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# 2007 Mars Phoenix Entry, Descent, and Landing Simulation and Modeling Analysis

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# Phoenix Overview



- Launch window: Aug 3-24, 2007
- Arrival: May 25 – June 5, 2008
- EDL
  - 600kg entry vehicle
  - Ballistic 3-axis stabilized entry
  - Propulsive terminal descent

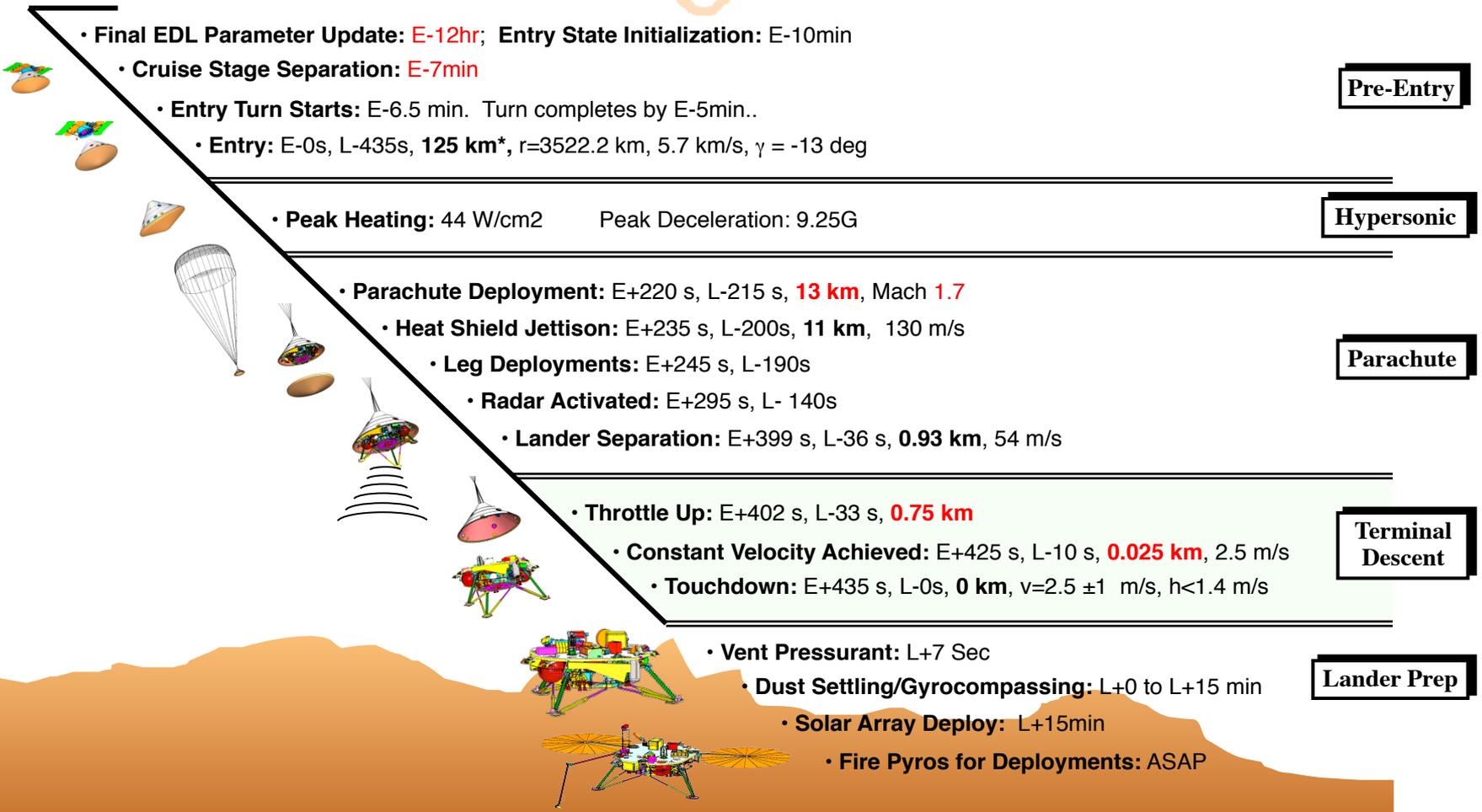


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# EDL Overview



\* Entry altitude referenced to equatorial radius. All other altitudes referenced to ground level

Note: Nominal Entry Shown. Dispersions exist around all values.

Landing at -3.4 km Elevation (MOLA relative)



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# EDL Simulation



- Program to Optimize Simulated Trajectories II (POST2)  
6-DOF simulation used to assess metrics, determine entry characteristics to meet EDL requirements
  - POST heritage: MGS, ODY, MER, MPF, MRO, Stardust, Genesis, etc
  - Simulation comparisons have been performed with additional simulation capabilities
- Metrics to track include:
  - Parachute deployment conditions – mach, dynamic pressure, opening loads
  - Lander separation conditions – altitude, velocity, time on parachute
  - Landing – footprint, fuel used, landing velocity



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# EDL Models



- IMU model
- Active hypersonic control system
- Atmosphere profiles
- Aerodynamics database
- Parachute
  - Deployment algorithm
  - Inflation model
  - Drag model
- Wind profiles
- Radar
- Terminal descent guidance
- Propulsive control model

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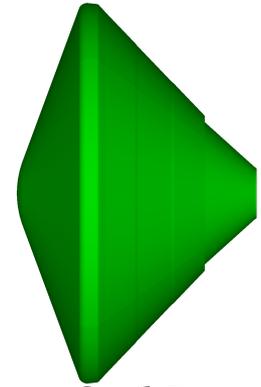
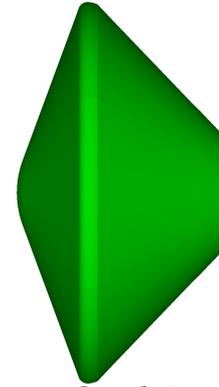
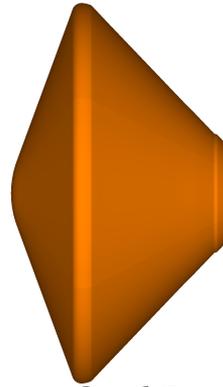


# Mars Aeroshell/Entry Comparison

Pathfinder

MER A/B

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Diameter, m

2.65

2.65

2.65

Entry Mass, kg

585

840

602

Relative Entry Vel., km/s

7.6

5.5

5.9

Relative Entry FPA, deg

-13.8

-11.5

-13

$m/(C_D A)$ , kg/m<sup>2</sup>

62.3

89.8

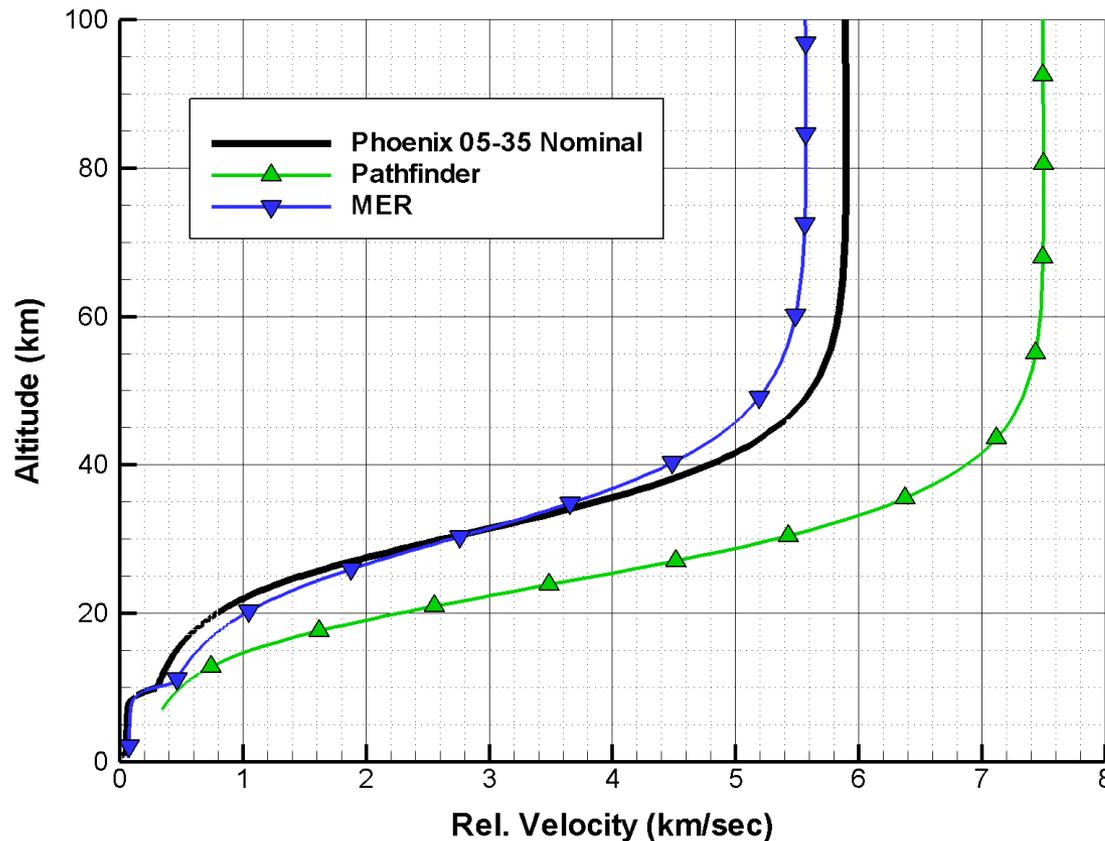
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# Mars Trajectory Comparison

- The Phoenix entry trajectory is most similar to the MER entries





# Aerodynamics Database Structure

- The database is divided into flight regimes that reflect different analysis methods and aerodynamics characteristics
  - v2.0 will have updated CFD data for hypersonic/supersonic continuum regimes and Viking data for  $0.8 < \text{Mach} \leq 1.5$
  - Still using MER free-molecular, transitional, and dynamics data

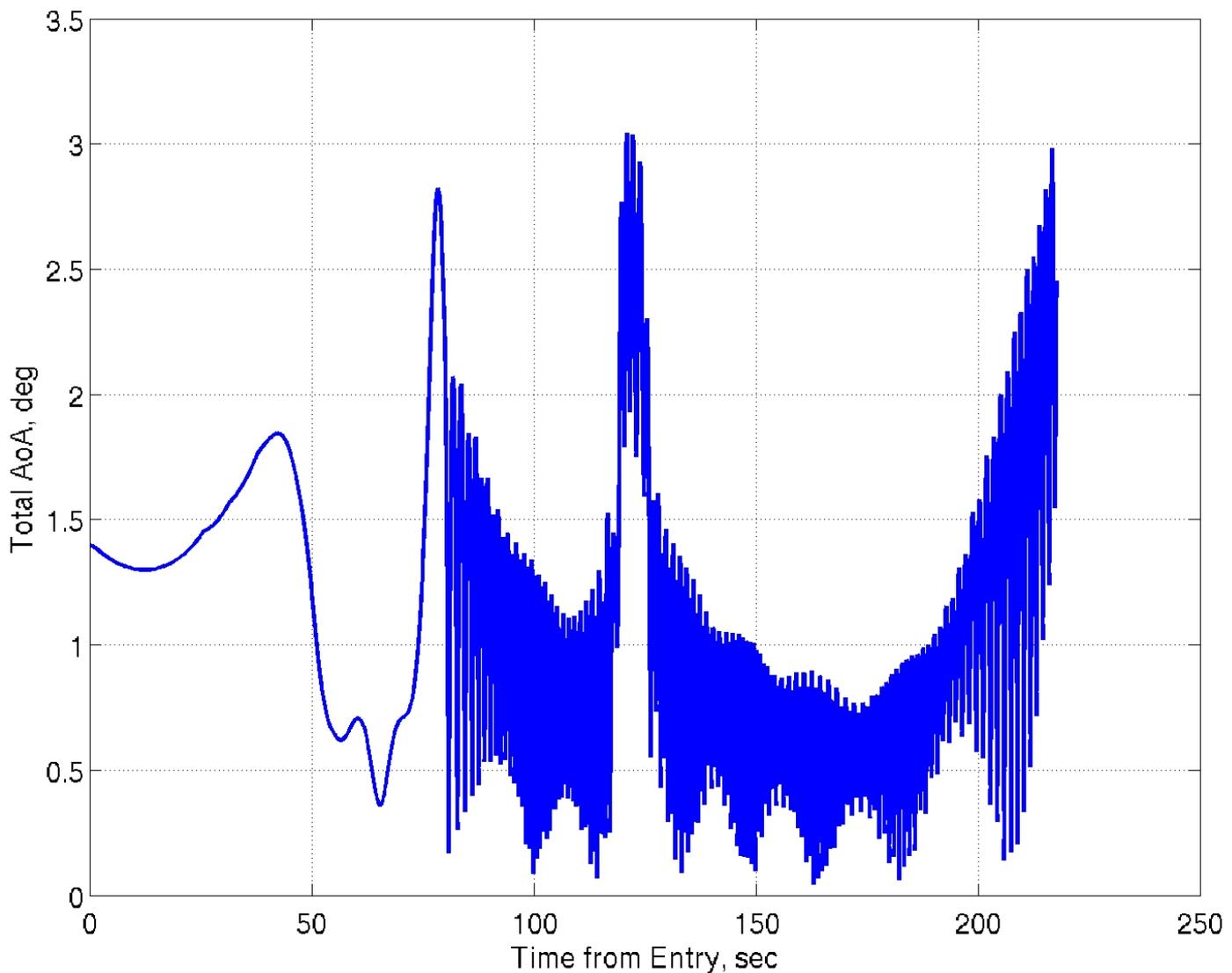
Rarefied	Transitional	Hypersonic	Supersonic	Supersonic Dynamics	Transonic/Subsonic
$Kn > 1000$	$1000 > Kn > 0.001$	$30.29 > \text{Mach} > 6.3$	$6.3 > \text{Mach} > 1.5$	$5 > \text{Mach} > 0.7$	$1.5 > \text{Mach} > 0.8$
<b>Analysis:</b> DAC DSMC code	<b>Analysis:</b> DAC DSMC code	<b>Analysis:</b> LAURA CFD (forebody)	<b>Analysis:</b> LAURA (full aeroshell)	<b>Analysis:</b> Viking Forced Oscillation	<b>Analysis:</b> Viking Wind Tunnel
<b>Current Data:</b> Phoenix Database Version 1.4.1	<b>Current Data:</b> Phoenix Database Version 1.4.1	<b>Current Data:</b> Phoenix Database Version 1.4.1	<b>Current Data:</b> Phoenix Database Version 1.4.1	<b>Current Data:</b> Phoenix Database Version 1.4.1	<b>Current Data:</b> Phoenix Database Version 1.4.1
<b>Heritage</b> Flight: MPF, MER Computation: MPF, MER	<b>Heritage</b> Flight: MPF, MER Computation: MPF, MER	<b>Heritage</b> Flight: Viking, MPF, MER Experiment: Viking Computation: MPF, MER	<b>Heritage</b> Flight: Viking, MPF, MER Experiment: Viking Computation: MPF, MER	<b>Heritage</b> Flight: Viking, MPF, MER Experiment: Viking, MER	<b>Heritage</b> Flight: Viking, MPF, MER Experiment: Viking, MER



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# Nominal Attitude Profile



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# Monte Carlo Parameters

- 2000 atmosphere profiles
- 2000 wind profiles
- Aerodynamics
- Mass properties
- Entry state
- Initial attitude
- Tip-off rates
  - Cruise stage separation
  - Lander separation
- Radar parameters
  - Slope distribution
  - Ground effects
- Propulsion parameters
  - RCS
  - TCM



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# Performance Criteria



**Two basic categories of performance criteria form the basis for performance assessments**

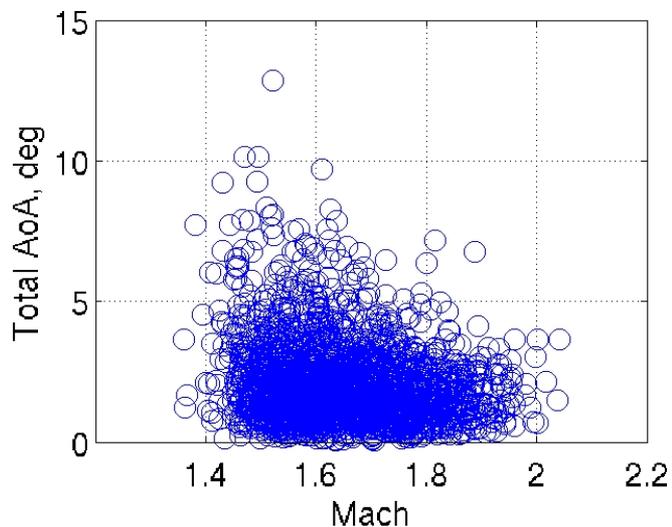
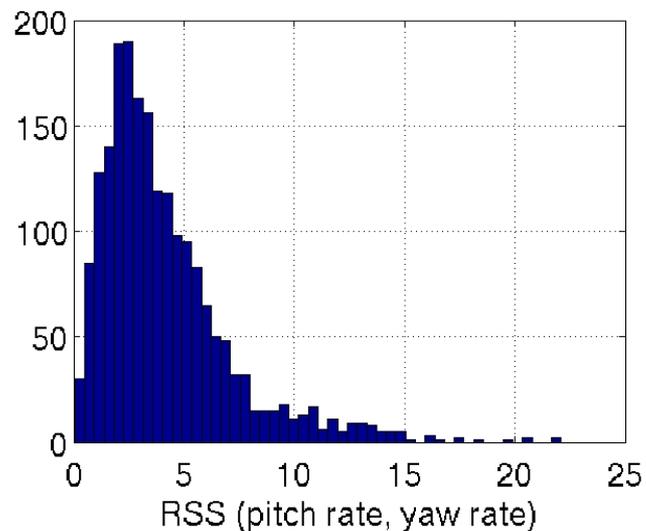
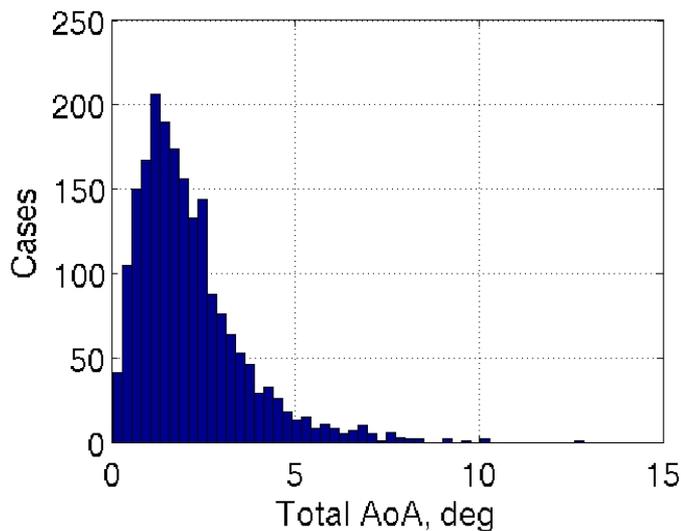
- **Entry and Descent (ED) Criteria**
  - Attitude behavior
  - Heating and loads
  - Deployment/separation conditions
  - Timeline and event timing
  - Sensor performance and state knowledge
  - Vehicle state at touchdown
- **Landing (L) Dynamics Criteria**
  - Touchdown/tip-over dynamics
  - Rock contact at landing
  - Rock contact during solar array deployments



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# Chute Deploy Statistics



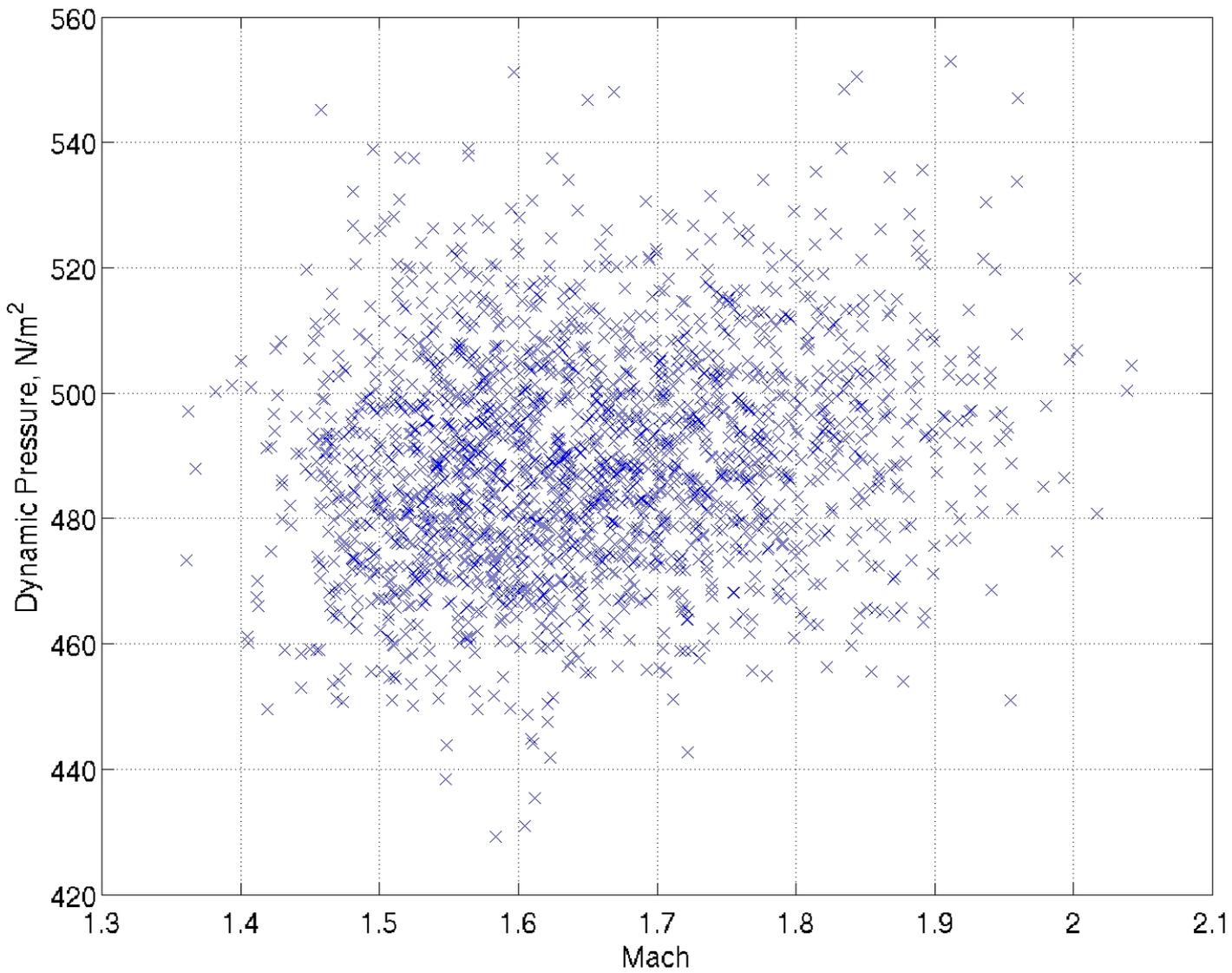
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# Mach-Q Box



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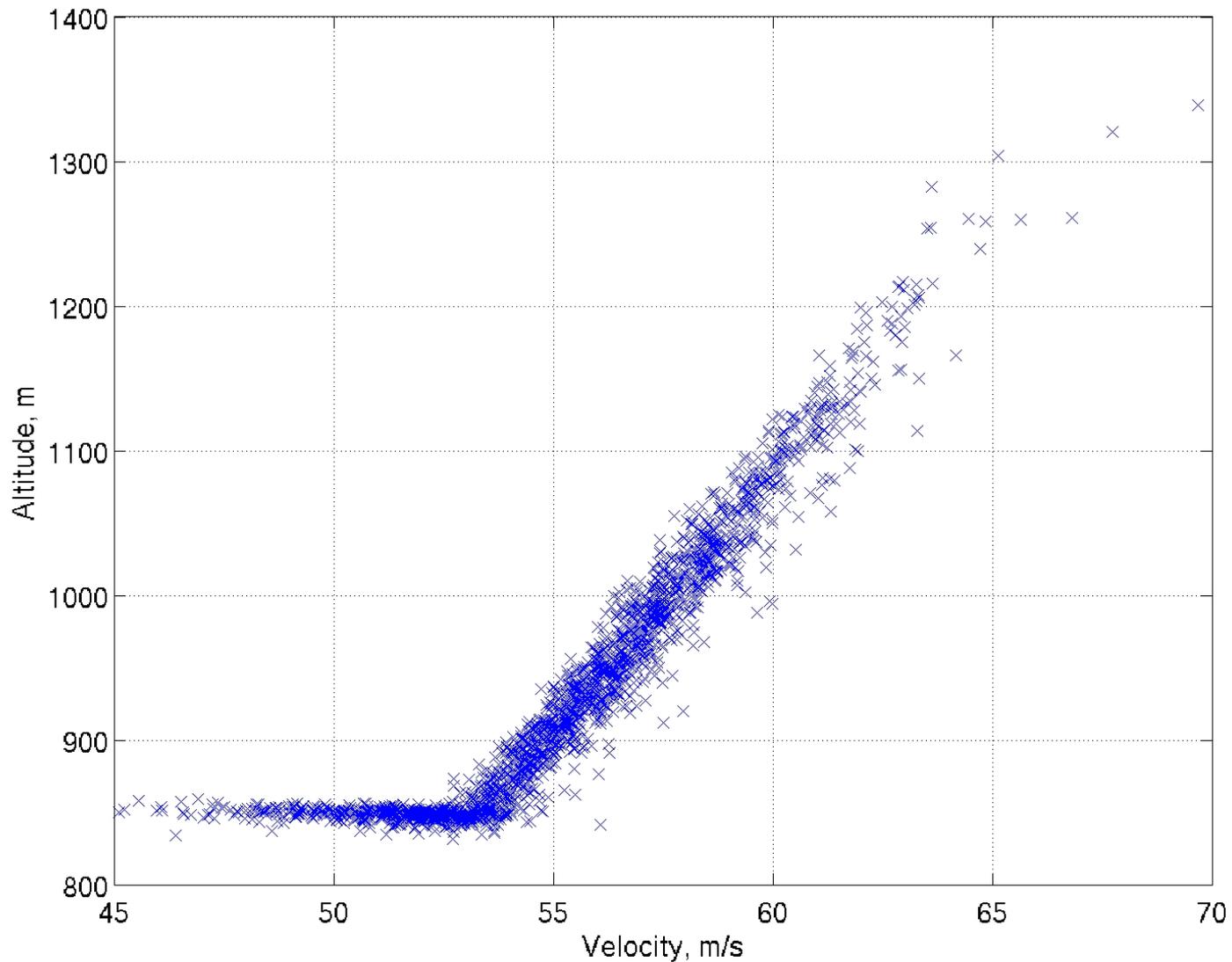
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# Lander Separation Altitude



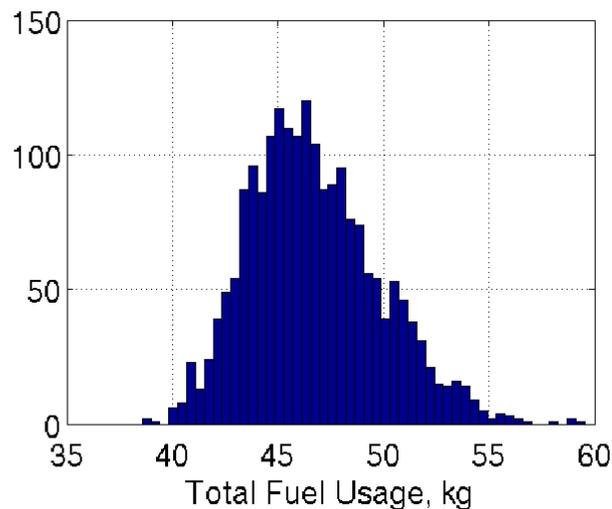
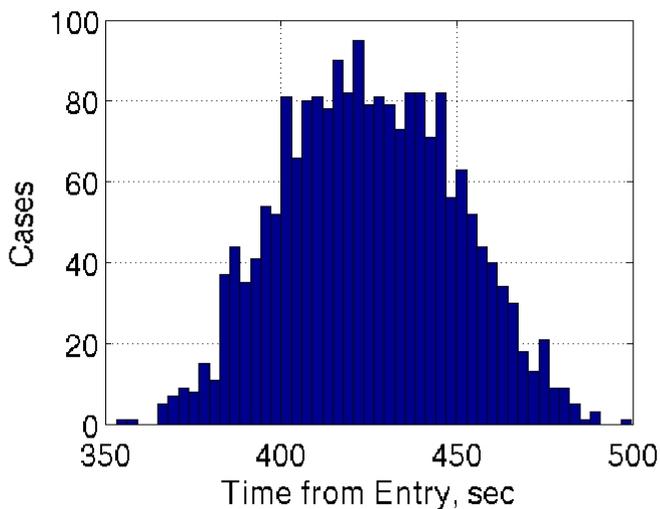
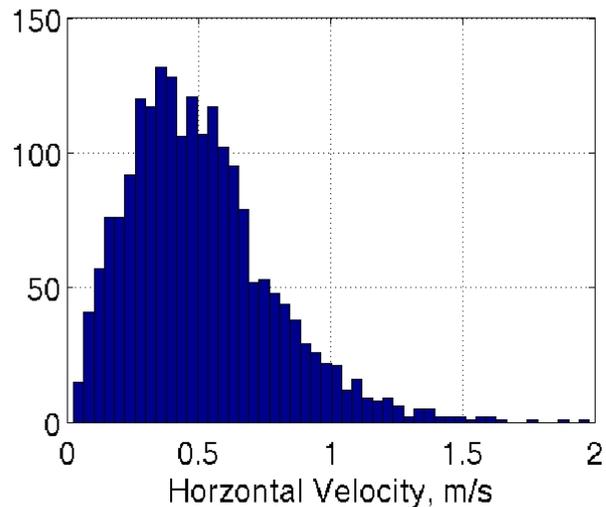
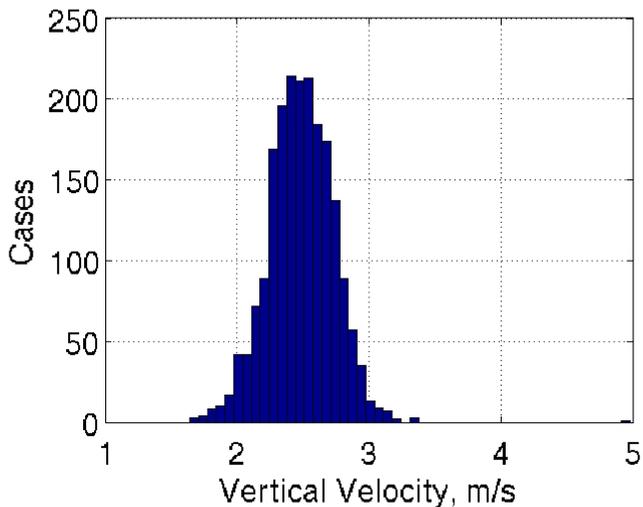
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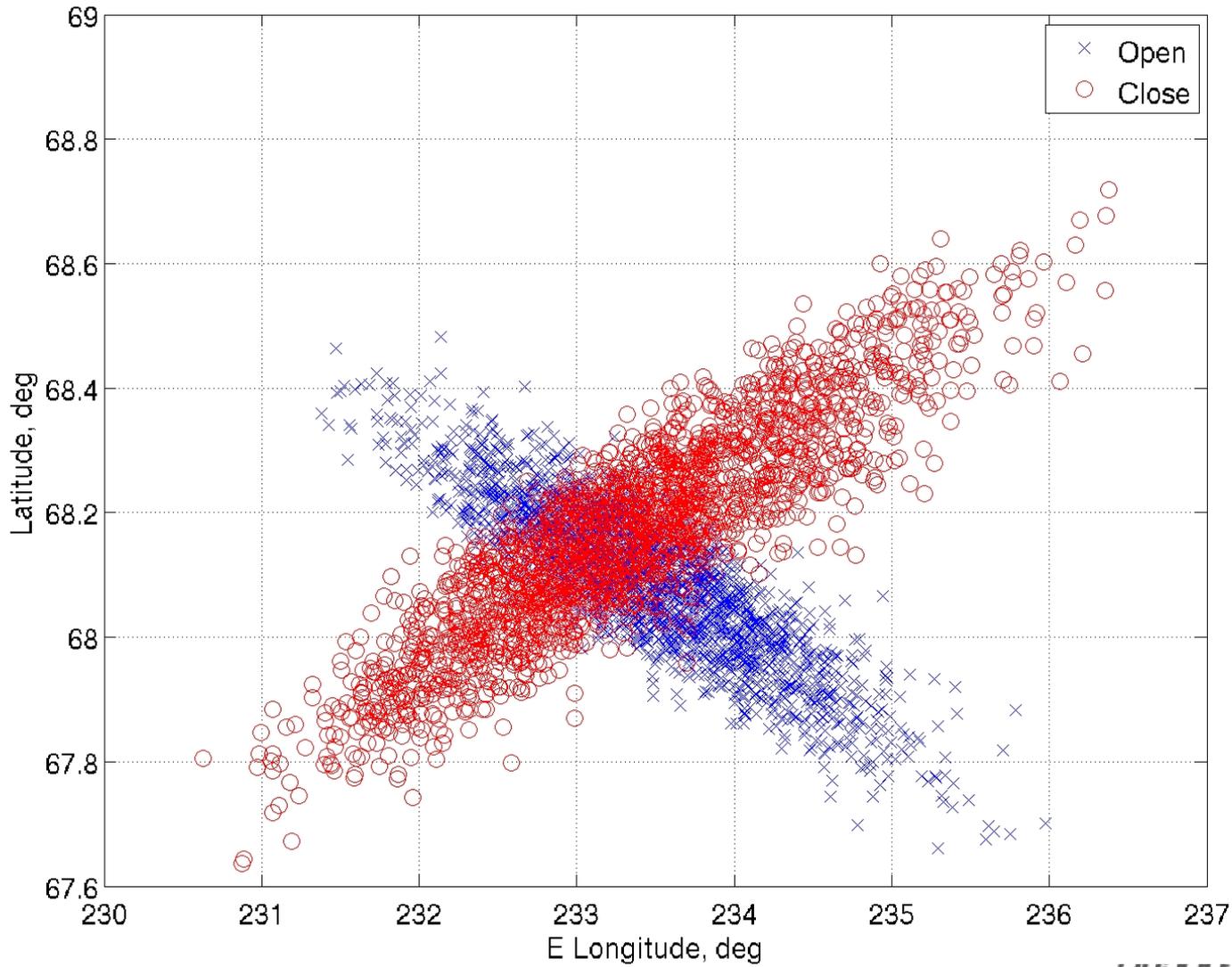
# Touchdown Statistics





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# Landing Ellipses



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# Phoenix Summary



- All results shown are for 68N landing site at open of launch window
- Results vary with latitude and launch date – Monte Carlos are analyzed for several launch and landing site opportunities
- Many trade studies and sensitivities have been analyzed but not discussed here



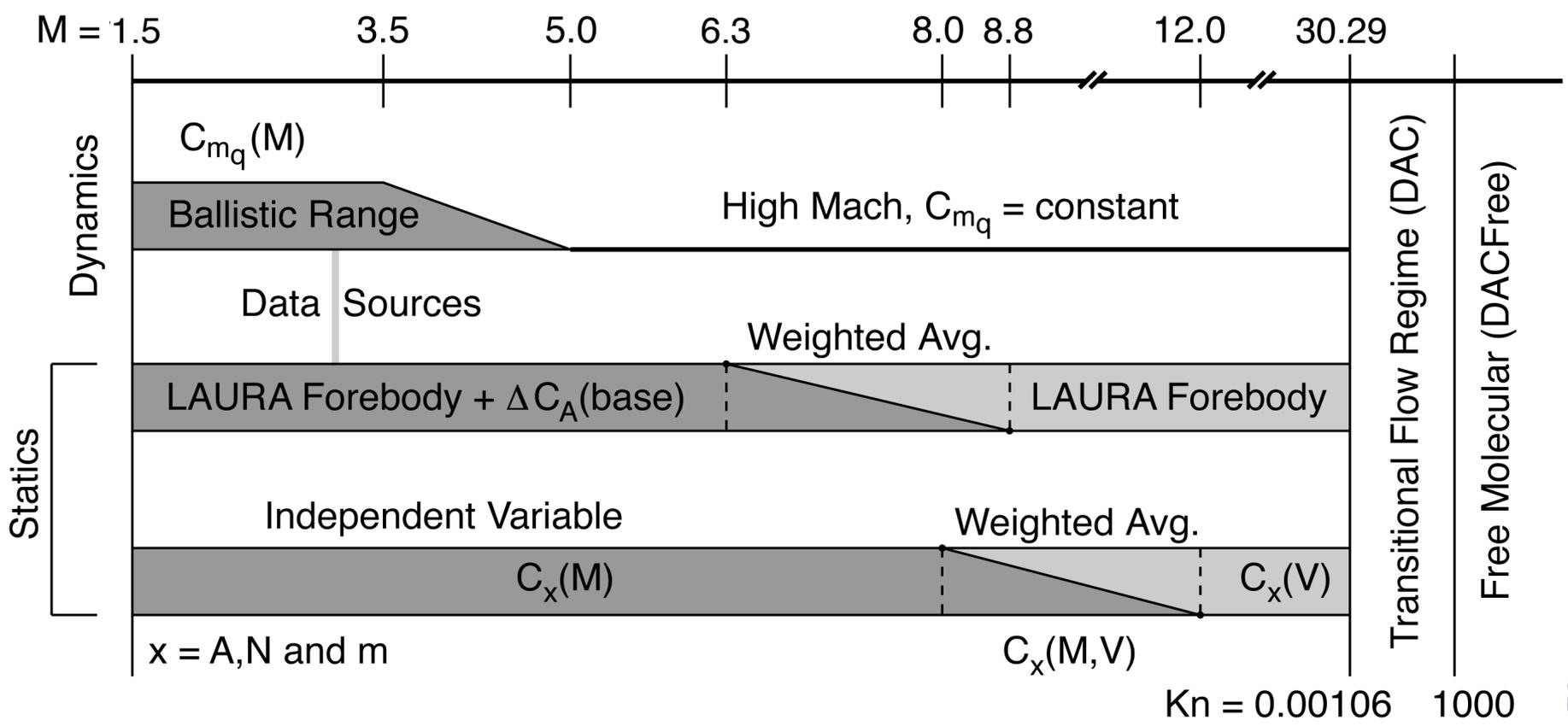
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# Backup



# Aerodynamics Database Implementation

- For rarefied flow,  $C_A, C_N, C_m = f(\alpha_T \text{ and } Kn)$

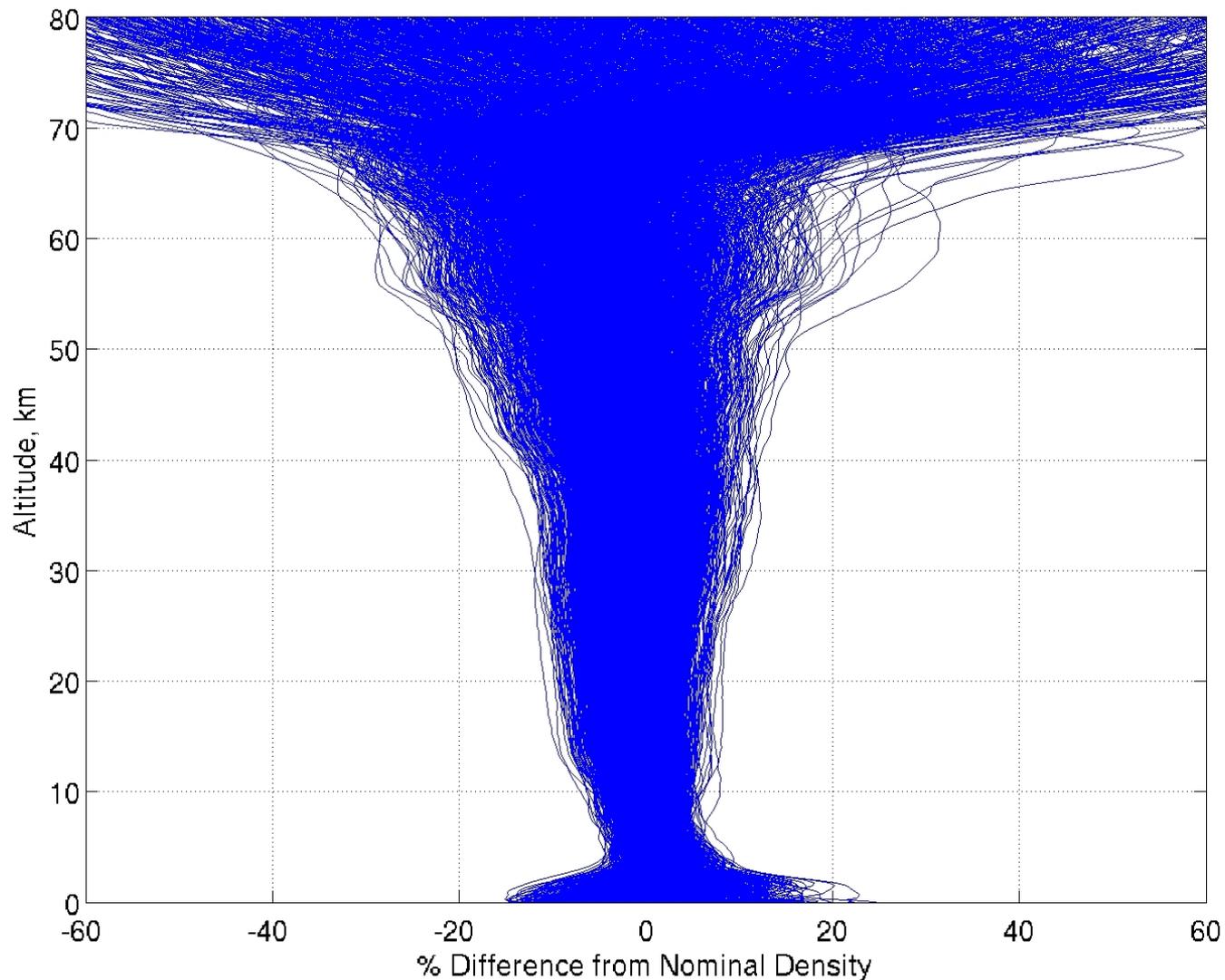




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# Atmospheric Variability



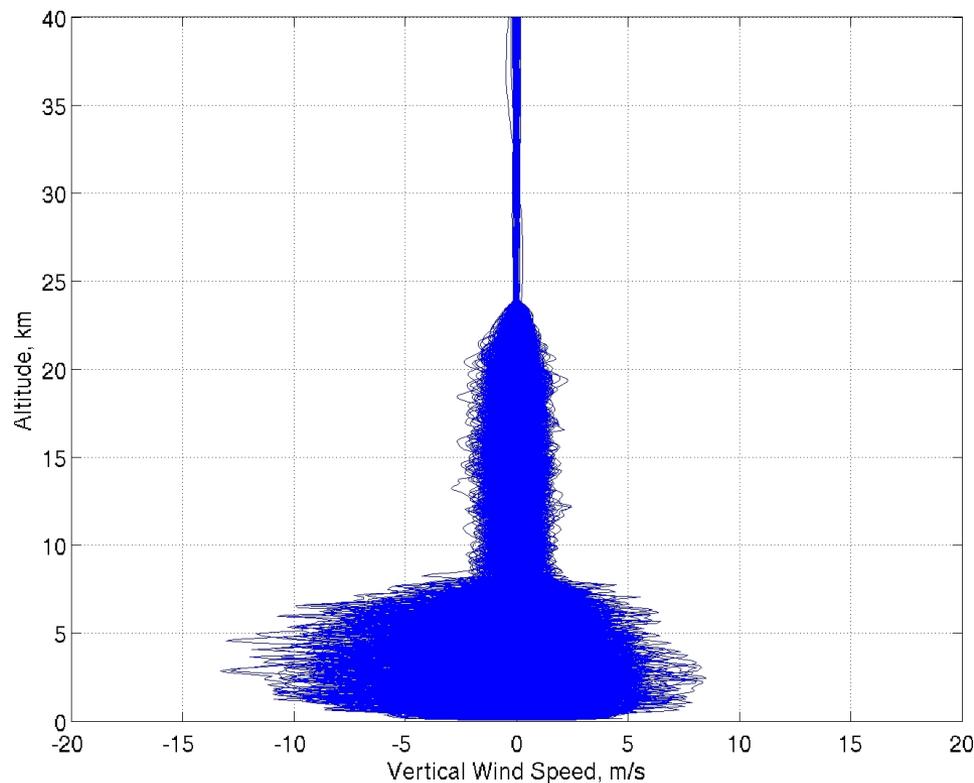
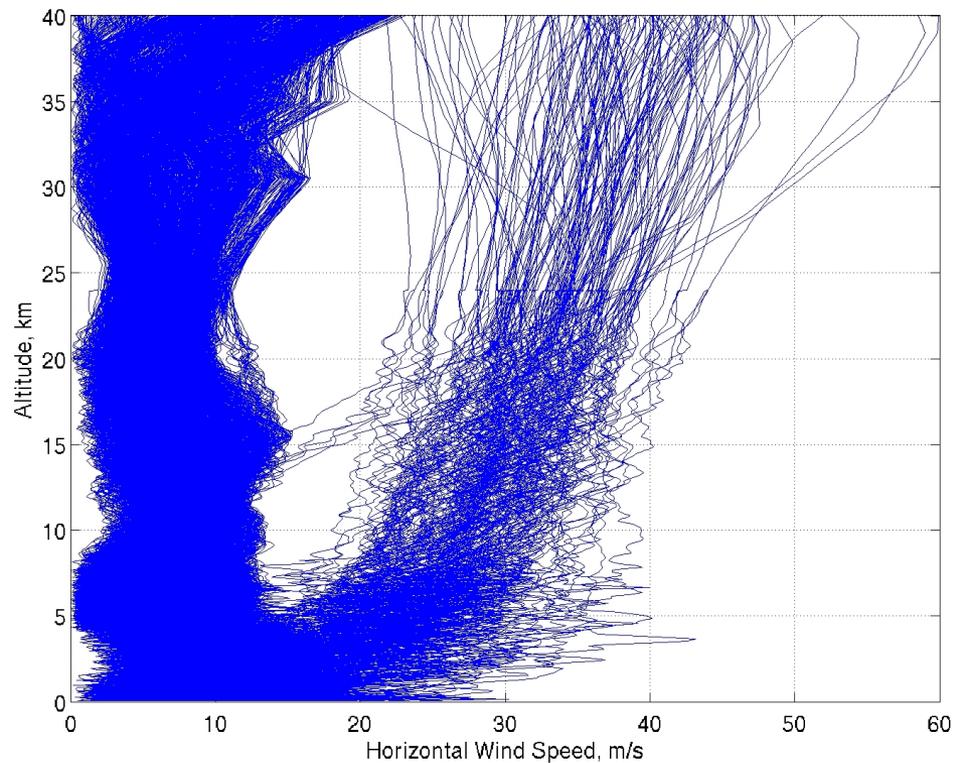
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# Wind Variability



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# Aerodynamic Uncertainties

Flight Regime	Coefficients	Uncertainty	Distribution
Free Molecular (Kn > 0.1)	$C_A$ $C_N, C_Y$ $C_m, C_n$ $C_{II}$	$\pm 5\%$ $\pm 0.01$ (Adder), $\pm 20\%$ (Multiplier) $\pm 0.005$ (Adder), $\pm 20\%$ (Multiplier) $1.24e-6$	Normal
Hypersonic Continuum (Kn < 0.001, M > 10)	$C_A$ $C_N, C_Y$ $C_m, C_n$ $C_{II}$	$\pm 3\%$ $\pm 0.01$ (Adder), $\pm 20\%$ (Multiplier) $\pm 0.003$ (Adder), $\pm 20\%$ (Multiplier) $1.24e-6$	Normal
Supersonic Continuum (Kn < 0.001, M < 5)	$C_A$ $C_N, C_Y$ $C_m, C_n$ $C_{II}$	$\pm 10\%$ $\pm 0.01$ (Adder), $\pm 20\%$ (Multiplier) $\pm 0.005$ (Adder), $\pm 20\%$ (Multiplier) $1.24e-6$	Normal
Free Molecular/Hypersonic Dynamics (M > 6)	$C_{mq}$	$\pm 0.15$	Normal
Supersonic Dynamics (M < 3)	$C_{mq}$	-50% to 100% (Multiplier), 0 to 0.1 (Adder)	Normal/ Uniform