PERSEUS

HADES Project

Design and optimization of space launch systems

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Context

- **CNES**
- **French Space Agency**

- **PERSEUS**
  European Student Project of Science and Research in Space Launch Vehicle

- **HADES**
  Help on Advanced launcher DESign

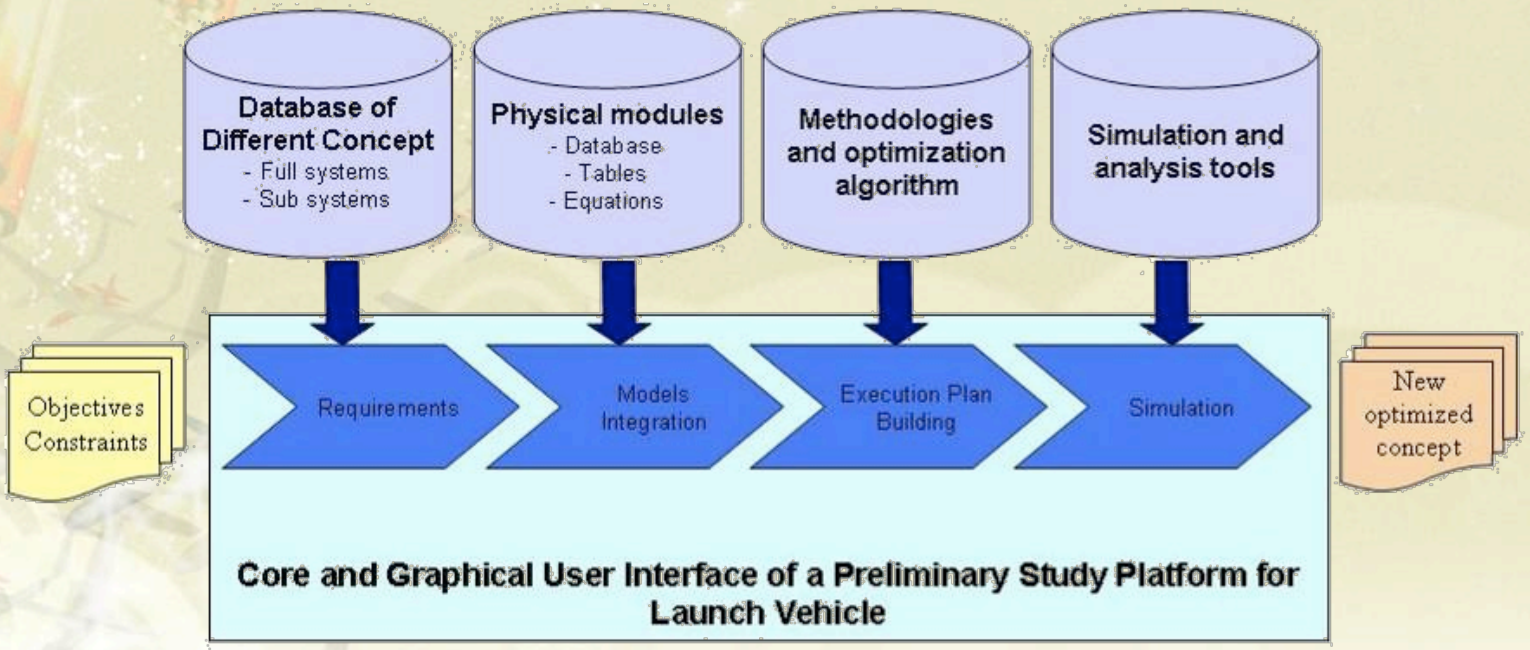
  Open project of pedagogic and innovative tool for global sizing and optimisation of space launcher concepts:
  - **Centralize and develop preliminary design codes**
  - **Improve the efficiency of engineer by achieving best solutions**
  - **Bring users to space vehicles' domain and teach them how to preliminary design**

Currently involved: CNES, Bertin, SIREHNA/ESTECO, IRRCyN, ONERA, INSA Lyon, etc.

HADES platform (1)

HADES is a software platform to perform feasibility design of space transportation systems and is intended to students and engineers

- **General objectives:**
  - To design and evaluate launcher, stage or sub-system concepts
  - To perform comparative and parametric analysis



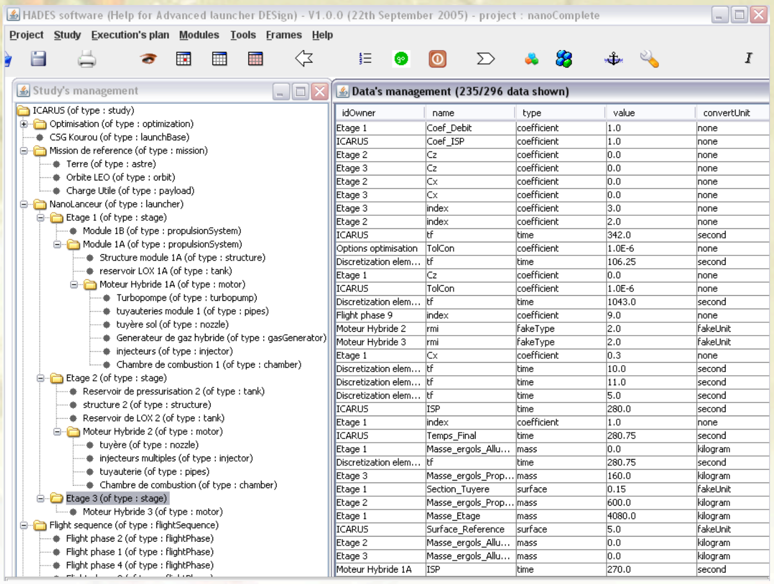
HADES platform (2)

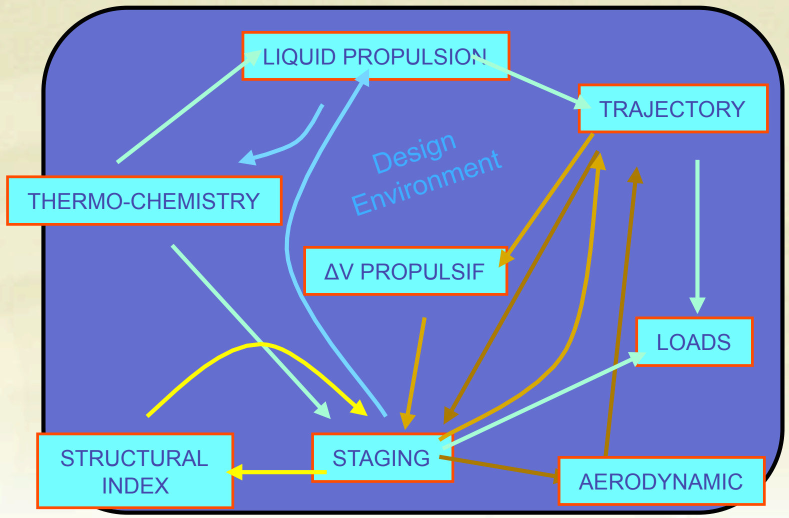
Design approach:

- Use elementary tools dedicated to preliminary design: simple, fast and robust
- Offer a quick estimation of launcher characteristics from basic choices
- Apply MDO to manage and optimize the design process

1st study case: Expendable Launch Vehicle preliminary design system loop

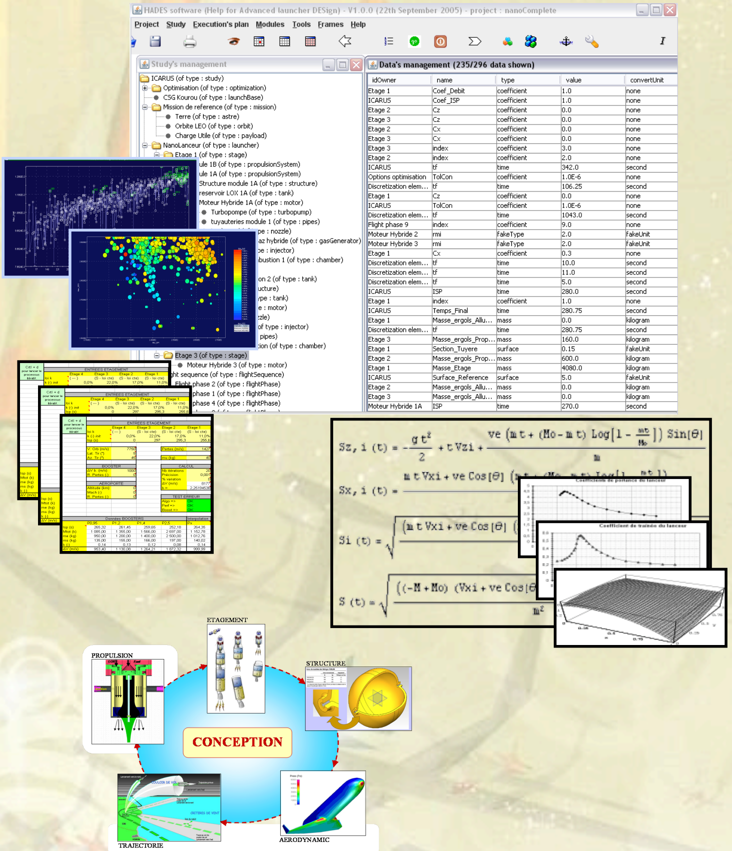
Find the most effective launch system for recurring cost and/or performance





Development approach

First works are based on a representative study case that is a **3 stages launch vehicle**



GUI
- Data management
- Execution of modules
- Execution of scenarii
- Guide for analysis
- Post-processing dedicated to space application

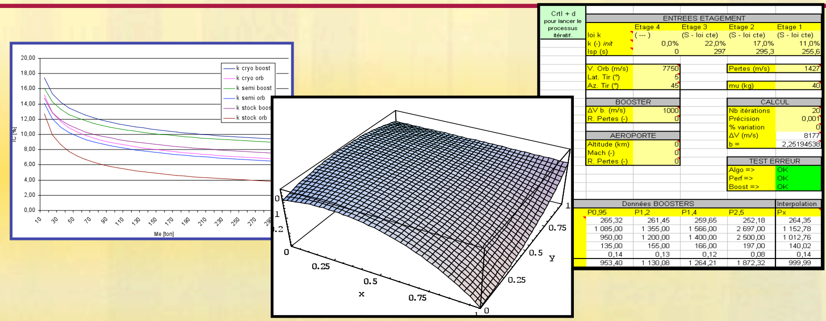
Modules
- Specification, development and integration of codes
- Refinements specification

Scenarii
- Definition of process
- Workflow development in modeFRONTIER
- Choice of optimisation algorithm and parameters

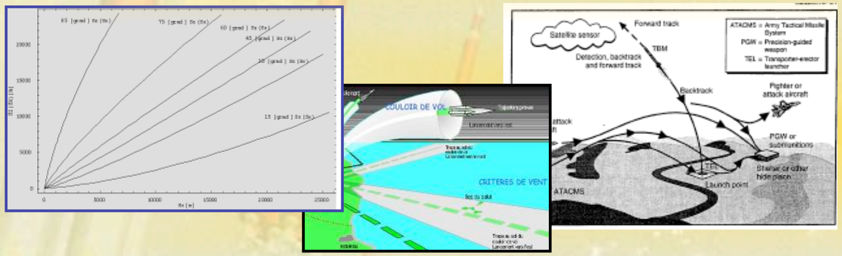
Platform administration
Project management

HADES Vx

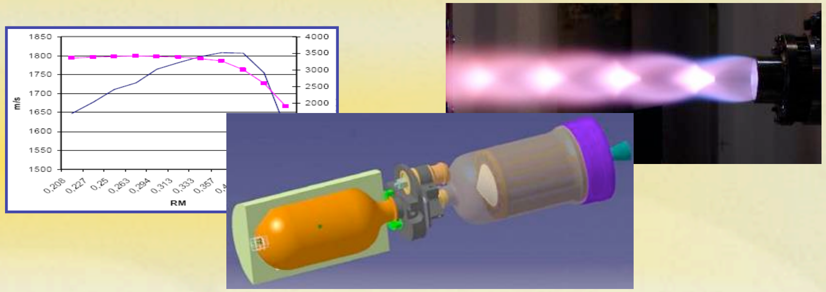
Preliminary design modules



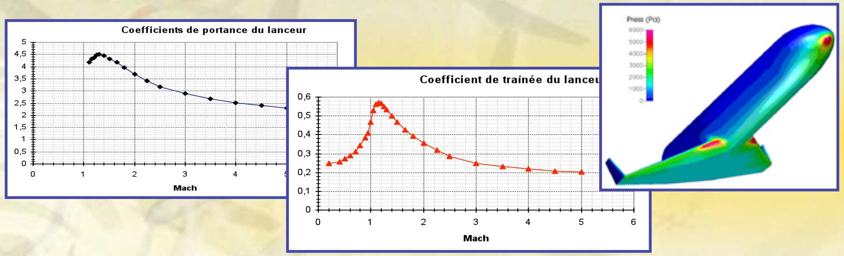
- **Staging and Structural Ratio:** Payload mass on Global Lift-Off Mass Optimization considering specific structural ratio database



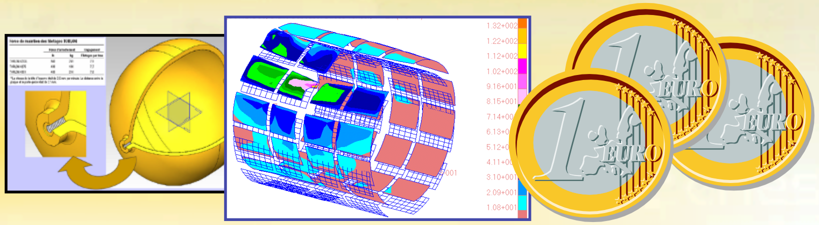
- **Trajectory:** Trajectory optimization and performance calculation for a multi-stage rocket.



- **Thermo-chemistry and Propulsion:** Design and performance calculations of a liquid propellant rocket engine



- **Aerodynamic and General Loads:** Drag and Lift coefficients, general loads calculation based on simplified geometry



- **Structure and Cost:** Tanks sizing, buckling of cylindrical tanks and specific cost calculation

Why using modeFrontier?

Offers HADES:

- **User-friendly and didactic interface**
- **Quick and simple integration procedure for both in-house codes and external applications (as Excel/OpenOffice, Matlab/Scilab, …)**
- **Easy chaining of modules : multi-platforms, any code executable on command line with input/output text files**
- **Executable in batch mode, with specification of parameters in XML file**
- **Wide range of statistical and graphical analysis tools**
- **Includes a collection of optimisation algorithms adapted to a variety of problems**

Limitations:

- **Management of equality constraints**
- **Embedded loops**
- **Batch mode seems restricted to some executions (like DOE)**

Application

- **Problem to solve:**
  - **Find the optimal launch vehicle for a fixed orbit (GTO) and a fixed payload**

- **Optimization parameters (for each stage):**
  - **Mixture ratio**
  - **Nozzle exit pressure**
  - **Thrust to weight ratio**

- **Objective functions (to maximize):**
  - **Payload mass on global lift-off weight ratio (Hall)**
  - **Specific impulse for each stage**

- **Constraints:**
  - **Payload mass calculated close to the payload mass targeted**
  - **Maximum diameter for each stage**
  - **Constraints on ascent trajectory (maximum loads admitted)**

Optimisation

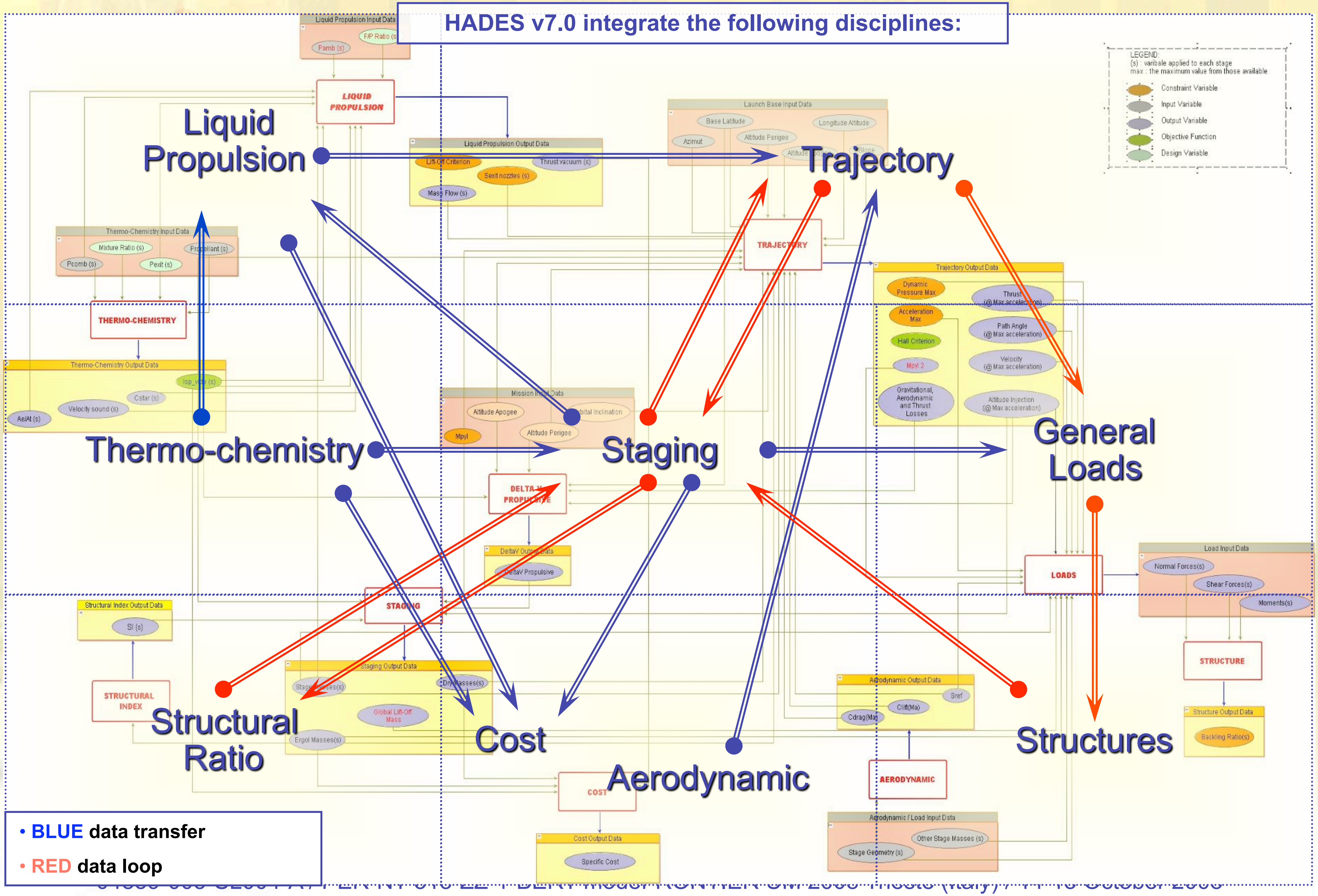
Several levels of optimisations:

- **Internal: inside a module**
  Ex: performance module searches optimal trajectory to desired orbit

- **Local: fixed point loop**
  Ex: a Structural Ratio based on experience is given to staging module which defines a given structure corresponding to another ratio, recomputed

- **Global: multidisciplinary process**
  Ex: find the best-cost launcher to achieve putting a given payload on required orbit

Global loop of conception



• **BLUE** data transfer
• **RED** data loop

HADES developments

Next

- **HADES GUI for data and modules management, including batch execution of modeFRONTIER**
- **Physical modules for propulsion options**
- **Integration of modules in the design process (workflows, role of variables, adaptation of algorithms and parameters)**
- **MDO: re-arrangement of process, test of new functionalities (batch node for imbricated loop), pre-selection of adequate analyses**
- **Diffusion aspects**

Long term

- **GUI enhancements: customised specification and execution of optimisation, specific post-processing**
- **New/improved study cases: suborbital rocket, airborne launch vehicle, boosters management, etc.**
- **Integration/improvement of modules: interoperability, refinement, etc.**

Conclusion

- **modeFRONTIER offers a good framework for HADES ambition:**
  - Give students and engineers an easy access to space launcher's design
  - Allow comparison and optimisation of designs on a cost and performance basis
  - Offer them an open background for further developments

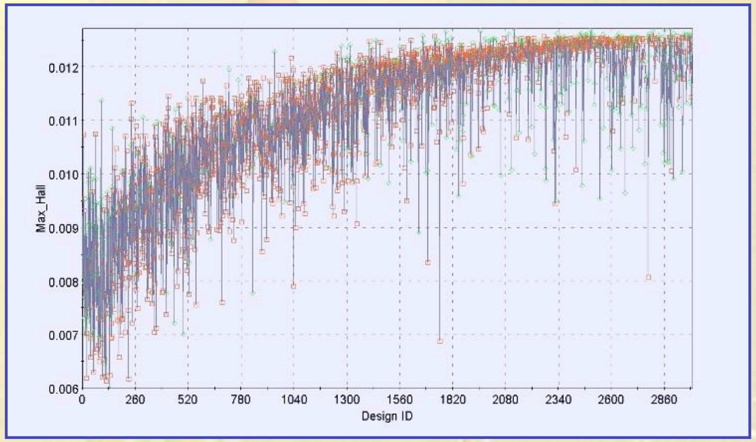
- **In addition to basic training, HADES team now needs also customised support and solutions on:**
  - Internal aspects for managing batch execution
  - Handling of multiple levels in process optimisation
  - Integration of structure and algorithms adapted to satisfy equality constraints

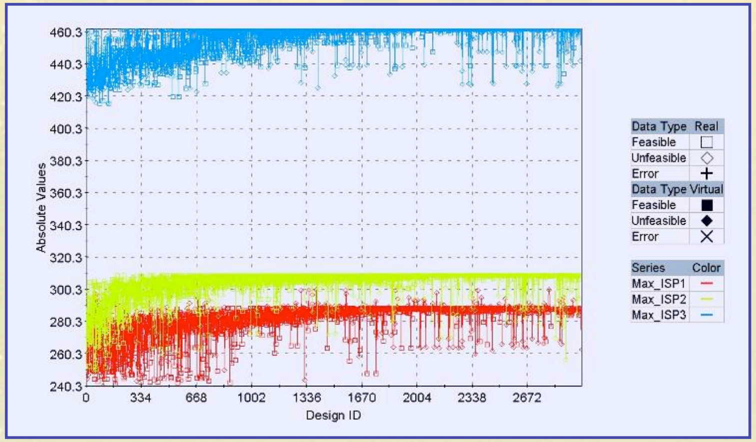
- **Expected perspectives:**
  - Targeted diffusion of HADES platform (and modeFRONTIER) to a selection of students' group and engineers
  - Various works planned on a wide range of aspects: specification/integration of process, MDO architecture
  - Feed-back of users from scholar to industrial practice on space domain's applications

Results

HADES v7.0 Results

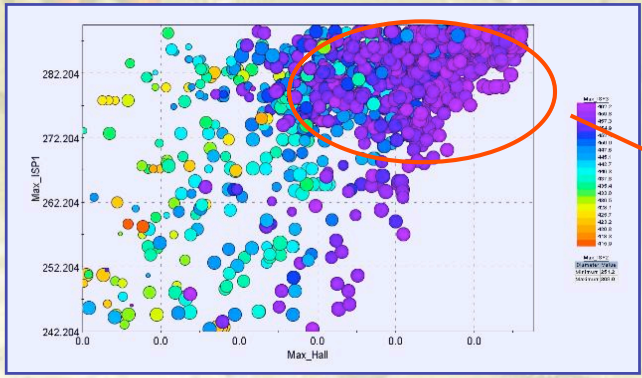
• The results have been obtained after convergence of a genetic algorithm (MOGA-II) with *60* designs and *50* generations)

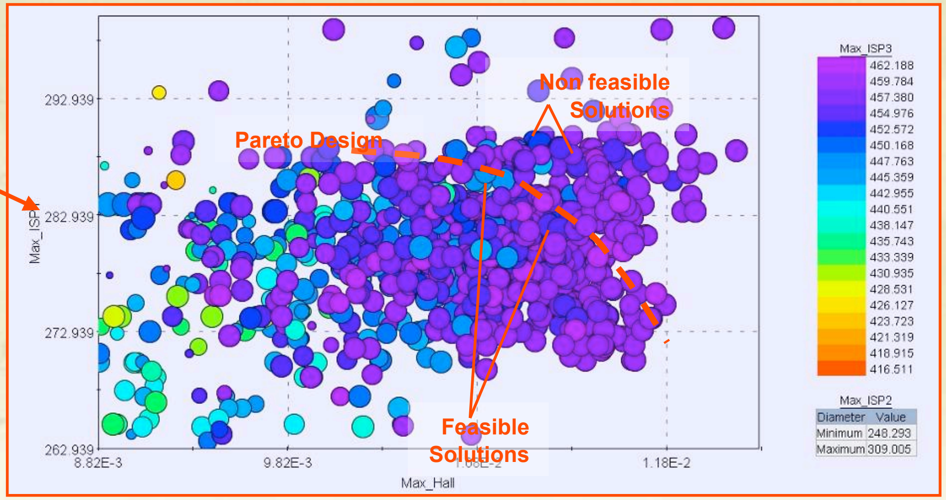




These curves verify the increase of the objective functions (*Mpl/Mtot* and the three stages Isp)

Pareto Designs on the objective functions





Results on the objective function:
Hall initial=0.009 → Hall max=0.012
Isp1 initial=279.7 → Isp1 max=295.7
Isp2 initial=295.2 → Isp2 max=303.4
Isp3 initial=440.6 → Isp3 max=460.3