SYSTEMATIC

Complex Systems Design Lab

Research project results

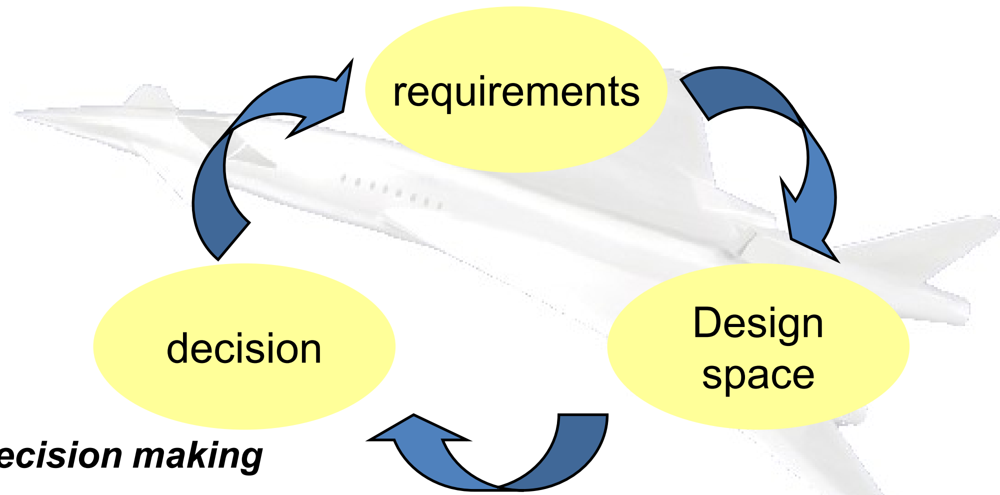
Simulation-Based Engineering Challenges for the future SystemX R&T Institute

CSDL

Complex System Design Lab

Decision Loop in design

Evaluate impact of requirements



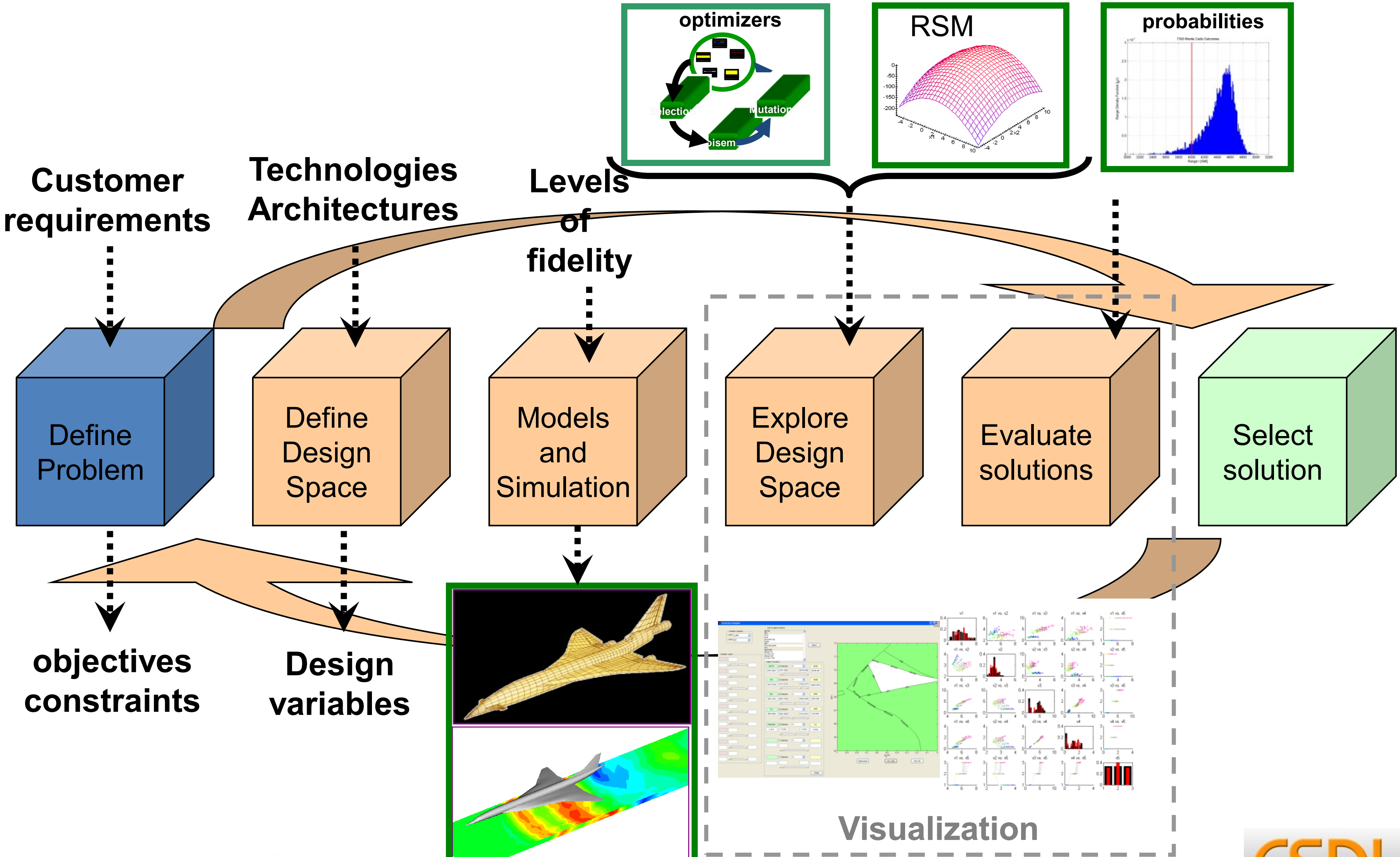
Synthesis to support decision making

- Synthesis of important parameters
  - What are the limits and where are they.
  - Impact of componant performances on global performances
- Propose trade offs
  - Between requirements
  - On design parameters
- Manage risks
  - Quantitative evaluation

Systematic and automatic exploration

- Understand the design space
  - What are the important parameters ?
  - How the requirements interact with each others?
  - Where are the most promising solutions ?
- Generate models dedicated to decision making
  - Trade offs
  - Evaluate risks

Design Loop


optimizers
RSM
probabilities
Customer requirements
Technologies Architectures
Levels of fidelity
Define Problem
Define Design Space
Models and Simulation
Explore Design Space
Evaluate solutions
Select solution
objectives constraints
Design variables
Visualization

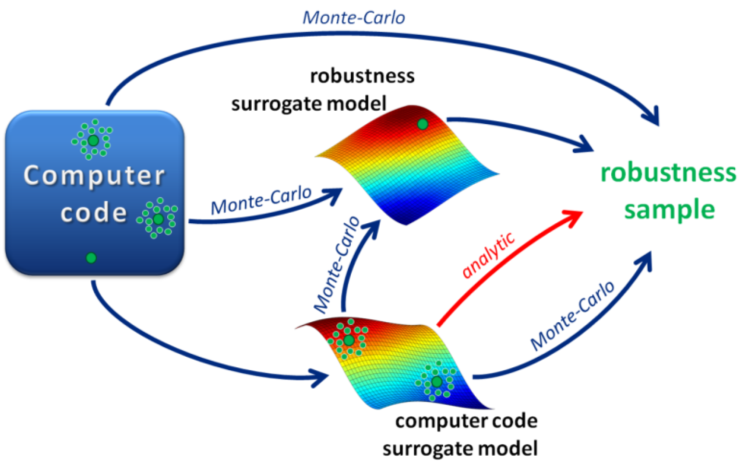
CSDL Project

- Consortium
  - 28 partners : 20 industrial partners (end users and techno providers), 8 Research Institutes and universities
  - 3 year project (started in sept. 2009), 18M€ budget (40% supported by French government (Industry))
- Technical challenges :
  - Manage a hierarchy of interoperable surrogate models
  - Evaluate robustness of a design with respect to risks and uncertainties
  - Exploration techniques adapted to the different level of fidelity of the models
  - Develop a methodology to analyze the design process of complex systems
  - Develop interactive visualization tools to support decision making

Some R&D results

Over 40 journal publications or conference proceedings

Probability of rare events

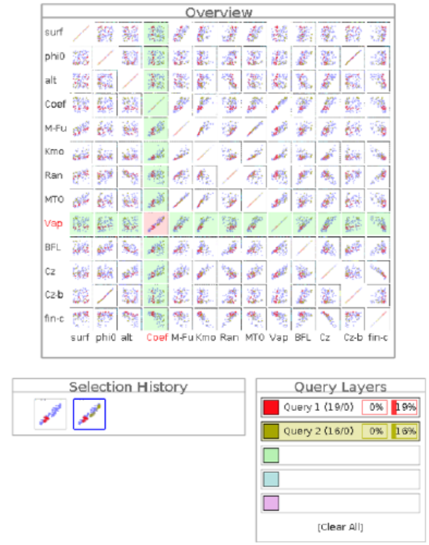


Target probability 10^{-7}

Standard Monte Carlo : 10^{9} points

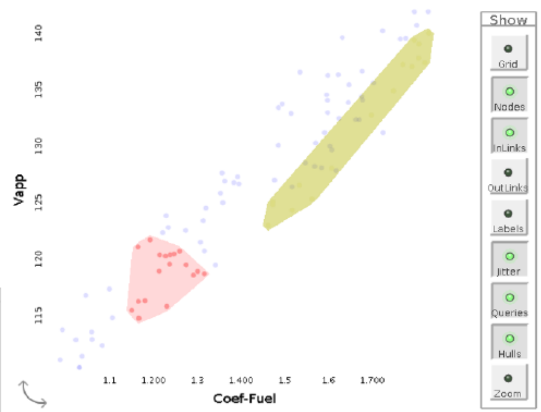
Importance Sampling with surrogate : less than 500 points

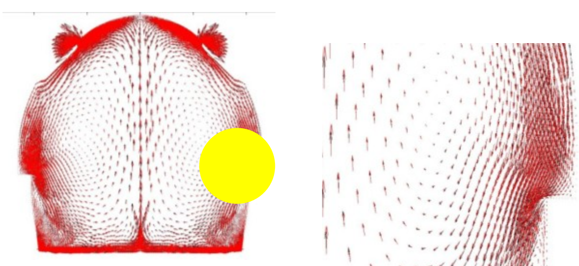
Visual Analytics



interactive exploration of multidimensional datasets

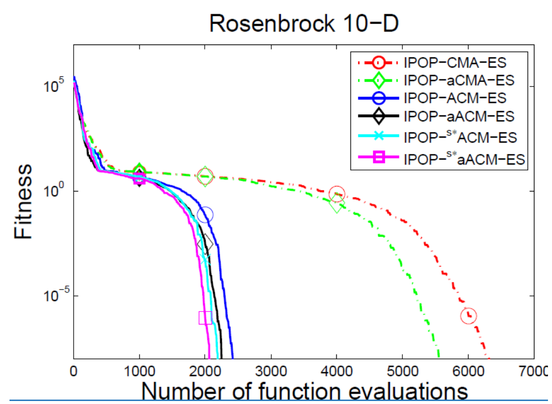
evolutionary programming to help discover trend in data

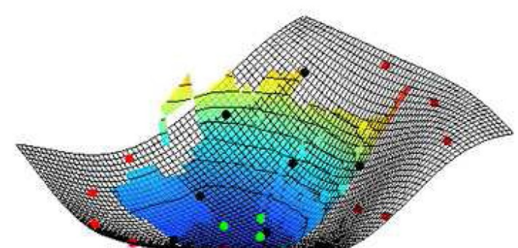




Comparison CFD computation POD reconstruction

Surrogate assisted optimisation





Surrogate model based optimisation with noisy and missing data

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Complex System Design Lab

Industrial Use Cases

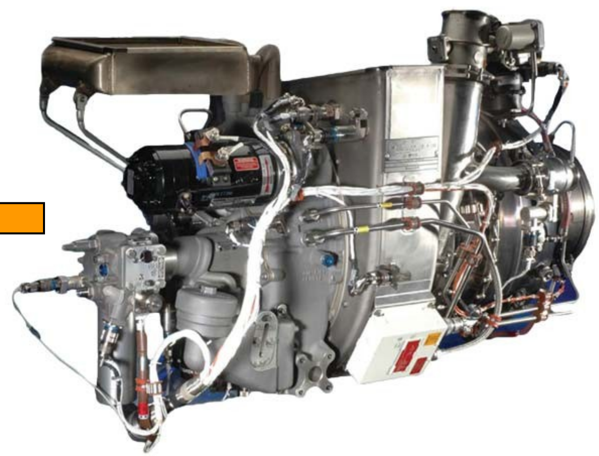
Objective : Provide actual design processes

- To illustrate the dataflow and workflow
- To support the development of methodologies to better manage the design of complex systems
- To give R&D directions
- To monitor and validate the software integration
- To specify the HPC needs to carry out such designs

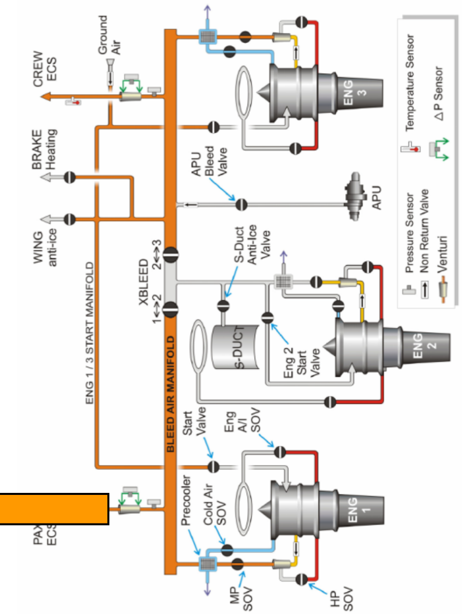
5 industrial use cases

- Aircraft Environmental Control System
- Thermal car engine
- Electrical car engine
- Catalytic exhaust
- Ramjet inlet

Aircraft Environmental Control System



ECS



Engine bleed air

Key Elements in this problem

- Coupling between physical and system simulations
  - Surrogate models
- Design of parts of ECS
  - Optimization methods
  - Sensitivity Analysis
  - Uncertainties propagation (robust design)
- Process
  - Integration of the different elements in a workflow to explore efficiently the design space.
- Synthesis of results
  - Interactive Visualization to support decision making

Design of an Aircraft ECS

Objective : Size the different elements of the ECS (turbine, heat exchanger) to maintain a comfortable temperature in the cabin on the ground during a hot day or during the high altitude cruise.

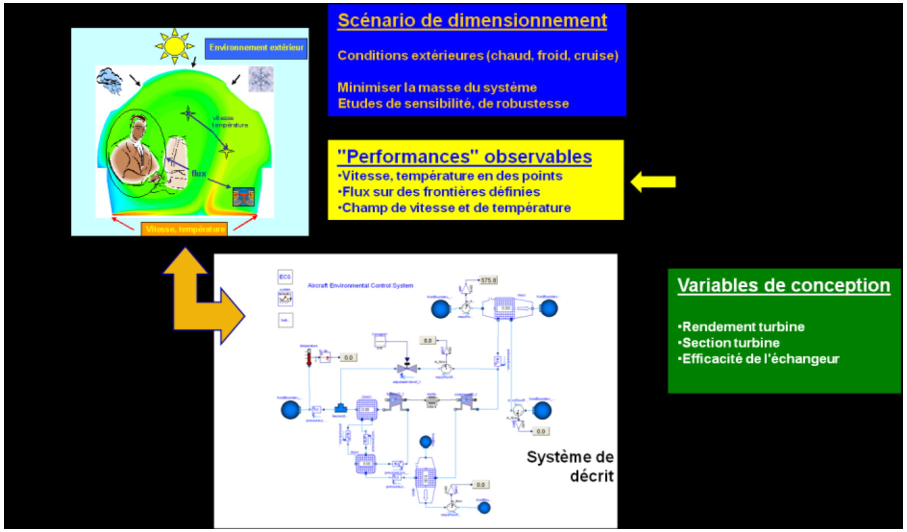
CFD computations in the cabin:
- air flow
- temperature

The boundary conditions are specified by the ECS.

The ECS is modeled using the Modelica language.

CFD computations : batch on HPC Clusters

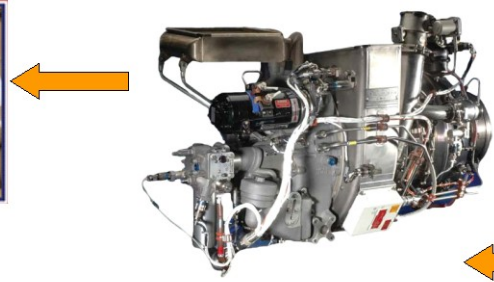
System simulation : interactive on PC (windows)

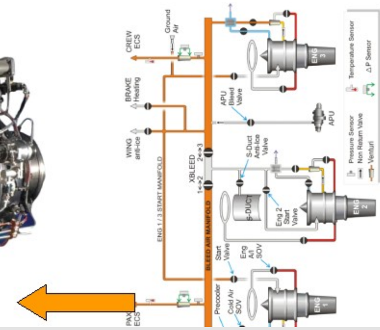


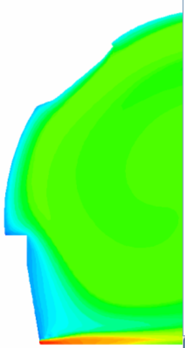
==> Methodology and process to
- perform each simulation in its native environment
- couple the different simulation to explore efficiently explore the design space
- synthesize the results and support decision making

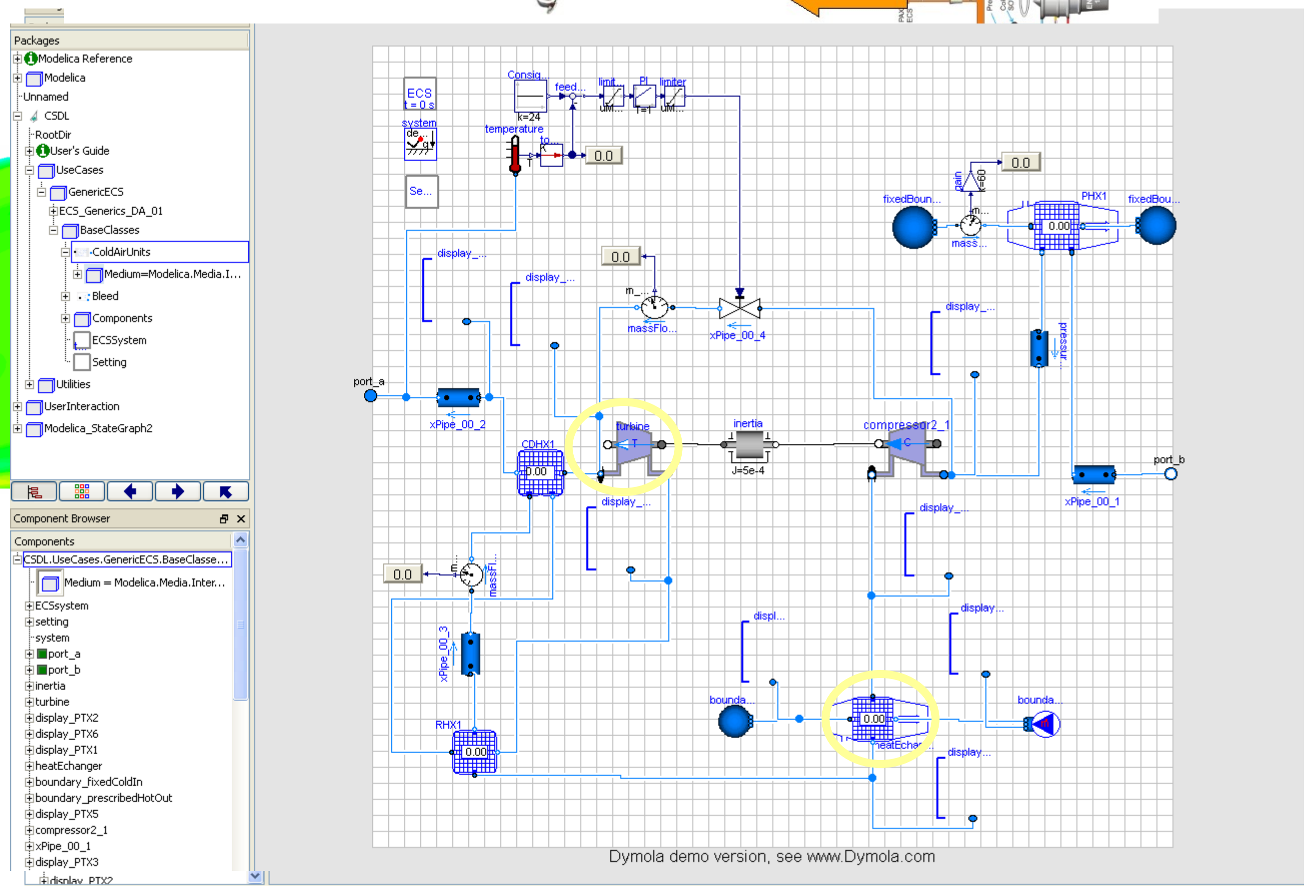
==> Develop and integrate the elements of the new process.

ECS Model





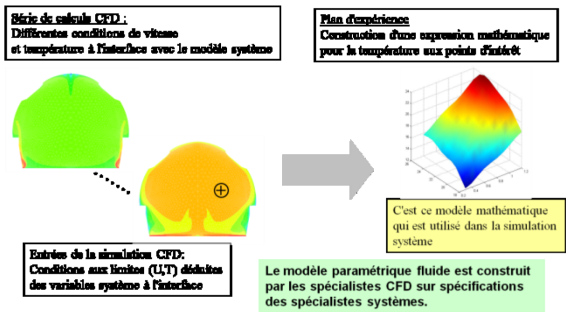




Packages
Modelica Reference
Modelica
Unnamed
CSDL
RootDir
User's Guide
UseCases
GenericECS
ECS_Generics_DA_01
BaseClasses
ColdAirUnits
Medium=Modelica.Media.I...
Bleed
Components
ECSSystem
Setting
Utilities
UserInteraction
Modelica_StateGraph2
Component Browser
Components
CSDL.UseCases.GenericECS.BaseClasse...
Medium = Modelica.Media.Inter...
ECSsystem
setting
system
port_a
port_b
inertia
turbine
display_PTX2
display_PTX6
display_PTX1
heatExchanger
boundary_fixedColdIn
boundary_prescribedHotOut
display_PTX5
compressor2_1
xPipe_00_1
display_PTX3
display_PTX2
ECS
system
temperature
port_a
xPipe_00_2
CDHX1
turbine
inertia
J=5e-4
compressor2_1
PHX1
port_b
xPipe_00_1
xPipe_00_4
xPipe_00_3
RHX1
Dymola demo version, see www.Dymola.com

Challenges

Surrogate model for the CFD results

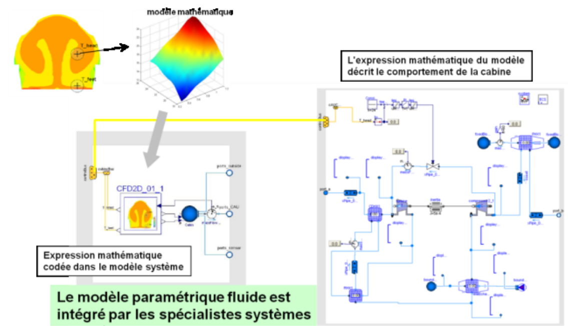


Surrogate constructed
BY the CFD specialist
FOR the ECS specialist

- Workflow
- DOE "minimum"
- "Qualified" surrogate model
  - > domain of validity
  - > error estimate

autonomy

Integrate the surrogate model In the modelica model

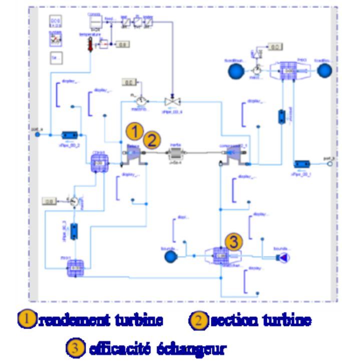


Surrogate model integrated
BY the system specialist

- Compatibility with system simulation
- Common interface for different models
- Ease of integration / modification

interoperability

Design the ECS

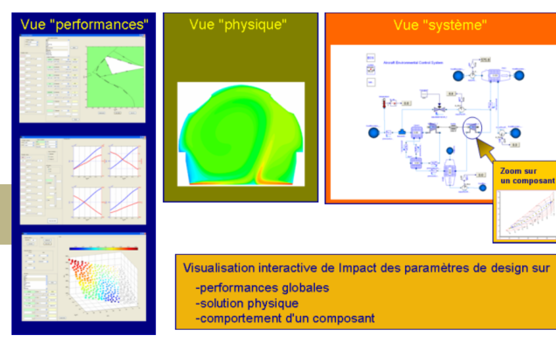


Surrogate model used BY the system specialist

- Workflow for exploration
- Mathematical tools
  - > Sensitivity analysis
  - > optimization
  - > evaluation of robustness

autonomy

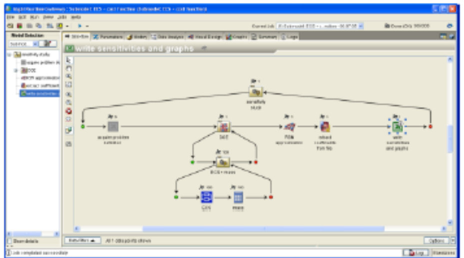
Synthesis for decision



Collaborative Visualization

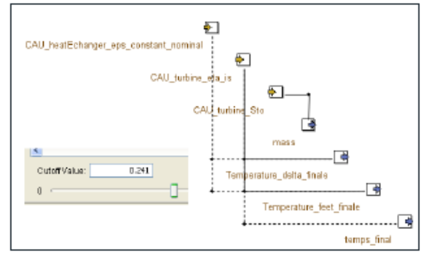
Sim-flow | Parameters | History | Data Analysis | Visual Design | Graphs | Summary | Logs

Sensitivity Analysis Post-Processing

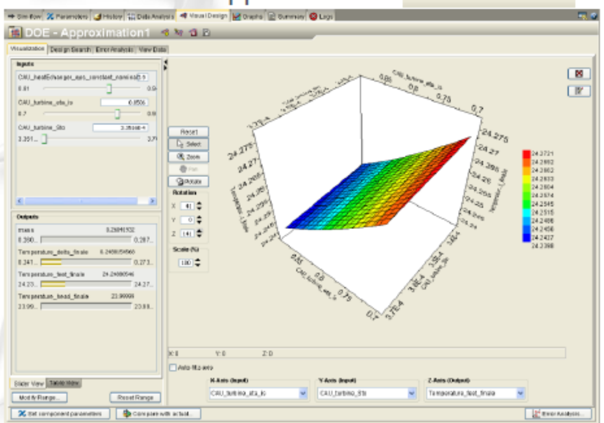


Run progress

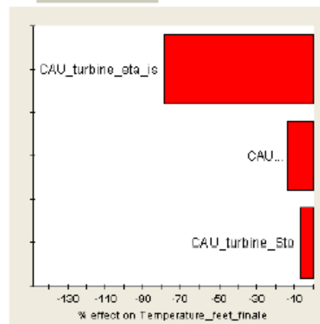
Correlation Map

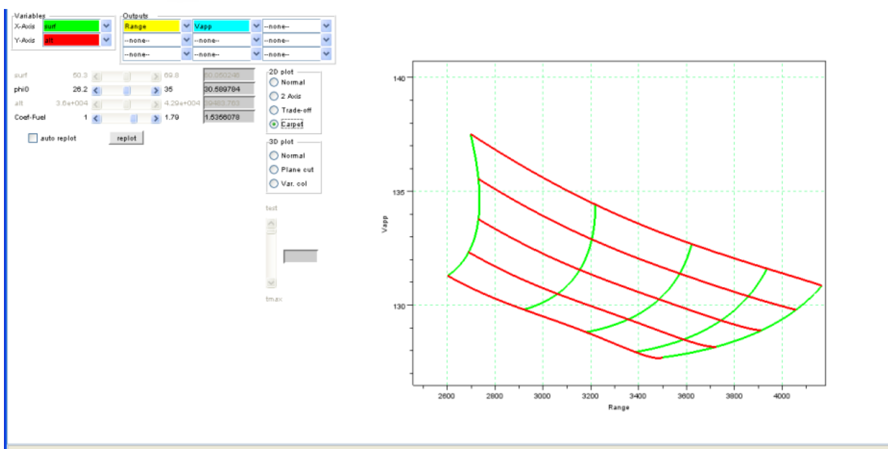


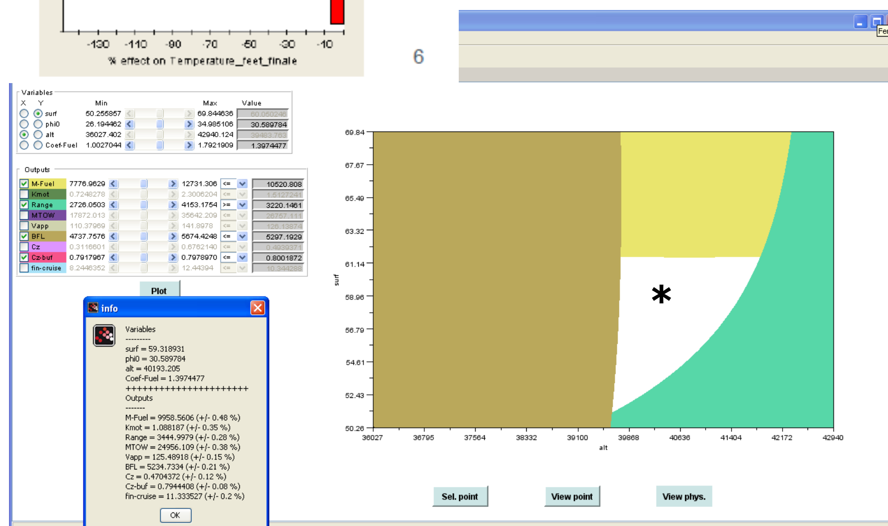
Approximation



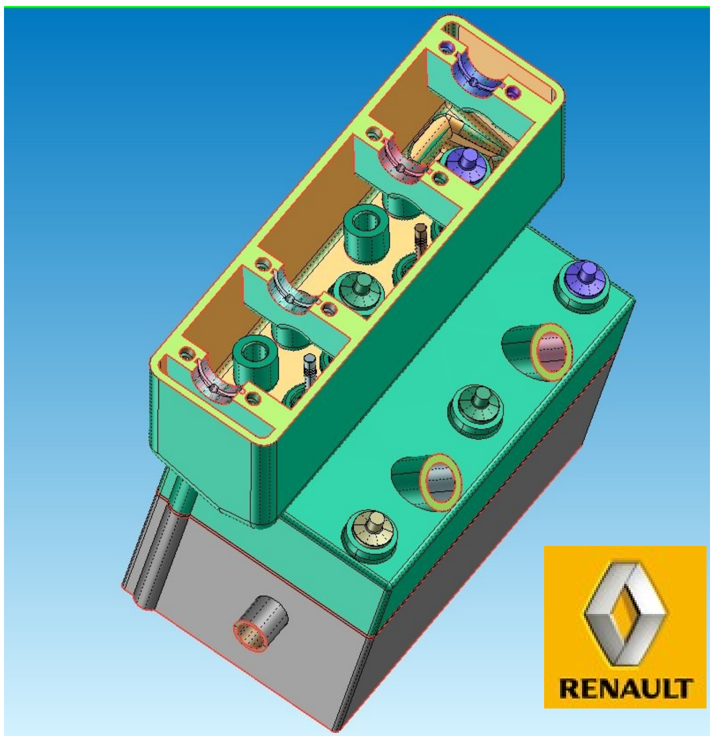
Pareto graph





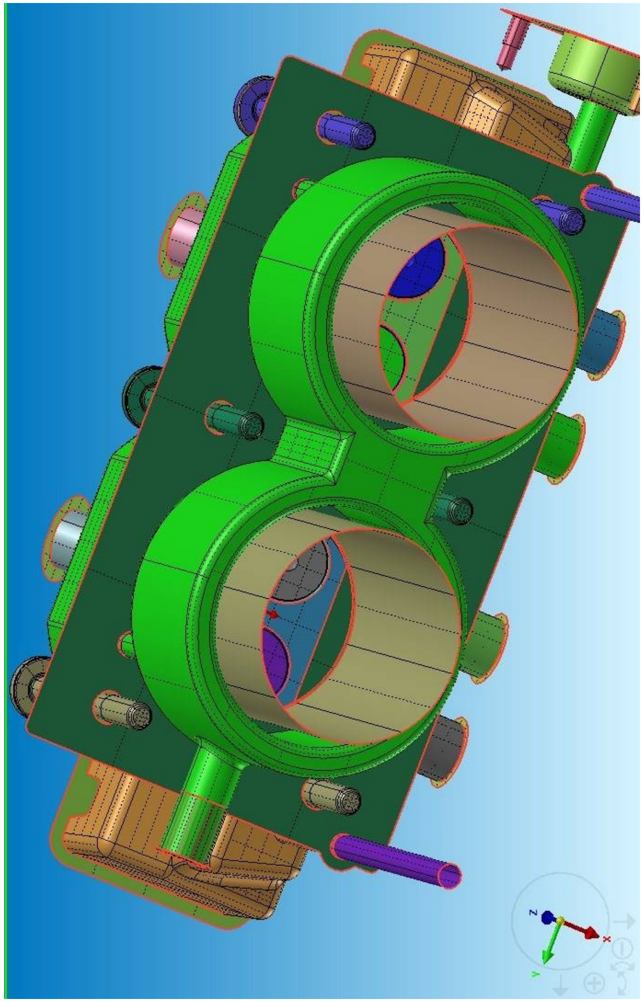


Car Engine (cylinder head) Use Case



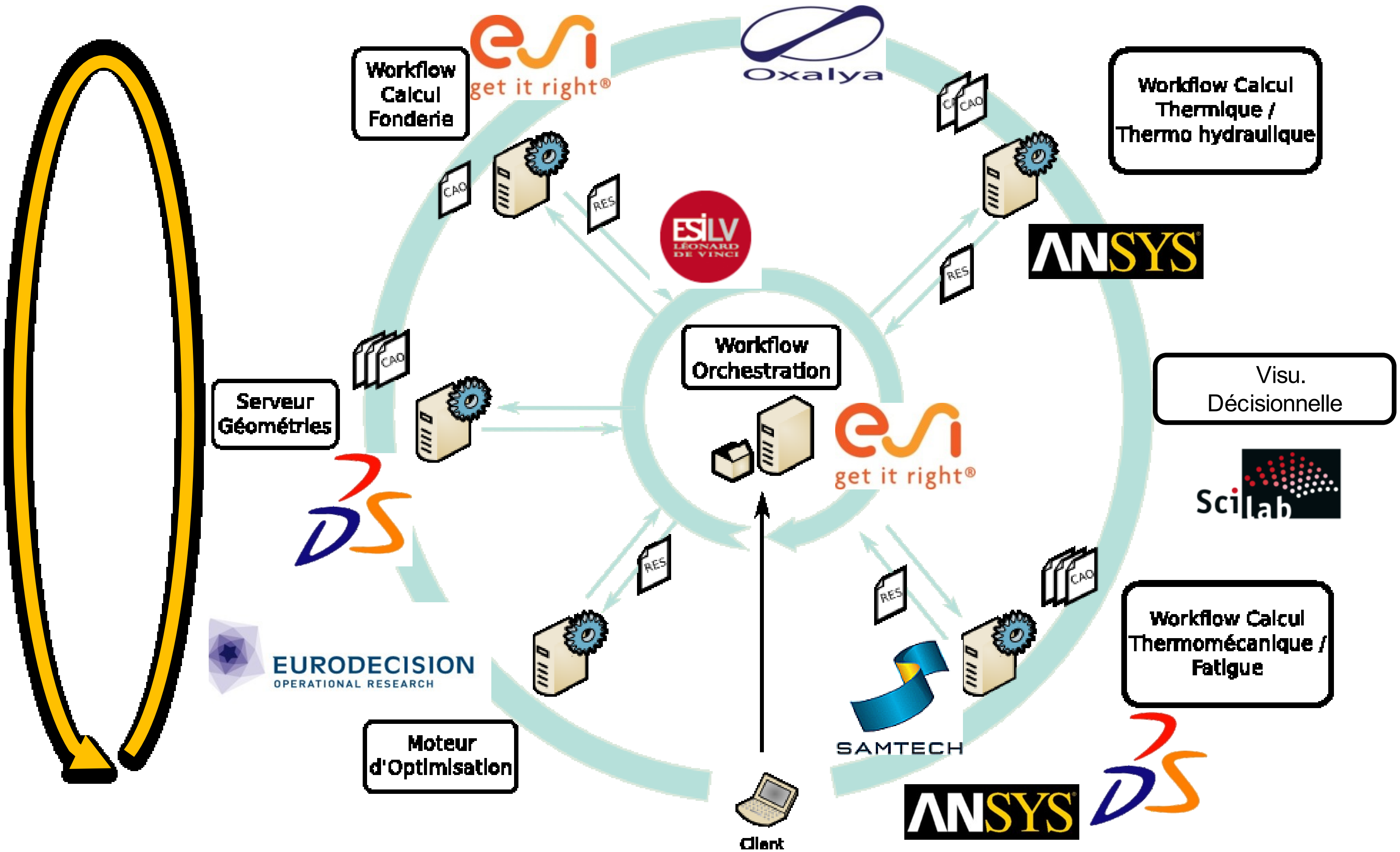
- Context: simulation at the earliest stage of design
- Objective :
  - Collaborative multi-disciplinary design
    - Seamless automatic data transfer
    - Interoperability
  - Take advantage of CPU power
    - optimization

Design parameters

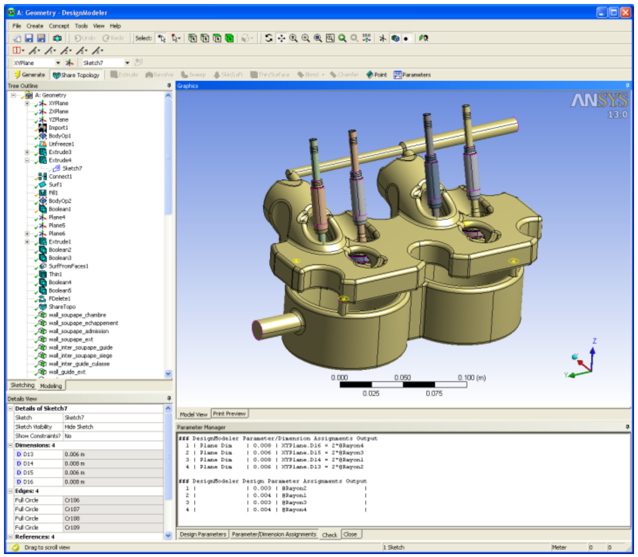


- 6 geometric parameters
  - 4 radius water pipes:] 20mm, 40 mm [
  - Radius water inlet: 5 mm < Re < 9 mm
  - Separation between cylinders: 17 mm < d < 18mm
- 2 physical parameters:
  - Water mass flow: 3m/s < Ve < 8m/s
  - Water inlet temperature: 60°C<Te<90°C
- **Optimisation Objectives :**
  - Maximum solid temperature
  - Maximum water temperature
- **Constraints :**
  - Manufacturing (casting)

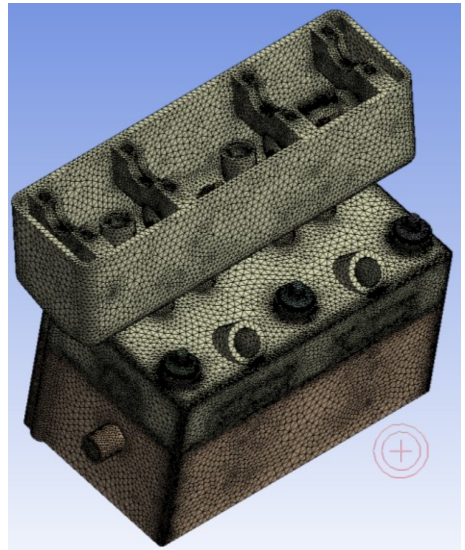
Original collaborative workflow



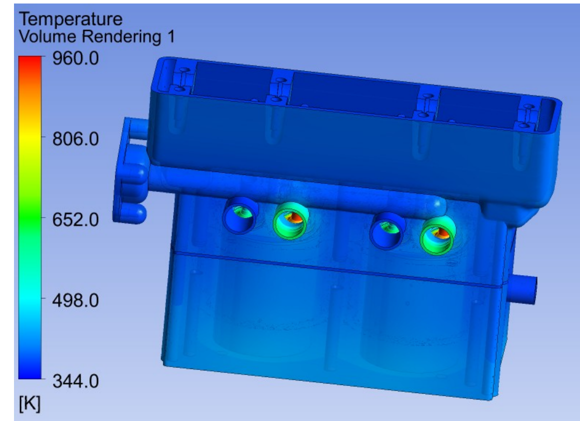
Examples of simulations involved



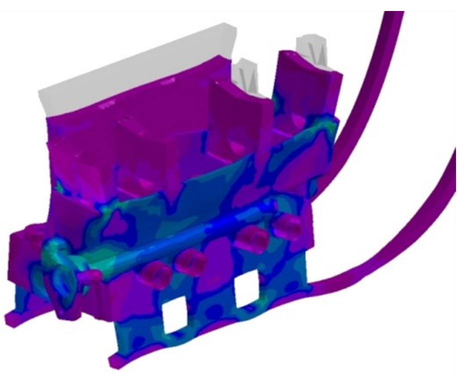
Parametric CAD



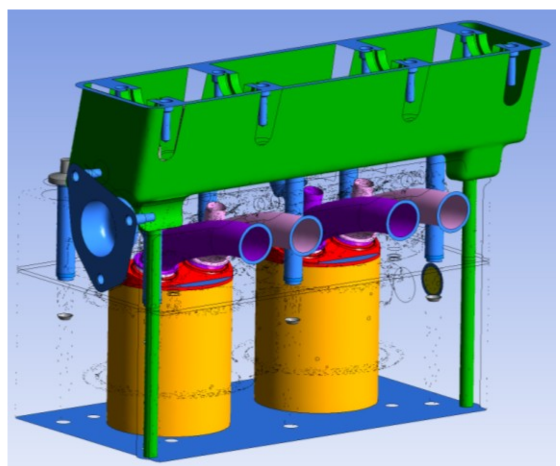
CFD Mesh



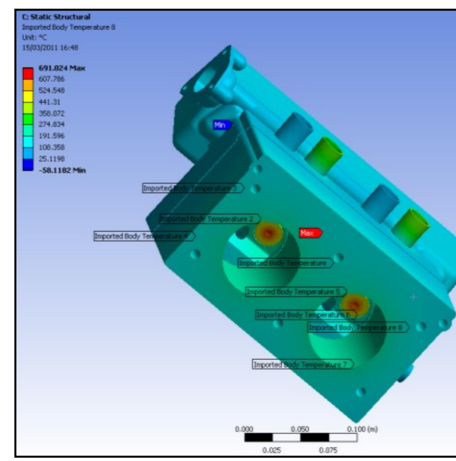
CFD Results



Residual stresses after casting



CFD Boundary conditions



Temperature

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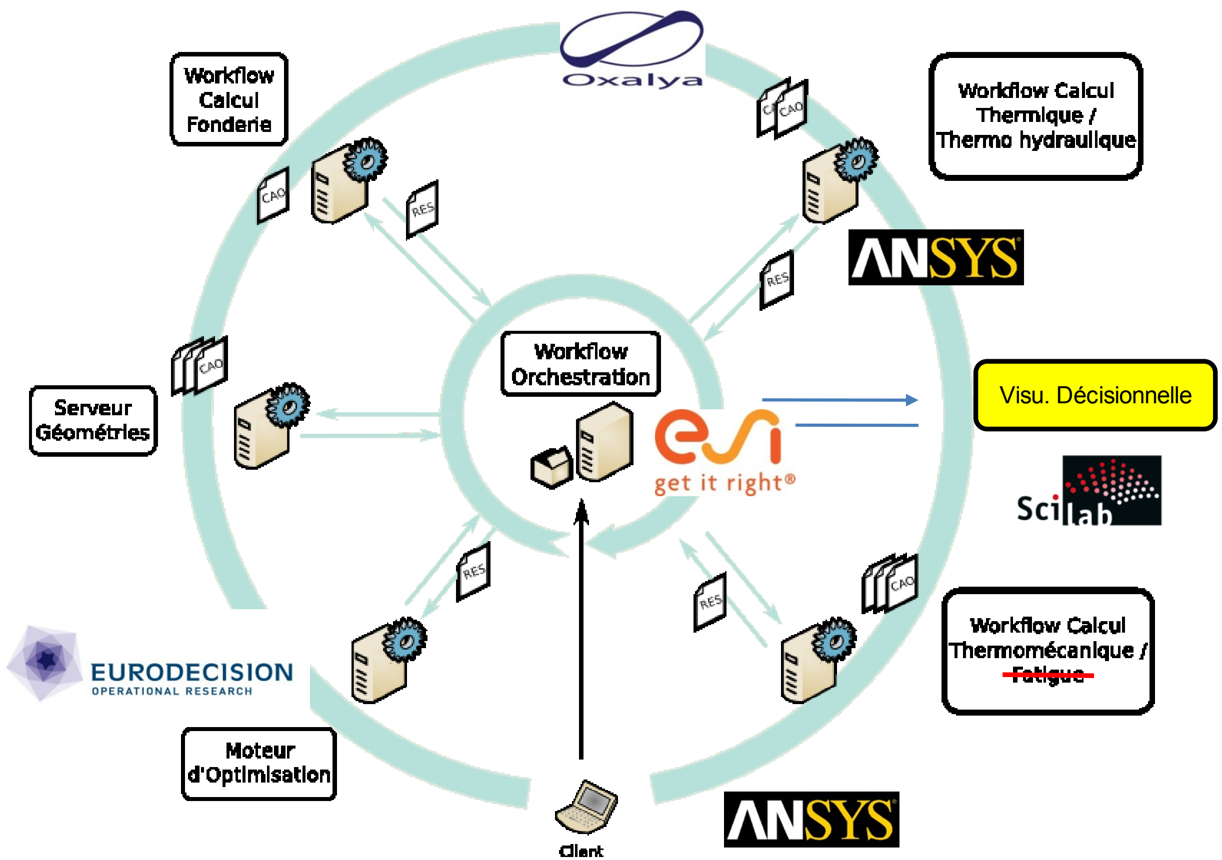
Simplified Optimization workflow

Original workflow difficult to make fully automatic
Very high CPU requirements

→ Simplified workflow for optimization



Original workflow kept to asses the solutions

CSDL Major Findings

- Surrogate models
  - Black box approach reaches its limits
    - Curse of dimensionality
    - Difficulty to have error estimates
  - Progress being made with intrusive models (but still open for compressible flows)
- DOE
  - Dimensionality reduction ….
  - “optimal sampling” for multiple outputs
  - Difficult to explore a constrained domain : many expensive evaluation are wasted : need to be able to “orientate” the DOE
- Optimization
  - Multiple objective optimization with expensive objectives / constraints evaluation still a challenge
  - Robust optimization (OOU far from being an every day tool)
    - Some ideas have emerged for probabilistic constraints (but mono objective)
- Visualization
  - Intuitive representation of uncertain values

CSDL conclusions

- Real progresses have been made
  - CSDL benefits a LOT from previous projects (OPUS, etc…)
  - Real life problems are necessary to stress the new methods
  - Unique collaborative action
  - Results being integrated in commercial software
- …. But this should be a considered a beginning
  - Real scientific challenges have to be tackled
    - Support from scientific community absolutely required

SystemX Research and Technology Institute

Lab "Simulations for Design"

- Multi-physics systems design
- Behavioral simulation

- Objectives
  - Predictive simulation capabilities, uncertainties (models, conditions of use of the system) management
  - Robust optimal designs by using multi physics and multi scales simulations and virtual testing methods
- Missions
  - Develop new models and algorithms for simulation and optimization of large systems
  - Develop new design methods and the associate software
  - Apply the new tools on challenging and representative use cases
- Strong industrial and academic cooperation

Design of multi physics systems capability gap

- Efficient exploration of a large design space
  - Efficient generation of simulation models and Surrogate models (intrusive)
  - Optimization methods, DOE, sensitivity analysis
- Account for uncertainties especially in the case of innovative systems and qualify the quality of the numerical simulations
  - V&V
  - Uncertainties propagation in very large systems
- Synthesize the information for decision making
  - Data mining / farming (e.g. interpolation in data base)
  - Multi physics and multi-scale visualization

Behavioral simulation capability gap

- Predictive behavioral models
- Organize the information flow to support decision making
- Use simultaneously many different models and associativity between the models
- Integrate data and models in industrial PLM systems

Thank you for your attention !

Questions ?

The cluster and its projects are sponsored by:

For more information:
www.systematic-paris-region.org