OPTIMUM SIZING FOR DESIGN OF MARS PROBES

D.Bonetti
C.Parigini, R.Haya Ramos

presented by Davide Bonetti

DEIMOS Space S.L.U., Spain

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Table of Contents

- **Introduction**
- **Missions descriptions**
  - Mars Network Missions
  - Mars Single Lander Missions
- **Tool descriptions**
  - Local Entry Corridor (LEC)
  - Global Entry Corridor (GEC)
  - EDLS/GNC Sizing and Analysis Tool (ESAT)
- **Tool results**
  - Mars Network Missions
  - Mars Single Lander Missions
- **Conclusions**

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Introduction

- **Introduction**
  - Optimum design of a probe for planetary exploration:
    - complex task
    - several disciplines are involved, multiple mission phases
    - conflicting objectives => optimum equilibrium
    - multiple constraints
  - In general it can be states as a **constrained multi-objectives optimization problem**
  - Multiple design solutions have to be compared
  - Need for efficient and flexible tools for automatic support of system engineer trade-off design decisions

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Missions Descriptions

- **Mars Network Missions:**
  - ESA MREP (Mars Robotic Exploration Preparation) Programme
  - Multiple landers separate from the same orbiter/carrier and reach the planet surface in different sites.
  - Allow simultaneous measurements from a number of landers, which are spaced across the surface of the planet
  - Geophysics, geology, meteorology, atmosphere
  - Post-ExoMars candidate missions, "Europe led" with no strategic elements outside Europe
  - Missions results presented for:
    - MarsNEXT (2009)
    - Small Mars Landers (2012)

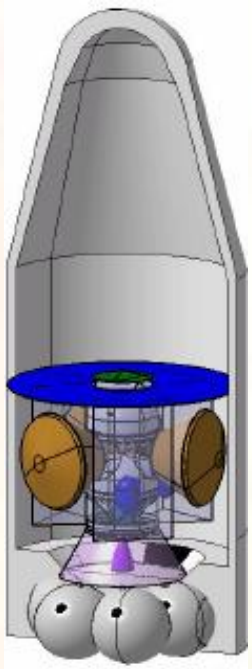
© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Missions Descriptions

- **MarsNEXT (2009)**
  - Three identical network science probes in different sites
  - Hyperbolic orbit, Ballistic entry, Parachute phase, (Retros), Airbags
  - Science payload ~55 kg, operating during one Martian year
  - Deimos: MA and EDL optimization support to Astrium ST
- **Small Mars Landers (2012)**
  - Mission concept similar to MarsNEXT
  - No orbiter, only a carrier
  - Payload ~130 kg, EIP mass < 350 kg
  - Deimos: E2E EDLS/GNC optimization

ESA CDF 2011 study: Mars Network Science Missions

ESA INSPIRE mission



Credits: ESA

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Missions Descriptions

- **Mars Single Lander Missions** where a guided entry phase is required to achieve high landing accuracy levels
  - **MarsPLAY (2011)**
    - Main goal is delivering a Rover on Mars in 2022-2026 timeframe
    - Guided Entry, Uncontrolled Descent and Landing
    - Deimos: Transfer and EDL mission analysis, support to TAS-I
  - **High Precision Lander (2012)**
    - High Precision (10 km Landing accuracy) scenario
    - Pinpoint landing (1 km Landing accuracy) scenario
    - Guided entry phase, descent phase, retros landing phase
    - Deimos: EDLS/GNC optimization support to Astrium ST

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Descriptions

- **Local Entry Corridor (LEC)**
  - Entry corridor definition

    range of flight path angle compatible with mission and trajectory constraints
  - LEC Tool is based on
    - Worst case approach

      Initial conditions, Vehicle aerodynamics, Environment and Triggering conditions
    - End-to-End simulations
      - Initial condition linked to exo-atmospheric analysis
      - Target to a specific landing site
  - Extension to a 2D domain
    - Ballistic coefficient: for design purposes
    - Commanded bank angle: in case of guided entries
  - Tool outputs
    - Entry corridor size, steepest and shallowest flight path angles
    - Parameter variability within the corridor and performances maps
    - Sizing trajectories and support to reference trajectory selection

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

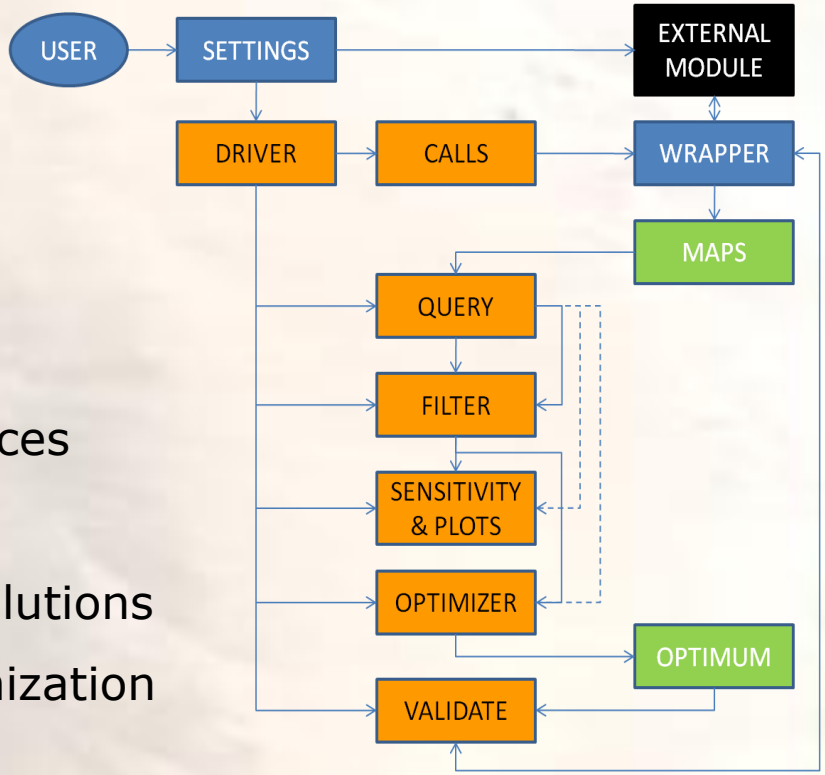
Tools Descriptions

- **Global Entry Corridor (GEC)**
  - extension of the LEC to a planetary or regional level
  - flexibility in the LEC boundary conditions (EIP/Landing), extending the corridor concept to wider dimensions
  - landing site feasibility and robust system performances in any point of the planet and in any epoch of the year
  - Main outputs:
    - Planetary maps of performances
    - Performances at any epoch of the year / hour of the day
    - Sizing trajectories and sizing conditions
    - Statistics of mission feasibility
    - Candidate landing sites given mission objectives and constraints (EDL, terrain, landing ellipse…)

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

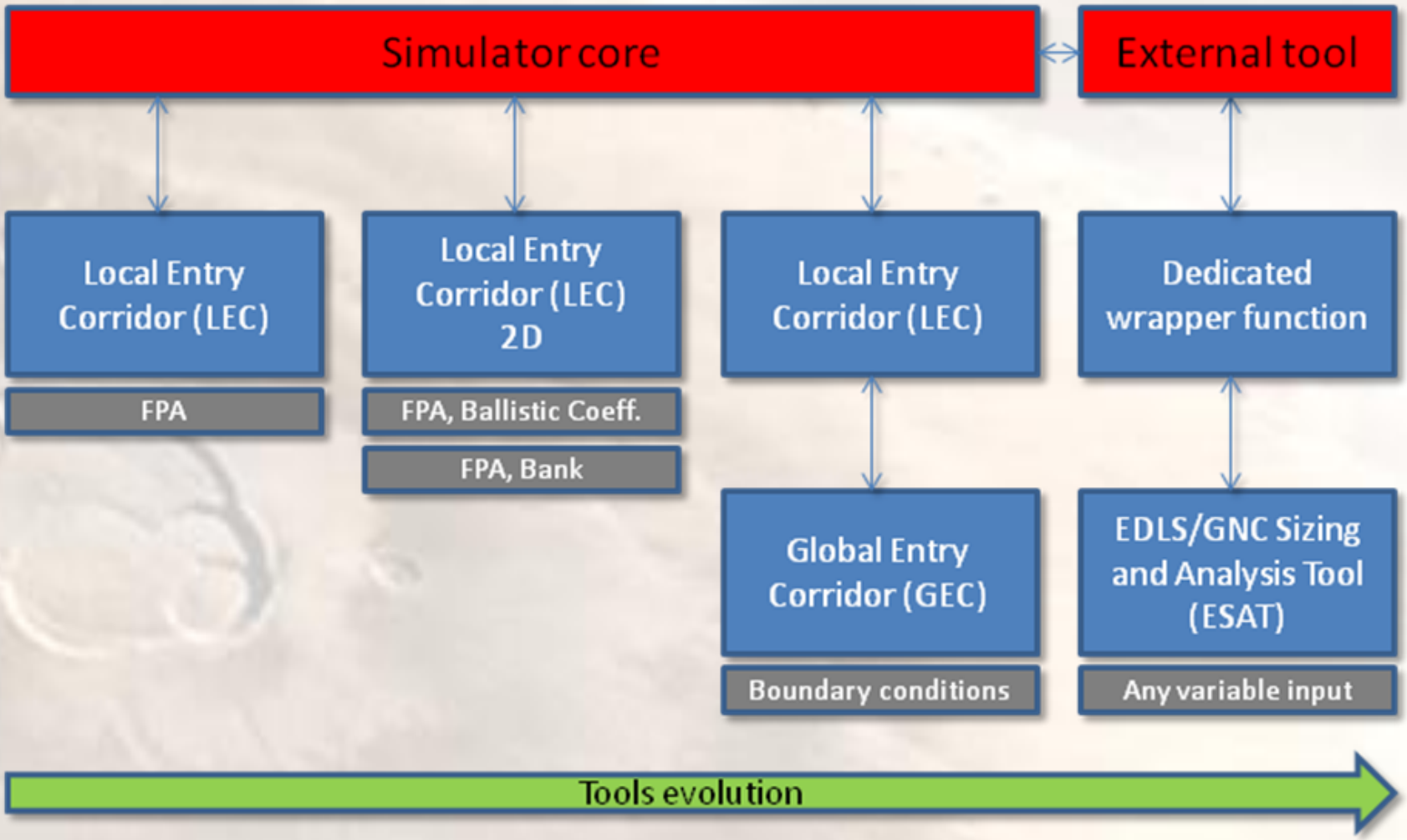
Tools Descriptions

- **EDLS/GNC Sizing and Analysis Tool (ESAT)**
  - Tool to support the system trade-offs process and the selection of optimum EDLS/GNC design solutions
  - Extend GEC concept to:
    - Any type of problem
    - Any problem dimension
    - Any number of outputs
  - Key features:
    - Based on maps of performances
    - Flexibility & Modularity
    - Quickly compares multiple solutions
    - Integrates filtering and optimization
    - Multiple outputs



© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

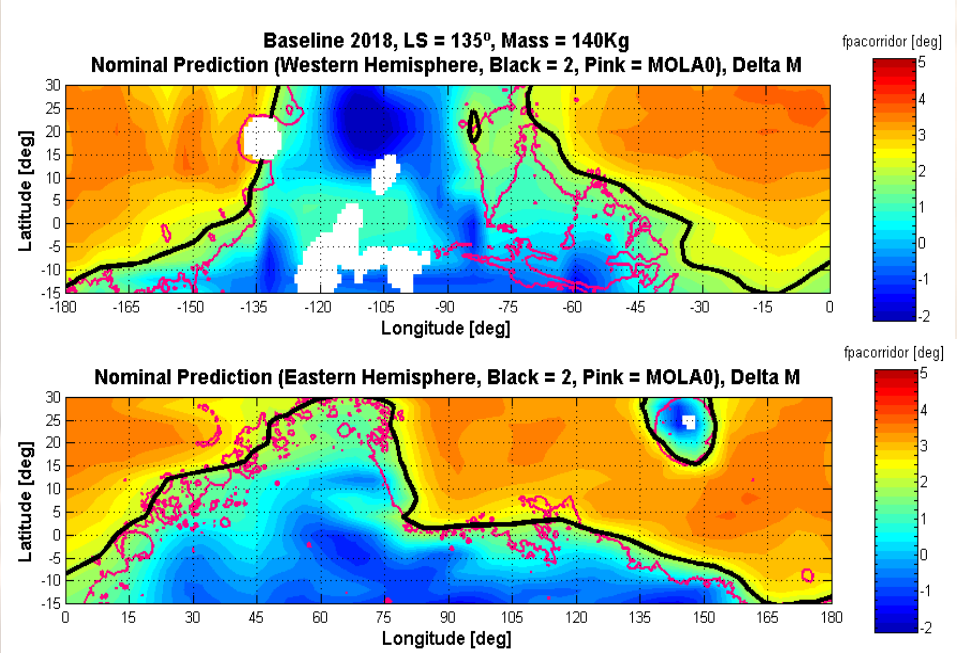
Tools Descriptions



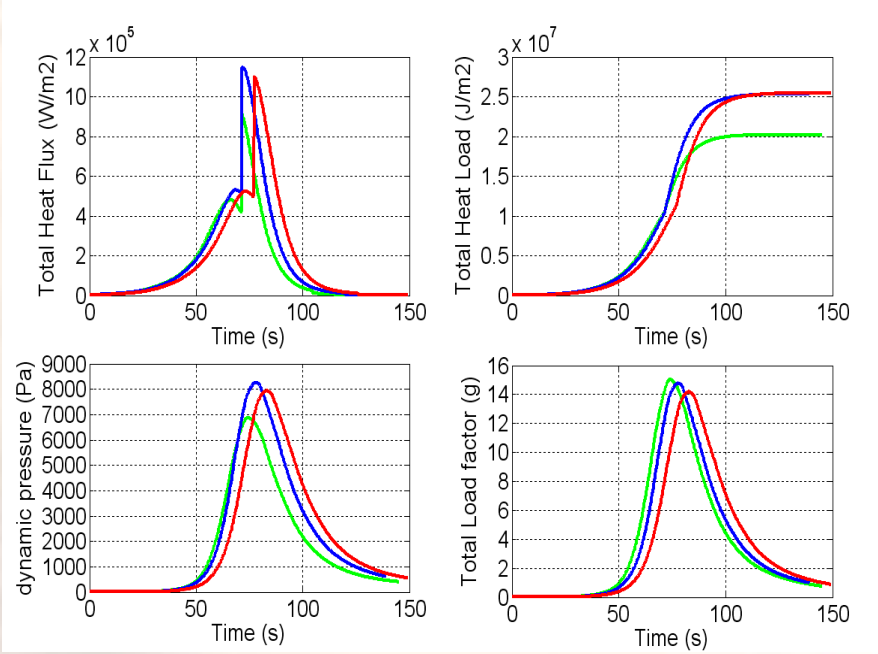
© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Results

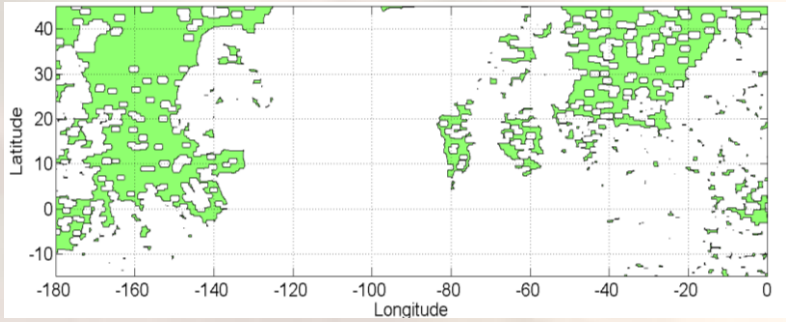
- **MarsNEXT**



GEC sizing trajectories



GEC map: FPA corridor

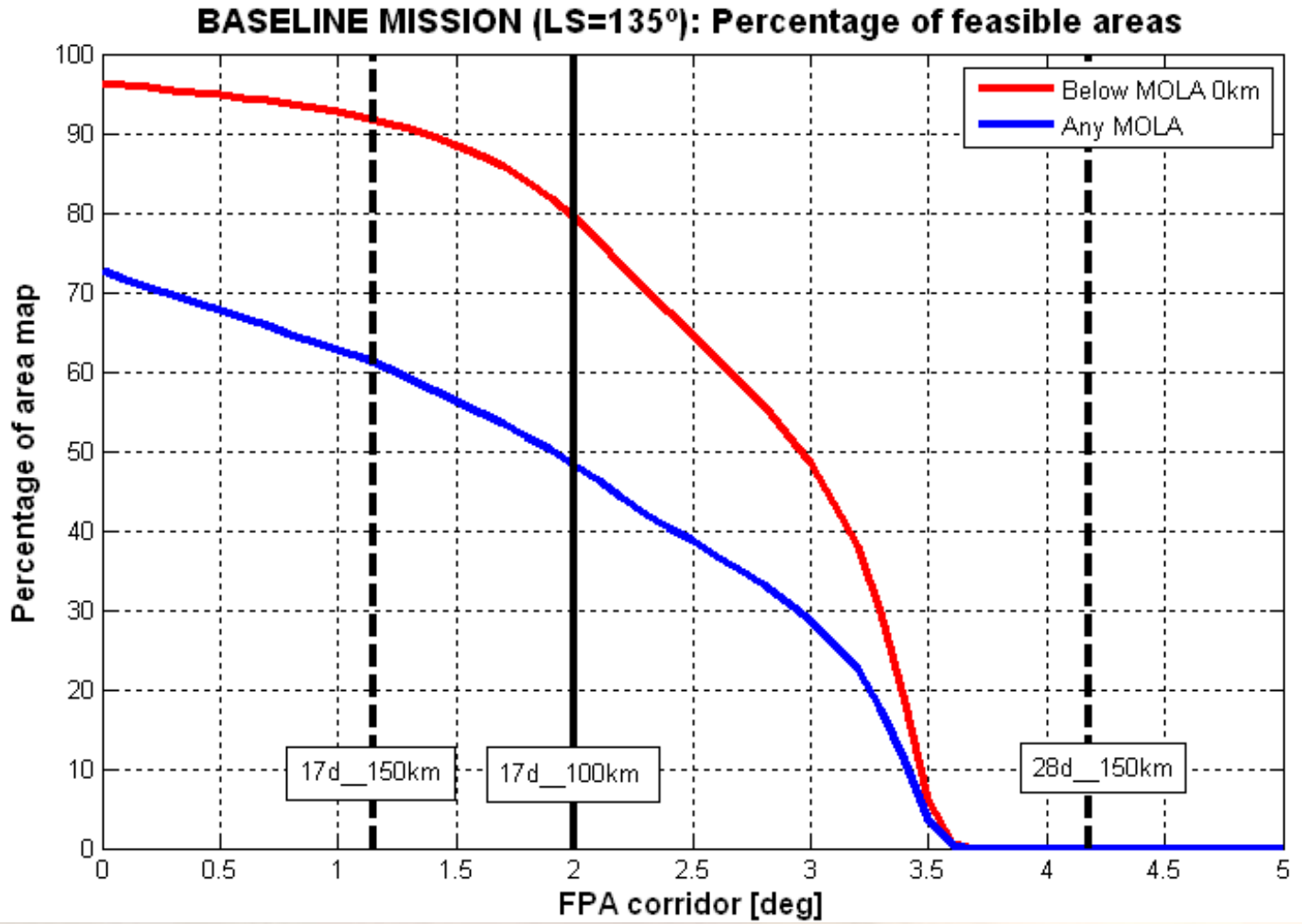


GEC filtering mask: slope, MOLA, ellipse

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Results

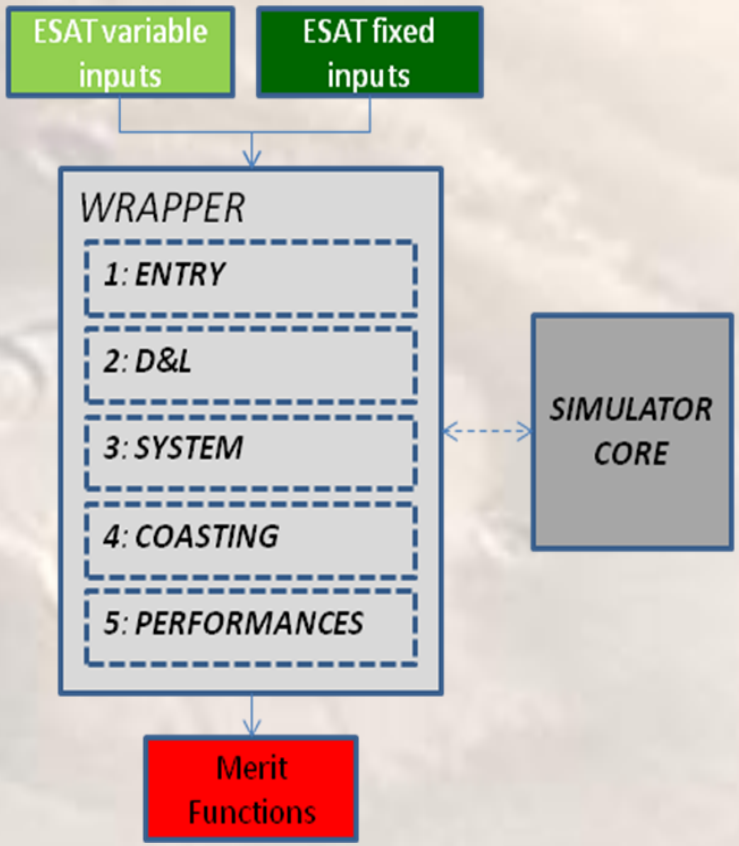
- **MarsNEXT**



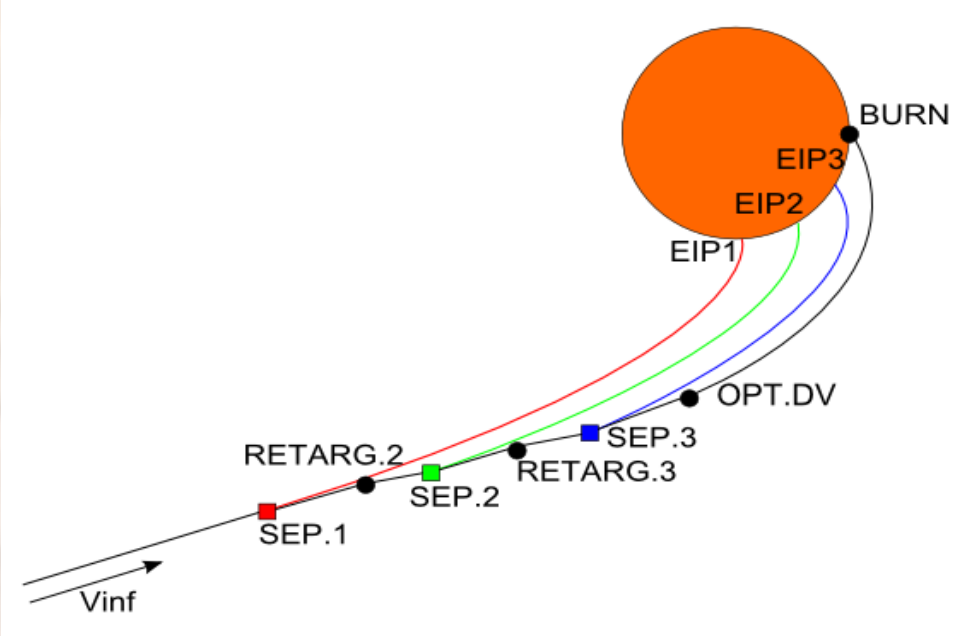
© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Results

- **Small Mars Landers**



ESAT wrapper for Small Mars Landers



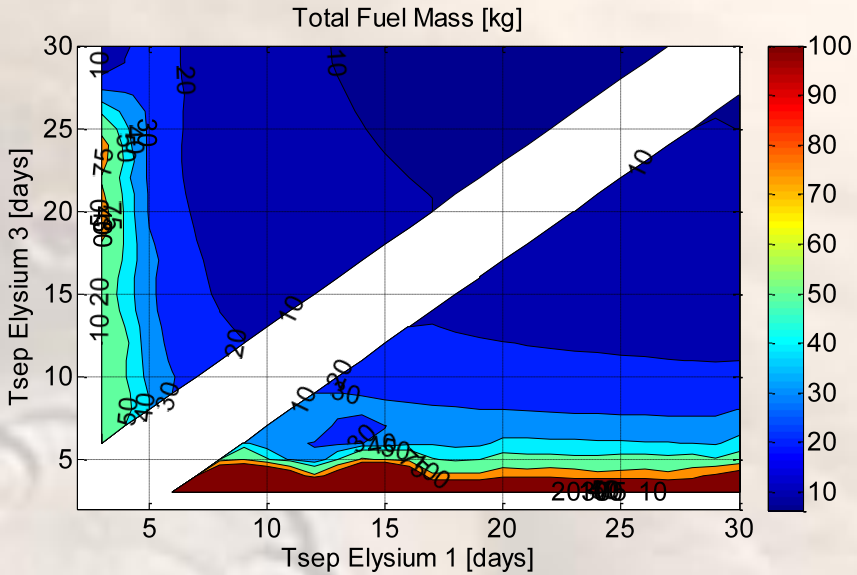
Coasting and separation overview

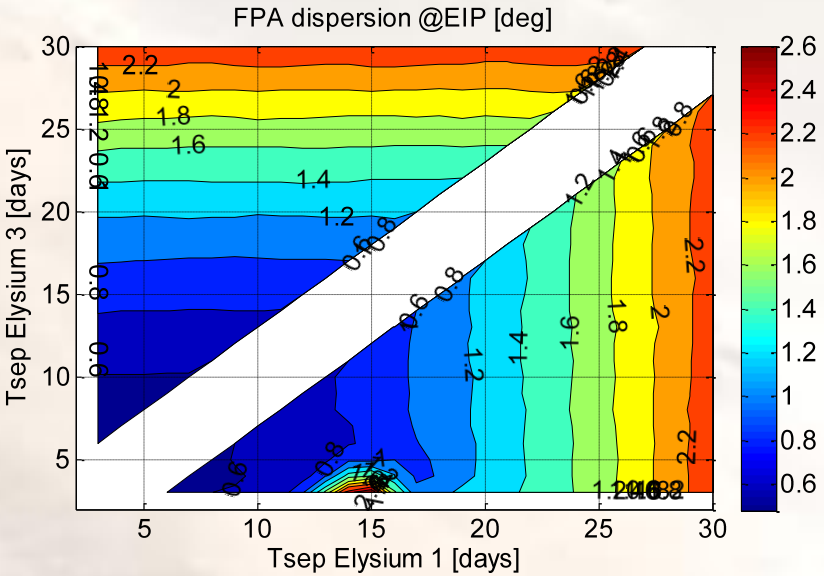
=> simplified ESAT example =>

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Results

- **Small Mars Landers**

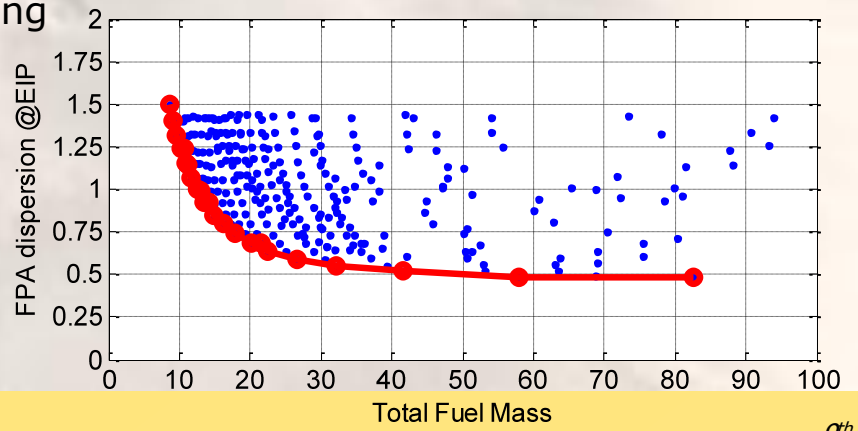




Fuel mass for retargeting

Pareto Front: Dominant solutions

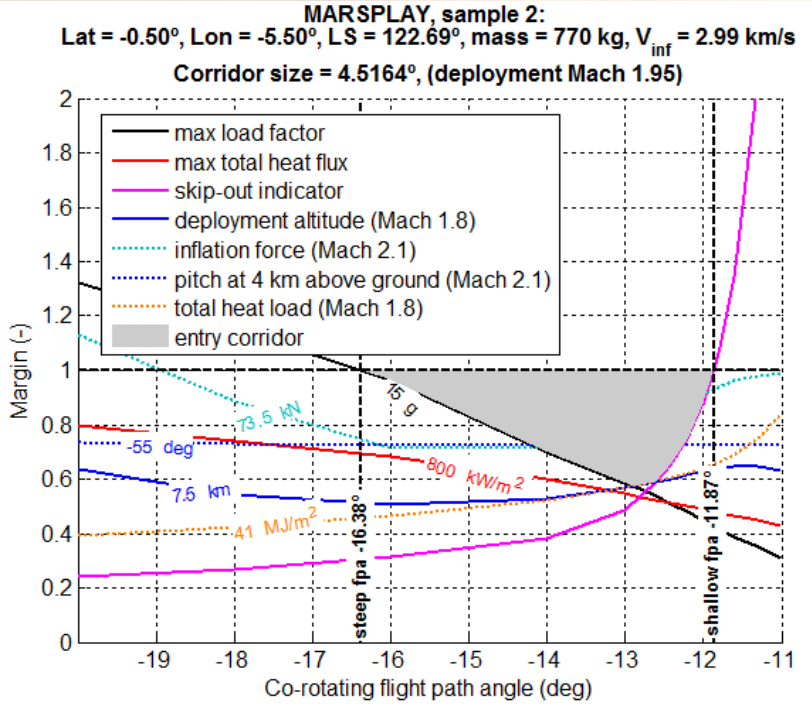
EIP FPA dispersion



© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Results

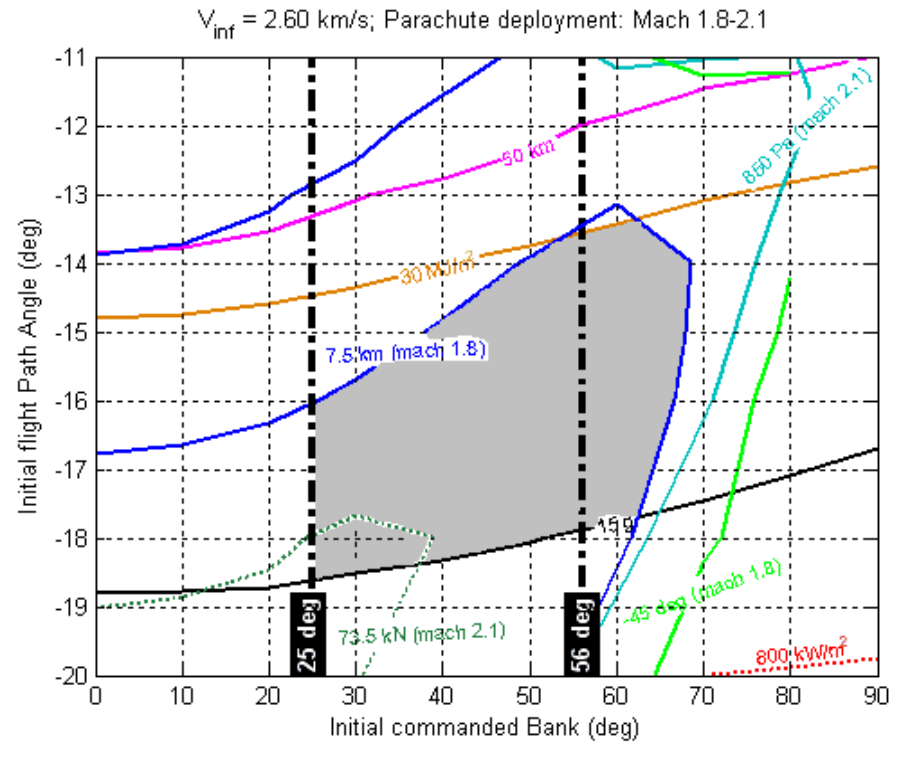
- **MarsPLAY**



1D LEC

2D LEC

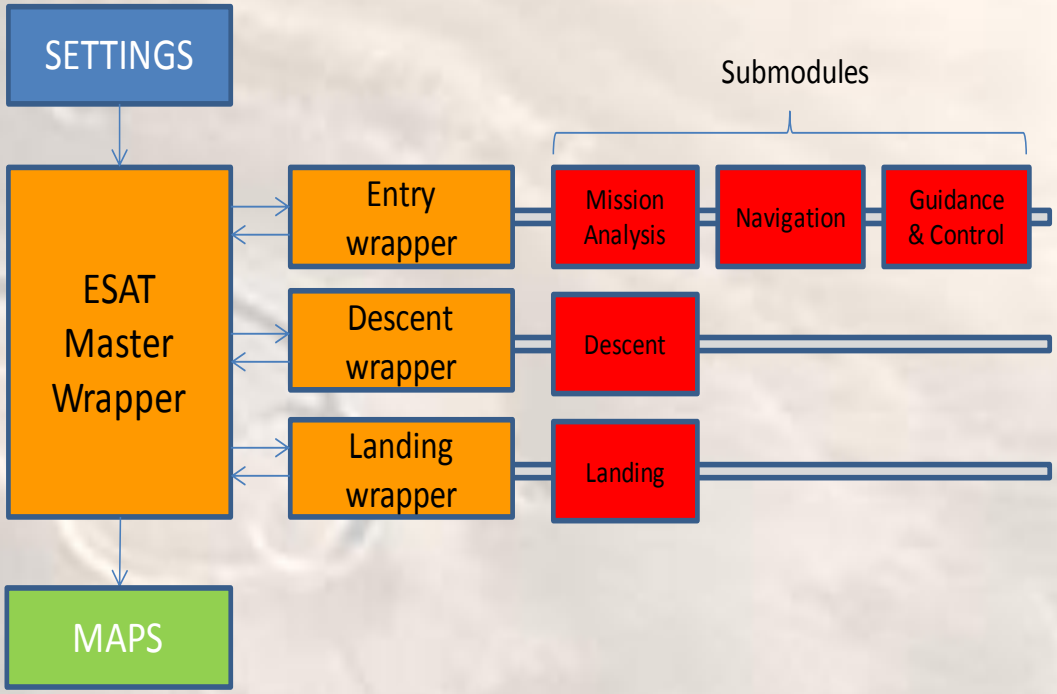
fpa VS commanded bank angle



© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Results

- **High Precision Lander**



ESAT wrapper for High Precision Landers

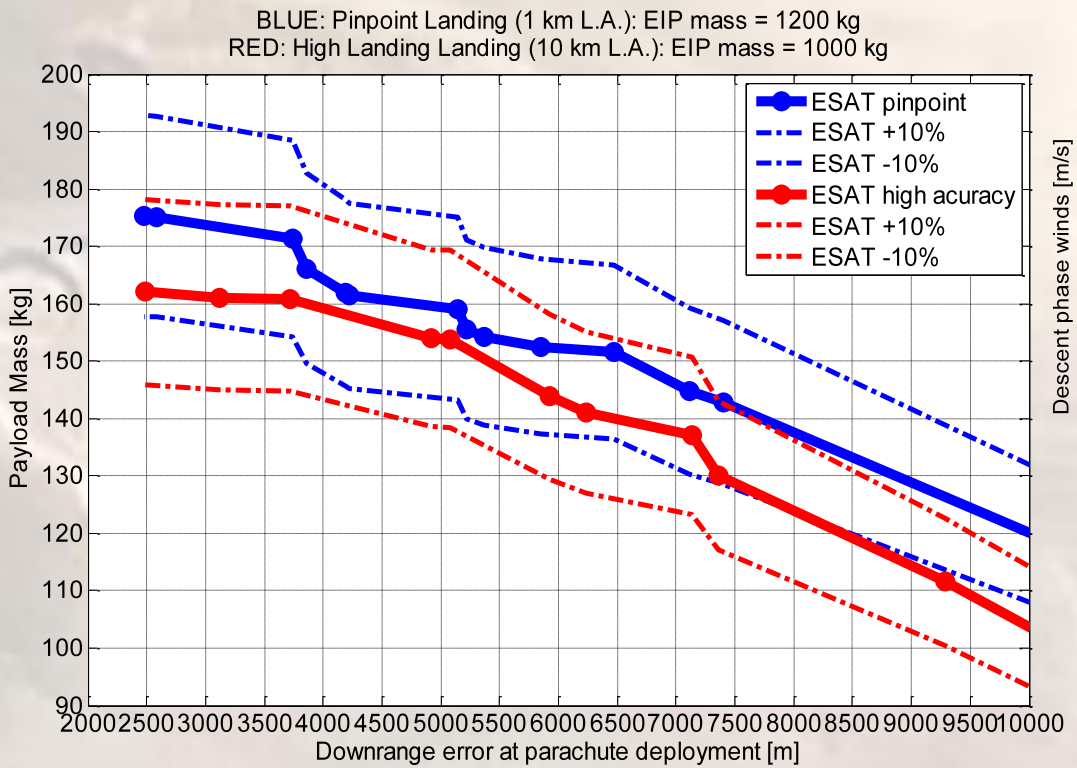
ESAT process:

- define the design space (6 dim.)
- call the wrapper that provides the system performances in the design space: ESAT calls 5000 different design points
- build up more than 100 different ESAT maps of merit functions in the design space to cover multiple aspects of the overall EDL&GNC system.
- run ESAT analysis based on maps predictions: feasible regions, correlations and optimum solutions (query of 55000 different design points)

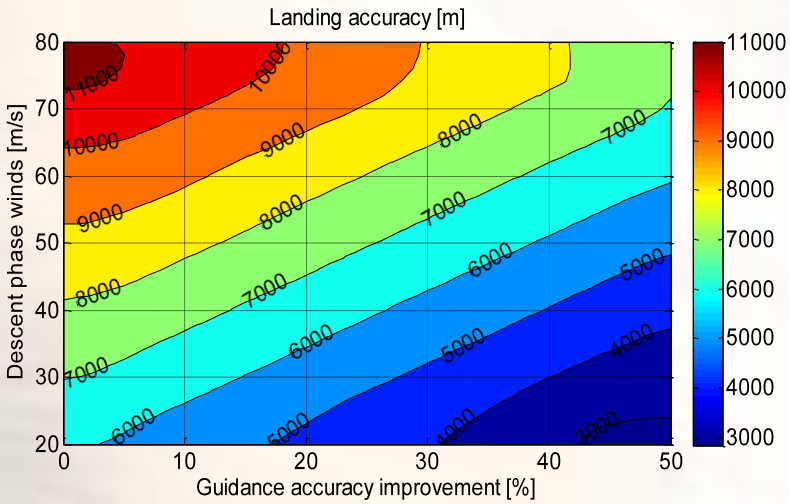
© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Tools Results

- **High Precision Lander**
  - Red: 10 km landing accuracy (1000 kg EIP mass)
  - Blue: 1 km landing accuracy (1200 kg EIP mass)



ESAT Pareto frontier of optimum solutions



Drive requirement on Entry Guidance improvement in downrange dispersion at drogue deployment

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Conclusions

- **Conclusions**
  - Tools for the optimum EDL and GNC design of Mars probes have been presented and results of their applicability to different ESA MREP studies have been shown.
  - Tools support the system engineer in the trade-offs activity and allow filtering of feasible solutions and multiple objectives optimization of different design criteria.
  - Flexibility of the suite of tools available and the capability of efficiently solving different problems: applications to Single Lander Missions and Network Science Missions
  - Continuous evolution is critical to maintain a set of consolidated and updated tools to efficiently support the trade-off and the optimum design of probes for planetary exploration

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com

Thank you!

© 2012 DEIMOS Space, S.L.U. - www.deimos-space.com