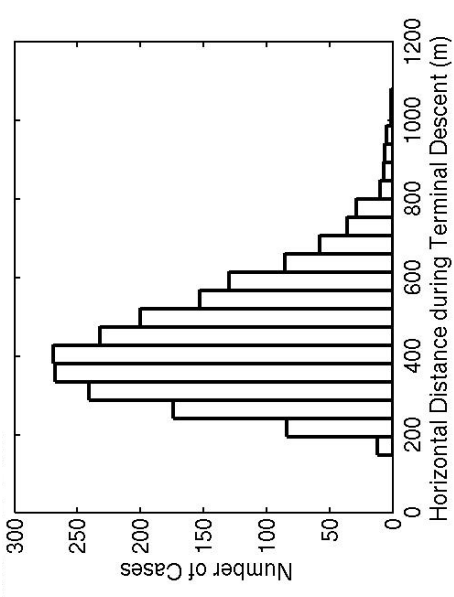
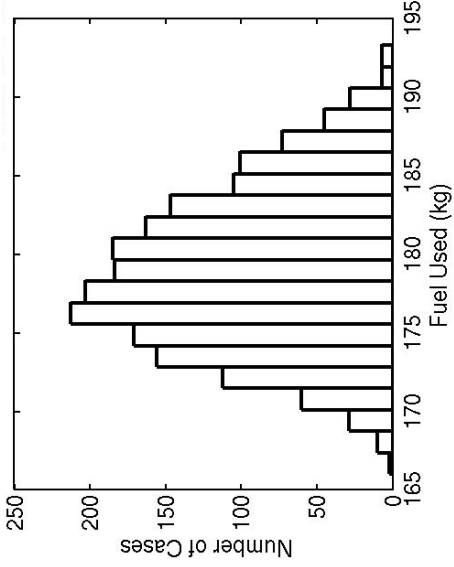
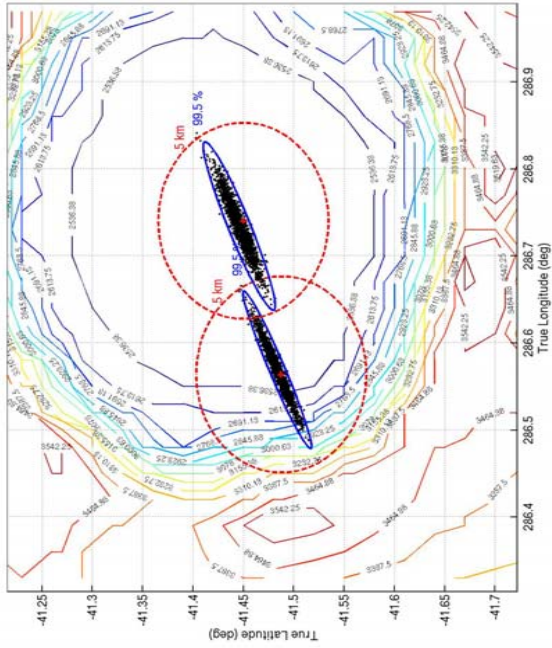
# Terminal Descent

04-08rev1, zero initial attitude knowledge errors



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100% touch down successfully with vertical vel < .75 m/s  
Fuel use less than 219 kg powered descent allocation





# 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**

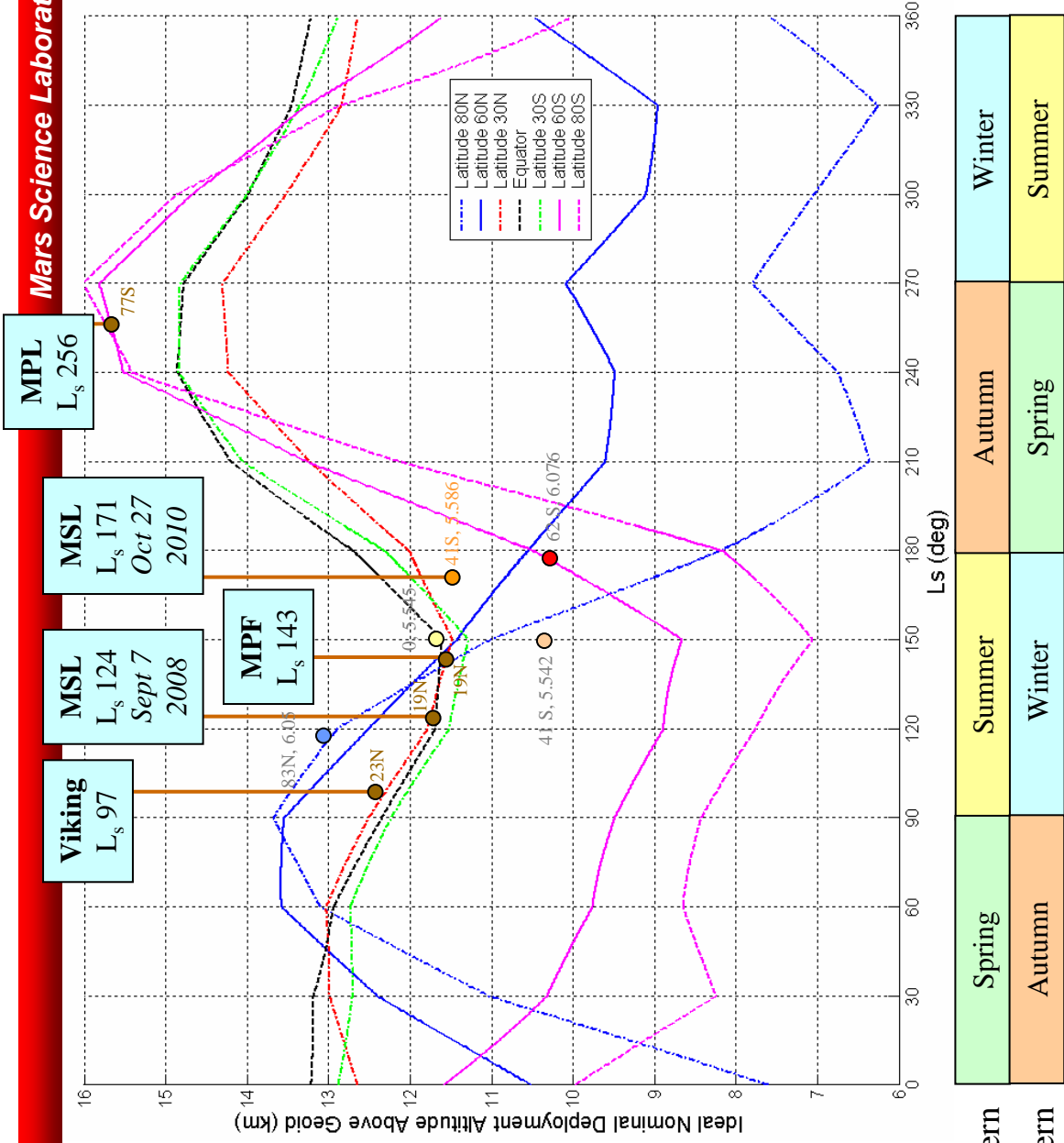




# How An Ideal Chute Deployment Altitude Varies with Time of Year and Latitude (JSC Chart)



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- 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