WE LOOK AFTER THE EARTH BEAT

IXV Development: An Integrated Approach for Performance Characterization

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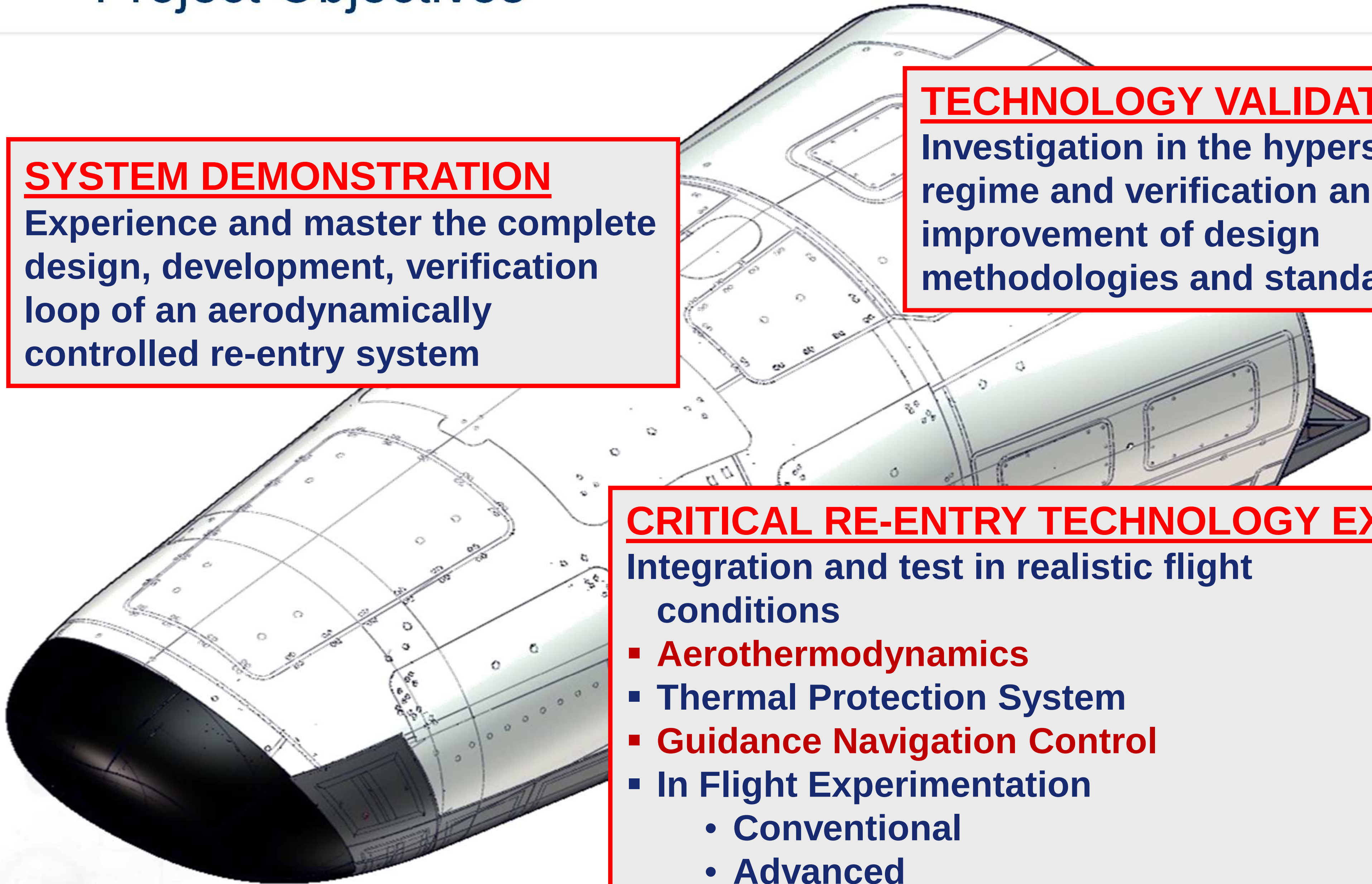
Hypersonic Flight: from 100.000 to 400.000 ft

ThalesAlenia Space
A Thales / Finmeccanica Company

Project Objectives



SYSTEM DEMONSTRATION

Experience and master the complete design, development, verification loop of an aerodynamically controlled re-entry system

TECHNOLOGY VALIDATION

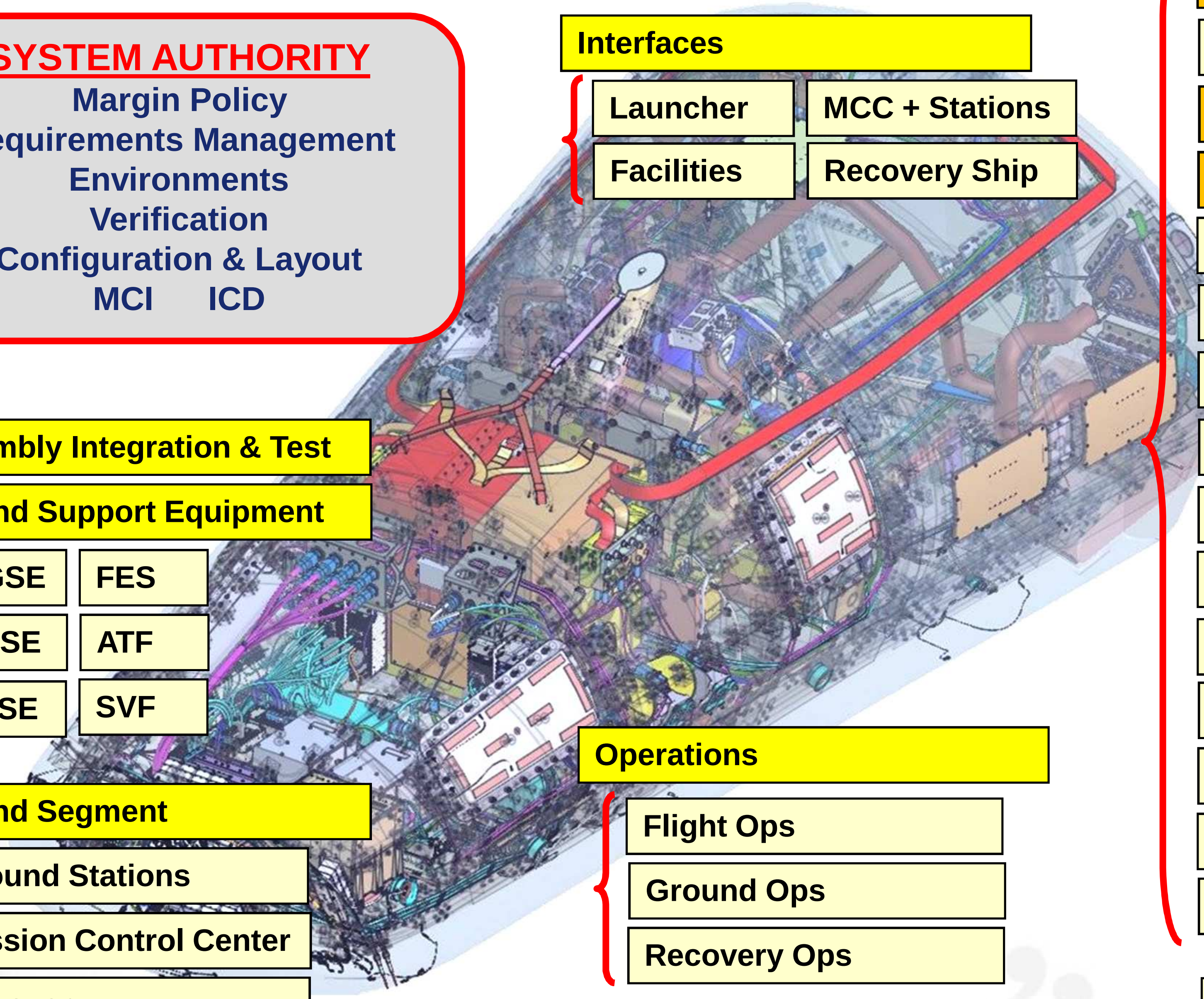
Investigation in the hypersonic regime and verification and improvement of design methodologies and standards

CRITICAL RE-ENTRY TECHNOLOGY EXP.

Integration and test in realistic flight conditions

- **Aerothermodynamics**
- **Thermal Protection System**
- **Guidance Navigation Control**
- **In Flight Experimentation**
    - **Conventional**
    - **Advanced**

The IXV System



SYSTEM AUTHORITY

Margin Policy
Requirements Management
Environments
Verification
Configuration & Layout
MCI ICD

Interfaces
- Launcher
- MCC + Stations
- Facilities
- Recovery Ship

Disciplines and Subsystems
- AED & ATD
- In Flight Experimentation
- Mission Analysis
- Guidance Navigation Control
- Thermal Control System
- Cold Structure
- TPS and HS
- Mechanisms
- Flap Control System
- Reaction Control System
- Descent System
- Recovery System
- Avionics (POW, DHS, RTC)
- Harness
- Software

System Drop Test

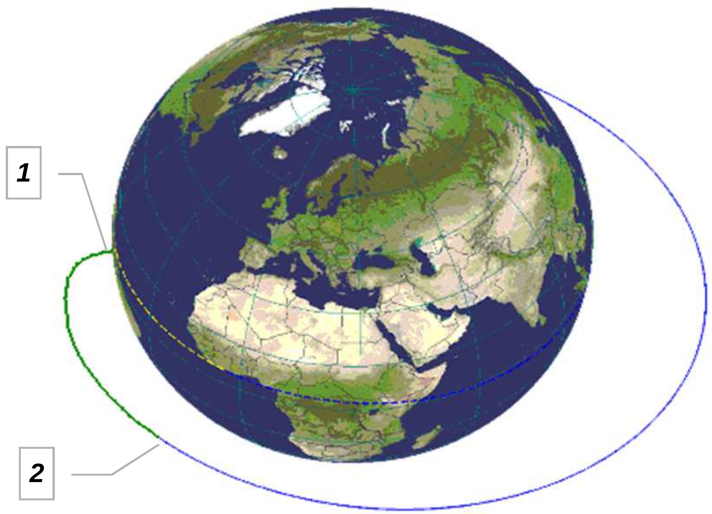
Assembly Integration & Test

Ground Support Equipment
- MGSE
- FES
- EGSE
- ATF
- FGSE
- SVF

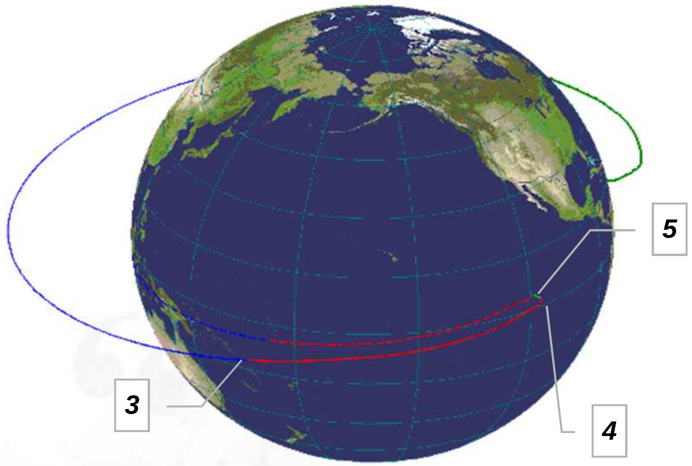
Ground Segment
- Ground Stations
- Mission Control Center
- Recovery

Operations
- Flight Ops
- Ground Ops
- Recovery Ops

Mission Profile

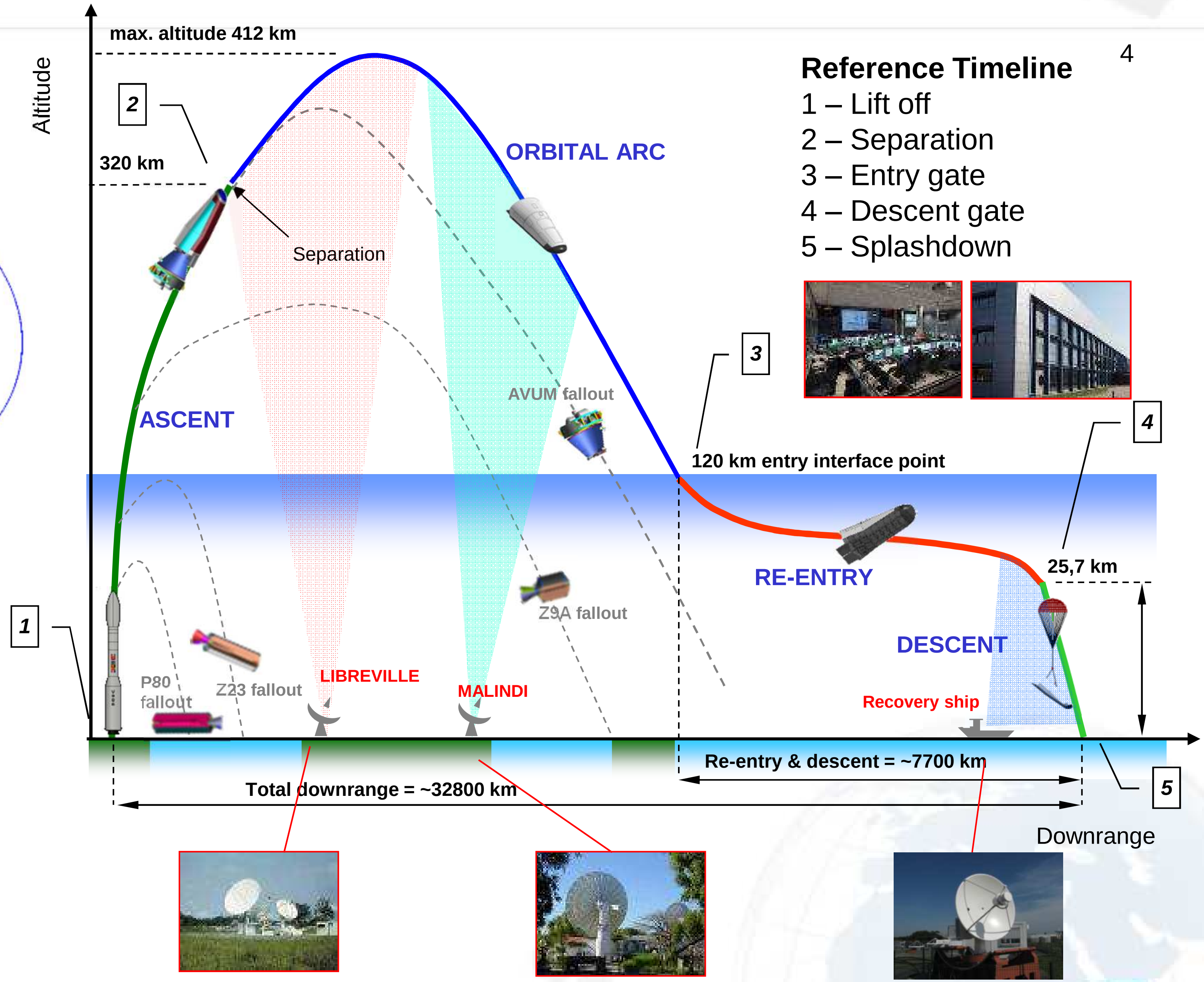


Reference Trajectory 3D view

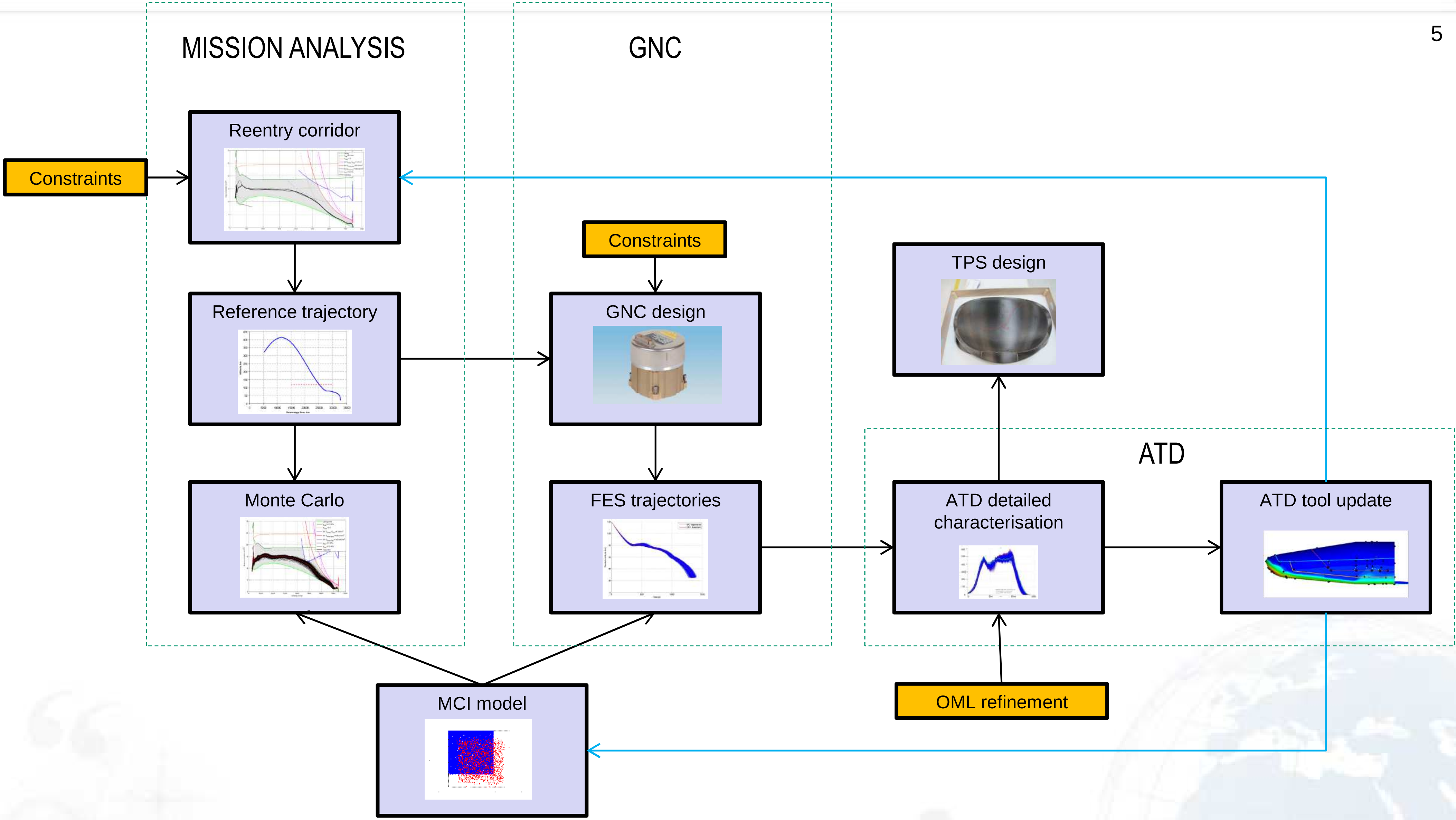


[Altitude scale: 10X]

Reference Timeline
1 – Lift off
2 – Separation
3 – Entry gate
4 – Descent gate
5 – Splashdown

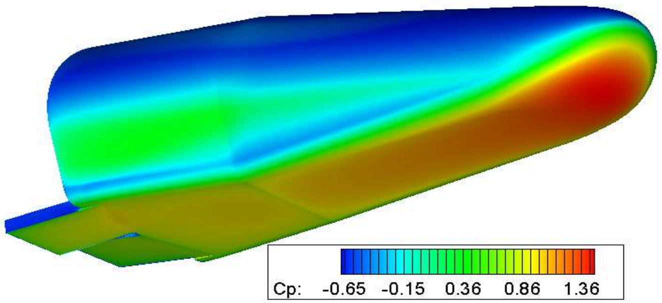


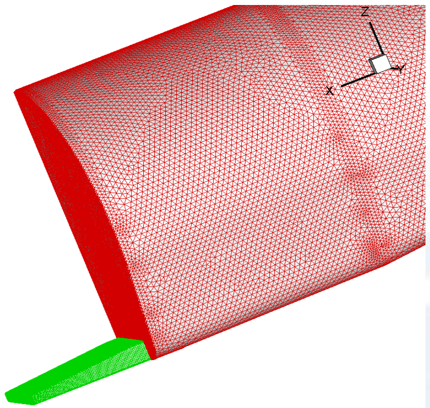
IXV Flight mechanics and aerothermodynamic study loop



IXV ATD Objective

- Computation of the aero-thermal loads on IXV vehicle, taking into account all the physical phenomena depending on different flight conditions:
  - Flight parameters in trajectory:
    - Nominal trajectory
    - Hottest trajectory (Maximum Heat Flux)
    - Coldest Trajectory (Minimum Heat Load)
    - Dispersed trajectories
  - Vehicle attitude:
    - Angle of Attack
    - Angle of Sideslip
    - Elevon Flap deflection
    - Aileron Falp deflection





ATD previous phases approach

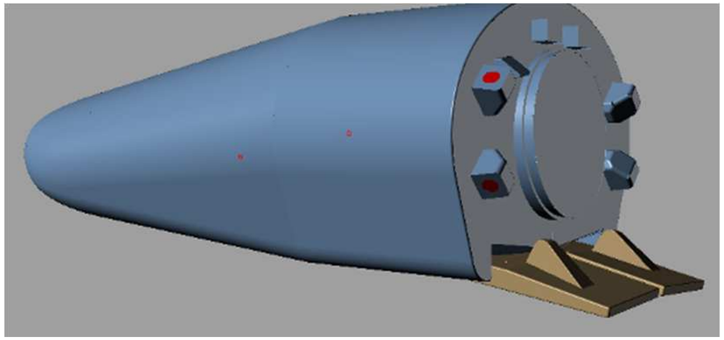
- Usually and in former projects and phases, the methodology adopted to identify the sizing ATD loads is split into different steps:

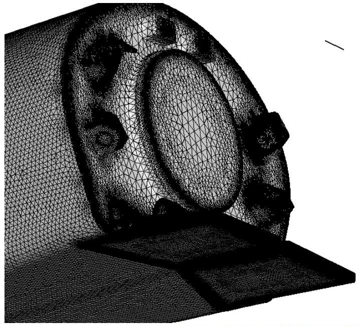
1. Optimization of a Reference trajectory (Mission Analysis):
   - ATD constraint is represented, usually, by the maximum heat flux/load on the stagnation point

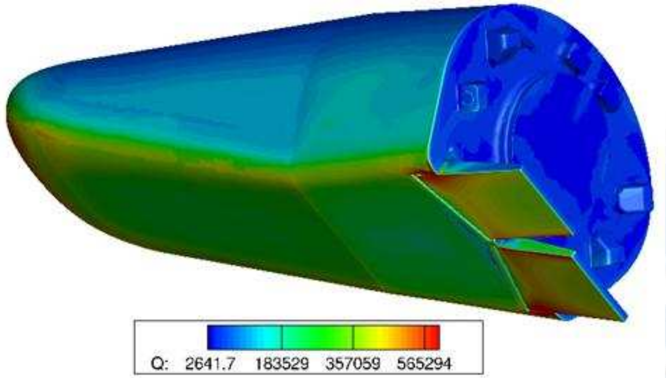
2. Verification of the flight mechanics aspects and GNC performance by means of a Monte Carlo (MC) analysis campaign (GNC)

3. Analysis of MC campaign results aiming to:
   - Estimate GNC performances
   - Identify the sizing trajectories and associated vehicle attitude

4. Computation of the aero-thermal loads for the selected sizing trajectories (ATD):
   - Heat Fluxes
   - Pressure
   - Skin Friction







ATD previous phases approach

- The mentioned approach entails some drawbacks:

  - ⇨ Non robust design in some zones of the vehicle:

    A trajectory, which is sizing (e.g. generating the maximum heat flux) on a specific point of the vehicle, is not necessarily sizing for other zones of the vehicle. The risk is to miss potential flight conditions that could be critical for other zones of the vehicle.

  - ⇨ Over-Design in other zones (i.e. flap):

    The worst attitude conditions found analysing all the MC results are used as sizing ones and combined with the worst trajectories:

    - worst *AoA*, worst *AoS*, worst flap deflections and worst trajectory

  - ⇨ Cost and schedule

    Several iterations between Mission Analysis and ATD teams can be necessary for the trajectory optimization itself

IXV ATD Methodology

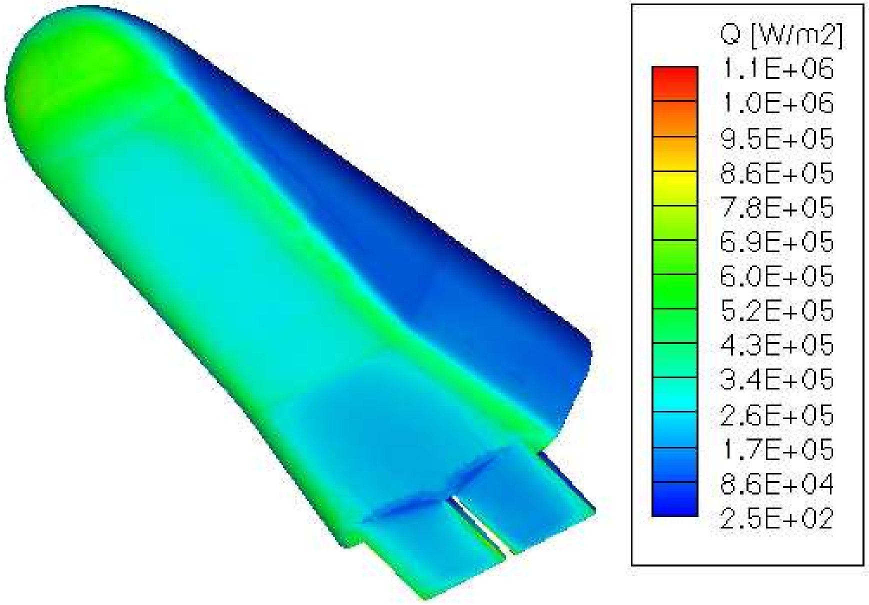
- The presented methodology, succesfully utilized in the phase C/D of IXV project, is based on a strong coupling between the Aerothermodynamics and Mission Analysis (MA) and GNC disciplines:
  - Development of an Aerothermodynamic Database (ATDB) Tool :
    - Able to compute automatically the ATD loads on the whole surface of the vehicle taking into account both the freestream conditions and the vehicle attitude.
  - Coupling between the ATDB Tool and the MA & GNC Tools:
    - Significant improvement and reduction of costs and duration of the iteration loops between mission, ATD and system design teams.
  - Performing of a Montecarlo GNC campaign, taking into account all the inaccuracies affecting the GNC performances.
    - ‘Light’ ATDB, integrated in FES, allows real-time ATD asessments.
  - Post-Processing of the GNC Montecarlo campaign by means of the ATDB Tool:
    - Identification of the sizing trajectories

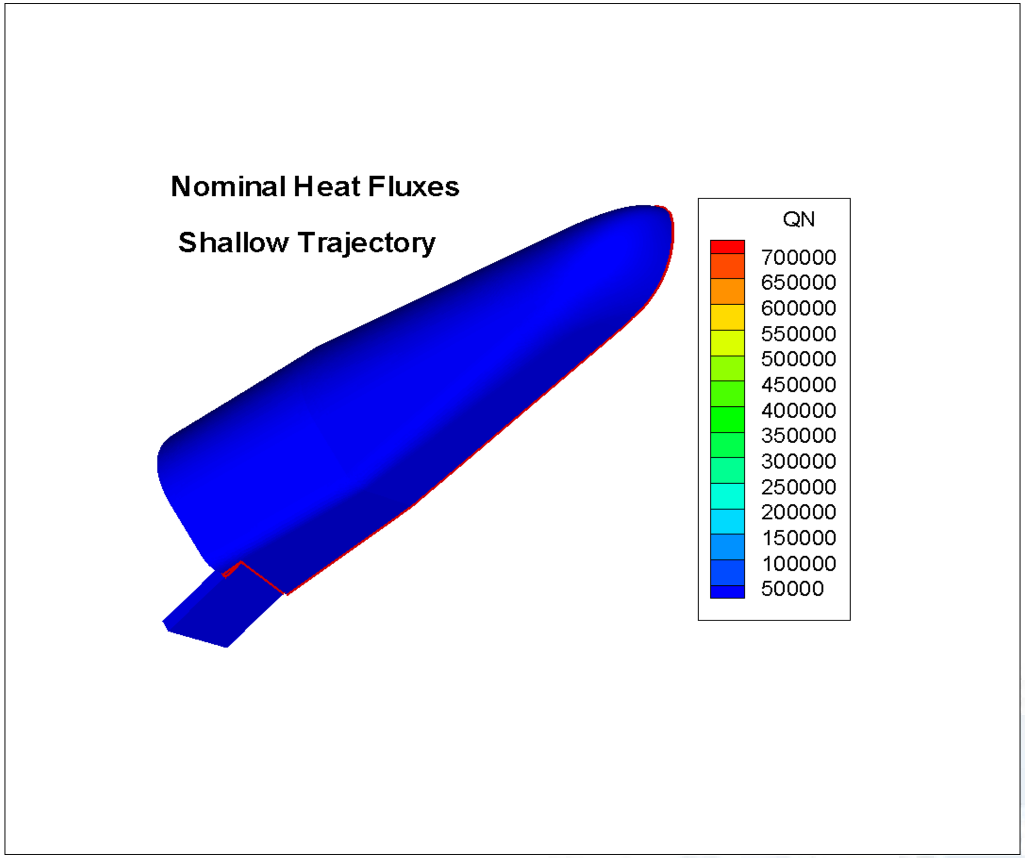
IXV ATDB Tool – Main functionalities

- An ATDB Tool has been developed by Dassault Aviation:
  - Free stream condition for any timestep of the analyzed trajectory:
    - M_∞, p_∞, T_∞, ρ_∞
  - Actual vehicle attitude:
    - *AoA (40÷50)* and *AoS (0÷8)*
  - Flap deflections:
    - Elevon *de* and Aileron *da*
  - Automatic detection of the transition from laminar to turbulent on both on the flaps and on the body of the vehicle.
  - Wall boundary conditions:
    - Radiative equilibrium or fixed temperature
    - Fully or partial catalytic wall
  - Both Sizing (including ATD uncertainties) and Nominal Heat fluxes

IXV ATDB Tool – Outputs

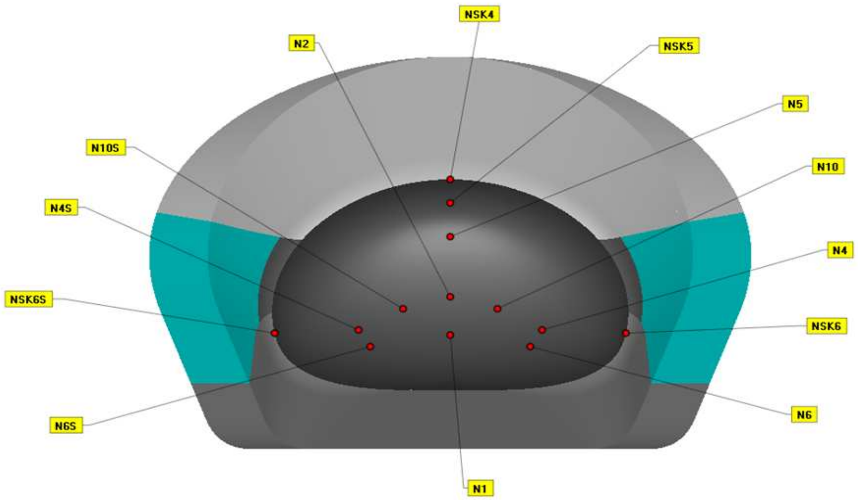
Skin Tecplot files

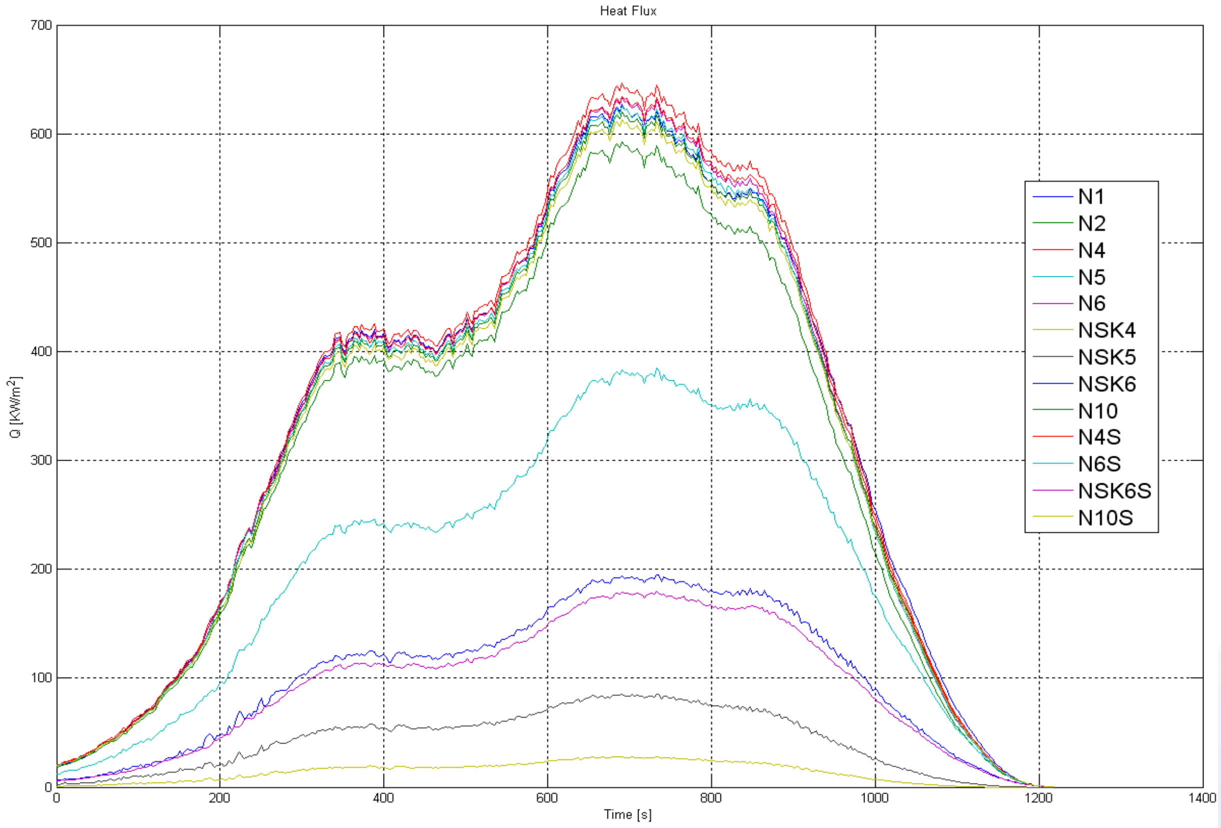




IXV ATDB Tool – Outputs

- Time-histories for any geometrical control point on the vehicle



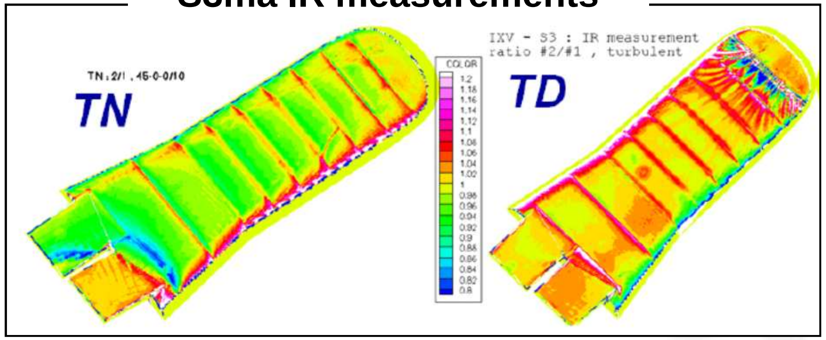


IXV ATD Tool - Development

- IXV ATDB Tool is based on the processing of
  - CFD computations by CFSe, R'Tech and University of Rome.
  - Complementary VKI LongShot WTT:
    - Combined effects induced by sideslip, aileron, AoA and transition
  - ONERA S3ma WTT:
    - IXV model featuring some disturbances (4 configurations)
    - Address potential LTT on both the body and the flaps and local overheating induced by steps.
  - VKI Plasmatron Tests:
    - Characterization of catalycity and emissivity values of SPS and MTA CMC thermal protection material

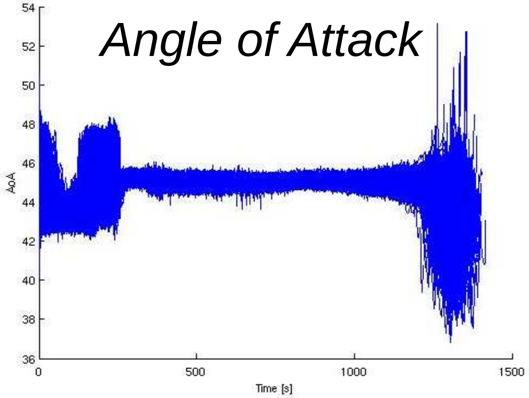
S3ma Model Conf. #4 w/o flaps

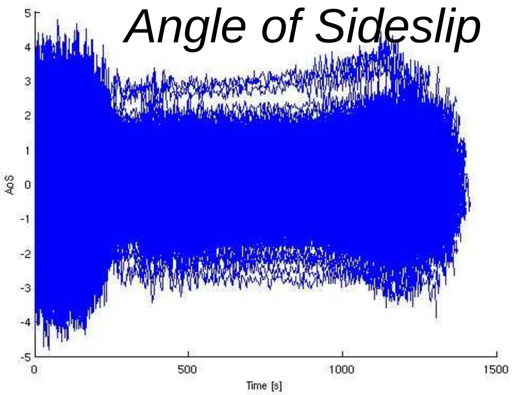
S3ma IR measurements



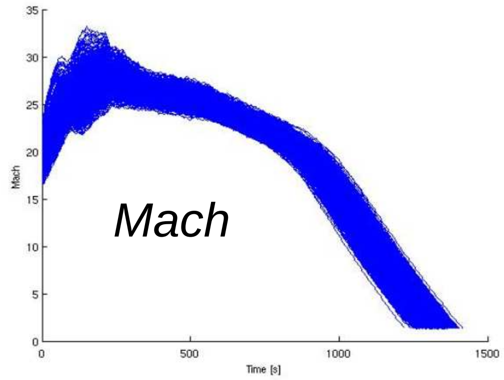
GNC Montecarlo campaign

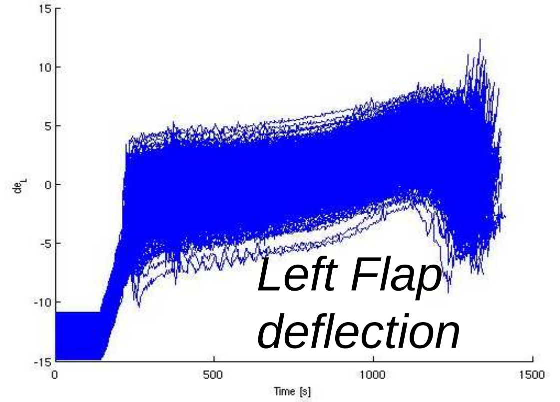
- In order to assess the GNC performances a MC analysis campaign has been performed, by means of the Functional Engineering Simulator (FES) Tool, with an embedded 'light' release of the ATDB Tool.





Parameter	Distribution
Initial Condition	
Position	Gaussian
Velocity	Gaussian
Attitude	Gaussian
Attitude rate	Gaussian
MCI	
Mass	Uniform
Inertia	Uniform
CoG	Uniform
Aerodynamics	
AED Continuum	Gaussian
AED Rarefied	Gaussian
Atmosphere	
Density	Gaussian
Temperature	Gaussian
Wind	Gaussian
RCS	
Thruster Location	Gaussian
Thruster Orientation	Gaussian
Torque	Uniform
Flap	
Static Offset	Uniform
Backlash	Uniform
IMU	
Drift of Gyros	Gaussian
Scale factor of Gyros	Gaussian
Misalign of Gyros	Gaussian
Bias of Accelerometers	Gaussian
Scale factor of Accel.	Gaussian
Misalign o Accel.	Gaussian
Error in alignment	Gaussian
Harmonization error	Gaussian





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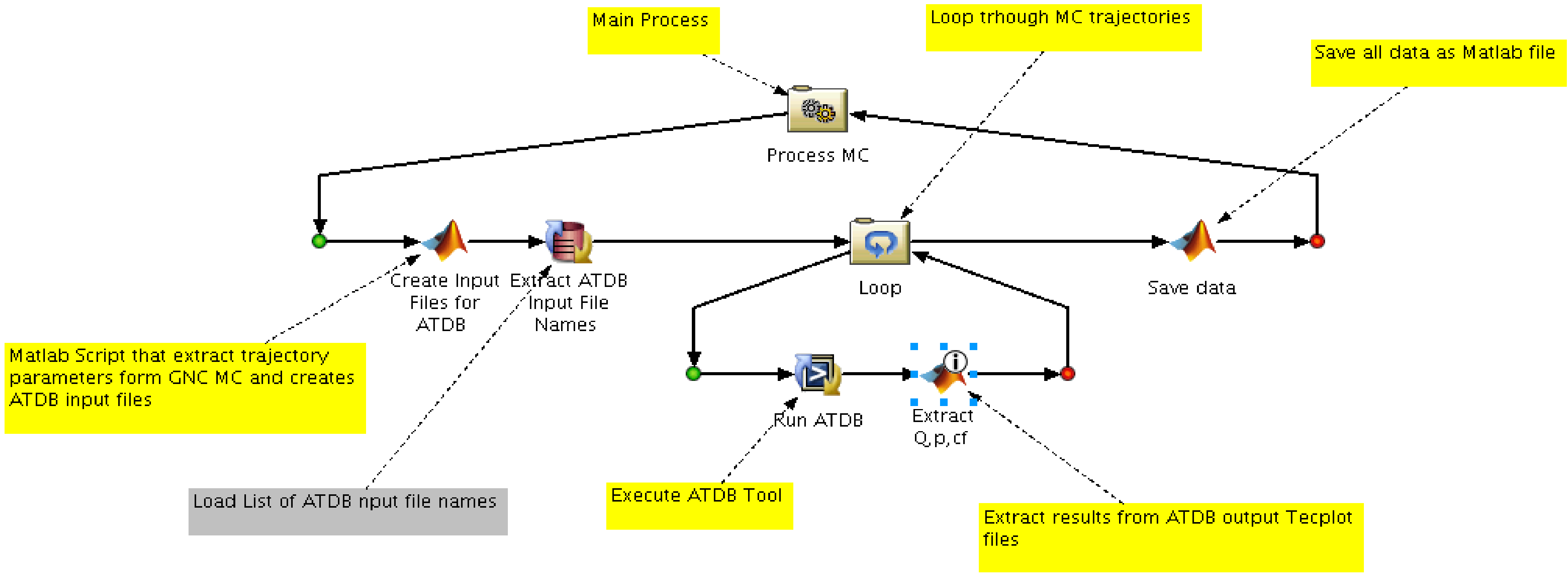
GNC MC Post-processing

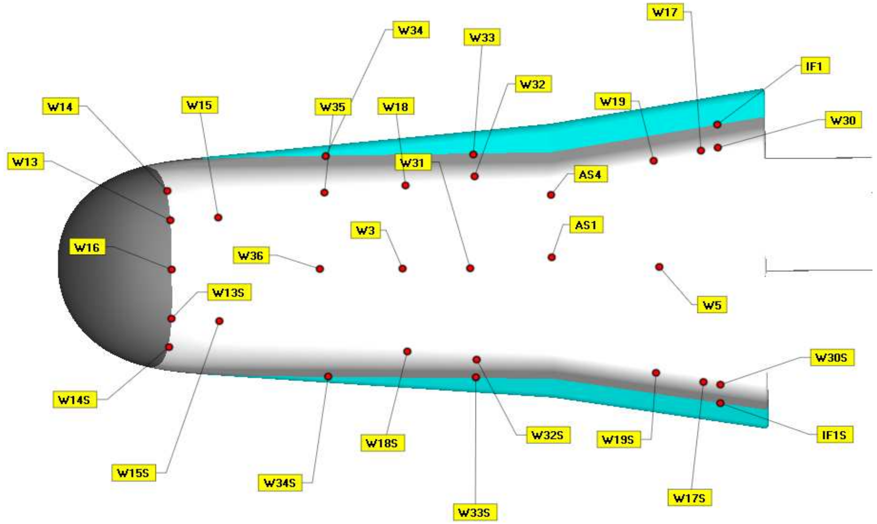
- All the dispersed trajectories, resulting from the GNC MC simulation, are processed by the ATDB Tool. The whole process has been integrated using the commercial software iSight (Simulia)

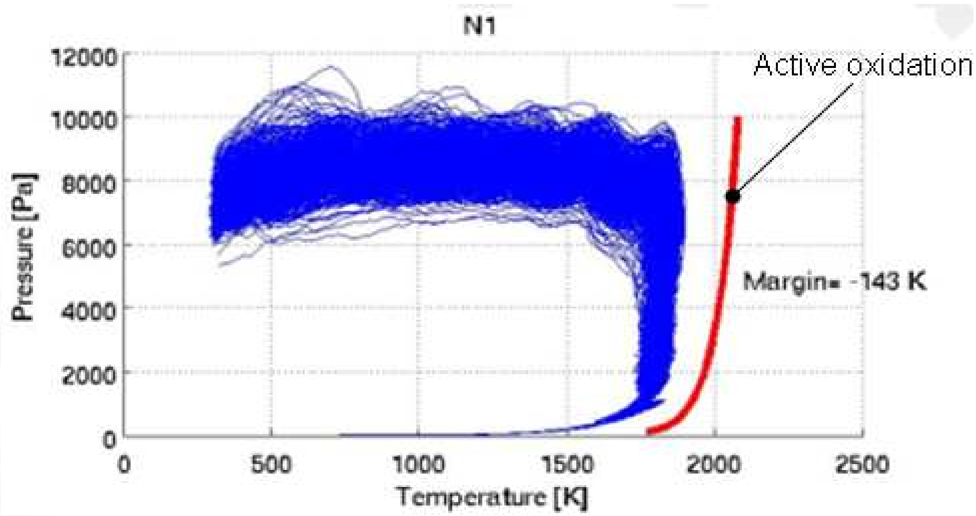


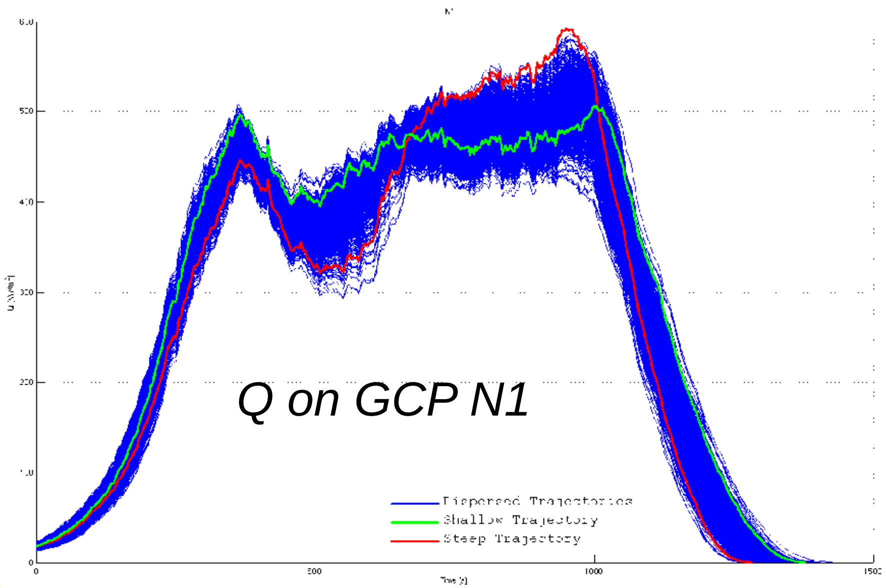
GNC MC Post-processing

STEP 1

- More than 200 geometrical Control Points have been selected on the vehicle
- Heat flux, *Cp* and *Cf* time-histories are extracted for all the trajectories and for more than 200 GCPs on the vehicle.
- On CMC assemblies the margin with respect to the Passive to active oxidation transition is computed



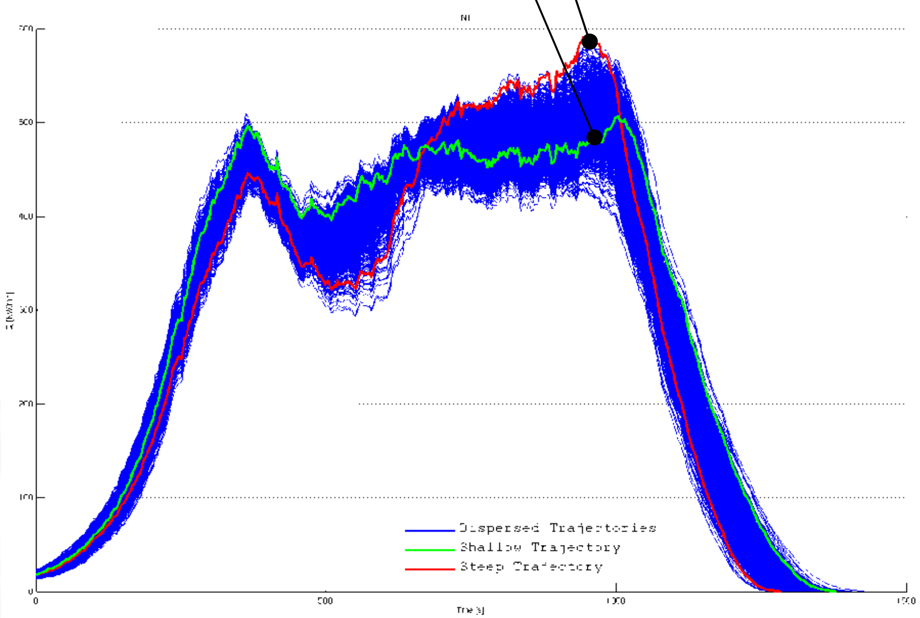


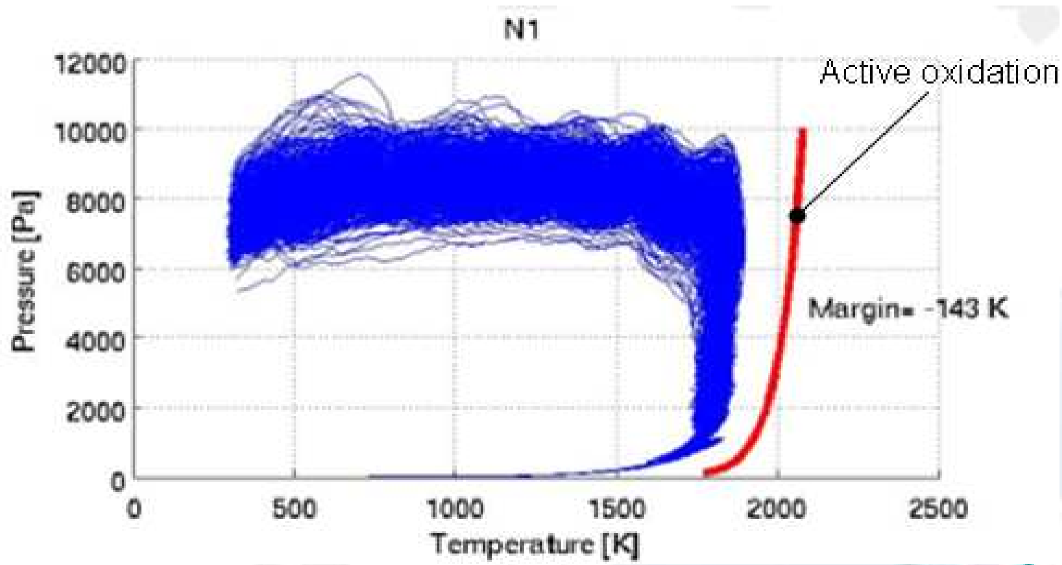


GNC MC Post-processing

STEP 2

- For each GCP all the available time-histories are analyzed in order to identify:
  - Local Steep Trajectory, generating the local maximum heat flux
  - Local Shallow Trajectory, generating the local maximum heat load (integral of Q along the complete trajectory)
  - Trajectories generating the combination of local Temperature and Pressure that can induce Passive to Active transition.

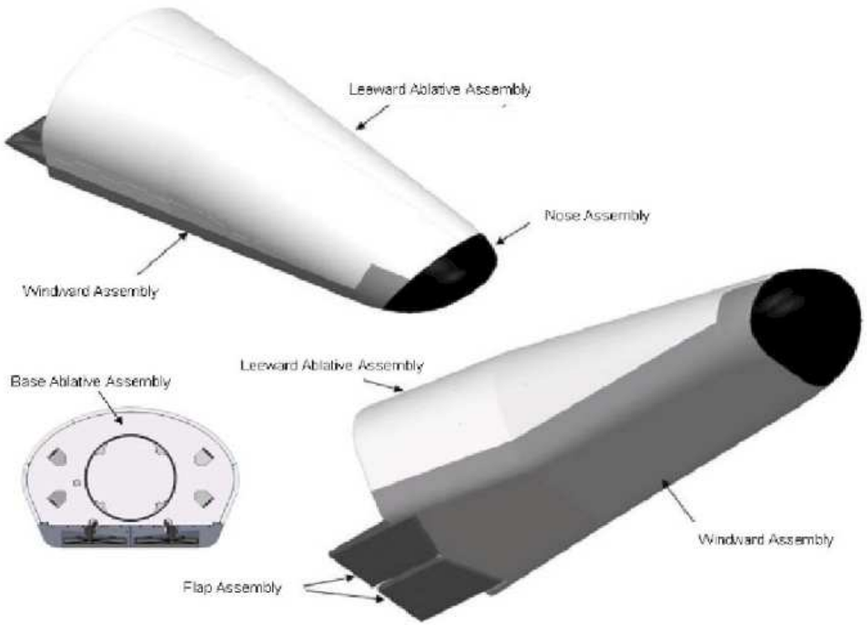


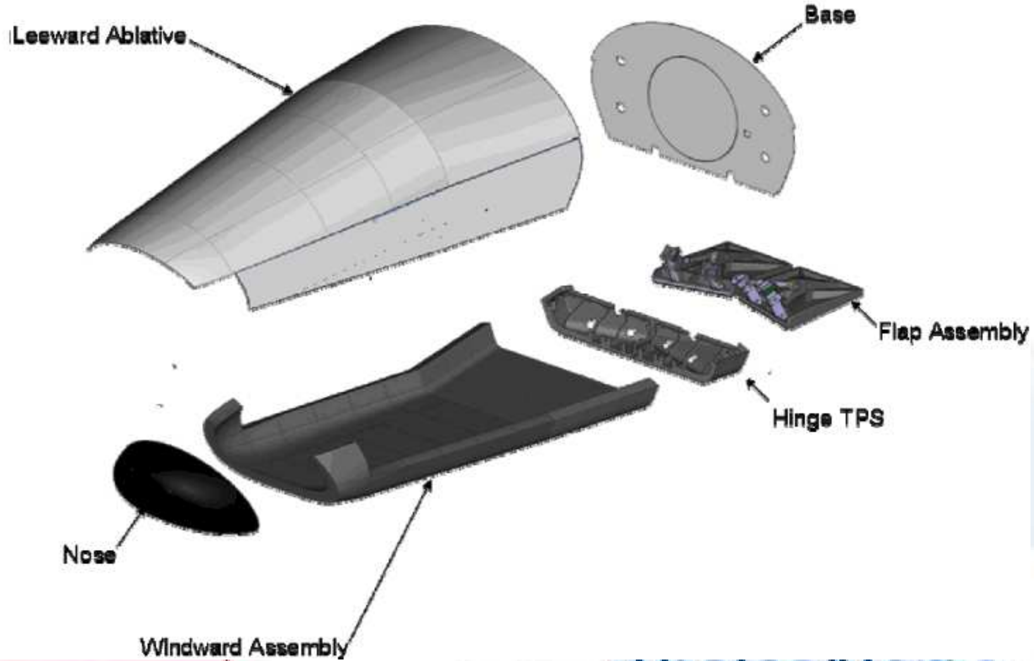


GNC MC Post-processing

STEP 3

- The geometrical control points are grouped in different assemblies, corresponding to different zones of the vehicle, identifying for each one of them:
  - Assembly Steep trajectory ⇨ Maximum GCP heat flux on the assembly
  - Assembly Shallow trajectory ⇨ Maximum GCP heat load on the assembly
  - Global Shallow trajectory ⇨ Maximum heat load on the whole vehicle



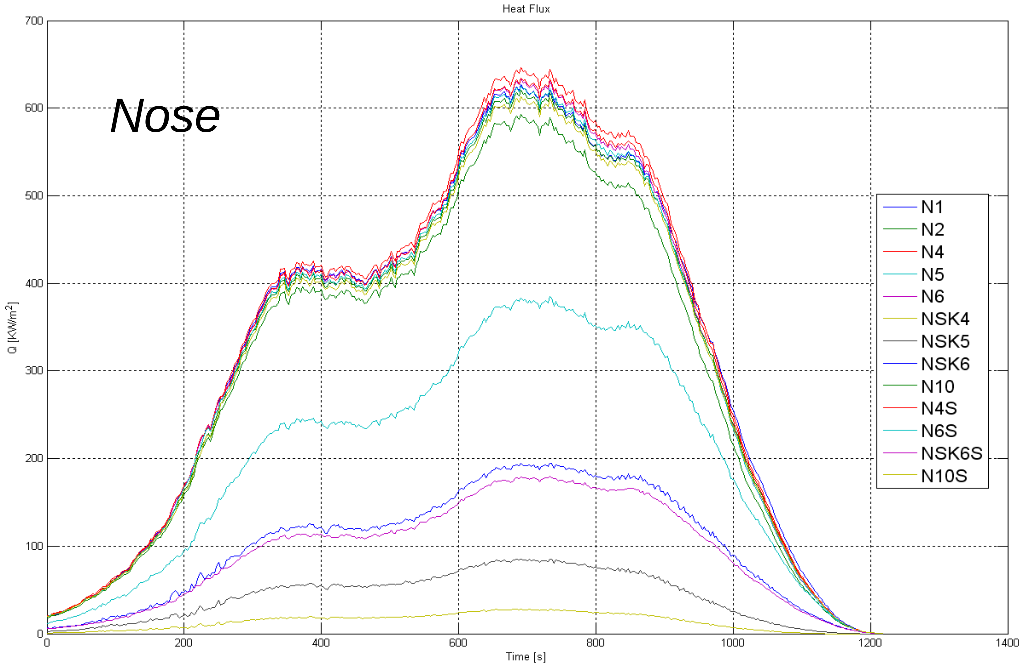


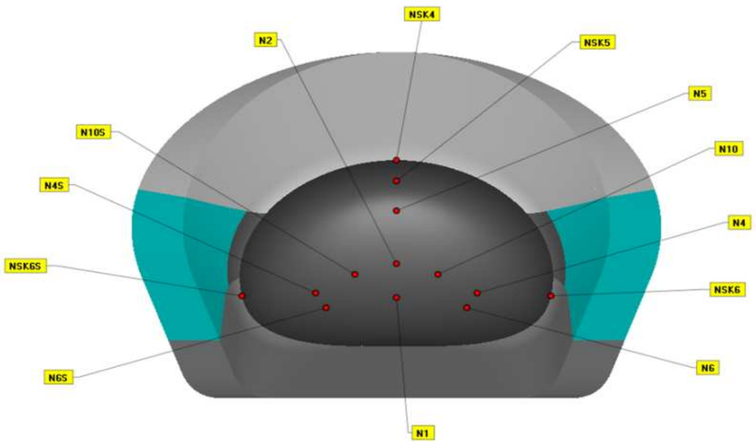
STEP 4

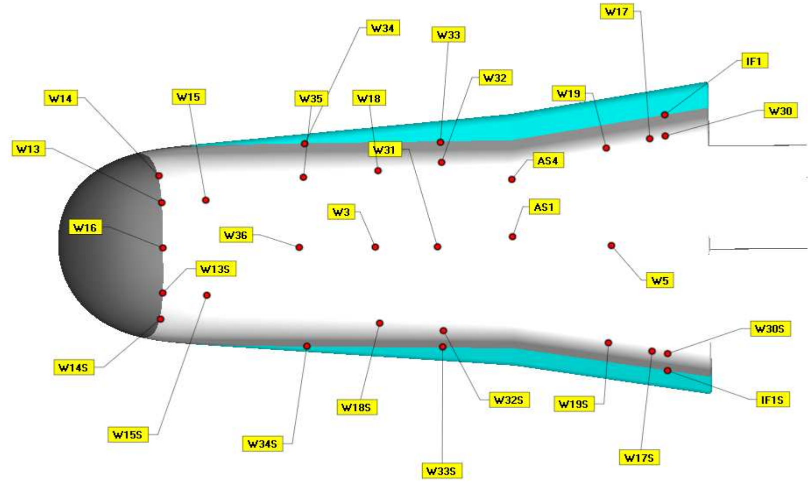
- **The Assembly Steep and Shallow trajectories are then used as reference ones for the computation of the Sizing ATDB data for all the GCP of the same Assembly**
- **The Global Shallow trajectory is used as reference one for the computation of the Sizing ATDB data for System level thermal design**

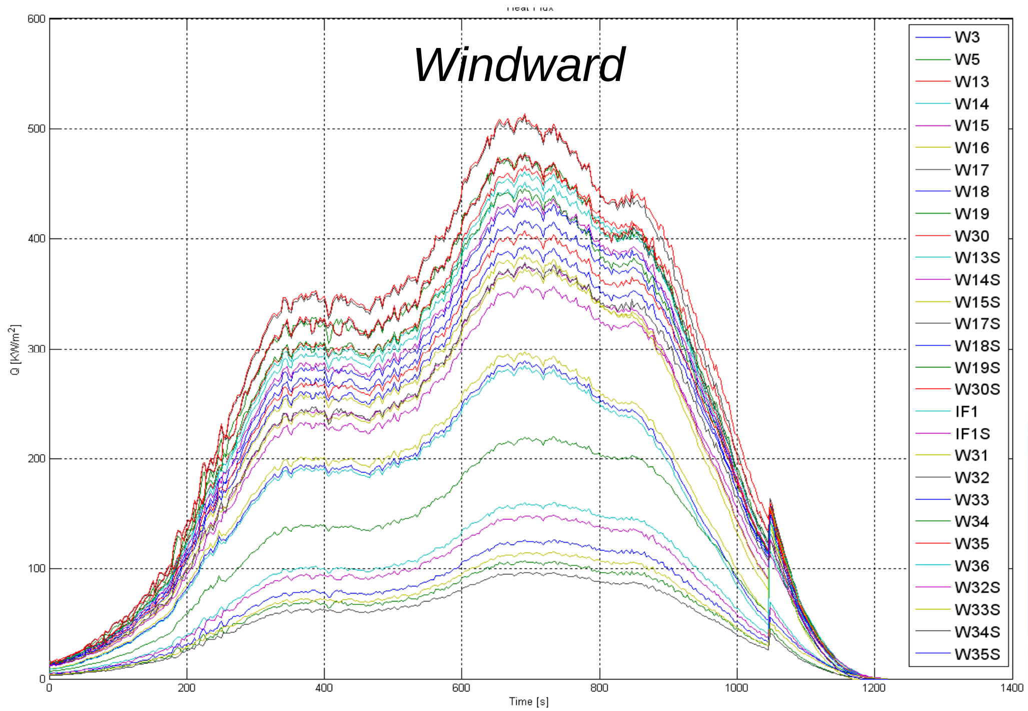
Assembly	Assembly Steep Trajectory	Assembly Shallow Trajectory	System Shallow Trajectory	Max Heat Flux	Max Heat Load
	#	#	#	[KW/m^2]	[MJ/m^2]
Nose	391	661	661	647	560
Windward	391	578	661	514	700
Leeward	421	866	661	116	115
Lateral	391	361	661	170	127
Hinge	421	851	661	516	491
Base	421	360	661	55	41
Flap	490	893	661	976	488

ATDB Computation









Conclusion

- An advanced ATDB Tool has been developed by DAA for the automatic computation of the main aerothermal data on IXV vehicle for any reference reentry trajectory.
- A 'light' release of the ATDB Tool has been generated by TAS-I and successfully implemented by DEIMOS Space in the Mission Analysis tools related to trajectory optimisation, simulation and flight mechanics, reducing drastically the iteration loops between Mission, ATD and System design teams.
- A dedicated light release on windward ablative panels has been implemented in FEC (GNC simulation) in order to feed input data for the MCI model
- A methodology for the aero-thermal characterization of IXV vehicle, based on a strong coupling between ATD and GNC disciplines and tools (ATDB and FES software), has been successfully developed and implemented by TAS-I, allowing a more robust and less conservative computation of the Sizing heat fluxes.
- The light ATDB tool will be used for the pre-flight predictions in phase E, in order to estimate the heat fluxes for the predicted trajectory, and compare with respect to the constraints and sizing trajectories.