# PETBOX: FLIGHT QUALIFIED TOOLS FOR ATMOSPHERIC FLIGHT

Davide Bonetti, Cristina Parigini, Gabriele De Zaiacomo, Irene Pontijas Fuentes, Gonzalo Blanco Arnao, David Riley, Mariano Sánchez Nogales (speaker)

DEIMOS Space S.L.U., Flight Systems Business Unit
Atmospheric Flight Competence Center

6th International Conference on Astrodynamics Tools and Techniques

# MOTIVATION

*Introduction and presentation objectives*

- The Planetary Entry Toolbox (PETbox) is a set of multiple SW modules developed by DEIMOS Space S.L.U. to support Mission Engineering and Flight Mechanics in the area of **Atmospheric Flight**.
- PETbox has been intensively and successfully used in multiple ESA projects, EU projects, and private initiatives covering a **very wide range** of vehicles (launchers, lifting bodies, capsules, UAVs, winged bodies, hypersonic transport vehicles, space debris…) in multiple environments (Earth, Mars, Titan) and in multiple flight phases (launch, coasting, entry, descent, landing, sustained flight).
- Practical **examples of use** and key applications in multiple projects are presented with special emphasis on the use of PETbox in the current ExoMars program (2016 and 2018 missions) and in the recent Intermediate eXperimental Vehicle (IXV) that successfully flew on February 11th, 2015.

# Selected DEIMOS Space S.L.U. projects in the area of Atmospheric Flight

*PETbox applications examples, selected projects:*

- EXOMARS: 2016 and 2018 scenarios, Coasting, Entry, Descent and Landing design and analysis in support to system prime TAS-I (ESA contract)
- MREP: Design of EDL and GNC for a network of Small Mars Landers. (ESA prime contract)

- IXV: End to end (launch to splashdown) Mission Analysis in support to system prime TAS-I (ESA contract).
- D4D: Design for Demise. Identification and analysis of a set of S/C design techniques to reduce the re-entry debris casualty risk. (ESA prime contract)
- HYPMOCES: Hypersonic Morphing for a Cabin Escape System. Project coordinator with responsibility on Mission Analysis and GNC. (EU commission, FP7 contract)

- PERIGEO: Project coordinator. Multidisciplinary Design Optimization (MDO) and flight tests on Earth of UAVs designed for the exploration of Titan. (CDTI, Spain contract).

# Atmospheric Flight: Mission Engineering Areas

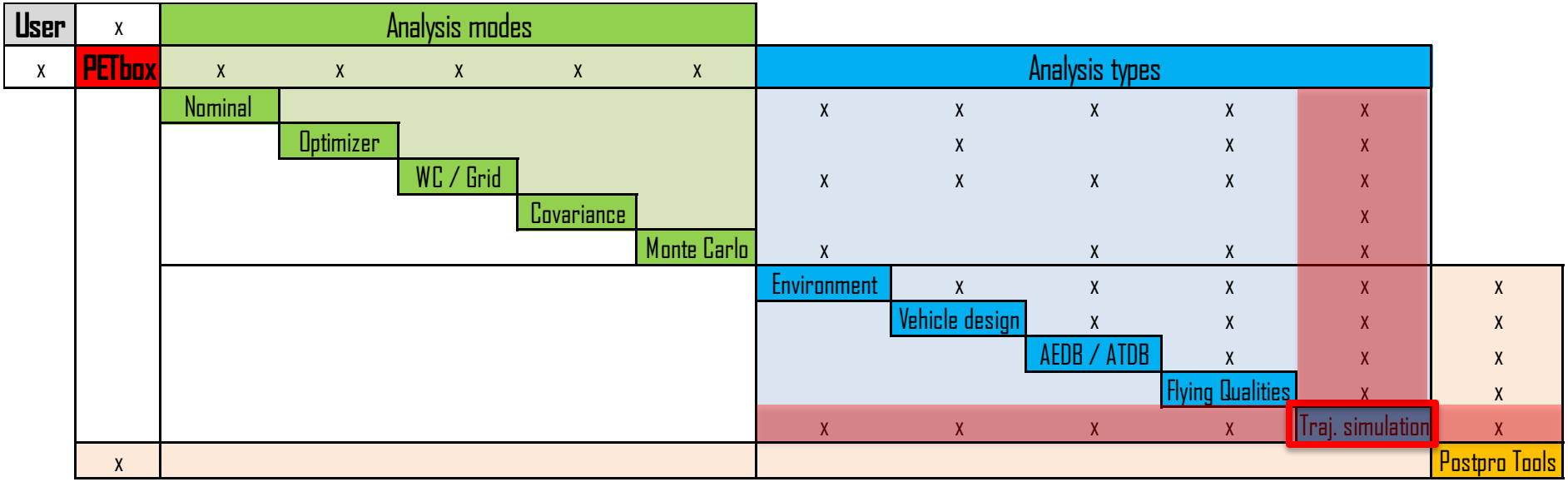
**ATMOSPHERIC FLIGHT**
**MISSION ENGINEERING**

| | |
|---|---|
| VEHICLE DESIGN | SHAPE DESIGN<br>CONFIGURATION DESIGN<br>SYSTEM SPECIFICATIONS |
| AEROTHERMODYNAMICS | DATABASE CREATION<br>DATABASE INSPECTION<br>DATABASE ANALYSIS |
| FLYING QUALITIES | TRIM<br>STABILITY, CONTROLLABILITY<br>GNC SPECIFICATIONS |
| GUIDANCE | DESIGN<br>PROTOTYPES<br>FUNCTIONAL VERIFICATION |
| TRAJECTORIES | MODELLING<br>END TO END SIMULATIONS<br>OPTIMIZATION<br>ANALYSIS<br>FLIGHT PREDICTIONS |
| SIZING CONDITIONS | PERFORMANCE & MARGINS V.<br>SPECIFICATIONS FOR SYS&S/S<br>CORRELATION ANALYSIS |
| VISIBILITY | FIXED/MOBILE GS<br>GPS<br>BETWEEN SPACECRAFTS |
| SAFETY | FOOTPRINT<br>DEBRIS SURVIVAB. AND RISK<br>S/C SEPARATION |
| POST FLIGHT ANALYSIS | TRAJECTORY RECONSTRUCTION<br>DATA FUSION<br>ANALYSIS |

**Planetary Entry Toolbox (PETbox)**

# PETbox Design Structure Matrix

: Inputs (Columns)
: Outputs (Rows)




Modularity

User configurable I/O

SVN repository

Common functions and models library

Reliability and reusability

XML interface

# Trajectory Simulation Core

Exo-atmospheric Design & Analysis:

- Simulation of 3DOF/6DOF trajectories (orbital coasting phase)
- Design of De-orbiting phase and EIP targeting

Endo-atmospheric **Open Loop** Design & Analysis:

- Simulation of 3DOF/6DOF trajectories
- Entry, descent, approach and landing phases
- Main application: re-entry vehicles

Endo-atmospheric **Closed Loop** Analysis & Design:

- Ascent, Entry, Descent, Approach and Landing phases
- Guided Re-entry Approach for generating entry trajectories
- Simulation of 3DOF controlled entry trajectories
- Test bench for 6DOF GNC analysis

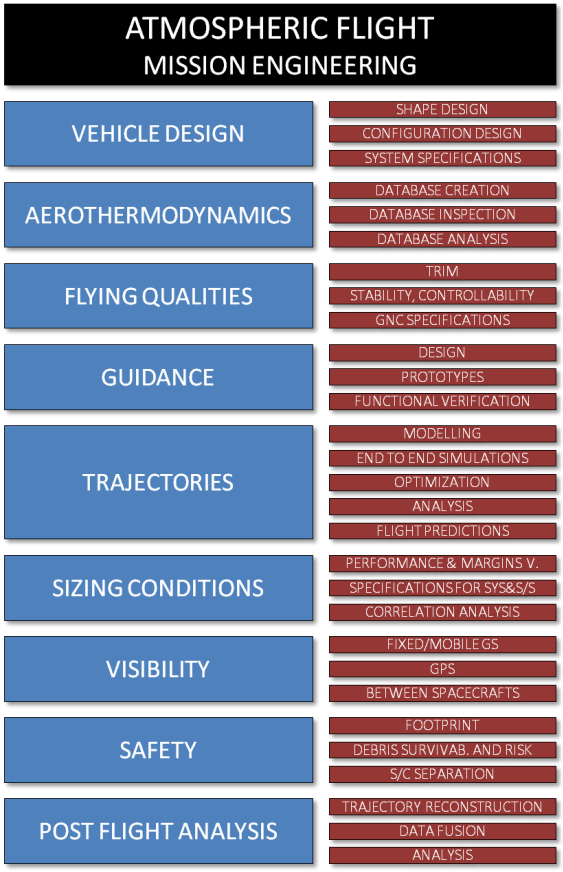
EndoSim can be used in any of the PETbox analysis modes:

- Nominal, Optimizer, WC/grid, Covariance, Monte Carlo

Common core simulation module for multiple analysis:

- Statistics, Sizing Conditions, Safety, Visibility, Debris…

# Selected examples of use of PETbox in Atmospheric Flight / Mission Engineering Areas



# VEHICLE DESIGN (1/9)

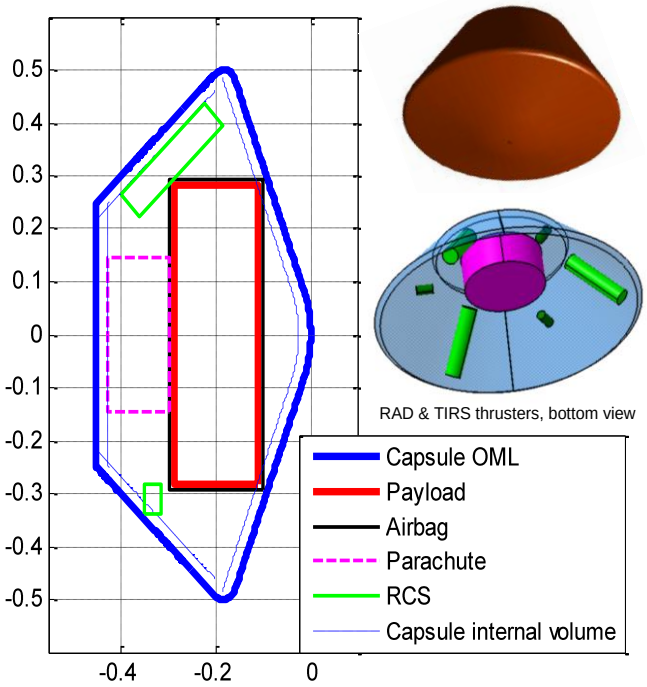
VEHICLE DESIGN

- SHAPE DESIGN
- CONFIGURATION DESIGN
- SYSTEM SPECIFICATIONS

## *Examples:*

- EDL/GNC Design of Small Mars Landers (ESA)
- Hypersonic Morphing for a Cabin Escape System (EU)
- UAV for Titan Exploration (PERIGEO, CDTI)

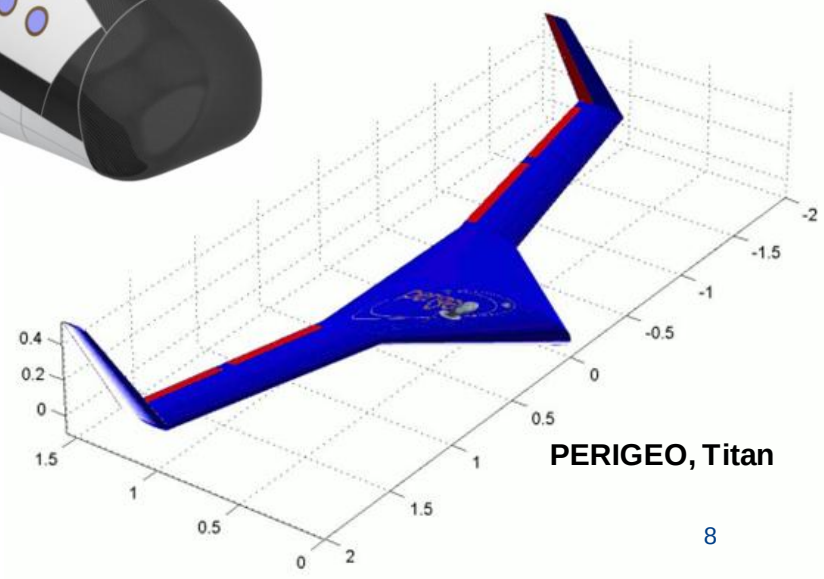
**SLEDLGNC, Mars (MER-like)**






RAD & TIRS thrusters, bottom view

**HYPMOCES, Earth**




**PERIGEO, Titan**

# VEHICLE DESIGN (1/9)

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- CONFIGURATION DESIGN
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## *Examples:*

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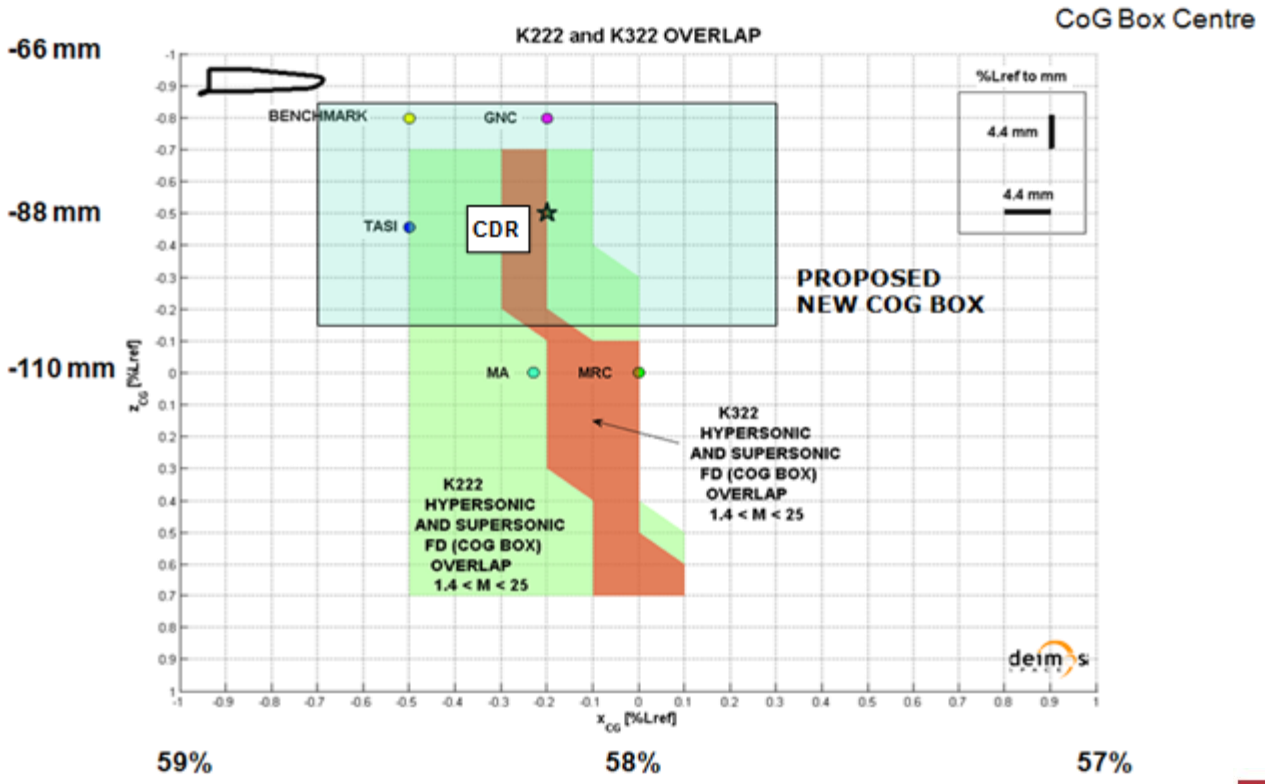
- Hypersonic Morphing for a Cabin Escape System (EU)
- UAV for Titan Exploration (PERIGEO, CDTI)
- IXV Centre of Gravity Specification (ESA)

**IXV, Feasible Domain**



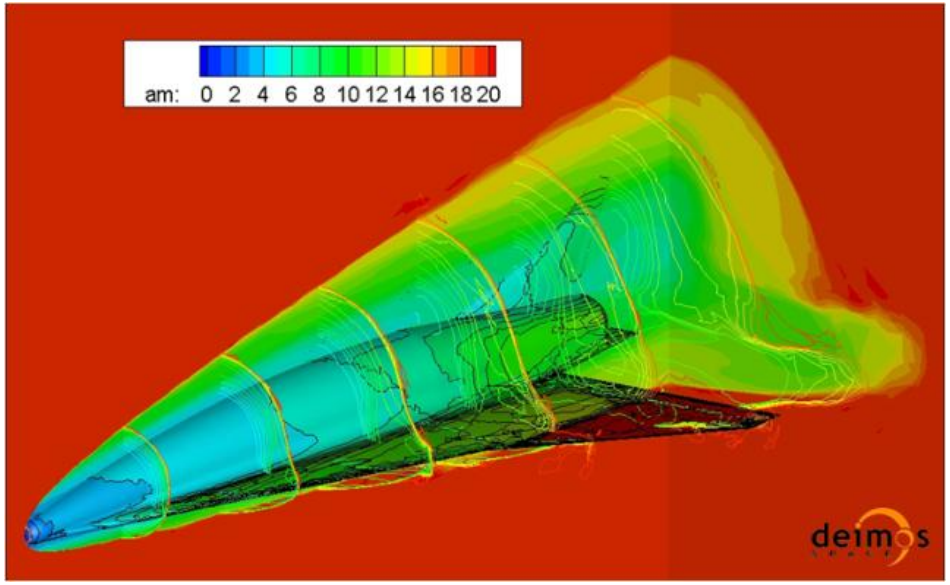
# AEROTHERMODYNAMICS (2/9)

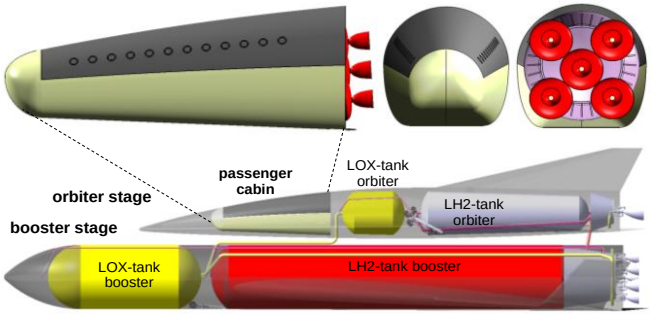
AEROTHERMODYNAMICS

- DATABASE CREATION
- DATABASE INSPECTION
- DATABASE ANALYSIS

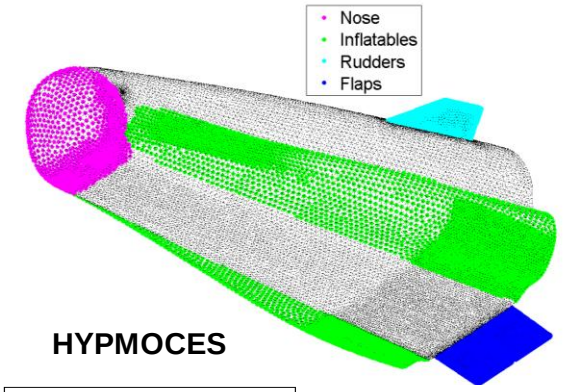
## *Examples:*

- Spaceliner Hypersonic CFD (FAST20XX, EU)
- ATDB for HYPMOCES (EU)

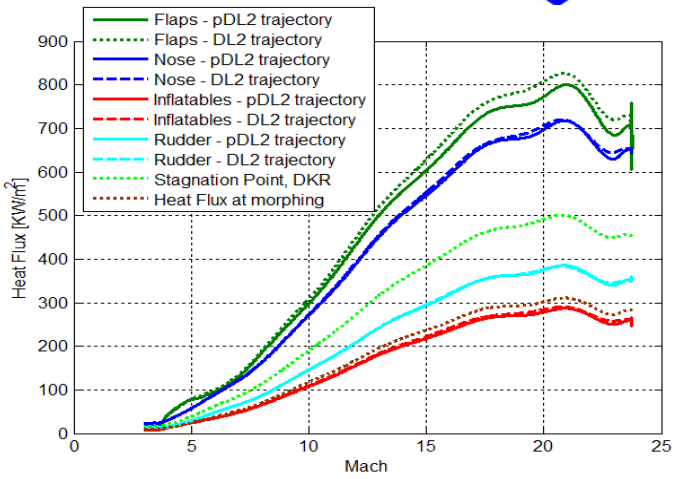



**FAST20XX Spaceliner**




**HYPMOCES**



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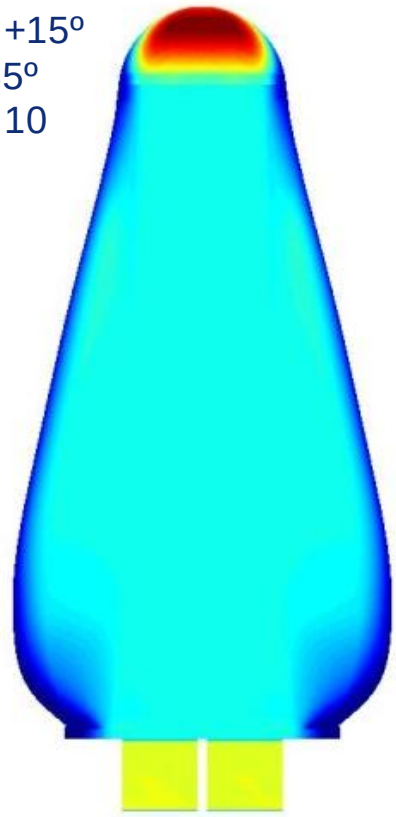
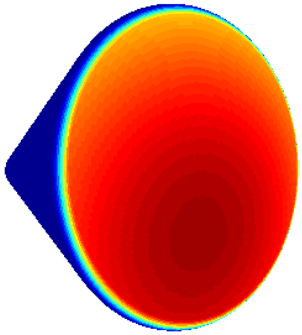
## *Examples:*

- Spaceliner Hypersonic CFD (FAST20XX, EU)
- ATDB for HYPMOCES (EU)
- Hypersonic Database and Real-Time Aerodynamics (HYDRA, $c_P$ distributions: HYPMOCES / APOLLO/ Envisat)

**HYPMOCES**

Flaps = +15º
AoA = 35º
Mach = 10

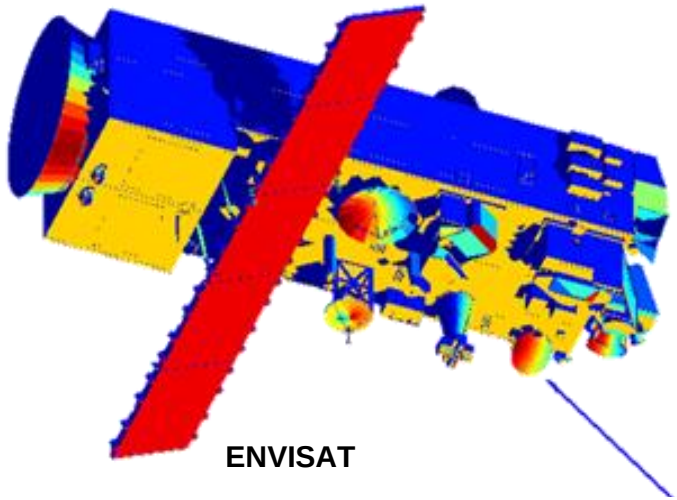




**APOLLO**

AoA = 20º
Mach = 20

Rarefied flow



**ENVISAT**

# AEROTHERMODYNAMICS (2/9)

AEROTHERMODYNAMICS

- DATABASE CREATION
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- DATABASE ANALYSIS

## *Examples:*

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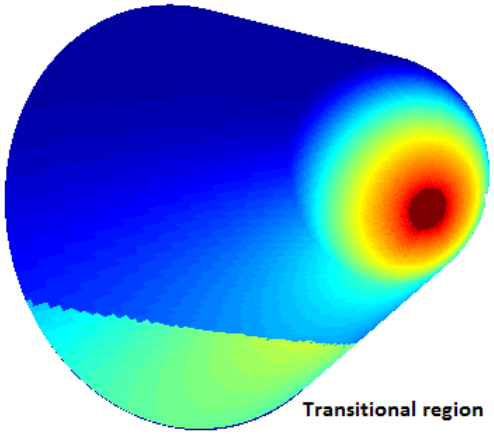
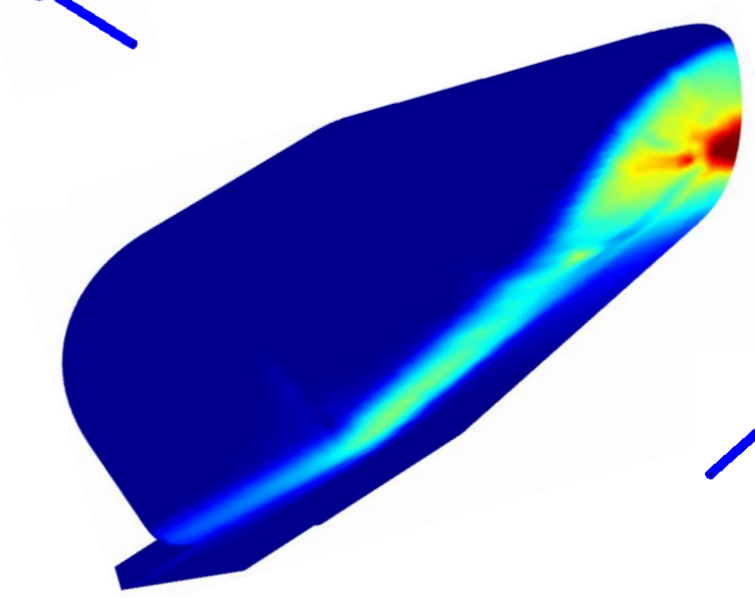
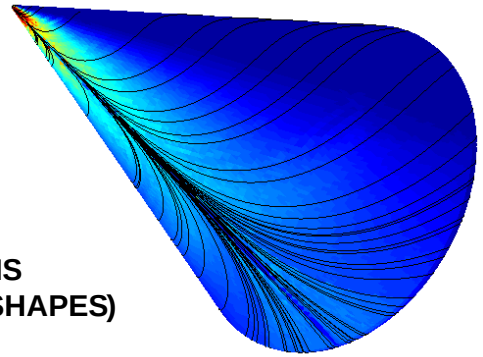
- ATDB for HYPMOCES (EU)
- Hypersonic Database and Real-Time Aerodynamics (HYDRA, $c_P$ distributions: HYPMOCES / APOLLO/ Envisat)
- Hypersonic Aerothermodynamics Database Estimation (HADES: qdot distribution on Blunted Bodies / IXV / Debris, Internal/ESA)




**BLUNTED BODIES**

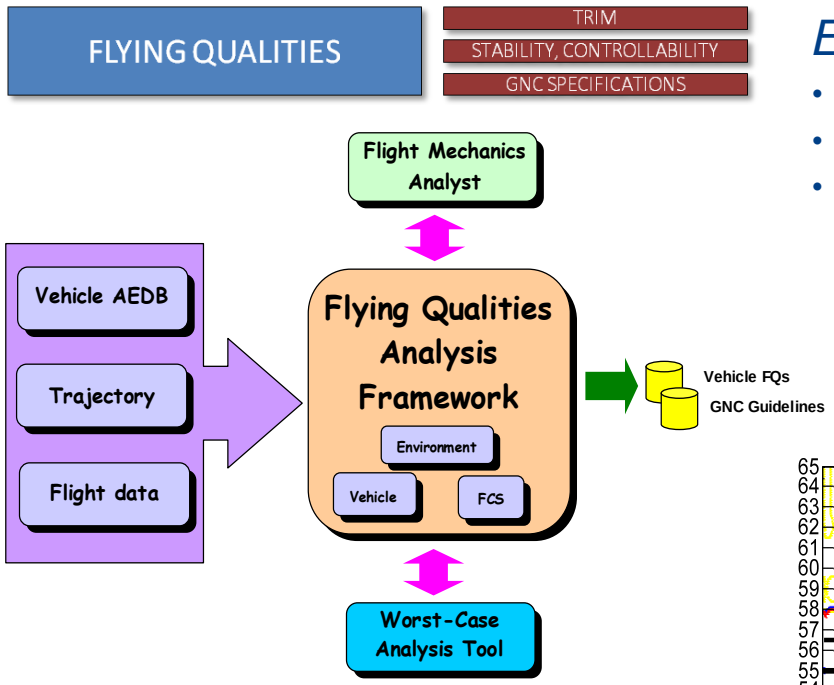


**IXV**



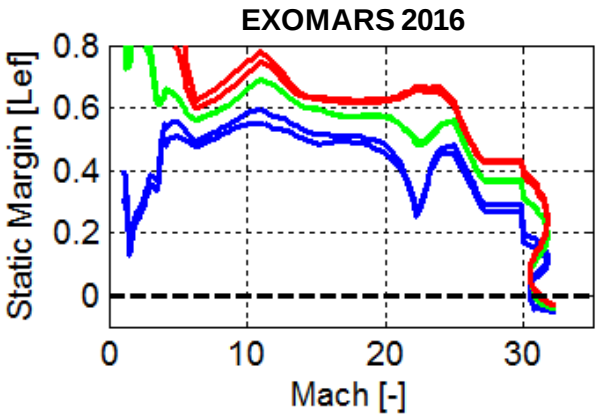
**DEBRIS (PRIMITIVE SHAPES)**

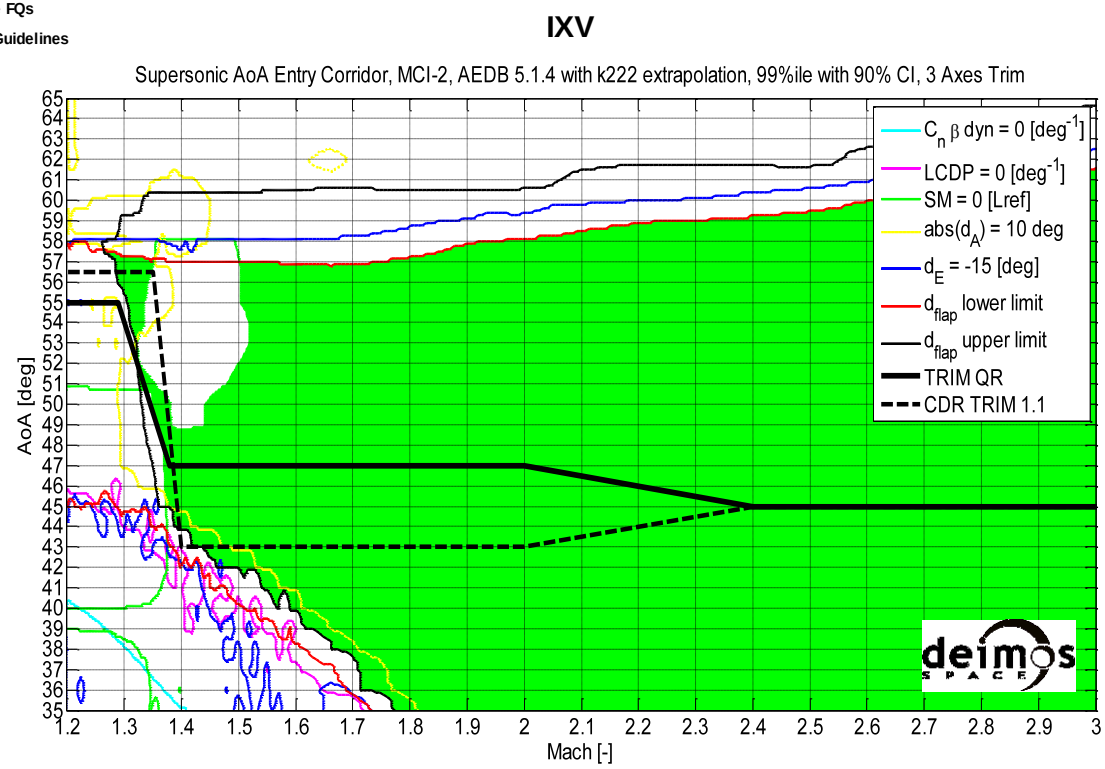
# FLYING QUALITIES (3/9)




## *Examples:*

- Flying Qualities Analysis Tool (ESA)
- ExoMars2016 Descent Module Long. Stability (ESA)
- IXV Entry Corridor Analysis (trim, stability, controllability) for the Trim Line design flown by the vehicle (ESA)



# GUIDANCE (4/9)

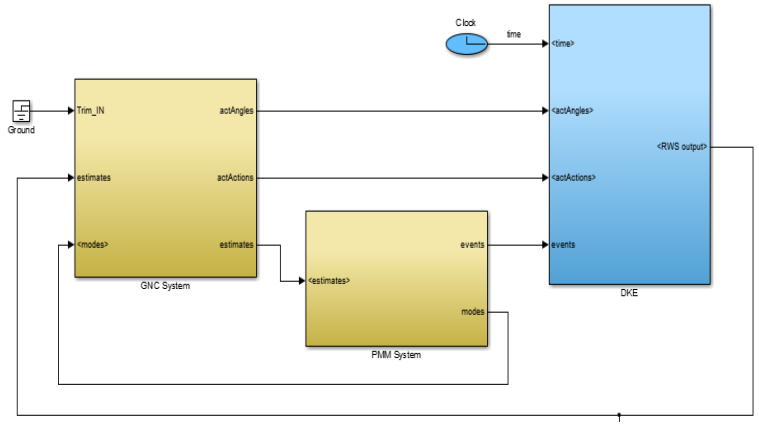
GUIDANCE

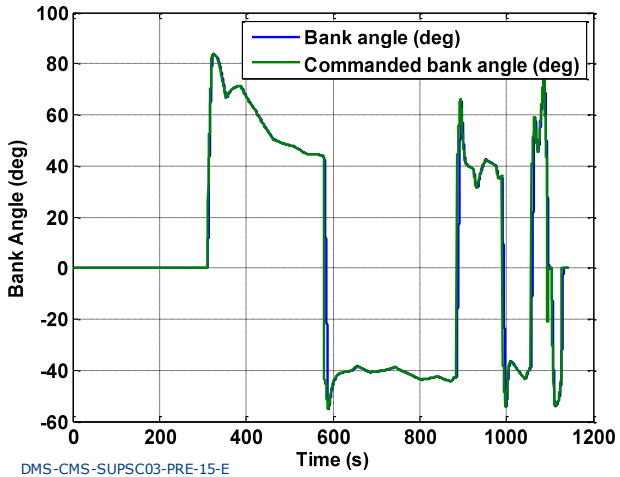
DESIGN
PROTOTYPES
FUNCTIONAL VERIFICATION

## *Examples:*

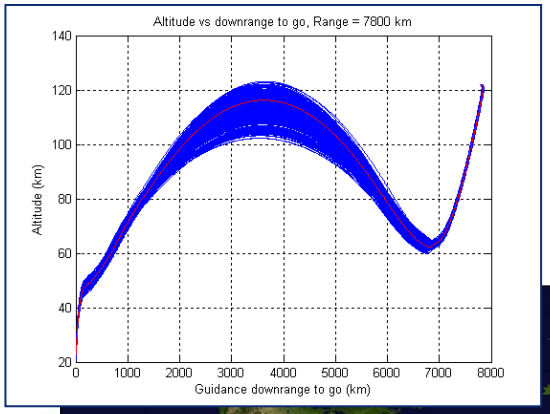
- IXV entry guidance design and prototyping
- Skip entry guidance for exploration missions return capsule (CSTS, CSTE, BLAST)

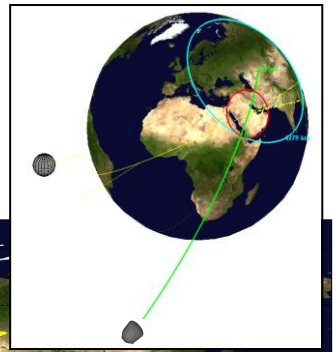
**IXV guidance prototyping**

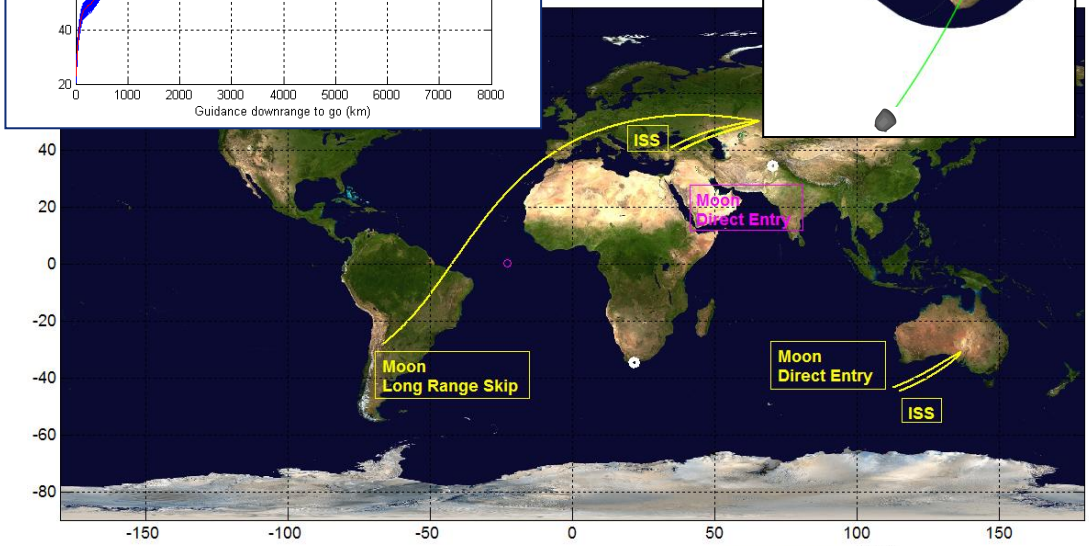



**CSTE Moon return targeting and direct/skip entry guidance**





# GUIDANCE (4/9)

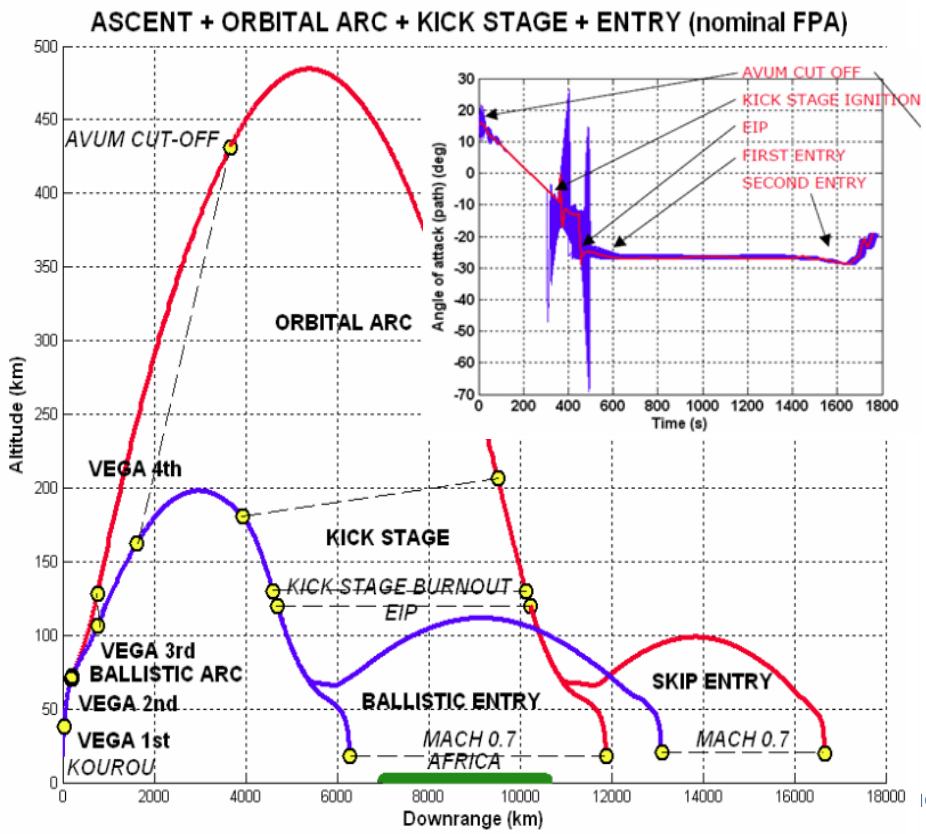
GUIDANCE

DESIGN
PROTOTYPES
FUNCTIONAL VERIFICATION

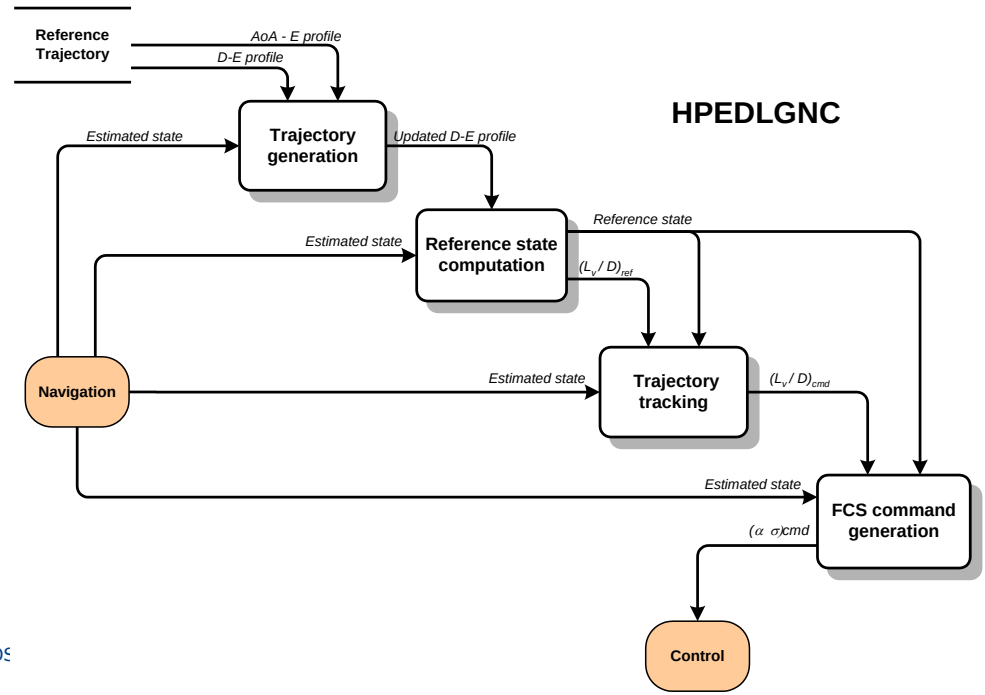
## *Examples:*

- IXV entry guidance design and prototyping
- Skip entry guidance for exploration missions return capsule (CSTS, CSTE, BLAST)
- Guidance prototyping for several scenarios/phases:
  - Exo-atmospheric TVC (BLAST)
  - **Earth**, entry guidance for capsules, lifting bodies, space planes (ARV, BLAST, IXV, HILIFT, FAST20XX)
  - **Mars** entry guidance for precise landing (HPEDLGNC)

**BLAST**




**HPEDLGNC**



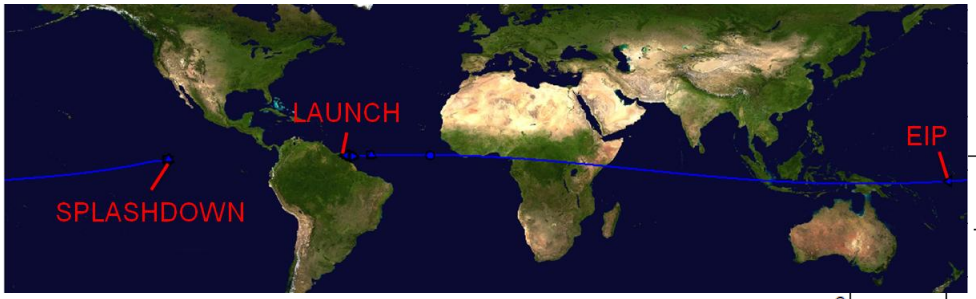
# TRAJECTORIES (5/9)

TRAJECTORIES

- MODELLING
- END TO END SIMULATIONS
- OPTIMIZATION
- ANALYSIS
- FLIGHT PREDICTIONS

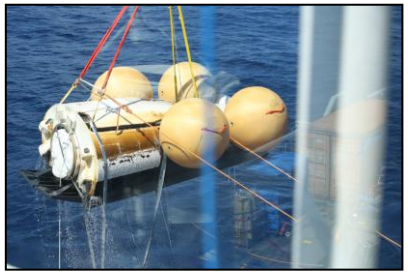
## *Examples:*

- IXV E2E (Launch to Splashdown) simulations (ESA)



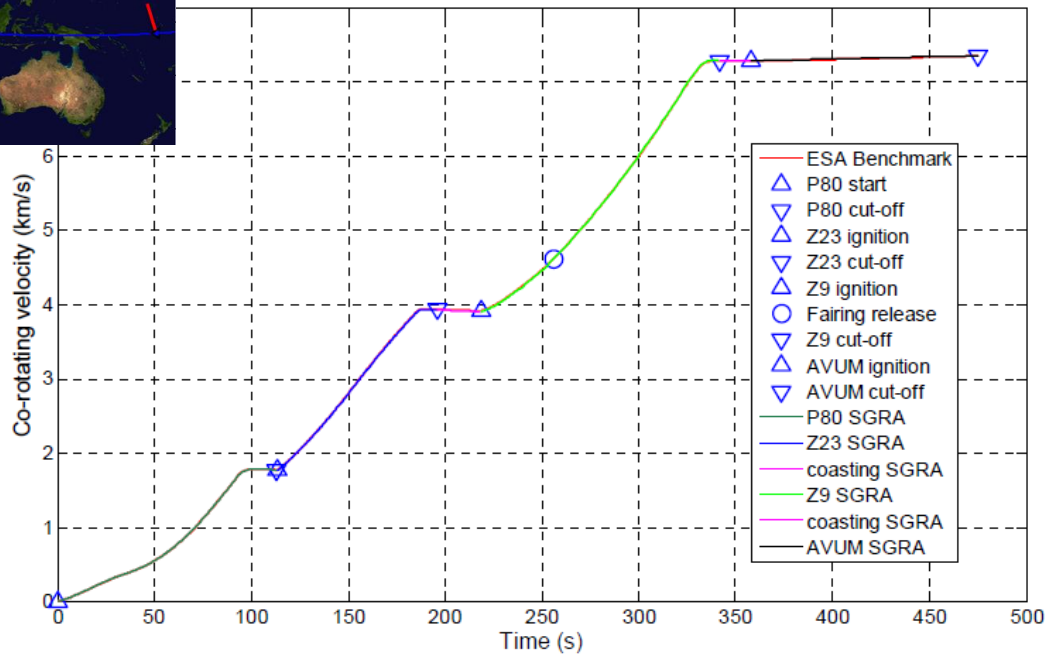

**3DoF / 6DoF modelling capability with closed loop GNC**

**IXV**



Credits: ESA

**Example of trajectory optimization of the VEGA launcher with SGRA**



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## *Examples:*

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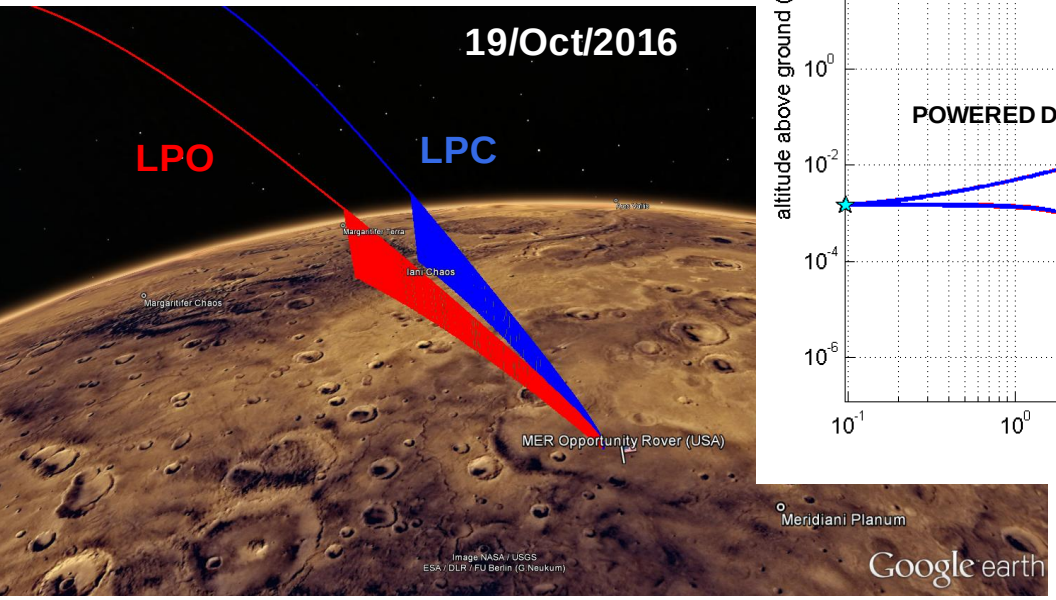
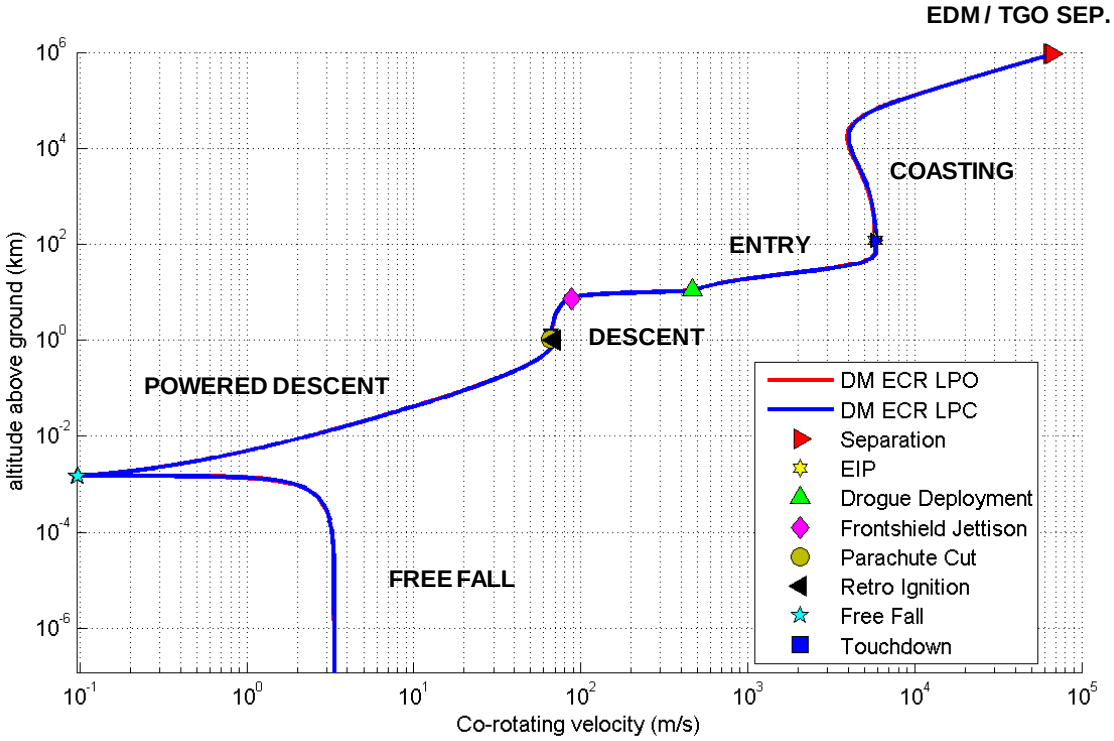
- ExoMars 2016 Coasting & EDL trajectory (ESA)

**EXOMARS 2016 EDL**



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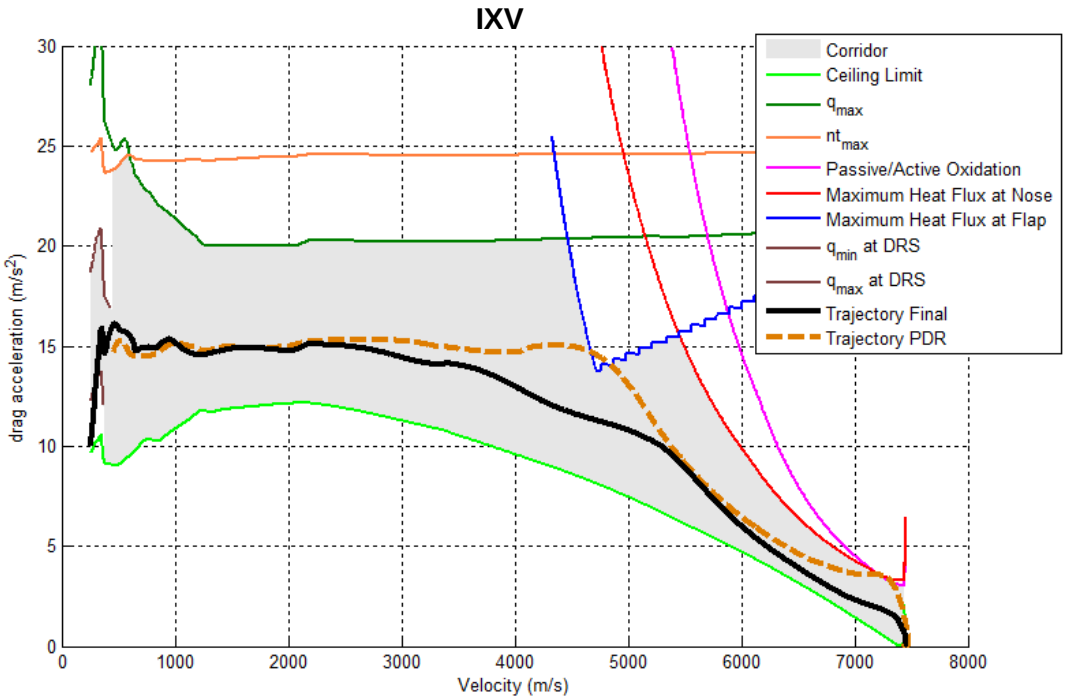
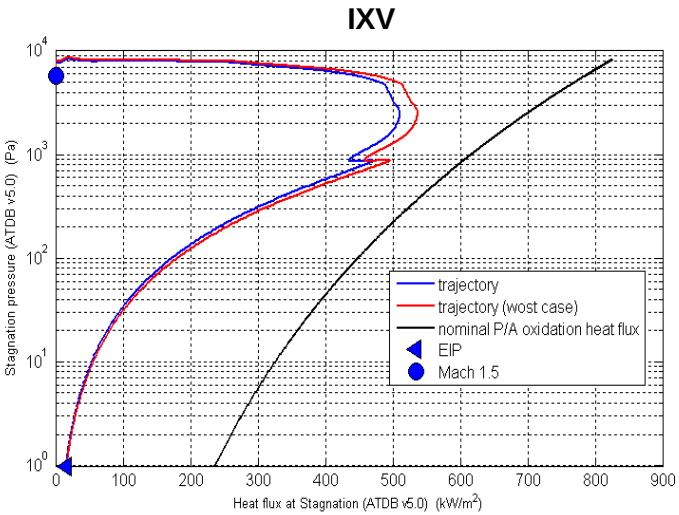
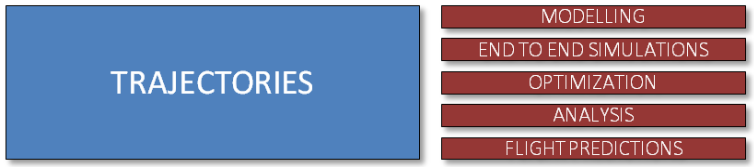
## *Examples:*

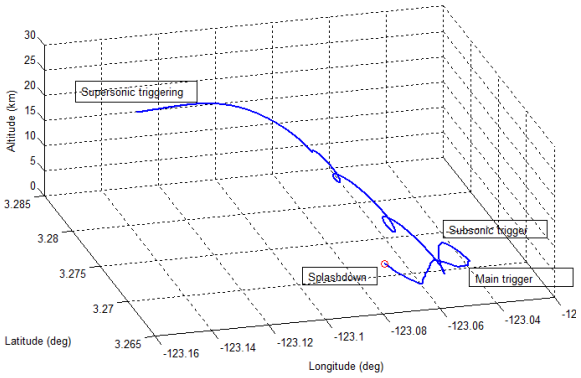
- IXV E2E (Launch to Splashdown) simulations (ESA)
- ExoMars 2016 Coasting & EDL trajectory (ESA)
- IXV Trajectory Optimization in the Entry Corridor and path constraints (Passive to active TPS oxidation) analysis (ESA)



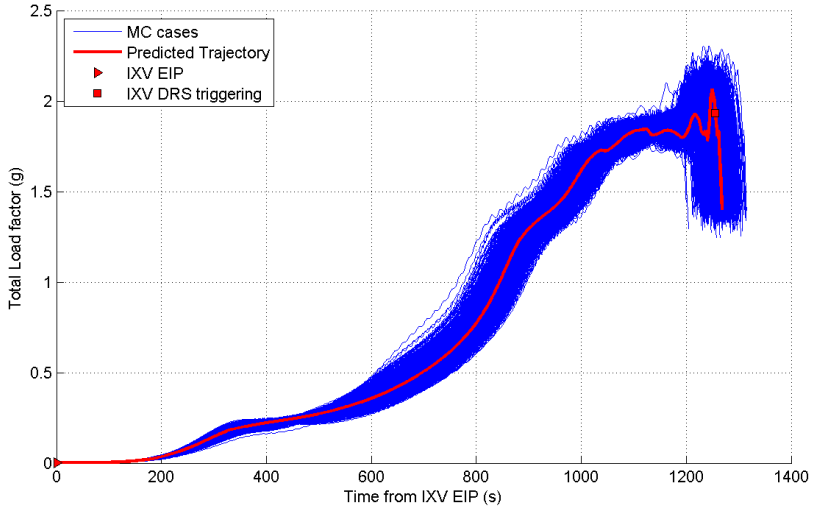



# TRAJECTORIES (5/9)



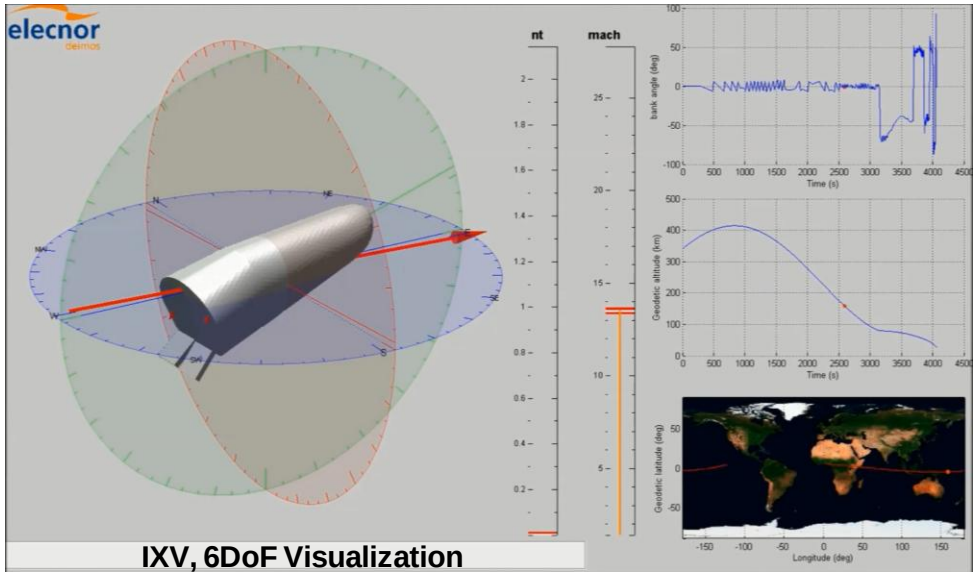




IXV




## *Examples:*

- IXV E2E (Launch to Splashdown) simulations (ESA)
- ExoMars 2016 Coasting & EDL trajectory (ESA)
- IXV Trajectory Optimization in the Entry Corridor and path constraints (Passive to active TPS oxidation) analysis (ESA)
- IXV flight predictions (ESA)




IXV, 6DoF Visualization

# SIZING CONDITIONS (6/9)

SIZING CONDITIONS

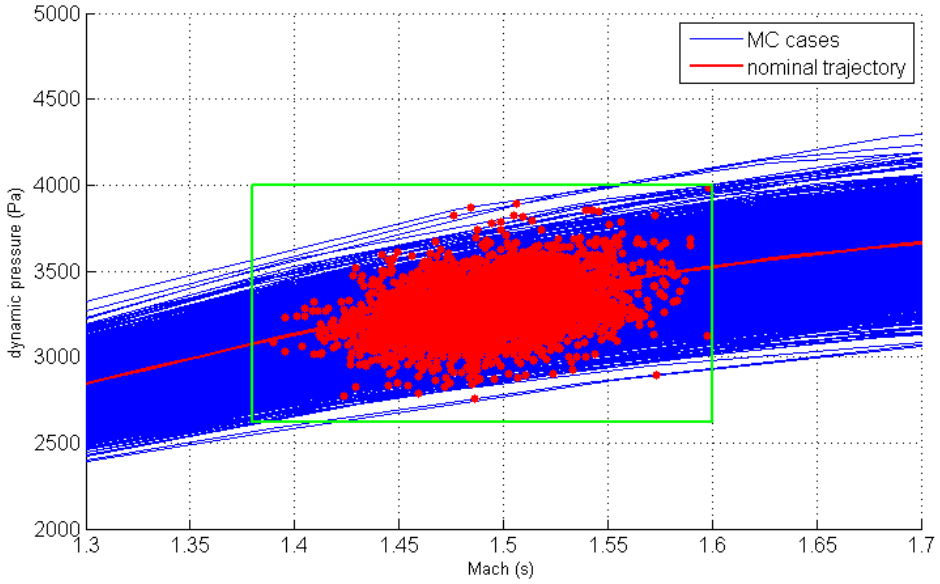
PERFORMANCE & MARGINS V.

SPECIFICATIONS FOR SYS&S/S

CORRELATION ANALYSIS

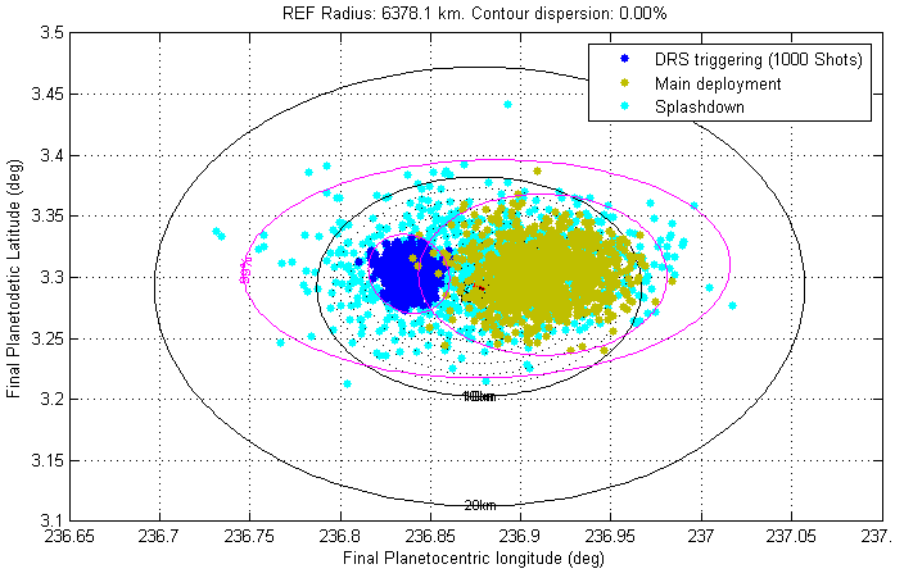
## *Examples:*

- IXV parachute deployment & Landing Accuracy (ESA)




**IXV, Mach vs Dynamic Pressure box**

**IXV, Position Accuracy**



# SIZING CONDITIONS (6/9)

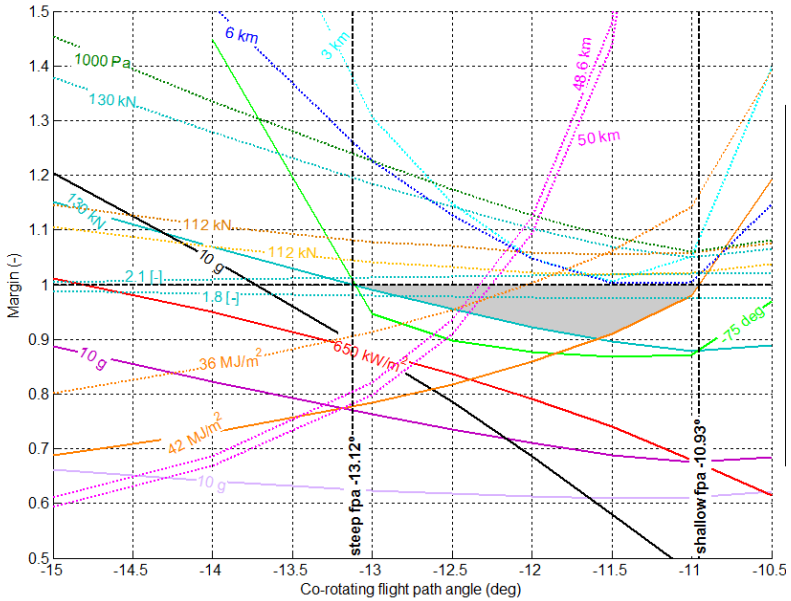
SIZING CONDITIONS

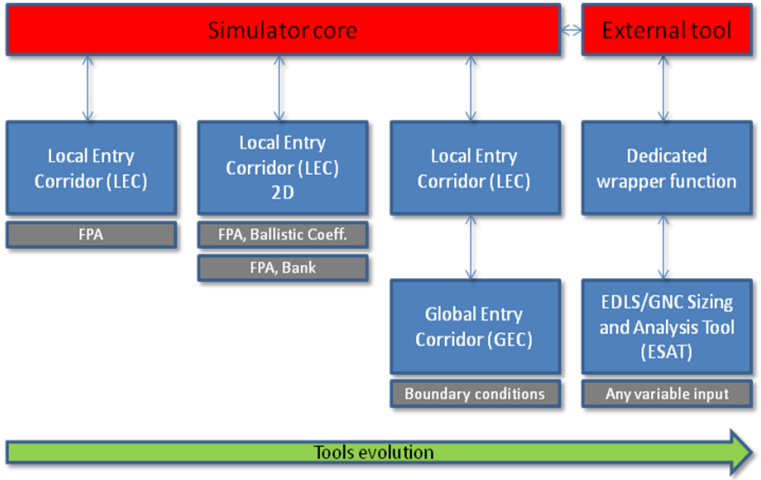
PERFORMANCE & MARGINS V.
SPECIFICATIONS FOR SYS&S/S
CORRELATION ANALYSIS

## *Examples:*

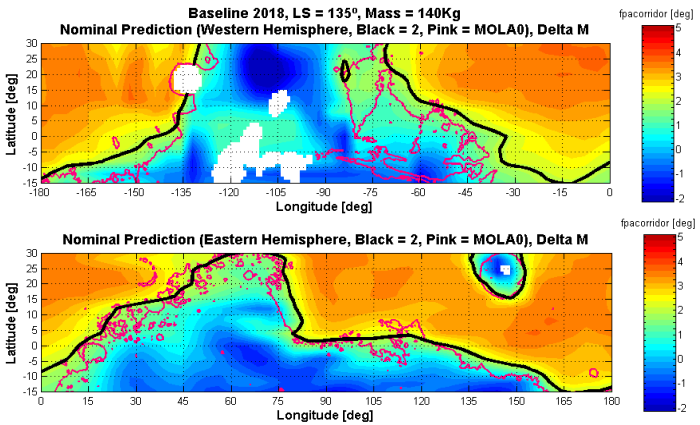
- IXV parachute deployment & Landing Accuracy (ESA)
- LEC (Exomars2018) / GEC (MarsNEXT) (ESA)

**Local Entry Corridor (LEC), EXOMARS 2018**




**Global Entry Corridor (GEC) MarsNEXT**



# SIZING CONDITIONS (6/9)

SIZING CONDITIONS

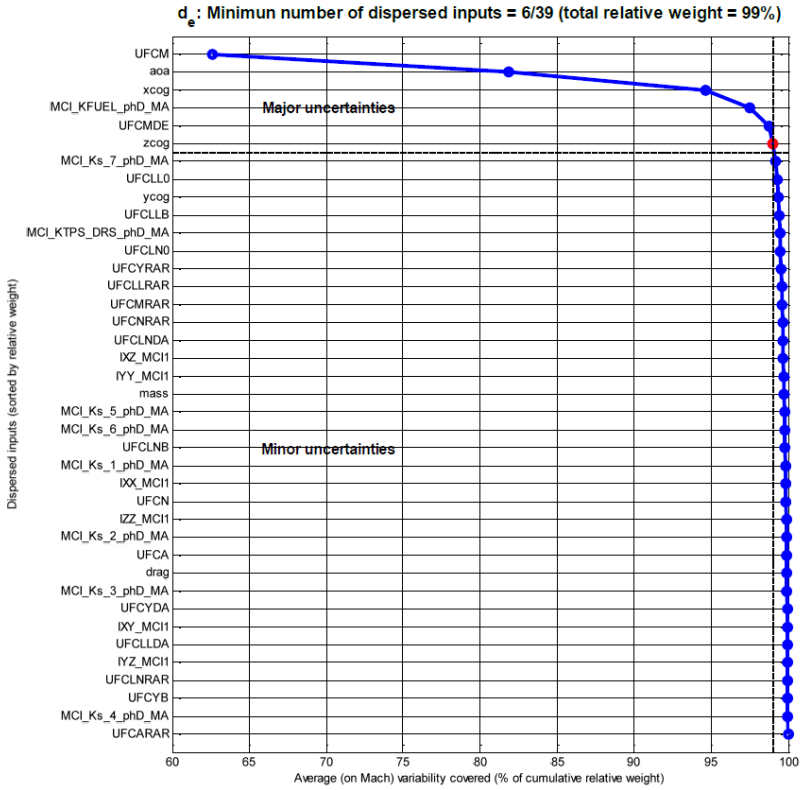
PERFORMANCE & MARGINS V.

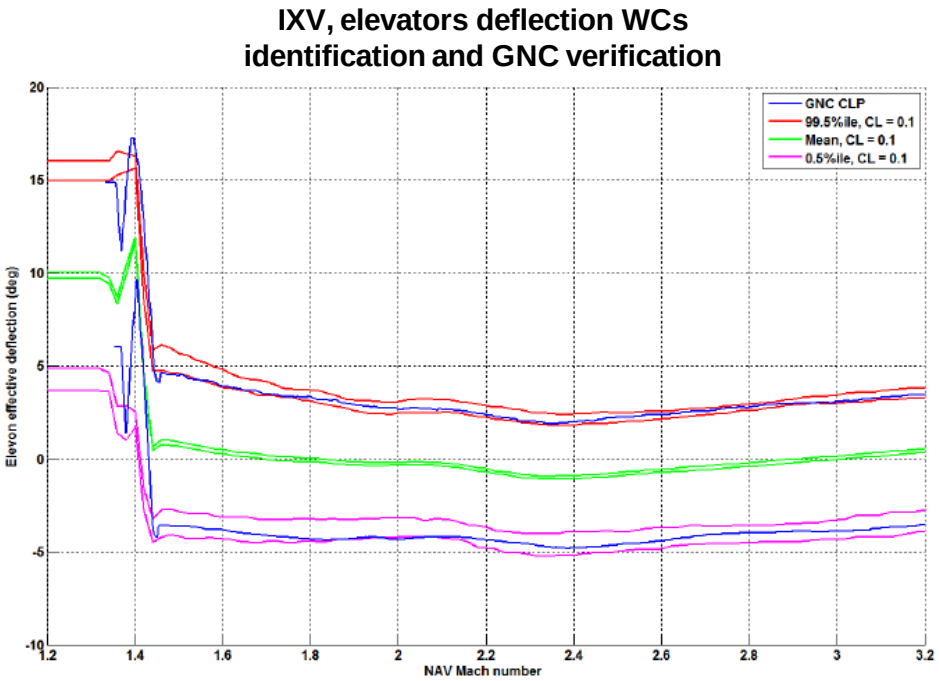
SPECIFICATIONS FOR SYS&S/S

CORRELATION ANALYSIS

## *Examples:*

- IXV parachute deployment & Landing Accuracy (ESA)
- LEC (Exomars2018) / GEC (MarsNEXT) (ESA)
- Correlation Analysis (Worst Cases for IXV GNC) (ESA)



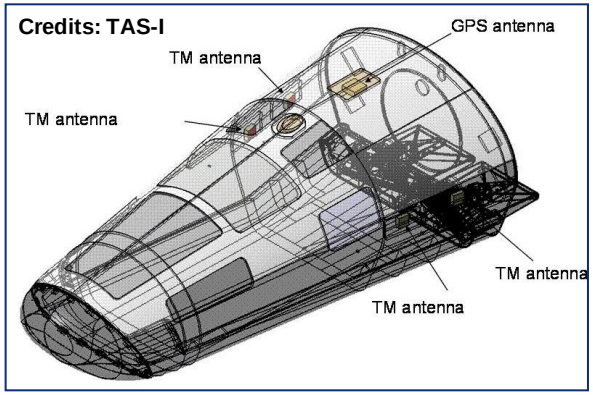
# VISIBILITY (7/9)

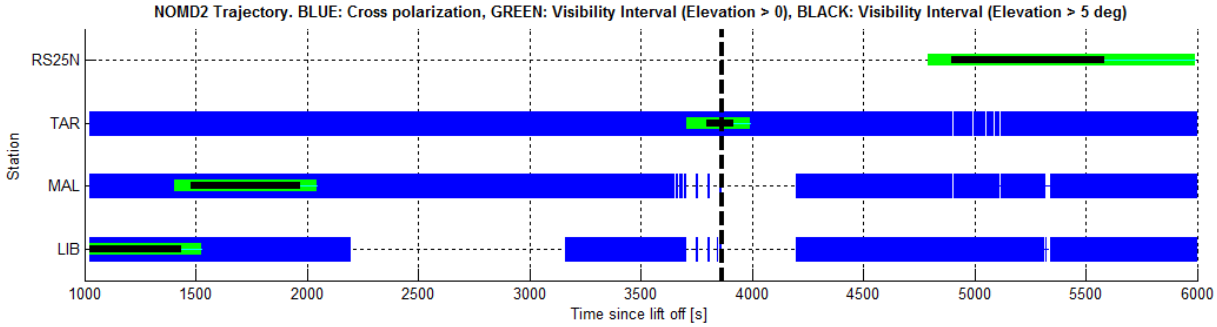
VISIBILITY

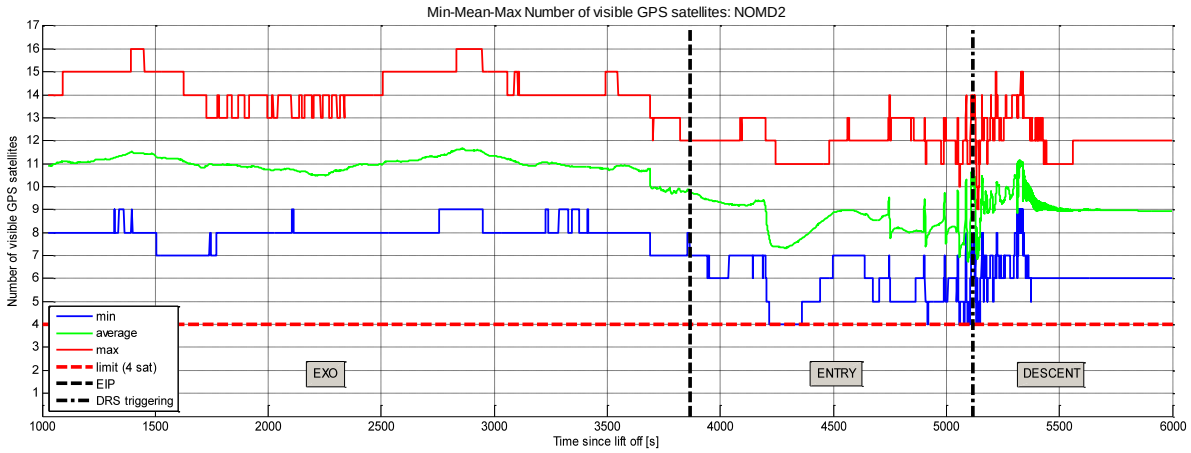
- FIXED/MOBILE GS
- GPS
- BETWEEN SPACECRAFTS

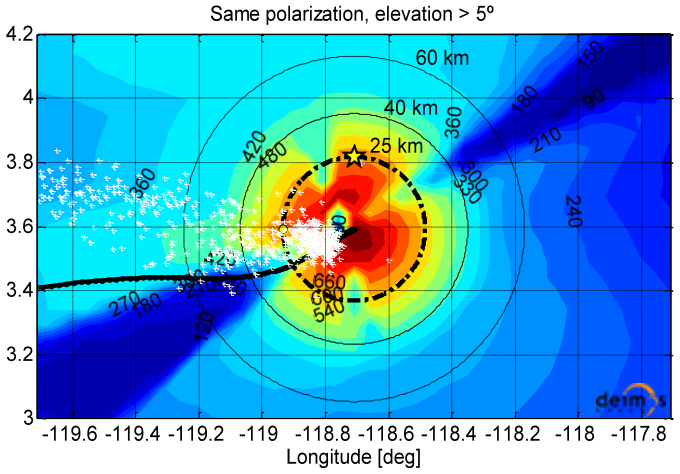
## *Examples:*

- Geometric visibility of IXV: Ground Stations and GPS (ESA)



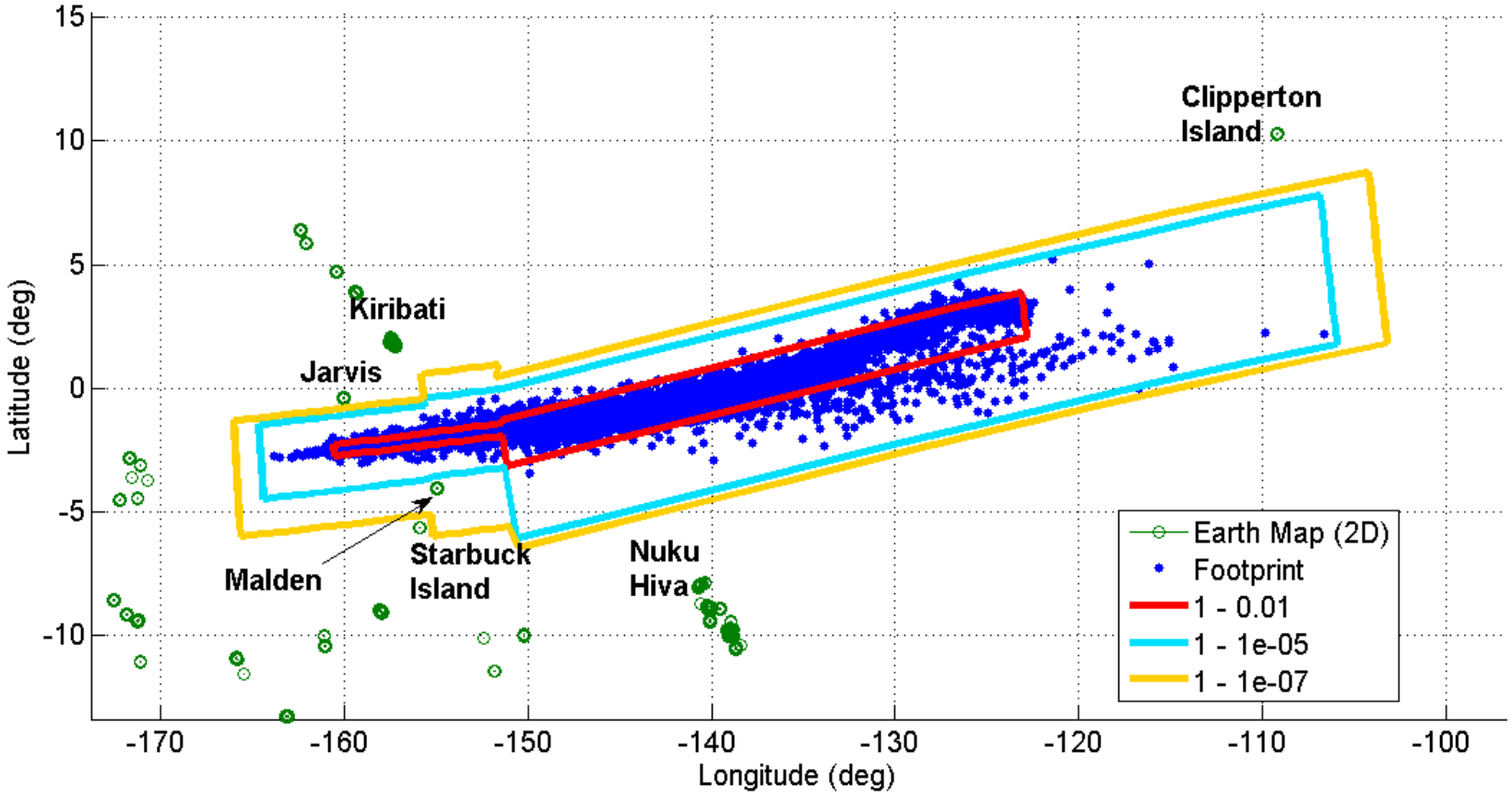
# SAFETY (8/9)

SAFETY

- FOOTPRINT
- DEBRIS SURVIVAB. AND RISK
- S/C SEPARATION

## *Examples:*

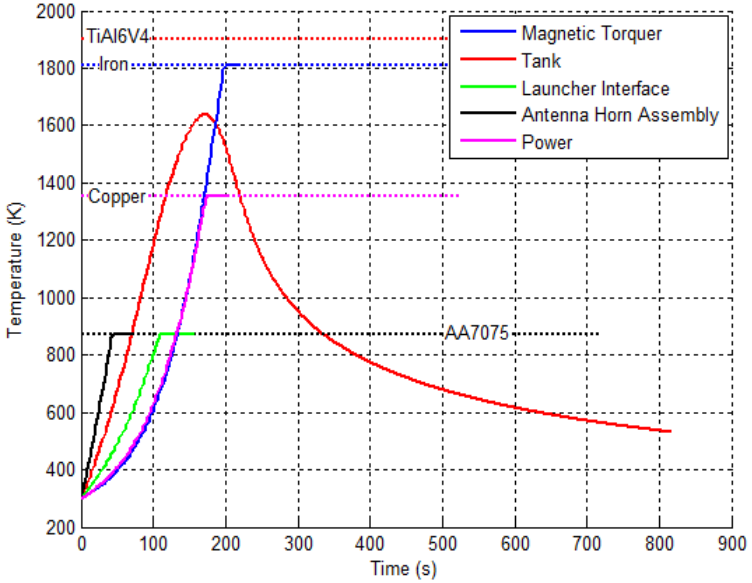
- IXV safety footprint analysis (ESA)

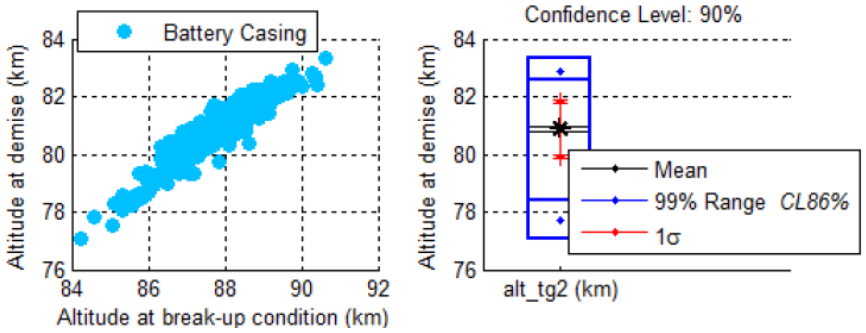


# SAFETY (8/9)

SAFETY

- FOOTPRINT
- DEBRIS SURVIVAB. AND RISK
- S/C SEPARATION

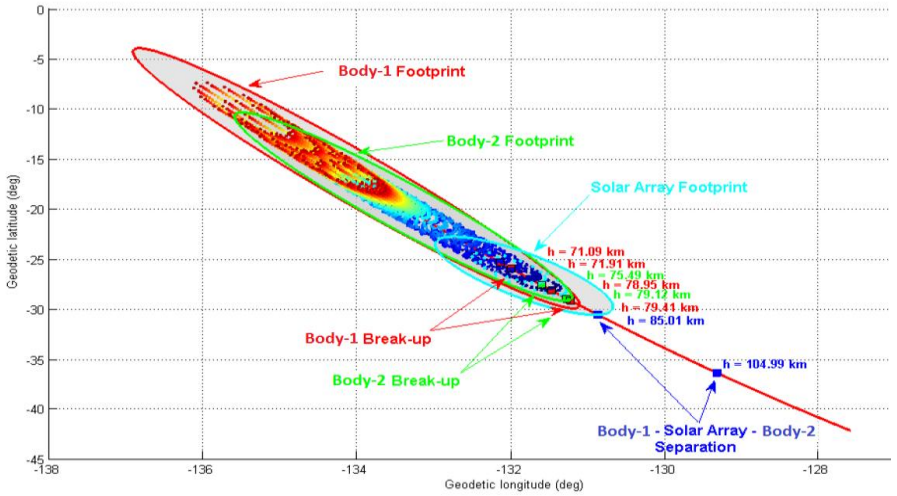



## *Examples:*

- IXV safety footprint analysis (ESA)
- Debris survivability and risk analysis (D4D/DRAMA, ESA)

**PETbox-embedded Object Oriented Tool: DEBRIS**
**(Debris survivability and risk analysis)**



# SAFETY (8/9)

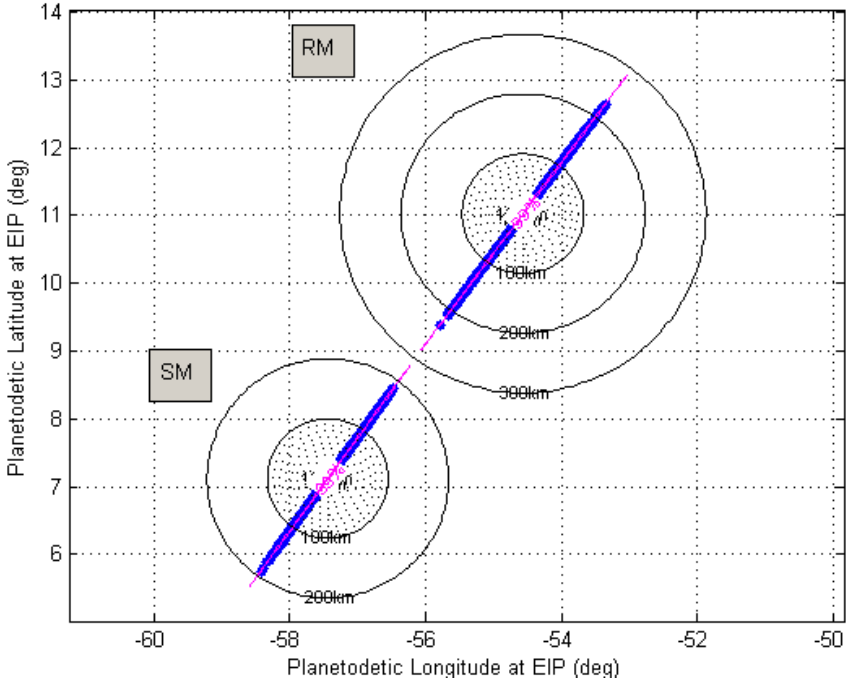
SAFETY

- FOOTPRINT
- DEBRIS SURVIVAB. AND RISK
- S/C SEPARATION

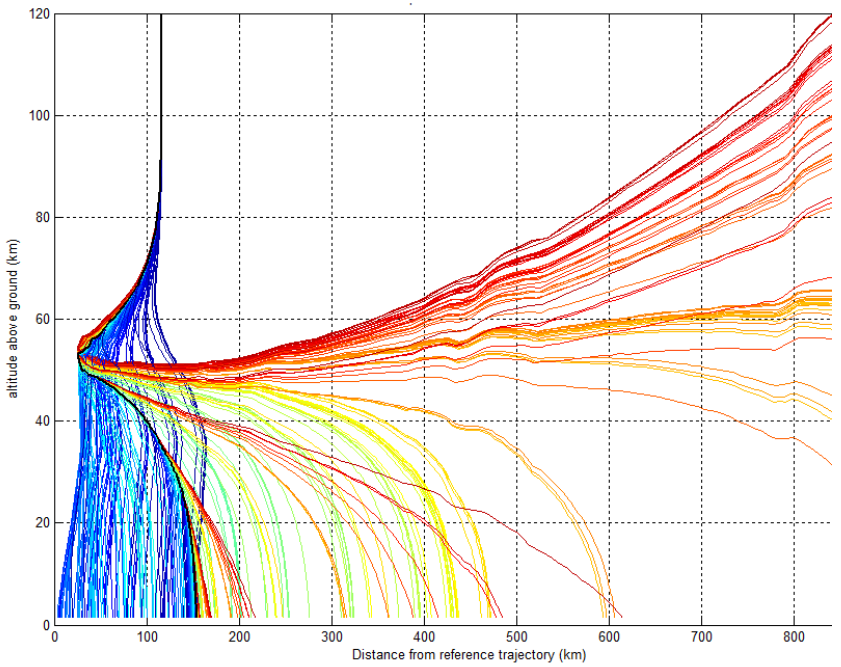
## *Examples:*

- IXV safety footprint analysis (ESA)
- Debris survivability and risk analysis (D4D/DRAMA, ESA)
- S/C Separation (ARV Service Module – Re-entry Module & Exomars 2018 Carrier Module debris – Descent Module separation) (ESA)

**ARV: Service Module – Re-entry Module**




**ExoMars 2018: CM debris - DM separation 24 h before EIP**



# POST FLIGHT ANALYSIS (9/9)

POST FLIGHT ANALYSIS

- TRAJECTORY RECONSTRUCTION
- DATA FUSION
- ANALYSIS

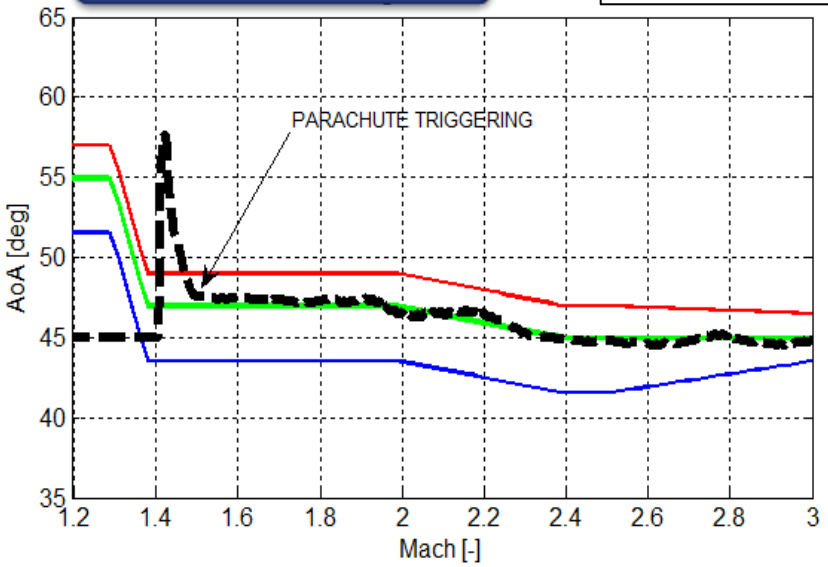
*Examples:*

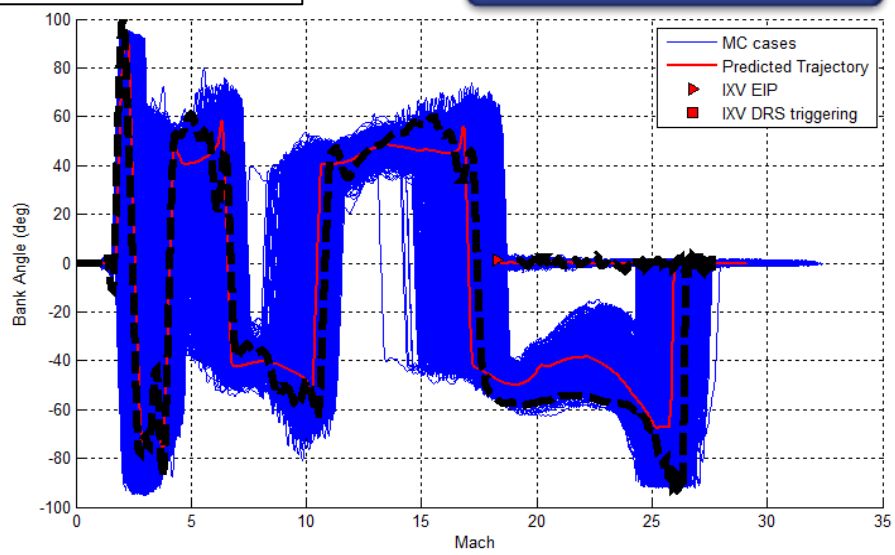
- IXV Mission Engineering design solution (PETbox-based) verification through flight data (ESA)

**Angle of Attack**

**- - - IXV trajectory:** GNC DATA

**Bank Angle**



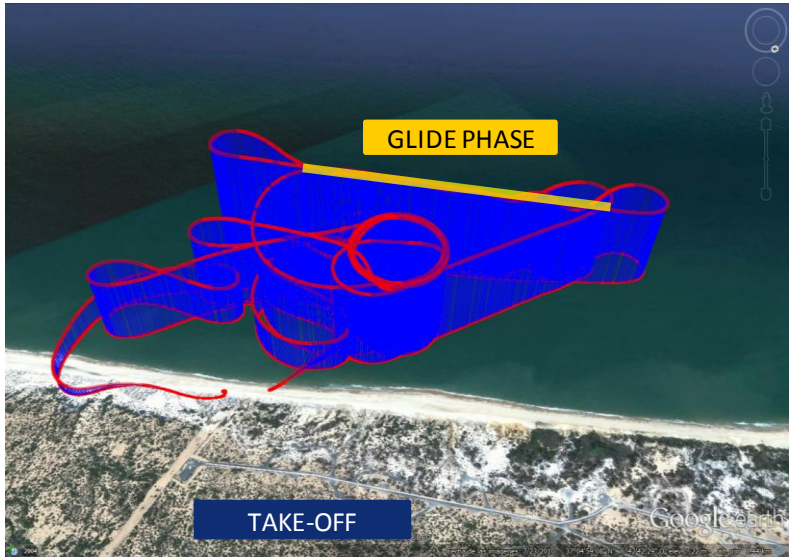




**Flight Qualification of Design Methodology and Tools**

# POST FLIGHT ANALYSIS (9/9)

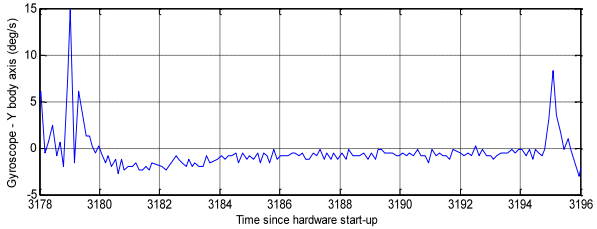
POST FLIGHT ANALYSIS

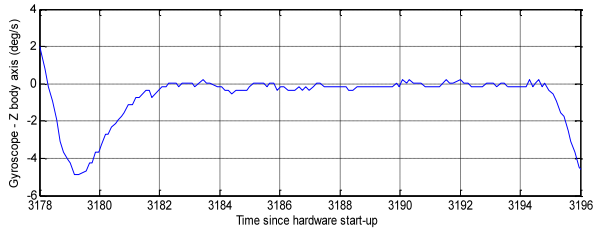
- TRAJECTORY RECONSTRUCTION
- DATA FUSION
- ANALYSIS



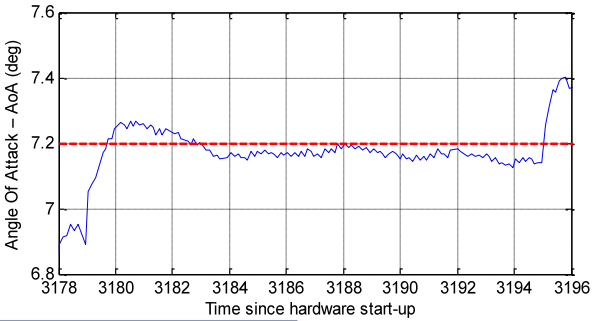

## *Examples:*

- IXV Mission Engineering design solution (PETbox-based) verification through flight data (ESA)
- PERIGEO open loop trim and stability of UAV (CDTI)




**Yaw and pitch stability**




**Glide Phase:**
**AoA design vs flight**

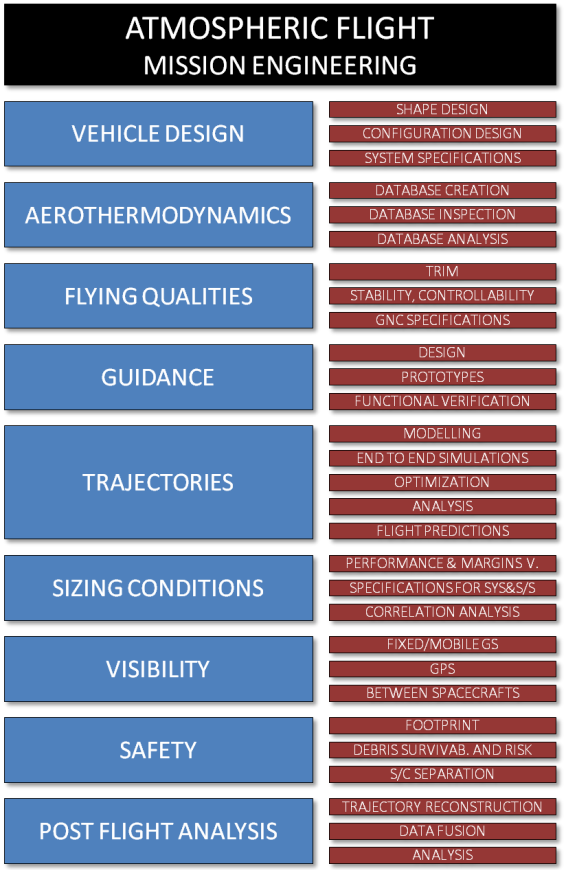
**Flight Qualification of Design Methodology and Tools**

# Conclusions

# CONCLUSIONS

## *Conclusions*

- Multiple practical examples of the use of PETbox in the area of Atmospheric Flight have been presented.
- The following features have been highlighted:
  - State of the art SW suite in Atmospheric Flight Mission Engineering
  - Flexibility to adapt to a very wide range of problems (different vehicles, flight phases, environments, analysis types)
  - Modularity and centralized SW
  - Flight qualification of design methodology and tools
  - Live tool under continuous upgrading by an expert team, ready for future challenges in Atmospheric Flight!



# Thank you

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