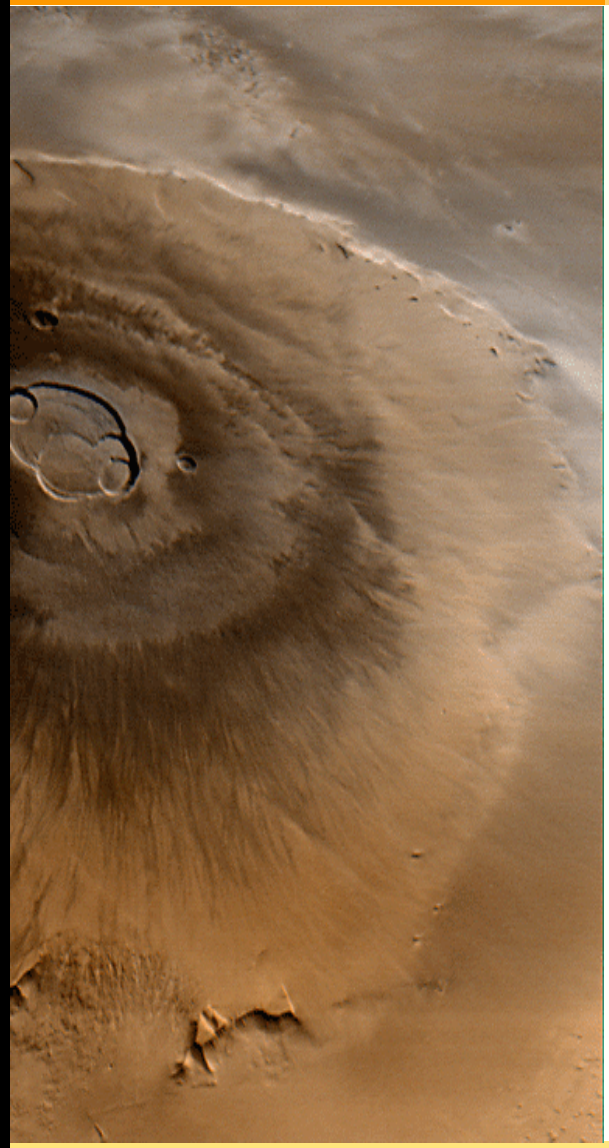
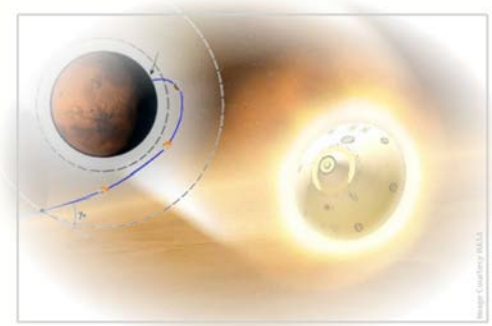


END TO END MISSION PERFORMANCES of EXOMARS 2016 EDM



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Speaker:
Rodrigo Haya
DEIMOS Space

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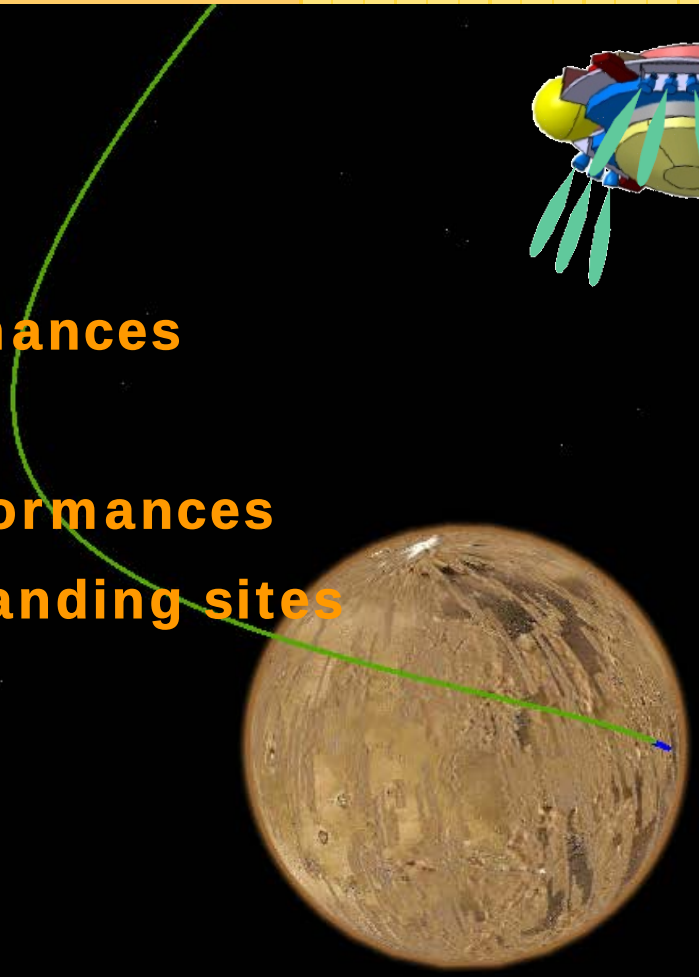
Agenda

- Motivation and Objective
- ExoMars Mission
- Mission Overview
- Approach to Mission Performances
- Local Entry Corridor
- Trajectory and Attitude Performances
- Performance in alternative landing sites
- Conclusions



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Motivation and Objective

- **Project Motivations**
  - ExoMars is ESA's current mission to planet Mars aimed for two launches: 2016 and 2018
  - Project has just passed the PDR and is facing Phase C studies under ESA management and Thales Alenia Space Italia project leadership
  - DEIMOS Space provides support to TAS-I on interplanetary and in-orbit Mission Analysis and Design
  - DEIMOS Space is responsible for the Mission Analysis and Design for the Entry, Descent and Landing (EDL) activities. Within this contract, Tessella is responsible for the support to sizing and analysis of the Descent and Landing System

- **Presentation Objectives**
  - Present the approach and results of the End to End Mission performances for the 2016 EDM mission

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Exomars Mission

- **Technological objectives**
  - Entry, Descent and Landing (EDL) of a payload on the surface of Mars;
  - Surface mobility with a Rover,
  - Access to the sub-surface to acquire samples;
  - Sample preparation and distribution for analyses by scientific instruments.

- **Scientific Objectives**
  - To search for signs of past and present life on Mars;
  - To investigate the water/geochemical environment as a function of depth in the shallow subsurface;
  - To investigate Martian atmospheric trace gases and their sources.

- **The ExoMars Mission will deploy two elements:**
  - EDL Demonstrator with a Surface Platform (SP)
  - A High-mobility Rover

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Actual Mission Scenario

- **This presentation focuses on 2016 EDM**

Atlas V (431)

Credits: LMCo

Credits: ESA

Mission Scenario & EDL: Nominal

• Mission Scenario

	Phase B1	Phase B1X	Phase B2	Phase B2X	Phase B2X / B2X2	
Option	Baseline	Baseline	Baseline	Baseline	Baseline	
Spacecraft	CM + DM	CM + DM	CM + DM (CM possibly as Orbiter)	OM + Enh.DM	OM + EDM	Rover (ESA) Carrier, EDL, Rover (NASA)
Opportunity	2011 / 2013	2013 / 2016	2013 / 2016	2016	2016	2018
Launcher	Soyuz 2-1b	Ariane 5	Ariane 5	Atlas V 551	Atlas V 431	Atlas V 531
Escape type	From HEO with 4 escape burns	Direct	Direct	Direct	Direct	Direct
Transfer type	T3 with DSM	T2 with DSM	T2 with DSM	T2 with DSM	T2 with DSM	T2 with DSM
Release type	Hyperbolic	Elliptic from 4-sol orbit	Elliptic from 4-sol orbit	Elliptic from 4-sol orbit	Hyperbolic	Elliptic

• EDL Architecture

DM	70°/47° aeroshell 3.4 m Diameter 1 Ton	70°/47° aeroshell 3.4 m Diameter 1.2 Ton	70°/47° aeroshell 3.4 m Diameter 1.2 Ton	70°/47° aeroshell 3.4 m Diameter 1.2 Ton	70°/47° aeroshell 2.4 m Diameter 600 kg	MSL derived
Descent System	Single / 2 Stage System (DGB, ringslot)	2 Stage System (DGB, ringslot)	2 Stage System (DGB, ringslot)	2 Stage System (DGB, ringslot)	Single Stage System (DGB)	
Powered Descent	Throttleable / Solid Retrorockets	Throttleable Retrorockets	Throttleable Retrorockets	Throttleable Retrorockets	Modulated Retrorockets	
Landing	Vented / non-ventedairbag	Vented airbag	Vented airbag	Vented airbag	Crushable Structure	

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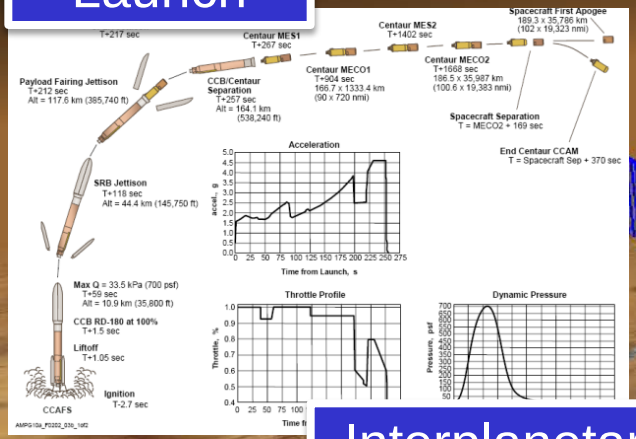
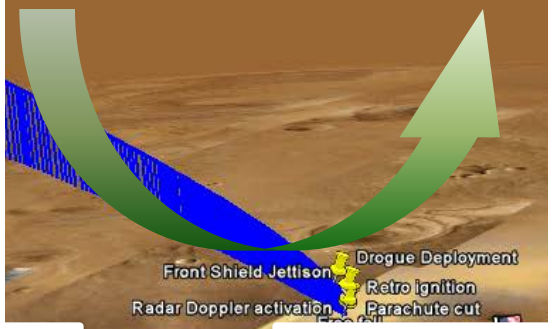
Mission Phases

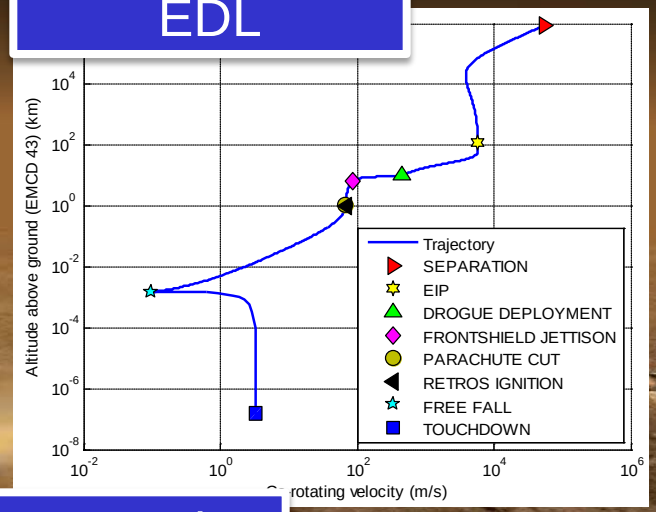
- **Multiphase Mission ⇒ End to End approach**

Launch

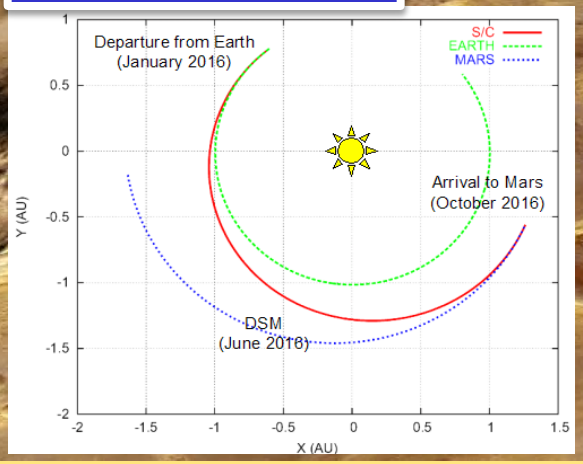




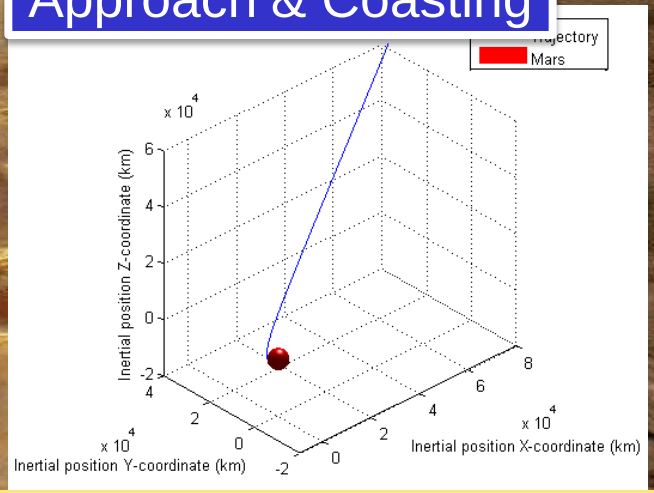
EDL



Interplanetary



Approach & Coasting



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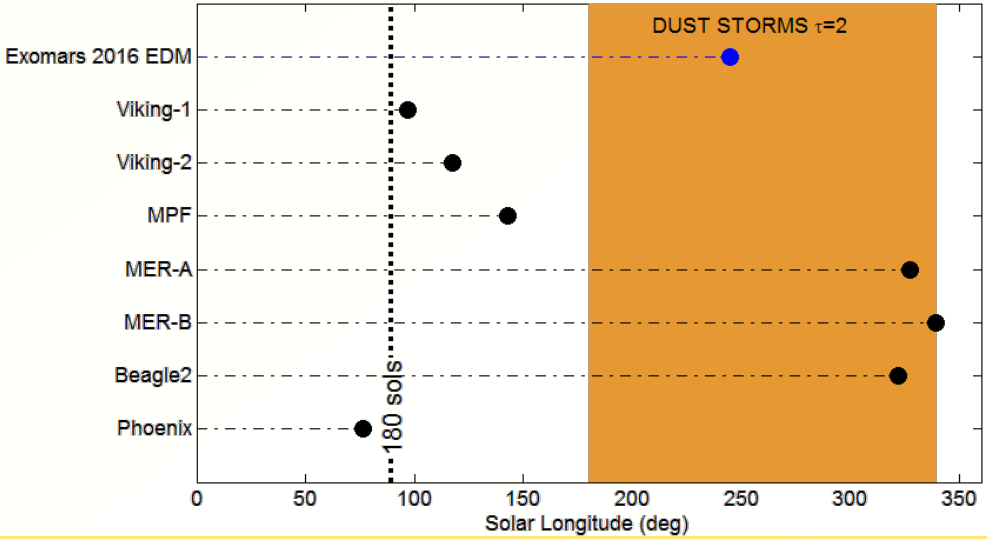
Mission Features

- **Mission drivers**
  - Direct escape
  - 21 days launch window with fixed arrival date
  - Direct T2 type tranfer with DSM
  - Early probe release (EIP-3 days)
  - Ensure visibility from the TGO of the EDM during the EDL phase
  - Landing in the middle of MGDS

- **Continuous end to end profile from injection to touchdown ensures perfect coupling between interplanetary and EDL legs:**
  - Precise **targeting** of landing site
  - Precise manoeuvers **timeline**
  - Precise manoeuvers **cost** estimation
  - Precise **margins** design & evaluation



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Mission Performances

- **Mission Performance is the characterisation of the Mission figures of merit**
  - Thermomechanical loads: heat, load factor…
  - Events dispersions
  - Parachute loads
  - Visibility (comms)
  - ….
- **Used for**
  - Validation of the Reference Mission Scenario
  - Assessment of margins
  - Input to Specification of System and SubSystems
- **Different assessment methods depending on stage**
  - Nominal scenario
  - Worst Case predictions
  - Monte Carlo simulations

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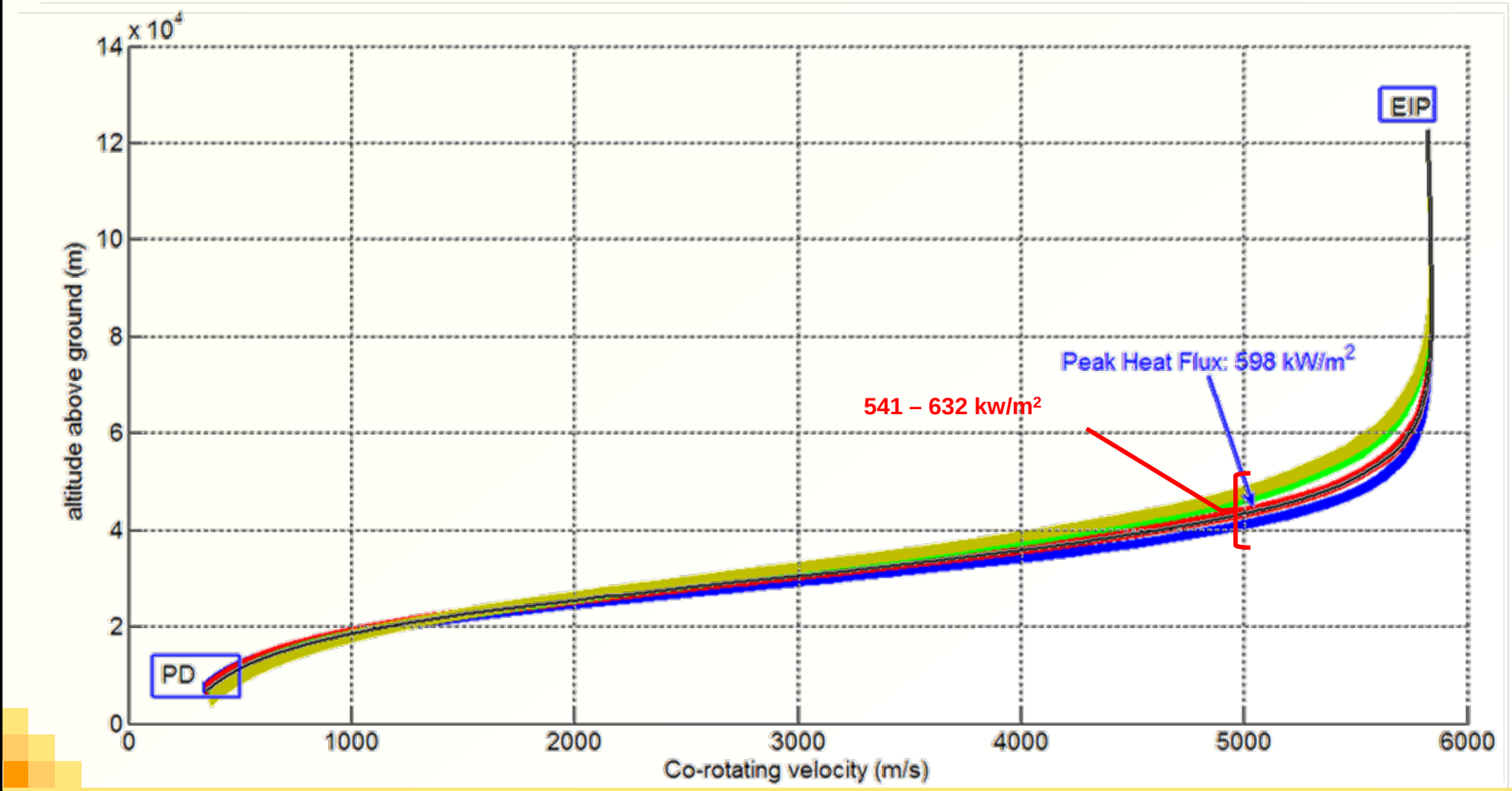
Performances: from nominal to dispersed

- **Mission Performances are properly described when uncertainties are considered on top of the reference mission: Monte Carlo & Worst Case**



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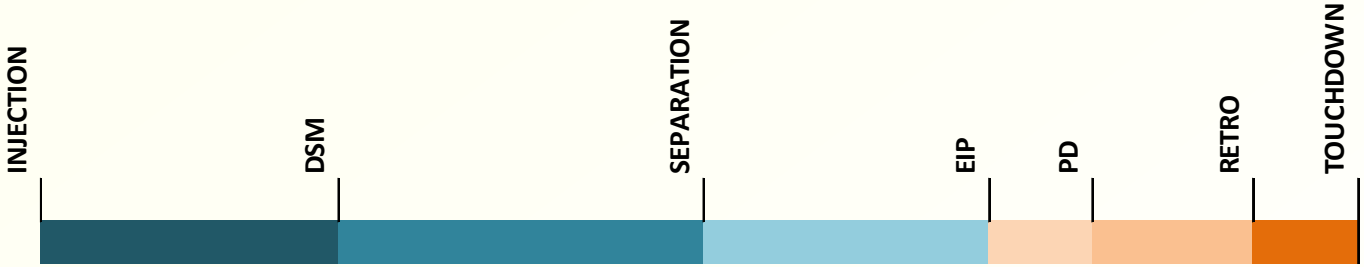
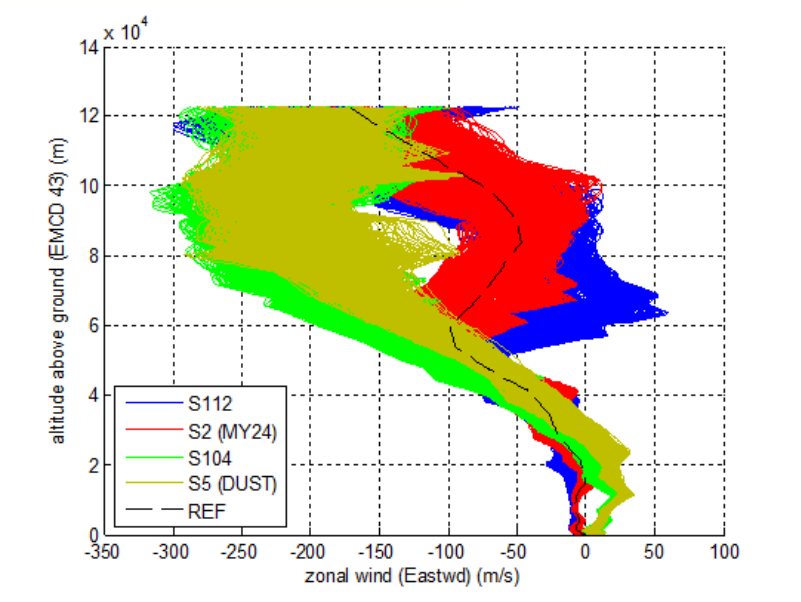
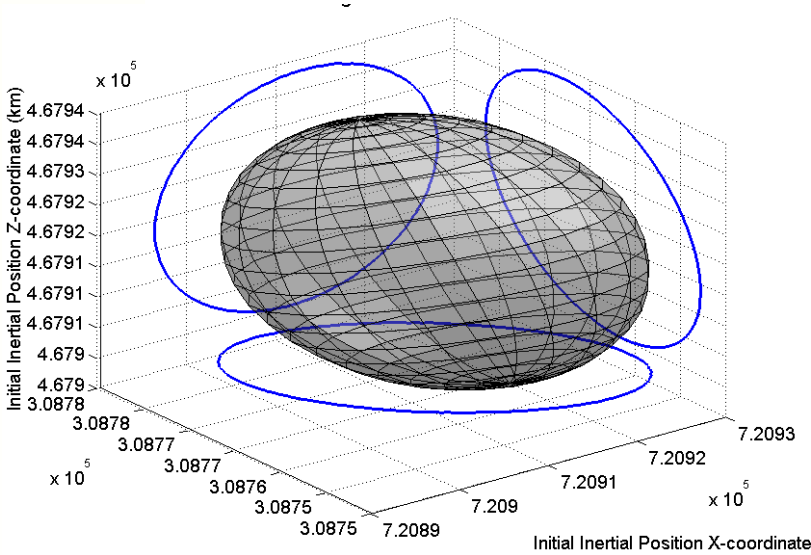
Sources of Uncertainty



Launcher Dispersions	ACS	Aerodynamics		
Manoeuvres: TCM's, DSM	Navigation	Atmosphere & winds		
Environment	Manoeuvres: Sep	MCI		
Navigation	MCI		Triggering	
				GNC





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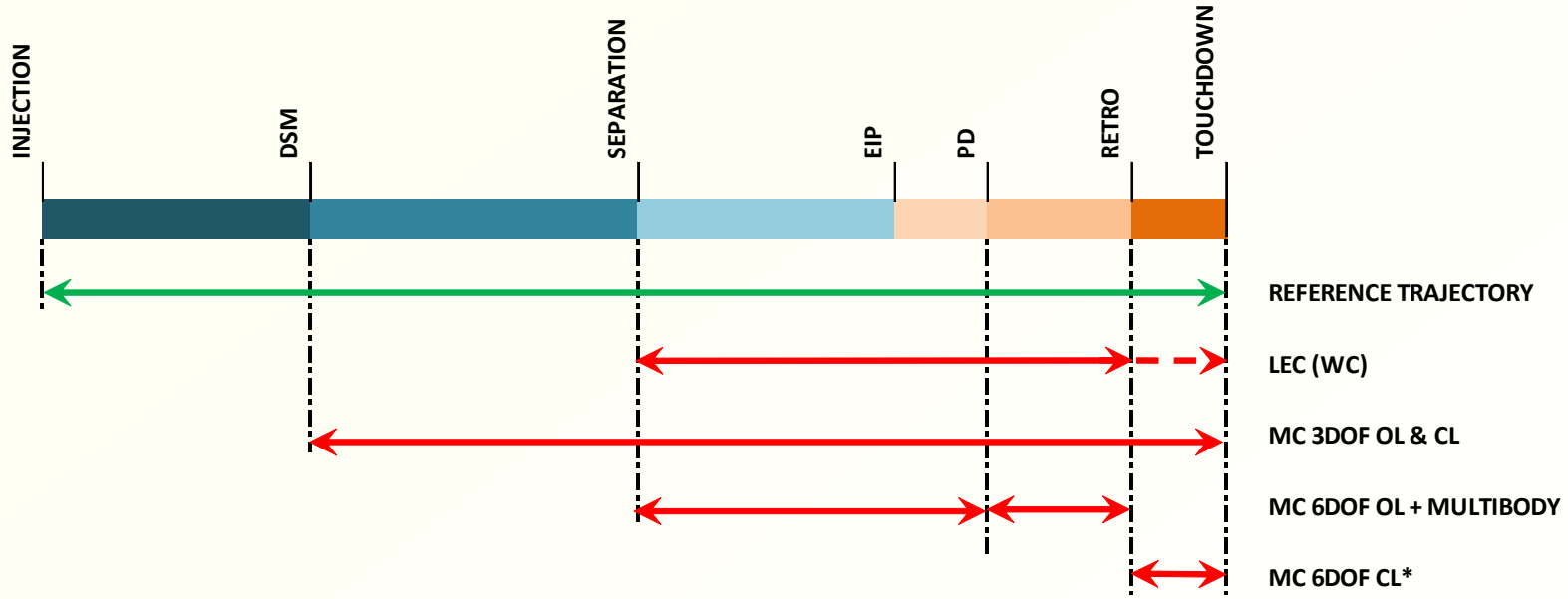
Approach to Performance Assessment



PERFORMANCE EVALUATION	CROSS VALIDATION	UNCERTAINTIES	DOF	GNC
REFERENCE TRAJECTORY		NOMINAL	3DOF / 6DOF / MULTIBODY	PERF. MODEL
LEC (WC)		DISPERSED WC	3DOF	OL
MC 3DOF OL & CL		DISPERSED RANDOM	3DOF	PERF. MODEL
MC 6DOF OL + MULTIBODY		DISPERSED RANDOM	6DOF / MULTIBODY	OL
*MC 6DOF CL**		*DISPERSED RANDOM*	*6DOF*	*FULL GNC*

* TASI

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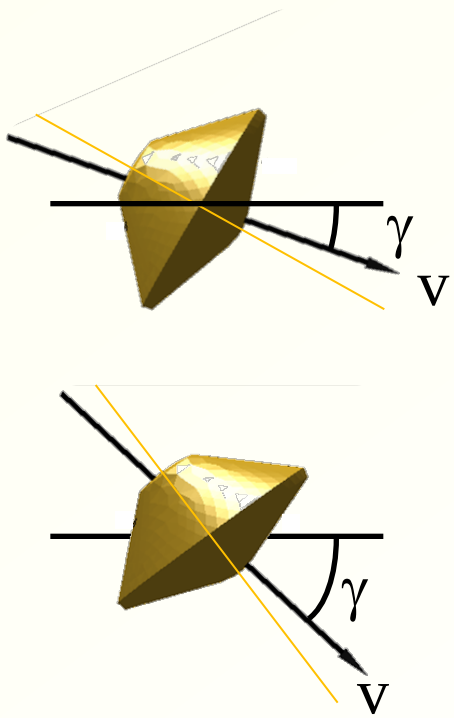
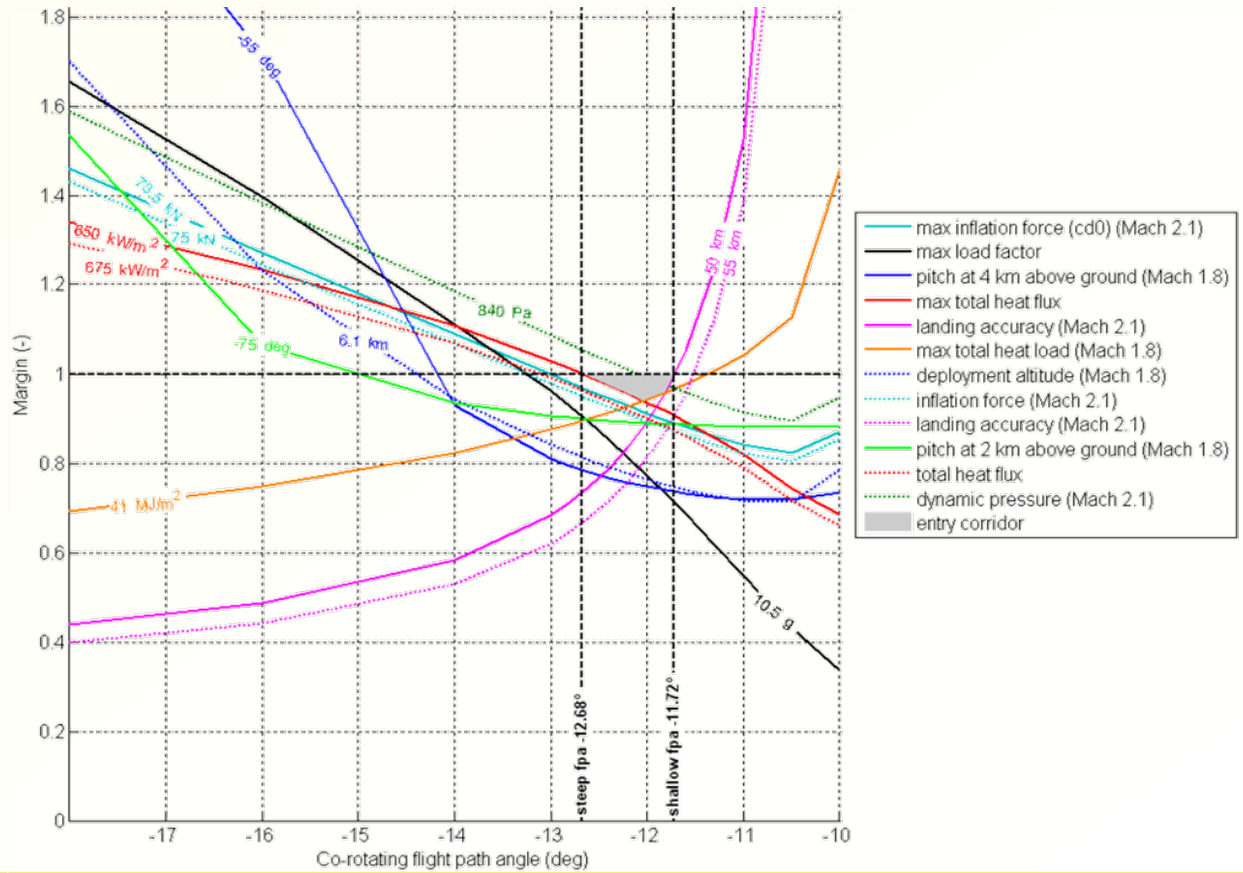
Local Entry Corridor Performances

- **The Local Entry Corridor (LEC) provides a Worst Case prediction of the Mission Performances (range of variability)**





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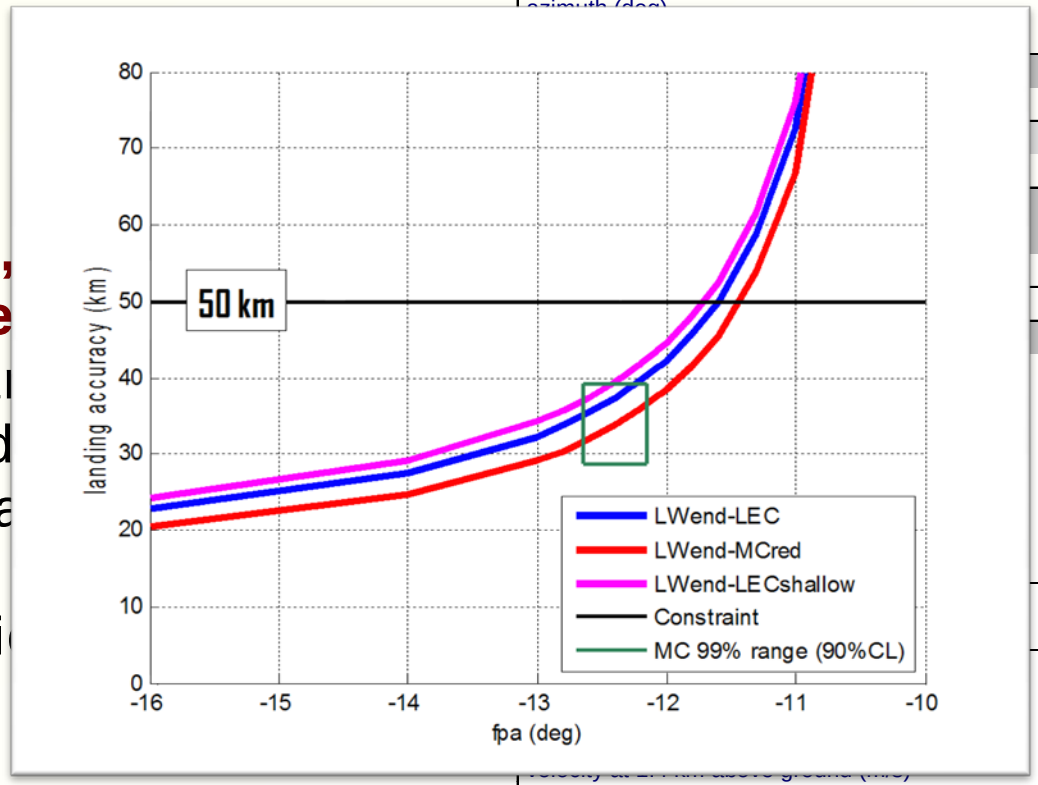
LEC predictions

- **From the LEC, a prediction of the variability due to uncertainties is provided.**
- **As shown later, by Monte Carlo**
- **A corridor exist, margins wrt the**
  - Thermomechan
  - Parachute load
  - Landing accura
  - Verticalisation
  - RDA initialisati



Parameter	Variability	
LS (deg)	244.87	
Latitude (deg)	-1.82	
Longitude (deg)	-6.15	
Mass (kg)	**600.00**	
velocity (m/s)	**3458.761**	
[illegible]	-157.25	
[illegible]	-30.75	
[illegible]	**0.96**	
[illegible]	-12.68	-11.72
[illegible]	**1.95**	
[illegible]	1.80	2.10
[illegible]	510.68	**650.00**
[illegible]	31.62	39.65
[illegible]	6.08	9.50
[illegible]	33.06	33.89
[illegible]	47.77	71.24
[illegible]	8.12	12.11
[illegible]	565.50	**885.77**
[illegible]	146.21	209.40
[illegible]	185.17	237.91
[illegible]	7.50	13.29
[illegible]	6.10	11.90
[illegible]	-28.11	-20.76
[illegible]	-89.27	-70.14
[illegible]	-89.04	-83.35
[illegible]	-89.60	-84.07
[illegible]	76.40	144.48
[illegible]	-73.36	-62.78
[illegible]	63.12	73.99
time from frontshield jettison to 1400 km (s)	36.40	104.48
Landing accuracy (km)	36.66	**50.00**

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Navigation Analyses

- **Key source of dispersion in interplanetary part before separation**
  - Full OD and TCM simulations from DSM to EIP
  - Analysis stages:
    - **Initial arc:**
      - Lasting 15 days and used to achieve a good knowledge of the state vector after DSM
      - OD done with range, doppler and DDOR daily from ESA's DSN
    - **Main arc:**
      - Extending for 94 days and down to 43 days prior to EIP
      - OD done with range, doppler daily and DDOR (once per week)
      - TCM2 is performed at start to mitigate dispersions from the DSM
    - **Final arc:**
      - Lasting 40 days and down to the separation event
      - OD done with range, doppler and DDOR (2 baselines) daily
      - TCM3 performed at EIP minus 30 days and TCM4 at EIP minus 5 days (2 days before separation)
    - **Terminal arc:**
      - Last 3 days of the trajectory from separation to EIP
      - Ballistic phase

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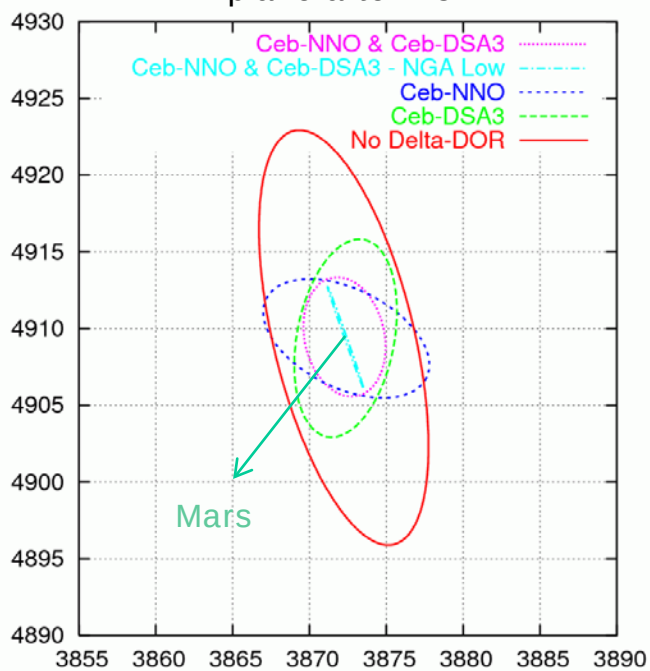
Navigation Analyses

- **Performance analysis**
  - Based on the analysis of the influence of the main parameters for the OD solution:
    - DDOR baselines used in the final arc
    - NGA acting on the S/C (WOL, fuel sloshing, etc.)

B-plane after TCM-4

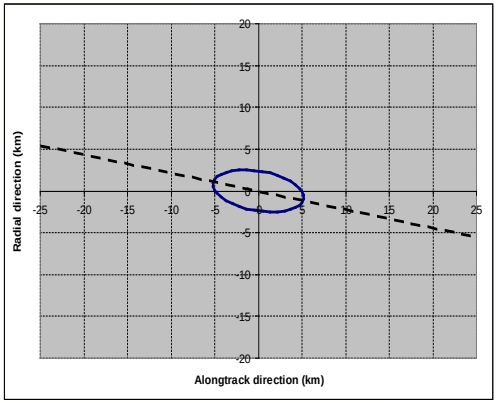


  - Cebreros-NNO is the baseline that most reduces the alongtrack landing dispersions
  - Both baselines are proposed in any case for OD

Obtained TCM values

TCM2 - 99% percentile	0.380 m/s
TCM3 - 99% percentile	0.021 m/s
TCM4 - 99% percentile	0.018 m/s

Dispersion ellipse at EIP (no separation errors)



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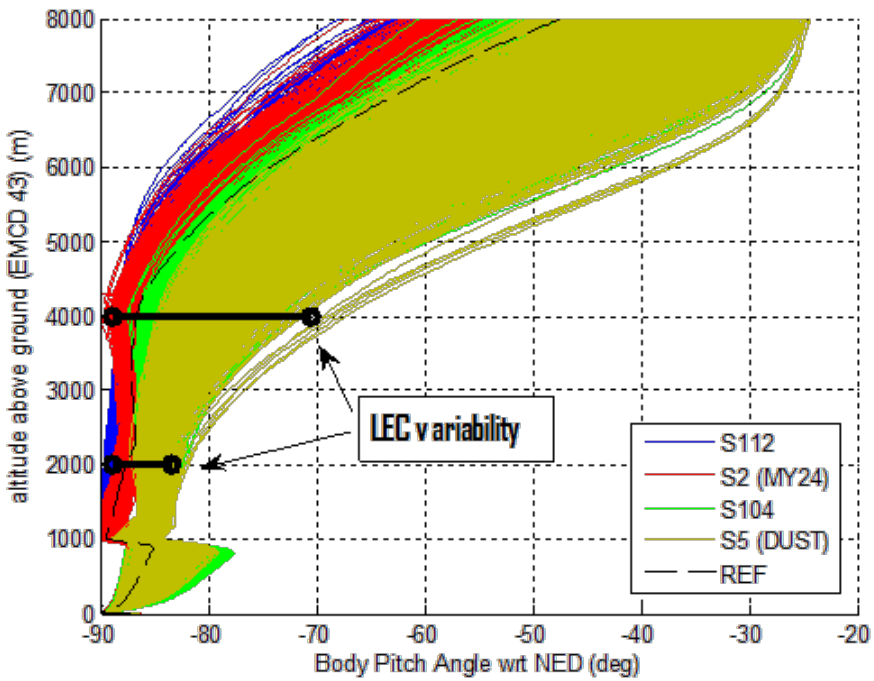
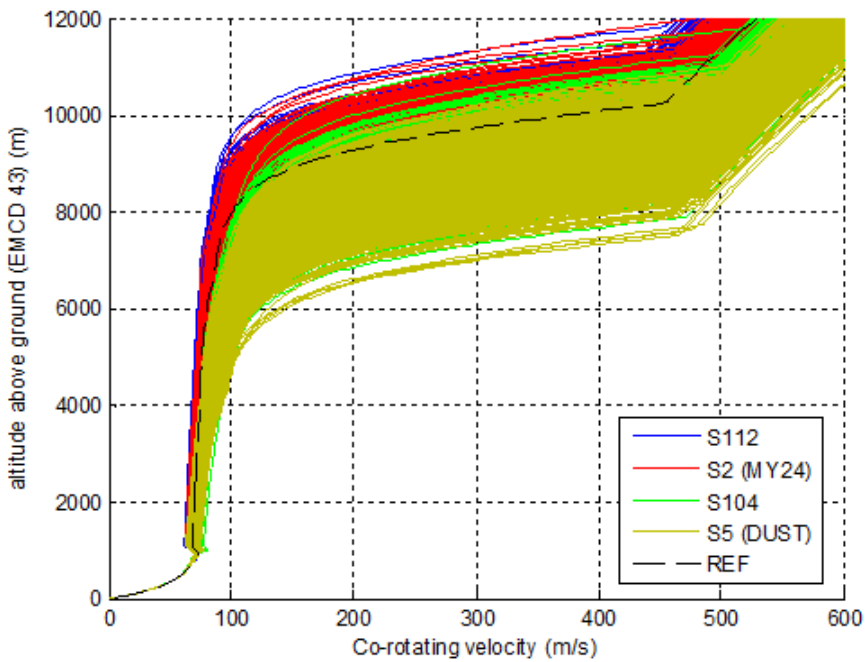
EDM Trajectory Performances

- **End to End MC 3DOF from DSM to splashdown**
  - 4000 shots campaign
  - Based on EndoSim DEIMOS Simulator
  - Large variability in environment





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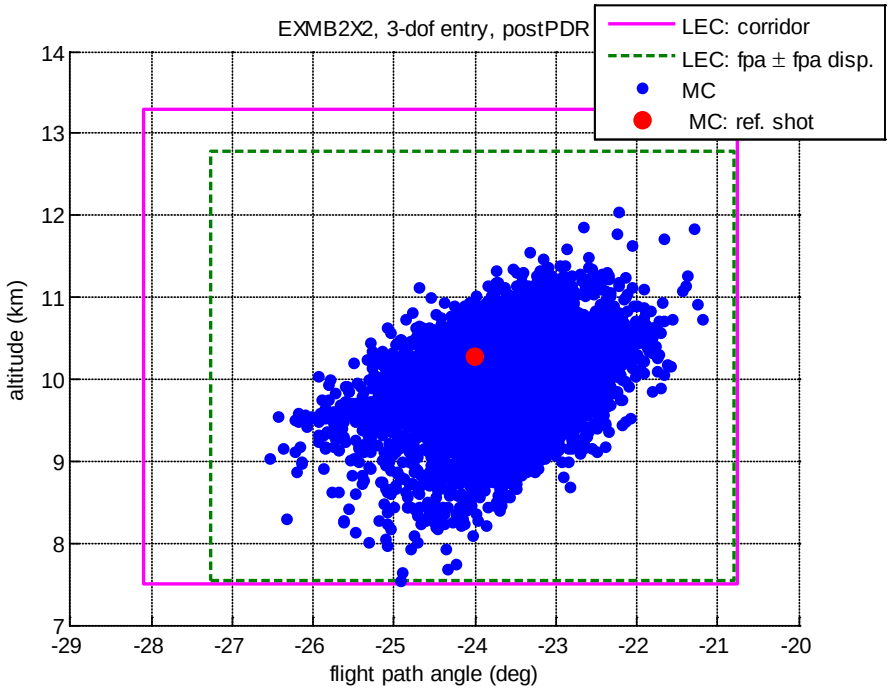
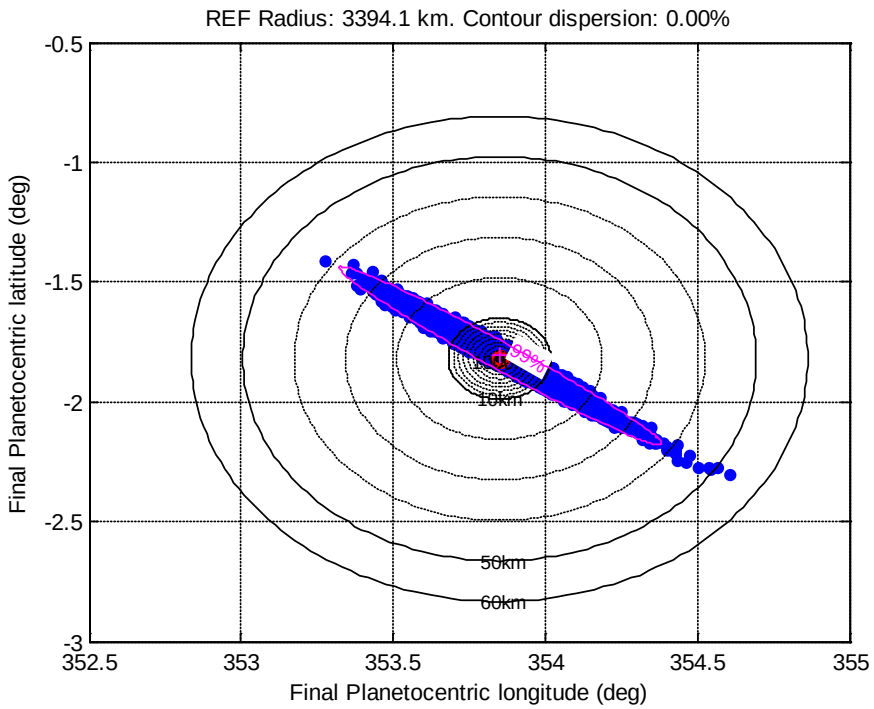
EDM Trajectory Performances

- **Compliance of all of the Misison Constraints**
  - Entry: path constraints
  - Descent: verticalisation, parachute loads, timing margings
  - Landing: accuracy





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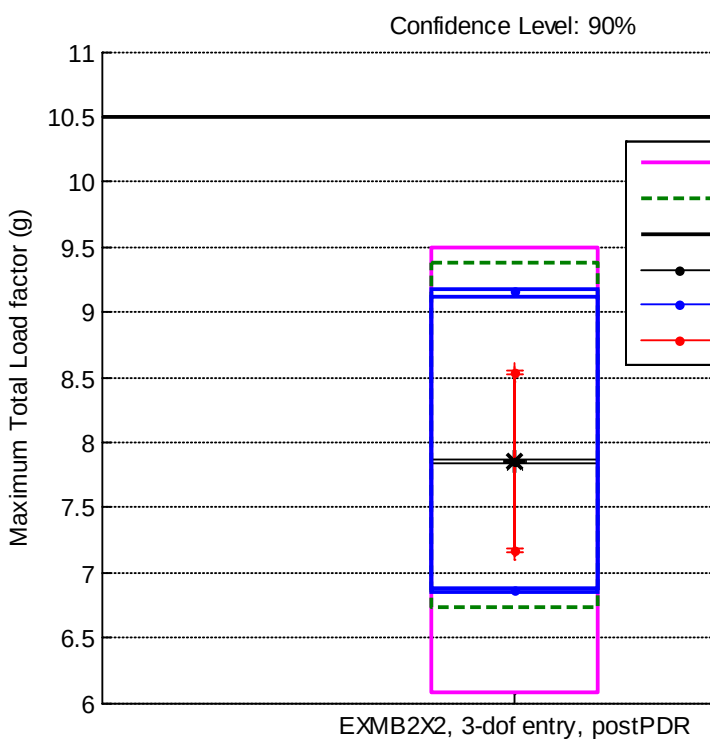
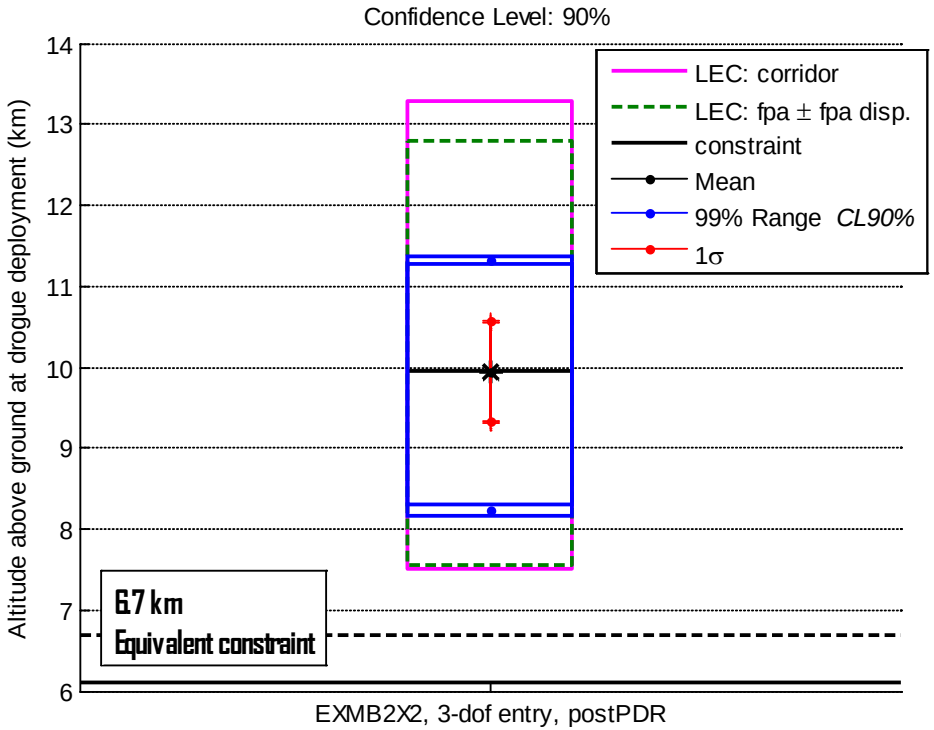
Verification of LEC predictions

- **The LEC performance prediction are verified**
  - Enables LEC as quick turnaround performance prediction tool





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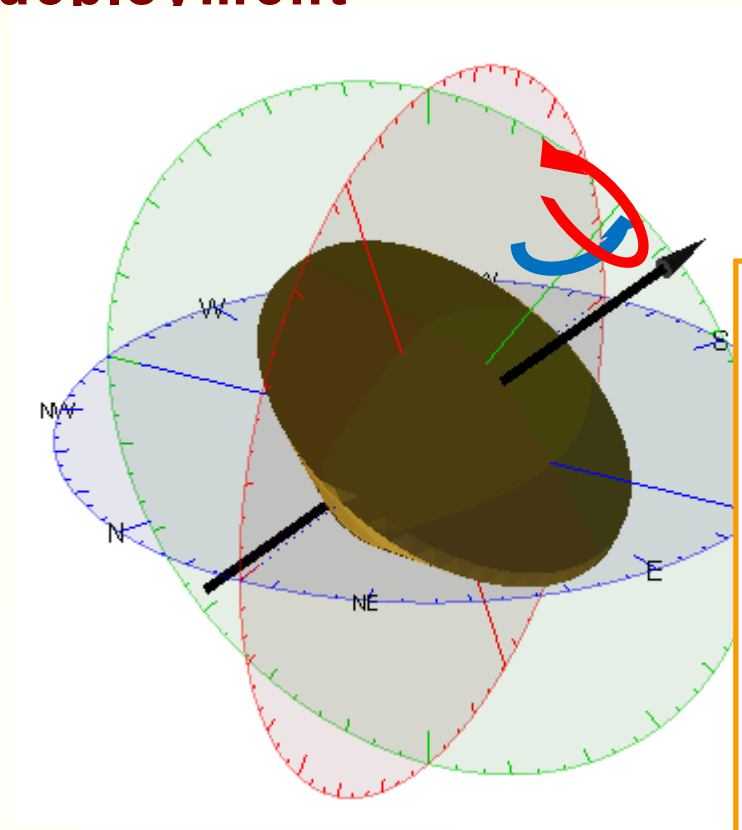
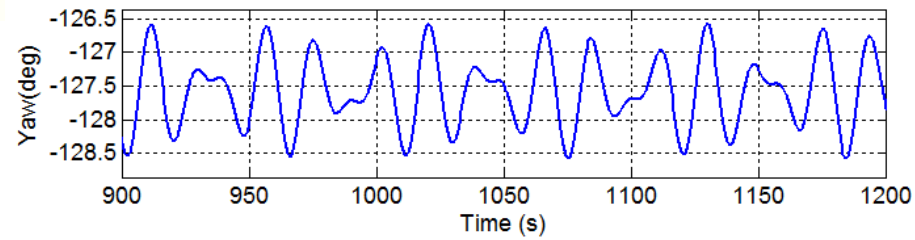
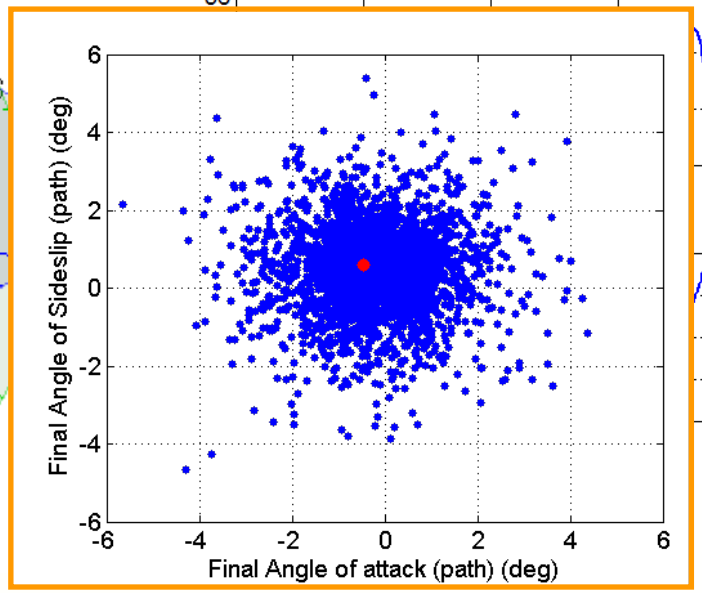
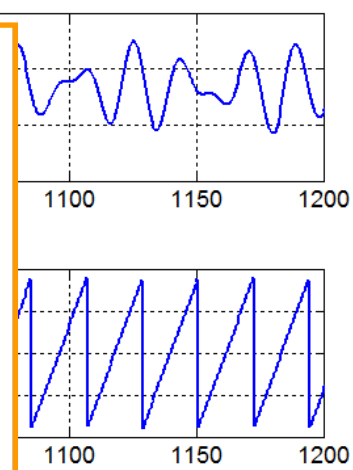
EDM attitude performances: coasting

- **Dominated by Poinsot motion**
- **Attitude dispersions at EIP are compatible with requirements at peak heat flux and parachute deployment**









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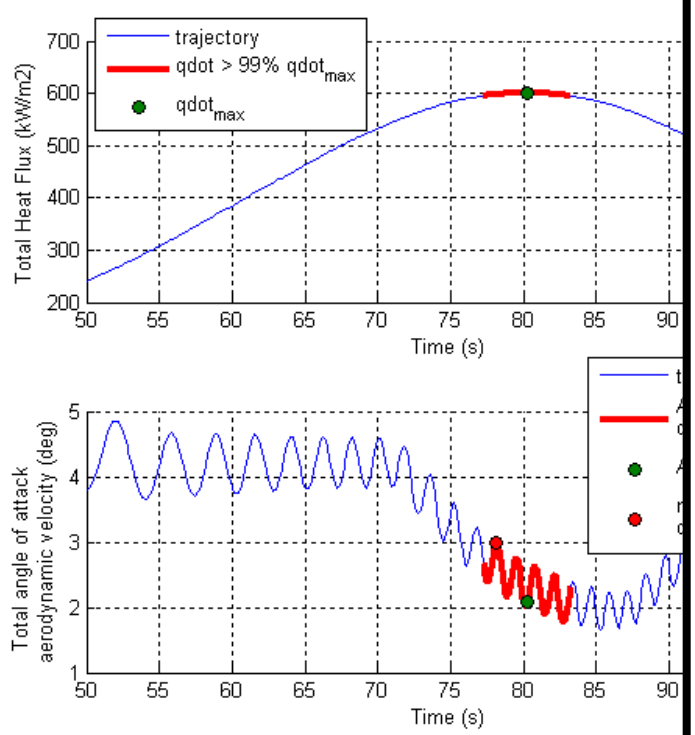
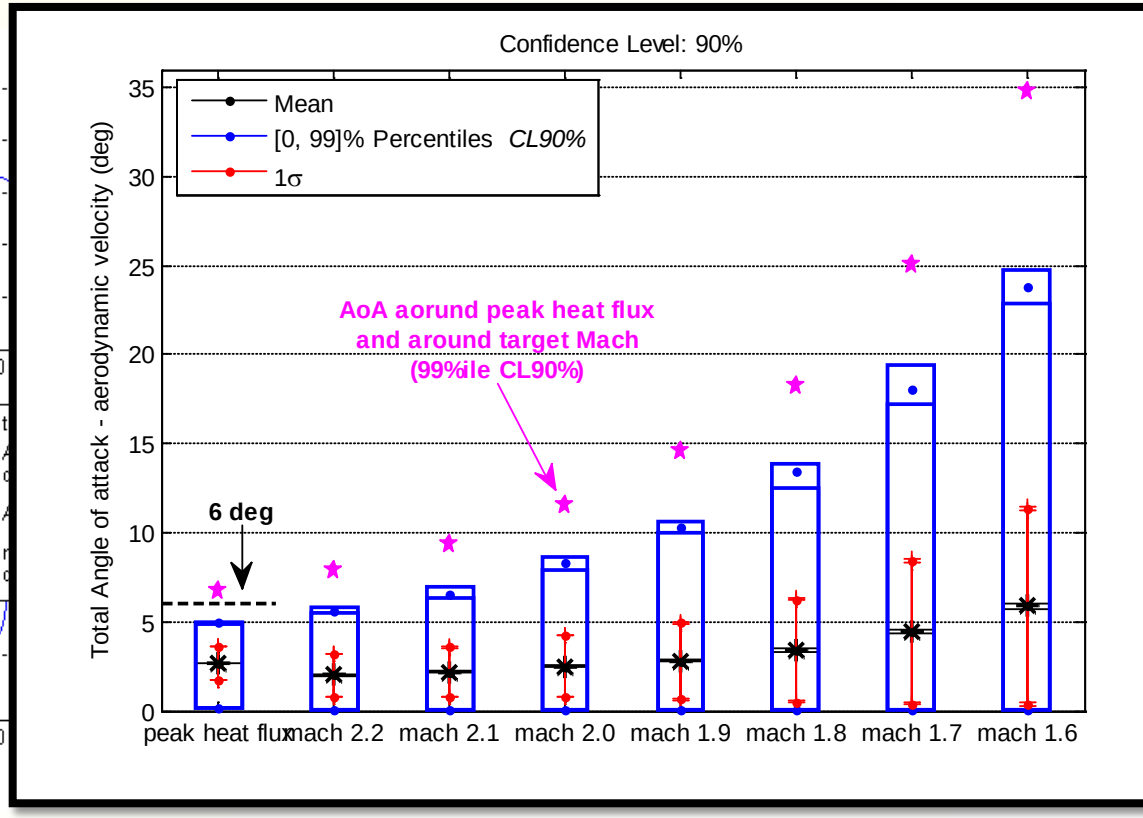
EDM attitude performances: Entry

- **Trajectory variability conforms 3DOF results (within 1% difference)**
  - Attitude constraints at peak heat and deployment fulfilled
  - Stability drives parachute deployment window





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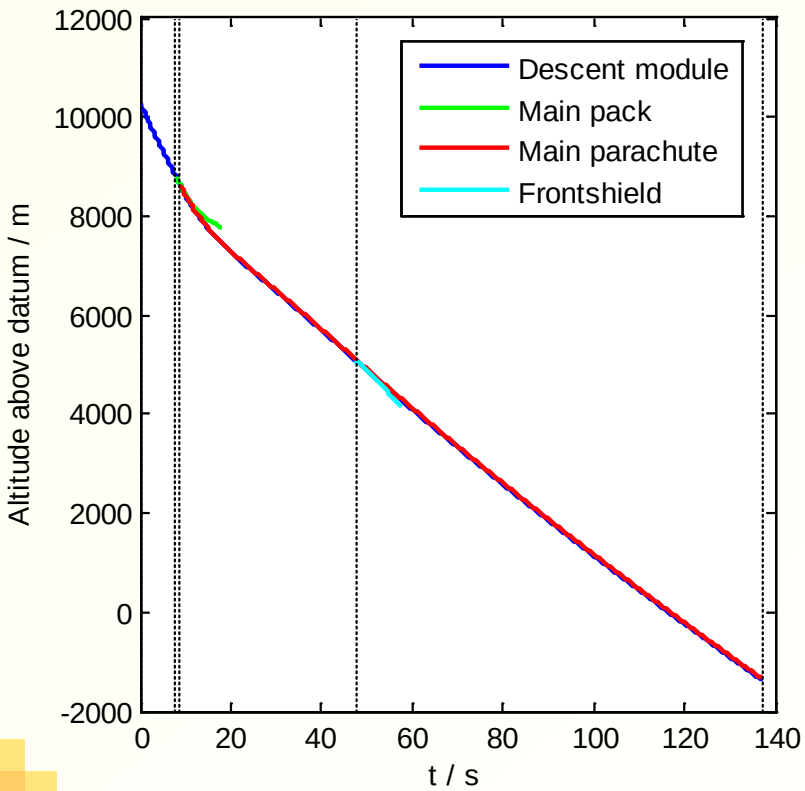
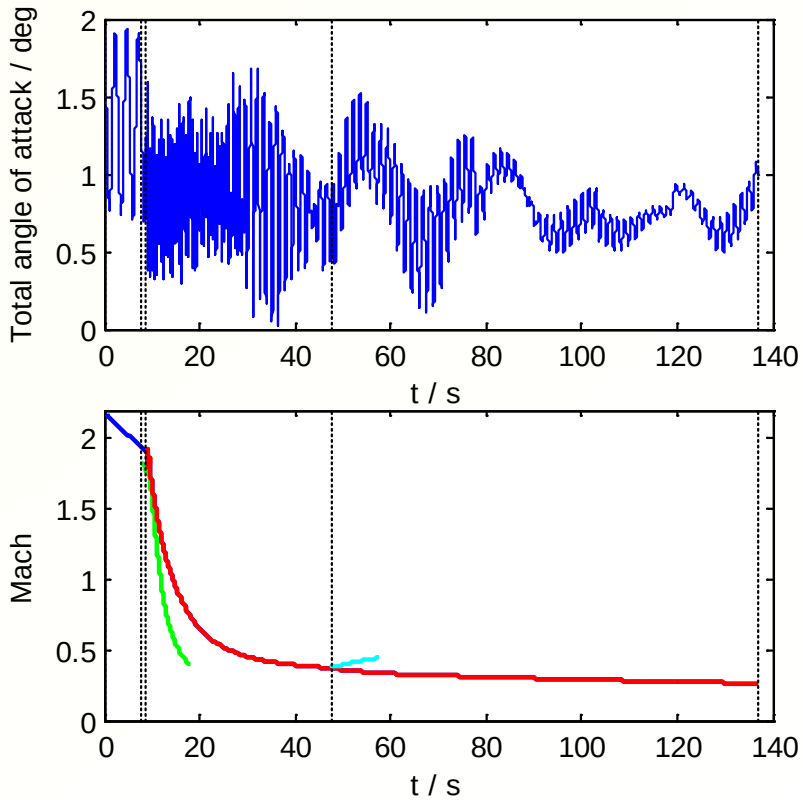
EDM attitude performances: Descent

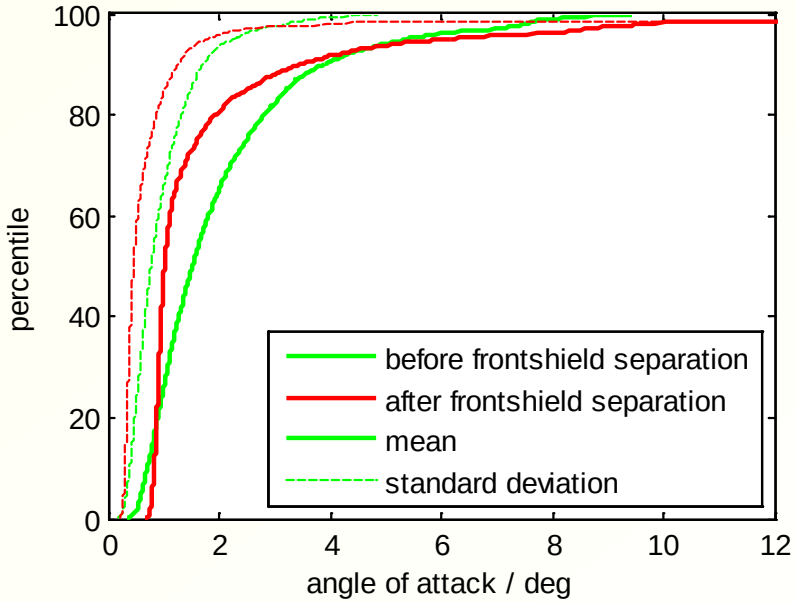
- **Multi-body 6-DoF descent simulations**
  - Run using the PASDA tool
- **Look at overall trajectory, safety of parachute deployment and frontshield separation, verticalisation**

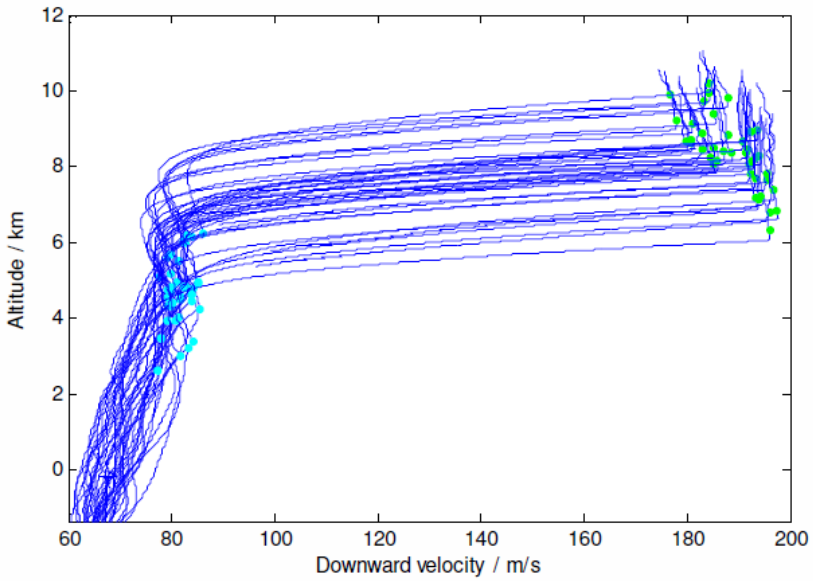




EDM attitude performances: Descent

- **Run a 4000-case Monte Carlo campaign**
  - Starting conditions for each case are taken directly from the entry simulations, i.e. continuous.
- **Use realistic wind profiles covering all length scales to examine the effects of turbulence**





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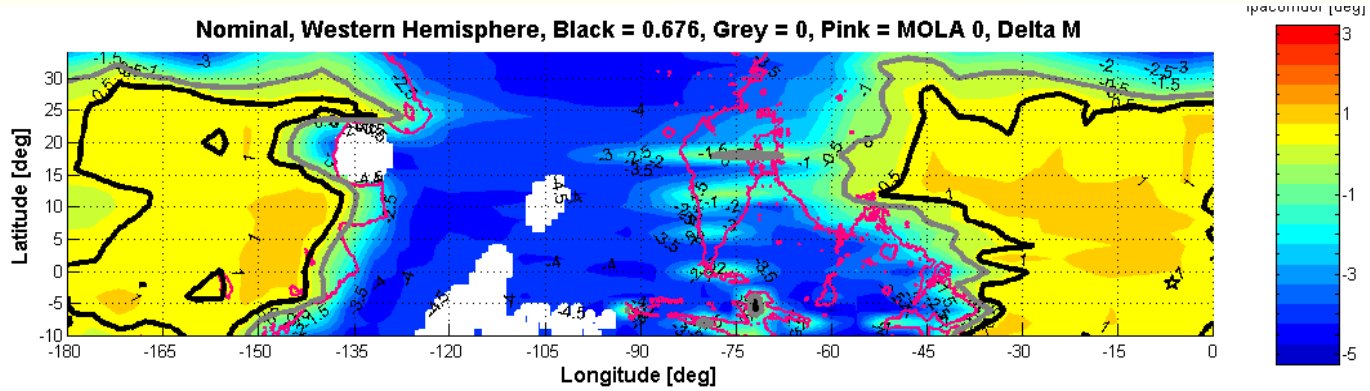
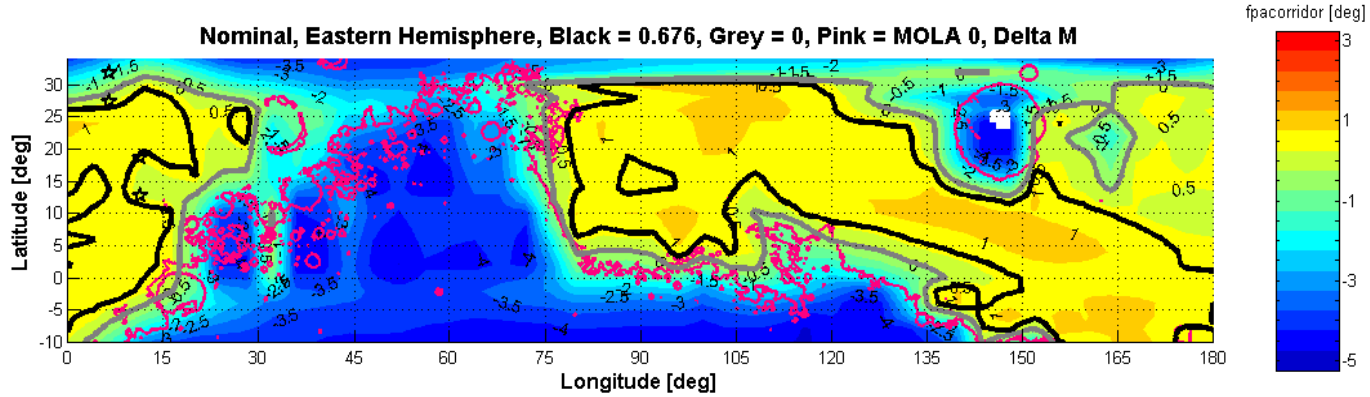
Performances In different sites

- **Global Entry Corridor: extension of LEC predictions at planetary level**
  - Mission Performances in sites different than Meridiani
  - Alternative sites identified





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Conclusions

- **An end to end philosophy has been applied for the design and assessment of the Exomars 2016 Mission**
- **Different levels of Performance Evaluation have been conducted showing Mission feasibility at a Mission Scenario level.**
- **The detailed Monte Carlo campaigns have been used to validate the performance predictions made at design level.**
- **The use of the LEC and GEC methods has alleviated the use of large Monte Carlo campaigns, being limited to the verification to the end of the design loop**

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Thank you!

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