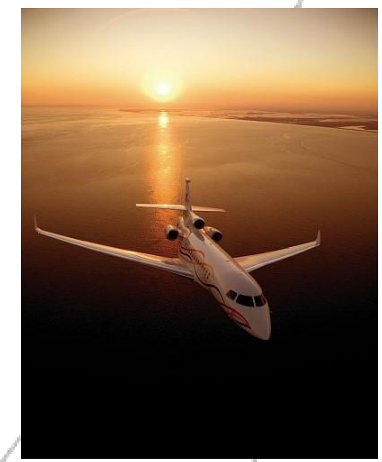
"For a plane to fly well it must be beautiful"



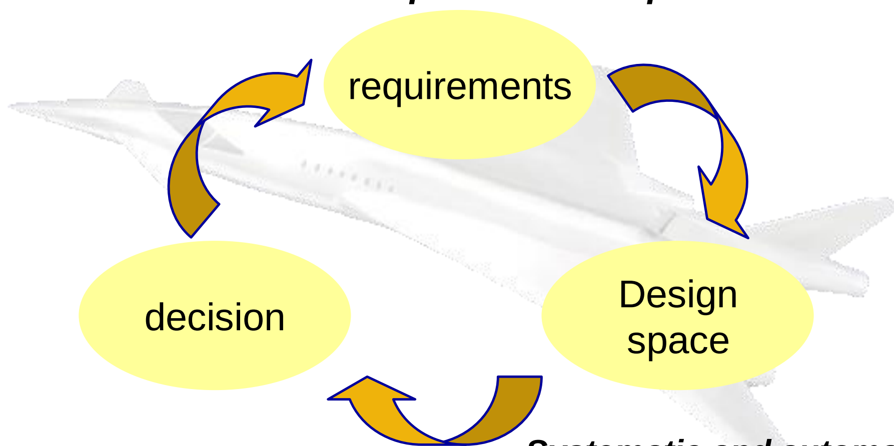
Multidisciplinary Optimization

M. Ravachol.

Dassault-Aviation, St-Cloud, France

Decision Loop in Design

Evaluate the impact of the requirements



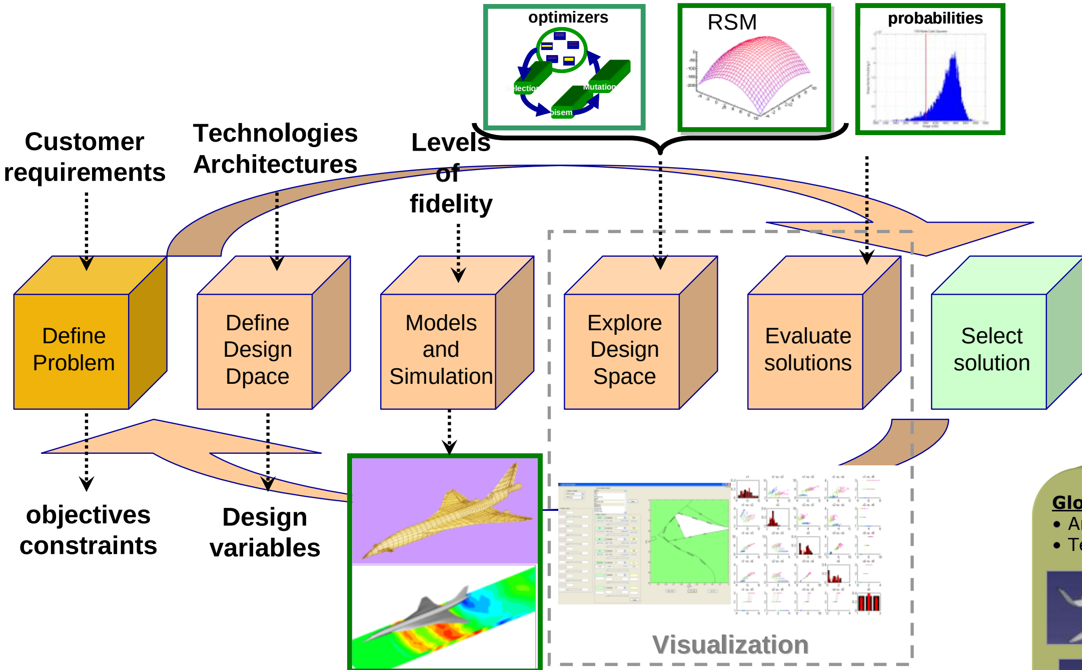
Synthesis to support decision making

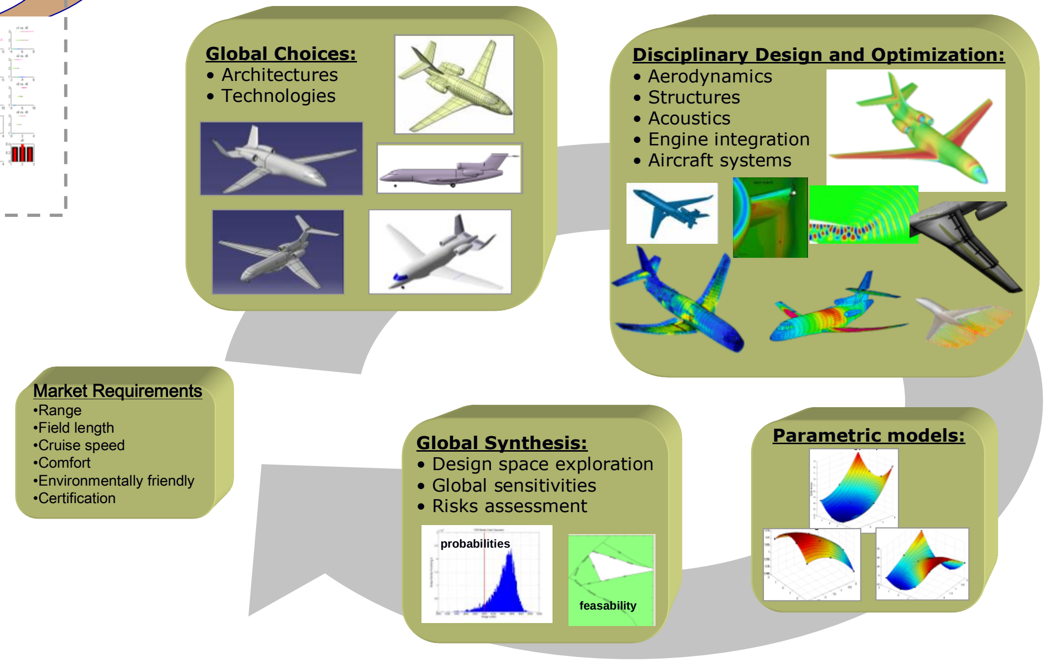
- Synthesis of important parameters
  - What are the limits and where they are.
  - Impact of component performances on global performances
- Propose trade offs
  - Between requirements
  - On design parameters
- Manage risks
  - Quantitative evaluation

Systematic and automatic exploration

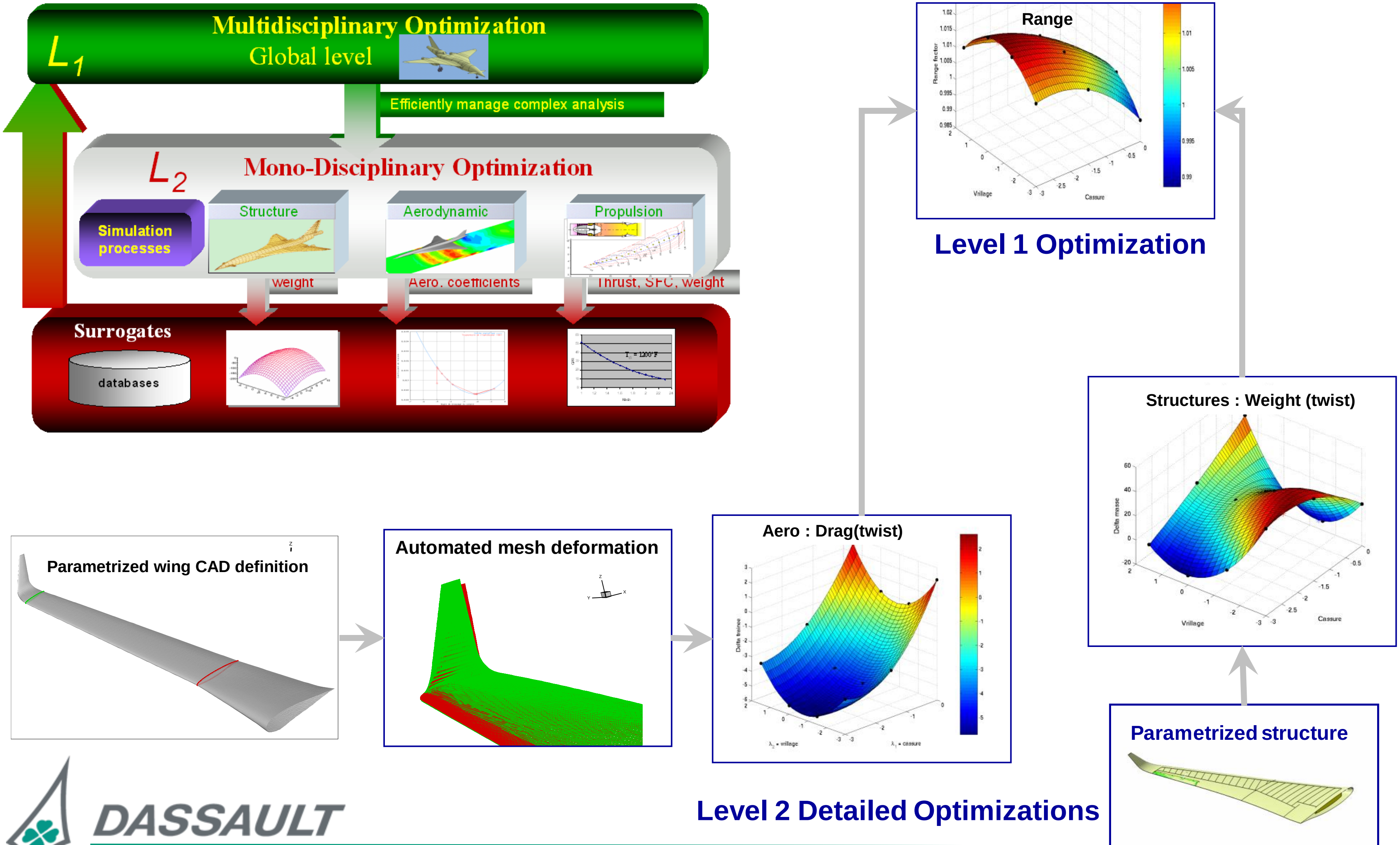
- Understand the design space
  - What are the important parameters ?
  - How the requirements interact with each others?
  - Where are the most promising solutions ?
- Generate models dedicated to decision making
  - Trade offs
  - Evaluate risks

Design Loop


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


Global Choices:
• Architectures
• Technologies
Disciplinary Design and Optimization:
• Aerodynamics
• Structures
• Acoustics
• Engine integration
• Aircraft systems
Market Requirements
•Range
•Field length
•Cruise speed
•Comfort
•Environmentally friendly
•Certification
Global Synthesis:
• Design space exploration
• Global sensitivities
• Risks assessment
probabilities
feasability
Parametric models:

Multilevel MDO



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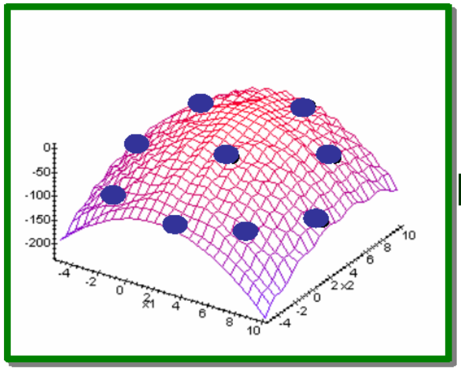
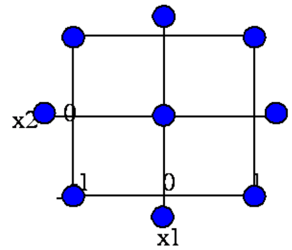
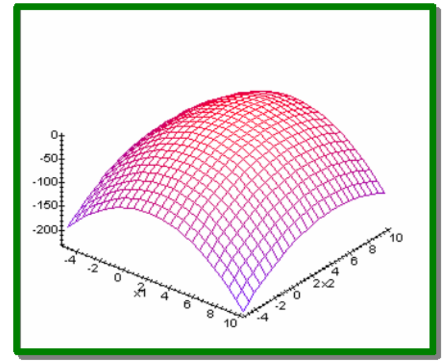
Surrogates models

System to model | **D.O.E** | **Surrogate**

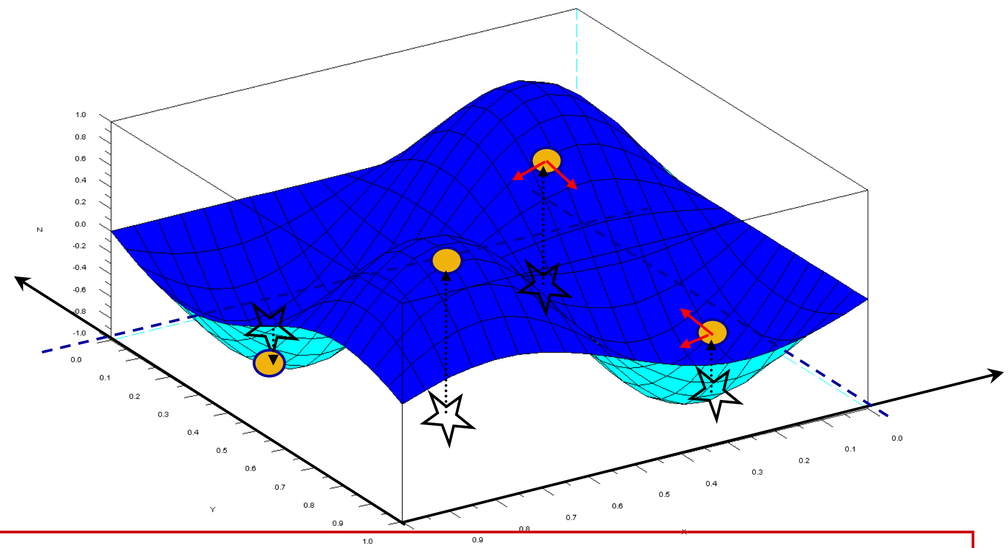






D.O.E: - LHS
- max(min)
- pseudo MC
- Adapted

Advanced models
- Radial basis functions
- Kriging



Surrogates = key ingredient to MDO

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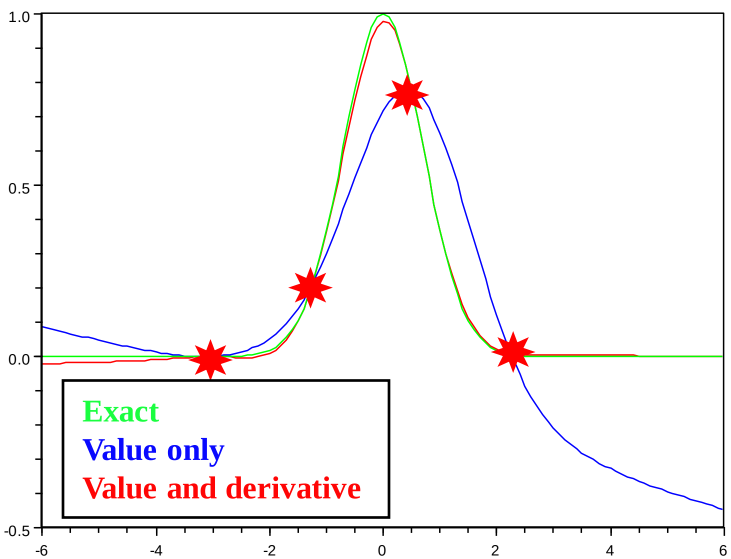
RBF using derivatives

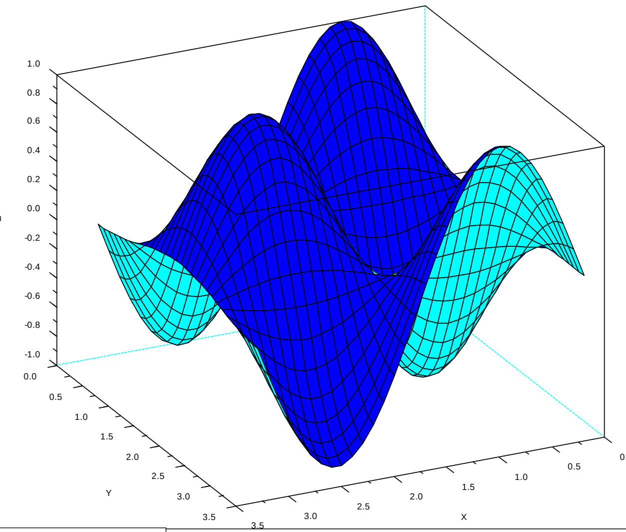
$$s(x) = p(x) + \sum_{i=1}^{n_s} \lambda_i \phi_i(x) + \sum_{l=1}^{d} \sum_{j=1}^{n_s} \mu_{lj} \frac{\partial \phi_j(x)}{\partial x^l} \quad (\phi_i(x) = \phi(x, x_i))$$

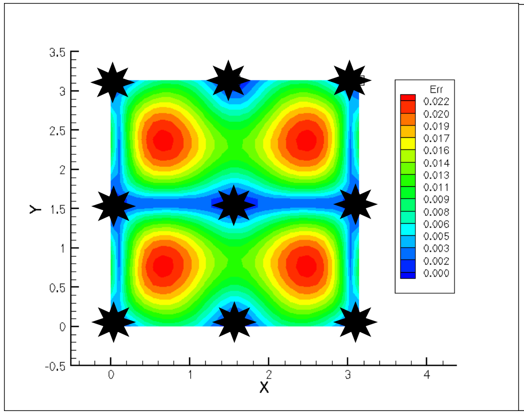
$$s(x) = f(x), x \in \{x_i\}_{i=1}^{n_s}$$

$$\frac{\partial s(x)}{\partial x^l} = \frac{\partial f(x)}{\partial x^l}, x \in \{x_i\}_{i=1}^{n_s}, \; l = 1,\dots d$$

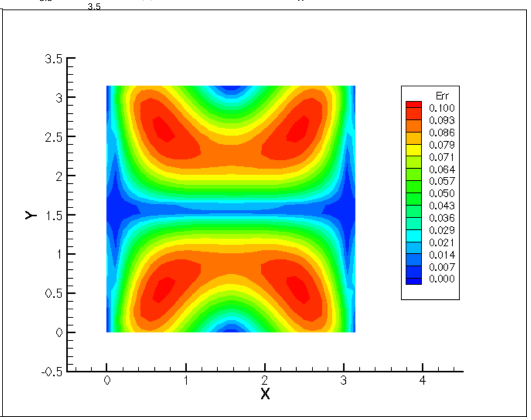


1D example





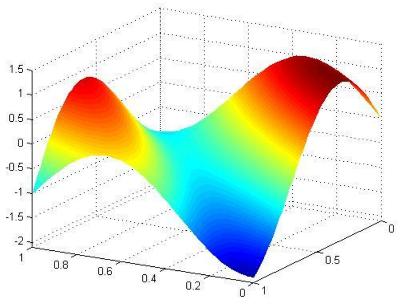
with gradients err_{max}=2.2%



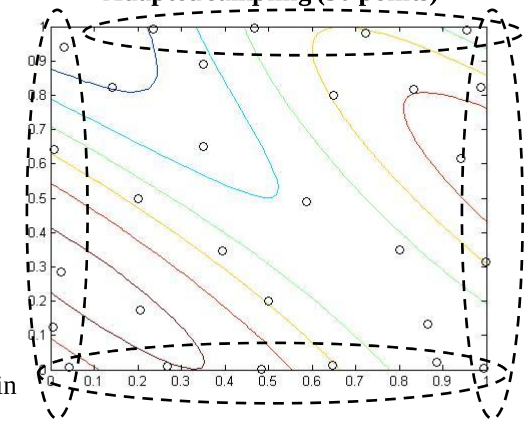
without gradient err_{max}=10%

DOE using Kriging MSE

True Surface

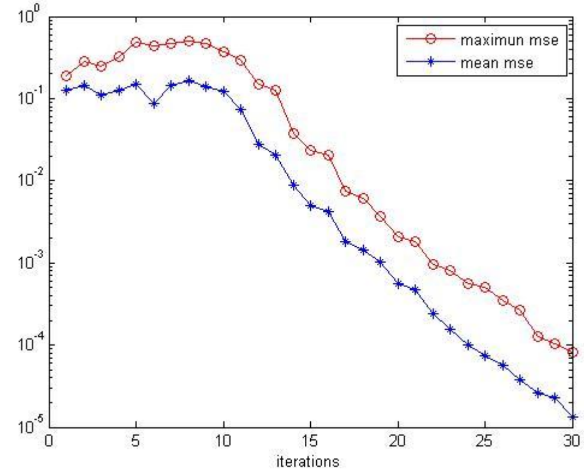


Adapted sampling (30 points)

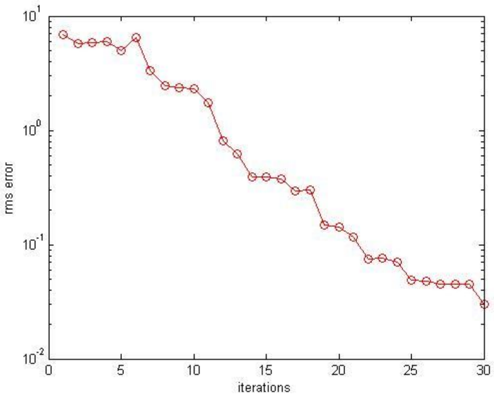


Points on the border of the domain

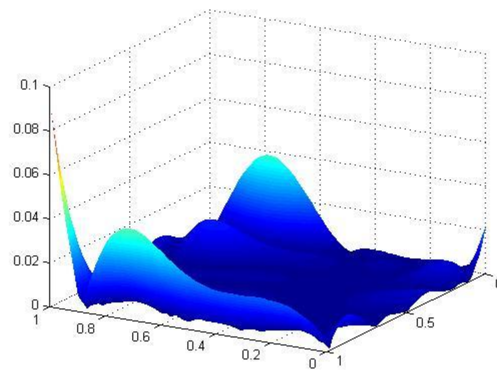
Sampling convergence (mse)



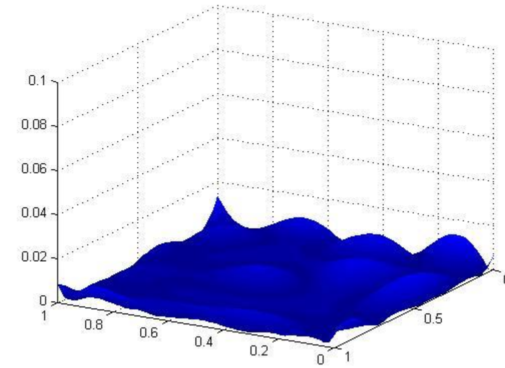
Sampling convergence (rms)



Error space filling sampling (30 points)



Error adapted sampling (30 points)



Adaptive sampling reduces interpolation error for given computationnal budget

Adaptive sampling is a sequential process

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Illustrative example

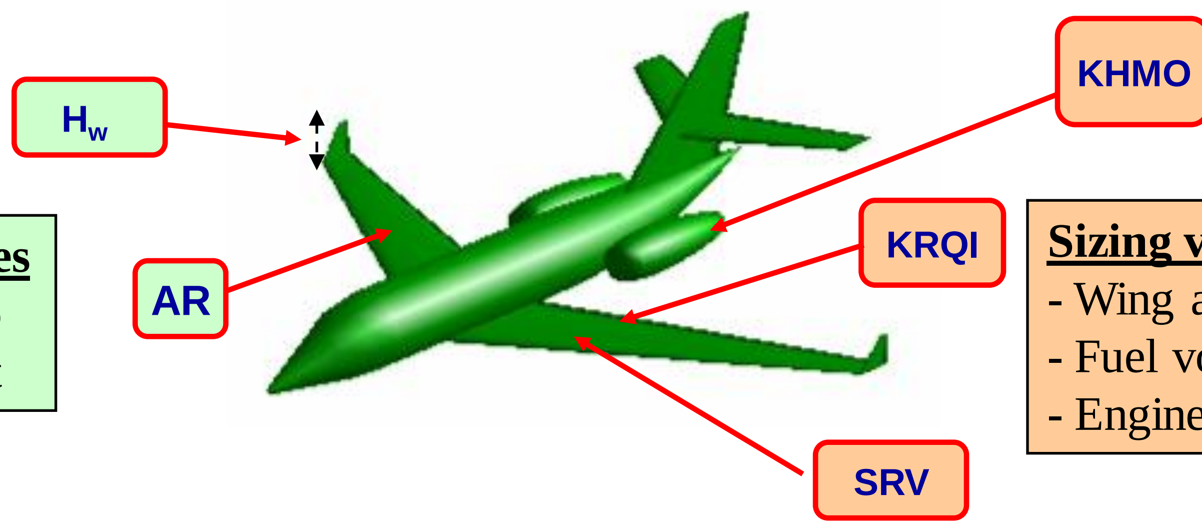
Trade off wing aspect ratio / winglet size for a given plan form

Requirements
- Low speed performances : BFL, LFL
- Range @ economic cruise Mach number
- Cruise altitude
- Pax cabine volume and payload

Sizing scenarios
- Minimize carbon footprint @ economic cruise
- Minimize weight

Detailed analysis
- Aerodynamics
- Structures

Sampling variables
- Wing aspect ratio
- Height of winglet



Sizing variables
- Wing area
- Fuel volume
- Engine size

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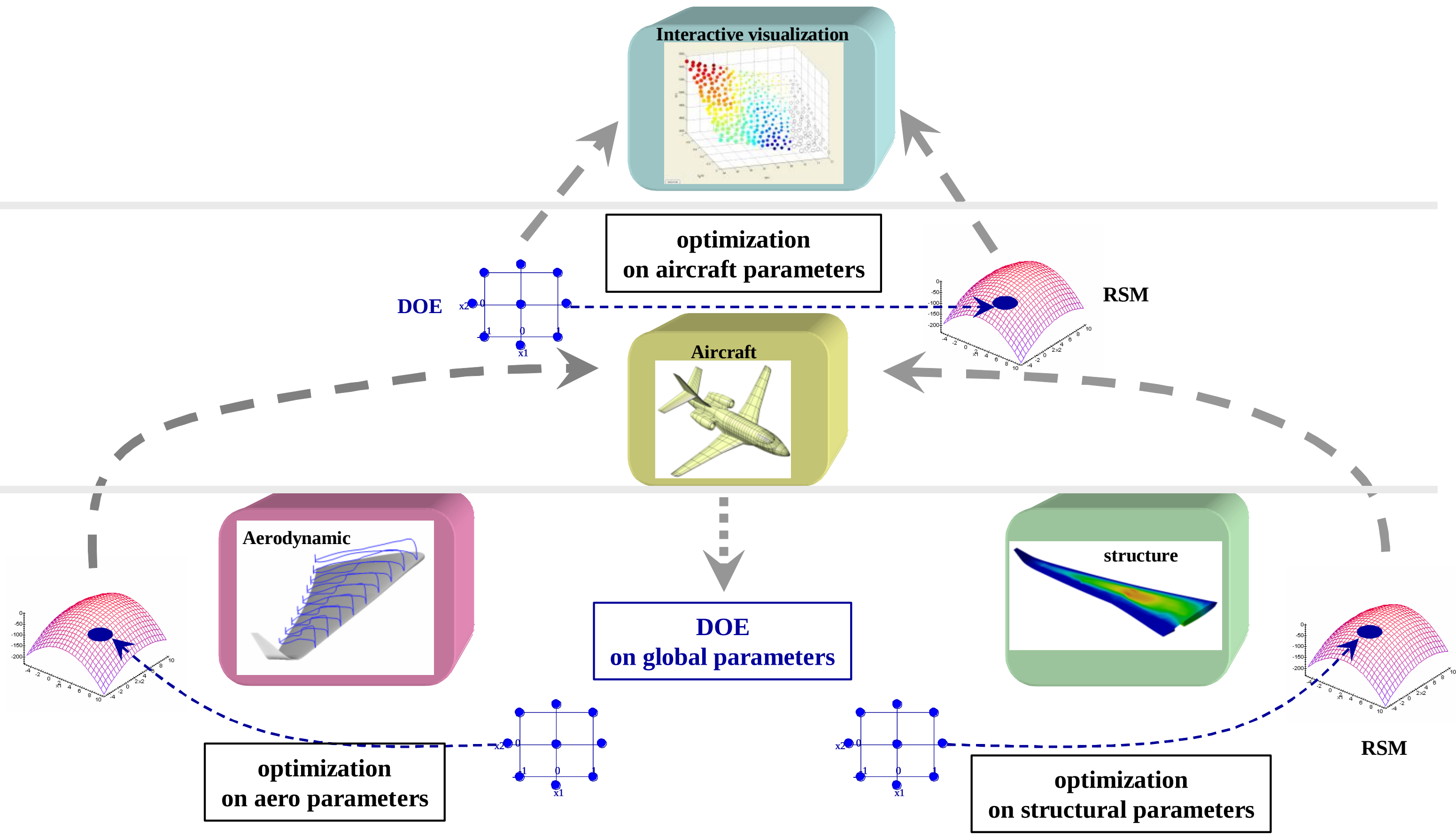
Sketch of the process

Exploration of Design Space

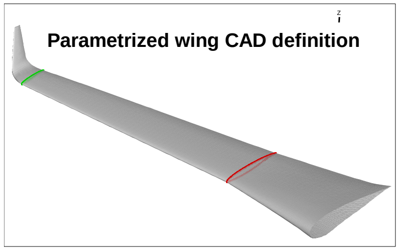
Synthesis at System level

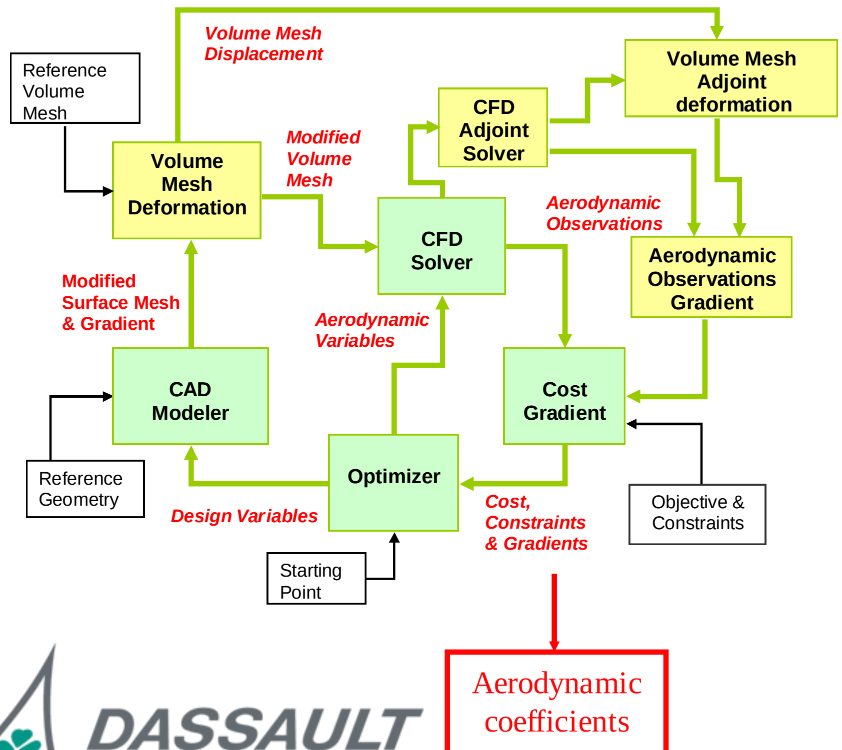
Components performances



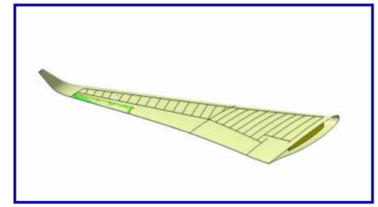
Detailed analysis workflows

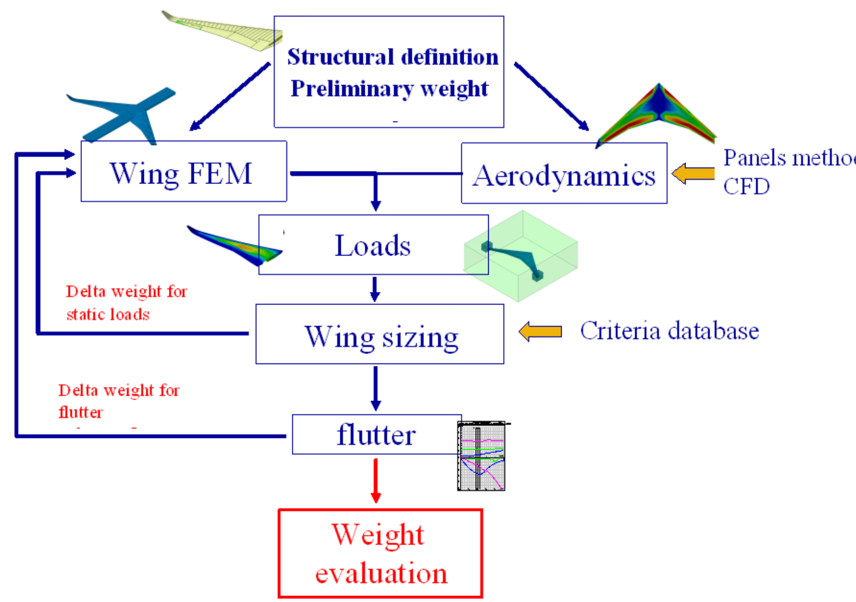
Aerodynamic





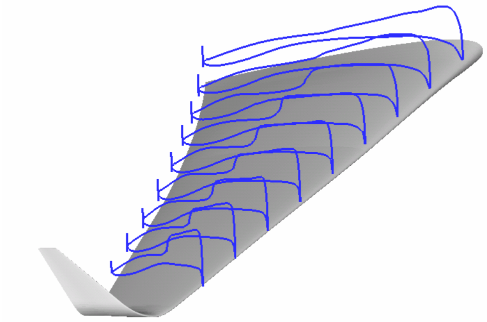
Structural analysis

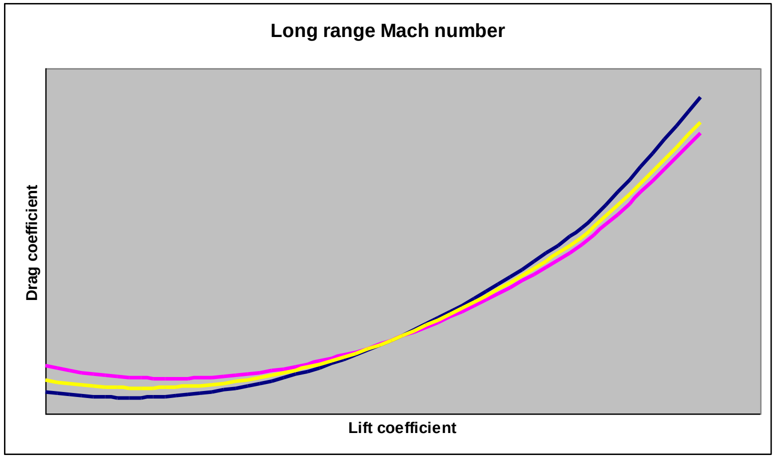


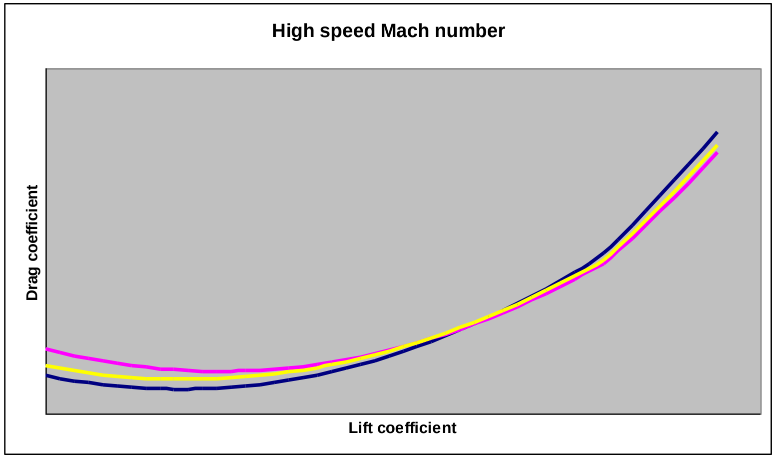


Aerodynamic

CFD analysis for 3 winglet heights

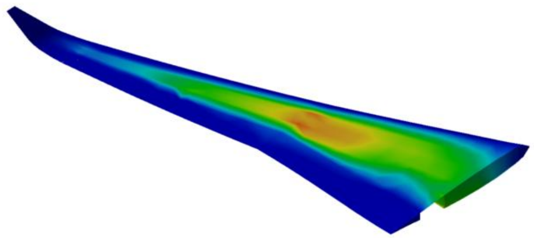




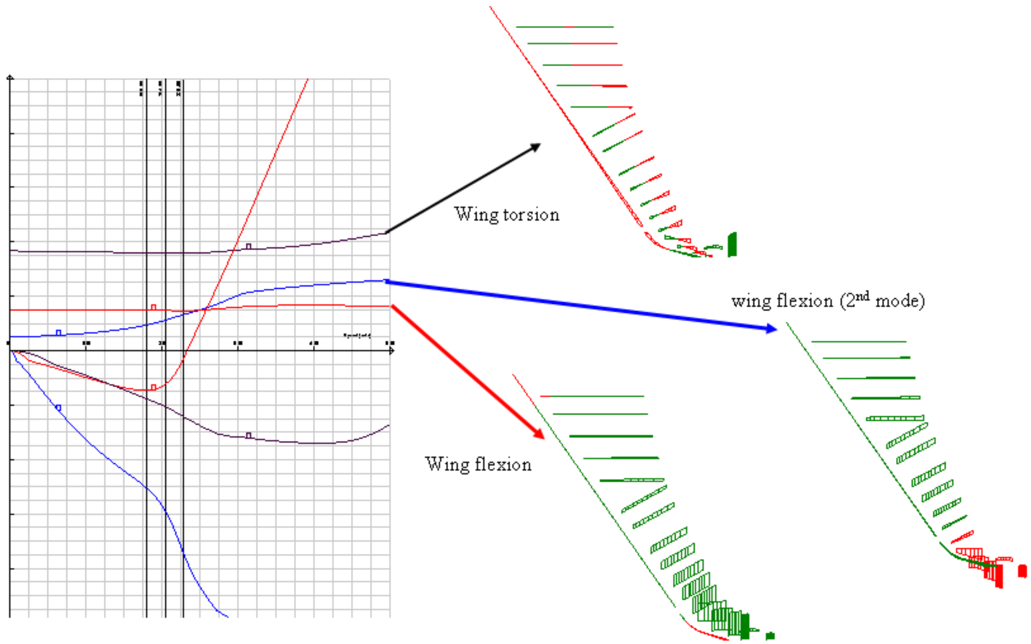


Aspect ratio : pre-existing surrogate model

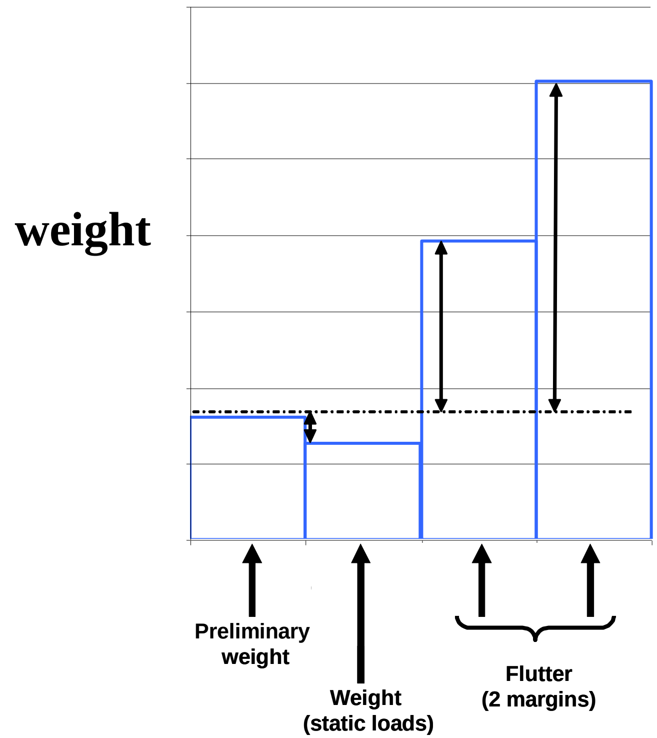
Structure



Stresses for a static load case

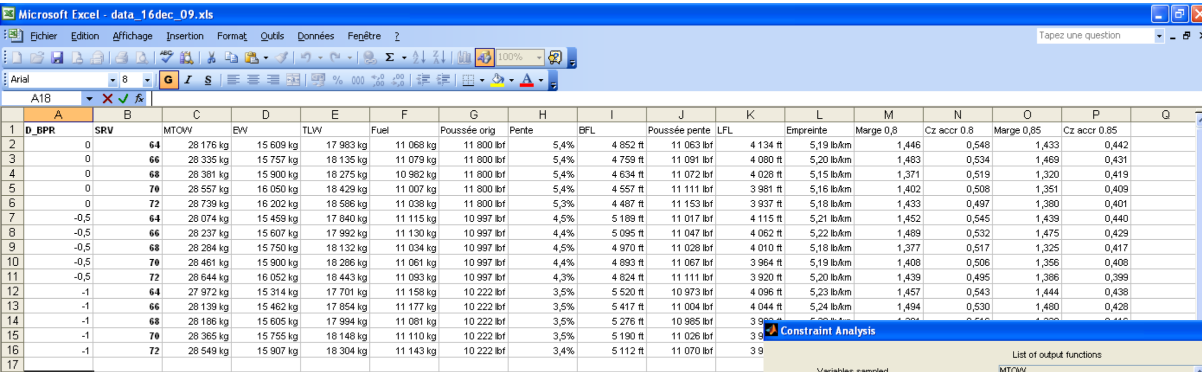


Flutter analysis



Direction Générale Technique

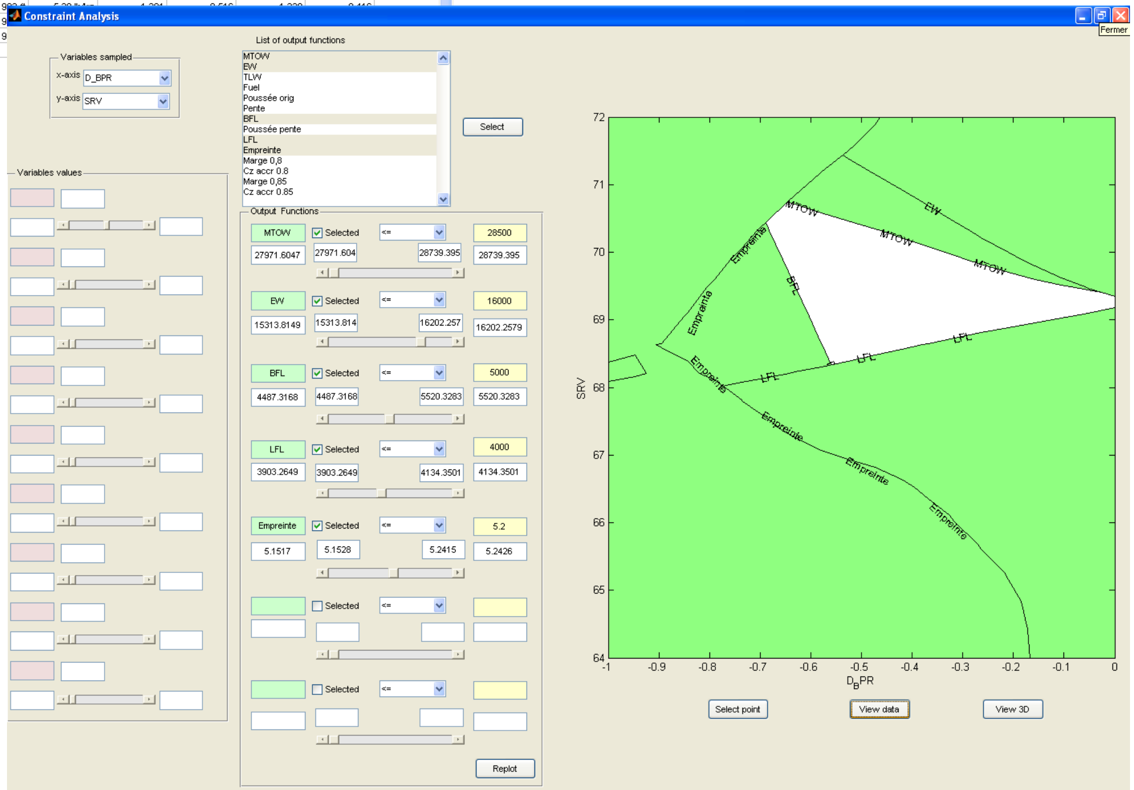
Interactive design space exploration



	D_BPR	SRV	MTOW	EW	TLW	Fuel	Poussée orig	Pente	BFL	Poussée pente	LFL	Empreinte	Marge 0,8	Cz accr 0.8	Marge 0,85	Cz accr 0.85
2	0	**64**	28 176 kg	15 609 kg	17 983 kg	11 068 kg	11 800 lbf	5,4%	4 852 ft	11 063 lbf	4 134 ft	5,19 lb/km	1,446	0,548	1,433	0,442
3	0	**66**	28 335 kg	15 757 kg	18 135 kg	11 079 kg	11 800 lbf	5,4%	4 759 ft	11 091 lbf	4 080 ft	5,20 lb/km	1,483	0,534	1,469	0,431
4	0	**68**	28 381 kg	15 900 kg	18 275 kg	10 982 kg	11 800 lbf	5,4%	4 634 ft	11 072 lbf	4 028 ft	5,15 lb/km	1,371	0,519	1,320	0,419
5	0	**70**	28 557 kg	16 050 kg	18 429 kg	11 007 kg	11 800 lbf	5,4%	4 557 ft	11 111 lbf	3 981 ft	5,16 lb/km	1,402	0,508	1,351	0,409
6	0	**72**	28 739 kg	16 202 kg	18 586 kg	11 038 kg	11 800 lbf	5,3%	4 487 ft	11 153 lbf	3 937 ft	5,18 lb/km	1,433	0,497	1,380	0,401
7	-0,5	**64**	28 074 kg	15 459 kg	17 840 kg	11 115 kg	10 997 lbf	4,5%	5 189 ft	11 017 lbf	4 115 ft	5,21 lb/km	1,452	0,545	1,439	0,440
8	-0,5	**66**	28 237 kg	15 607 kg	17 992 kg	11 130 kg	10 997 lbf	4,4%	5 095 ft	11 047 lbf	4 062 ft	5,22 lb/km	1,489	0,532	1,475	0,429
9	-0,5	**68**	28 284 kg	15 750 kg	18 132 kg	11 034 kg	10 997 lbf	4,5%	4 970 ft	11 028 lbf	4 010 ft	5,18 lb/km	1,377	0,517	1,325	0,417
10	-0,5	**70**	28 461 kg	15 900 kg	18 286 kg	11 061 kg	10 997 lbf	4,4%	4 893 ft	11 067 lbf	3 964 ft	5,19 lb/km	1,408	0,506	1,356	0,408
11	-0,5	**72**	28 644 kg	16 052 kg	18 443 kg	11 093 kg	10 997 lbf	4,3%	4 824 ft	11 111 lbf	3 920 ft	5,20 lb/km	1,439	0,495	1,386	0,399
12	-1	**64**	27 972 kg	15 314 kg	17 701 kg	11 158 kg	10 222 lbf	3,5%	5 520 ft	10 973 lbf	4 096 ft	5,23 lb/km	1,457	0,543	1,444	0,438
13	-1	**66**	28 139 kg	15 462 kg	17 854 kg	11 177 kg	10 222 lbf	3,5%	5 417 ft	11 004 lbf	4 044 ft	5,24 lb/km	1,494	0,530	1,480	0,428
14	-1	**68**	28 186 kg	15 605 kg	17 994 kg	11 081 kg	10 222 lbf	3,5%	5 276 ft	10 985 lbf	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	-1	**70**	28 365 kg	15 755 kg	18 148 kg	11 110 kg	10 222 lbf	3,5%	5 190 ft	11 026 lbf	[illegible]					
16	-1	**72**	28 549 kg	15 907 kg	18 304 kg	11 143 kg	10 222 lbf	3,4%	5 112 ft	11 070 lbf	[illegible]					

before

now



Direction Générale Technique

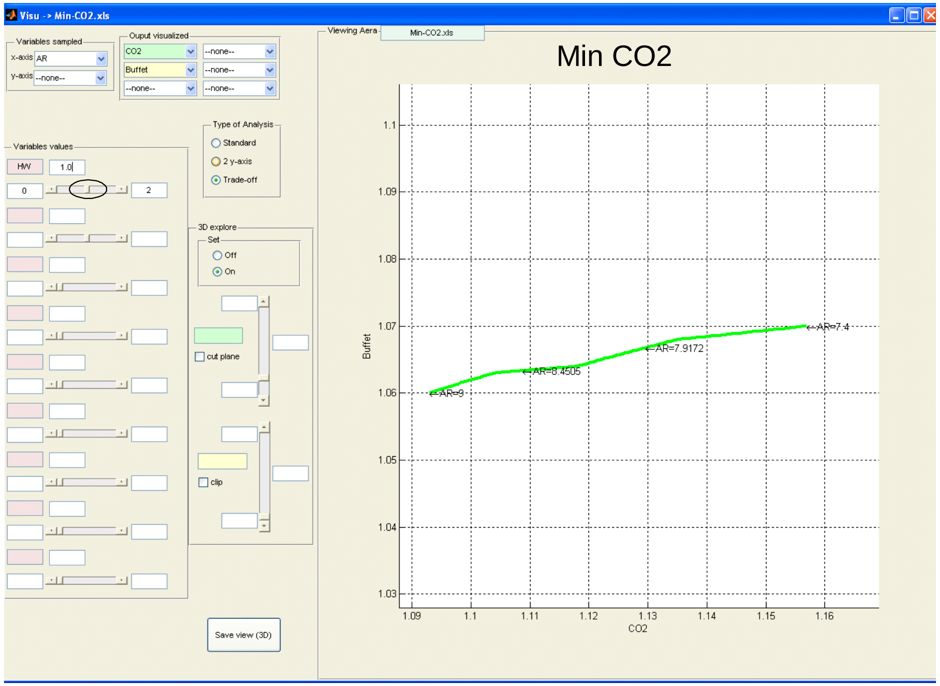
Interactive exploration benefits

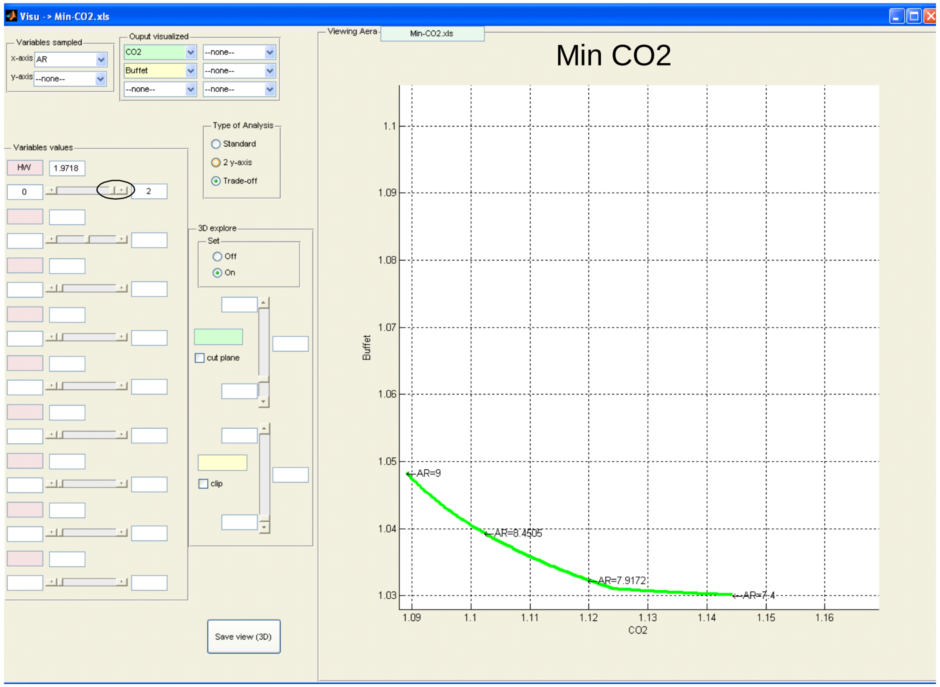
"Tell me and I'll forget; show me and I may remember; involve me and I'll understand."

Chinese proverb

- **Immerse the decision makers within the space of compromise to enable them to better understand what they need by providing them immediate answers to their questions.**
- **Collaborative visualization ensures that all stakeholders can measure the impact of the multiple interactions and be able to trace the analysis at the system level.**
- **Efficiently manage the trade off between breadth and depth: each compromise decided at the system level allows focusing future efforts on smaller areas but with an increase in the depth of details.**

Interactive trade off analysis





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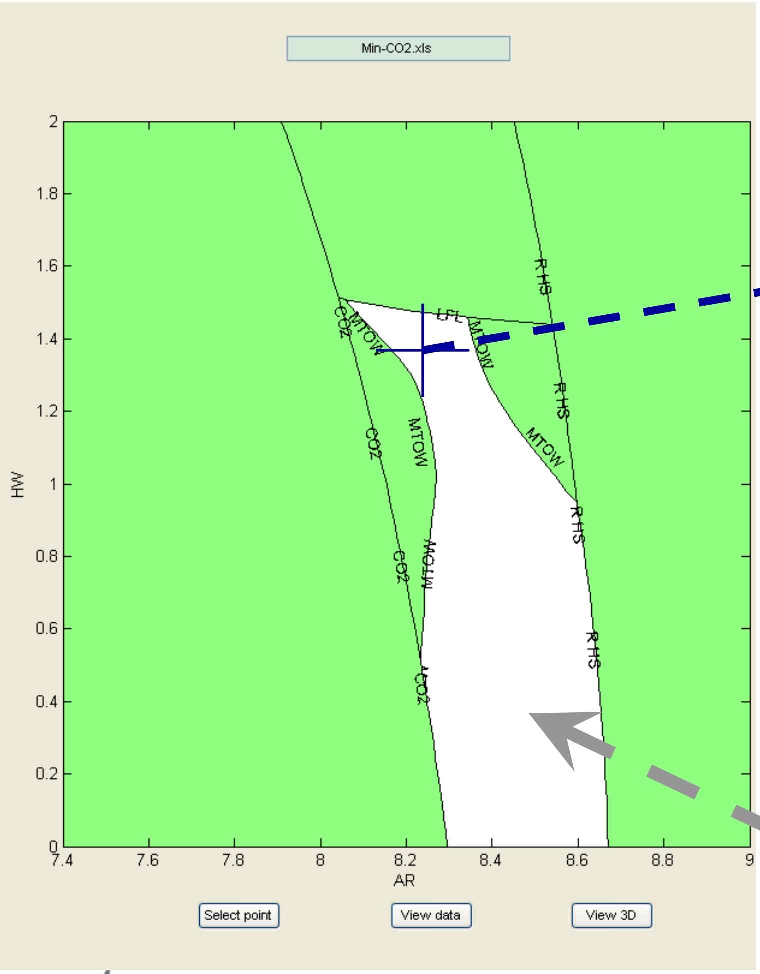
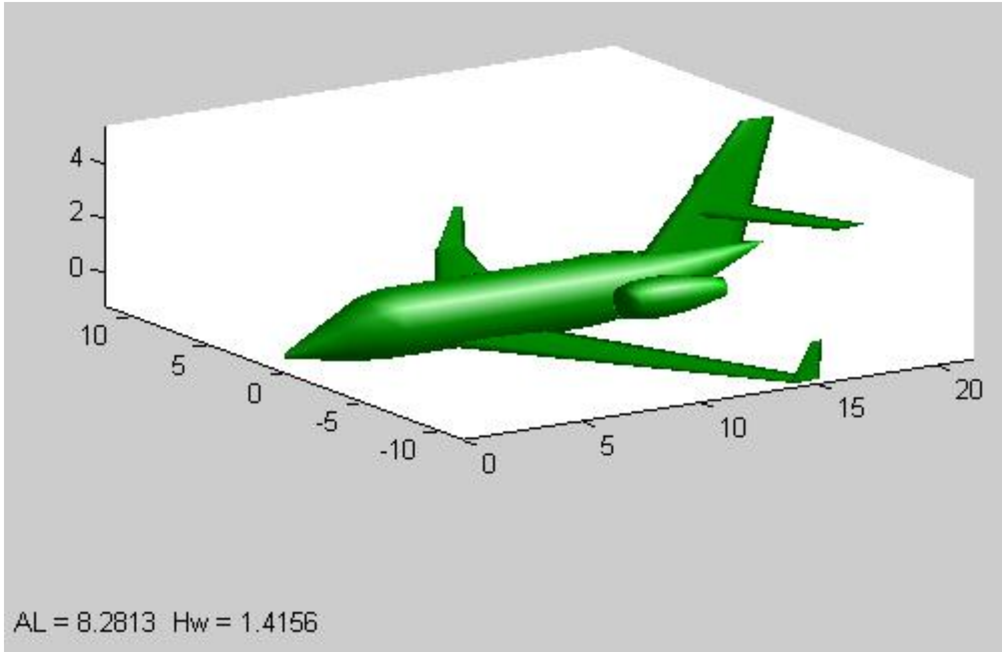
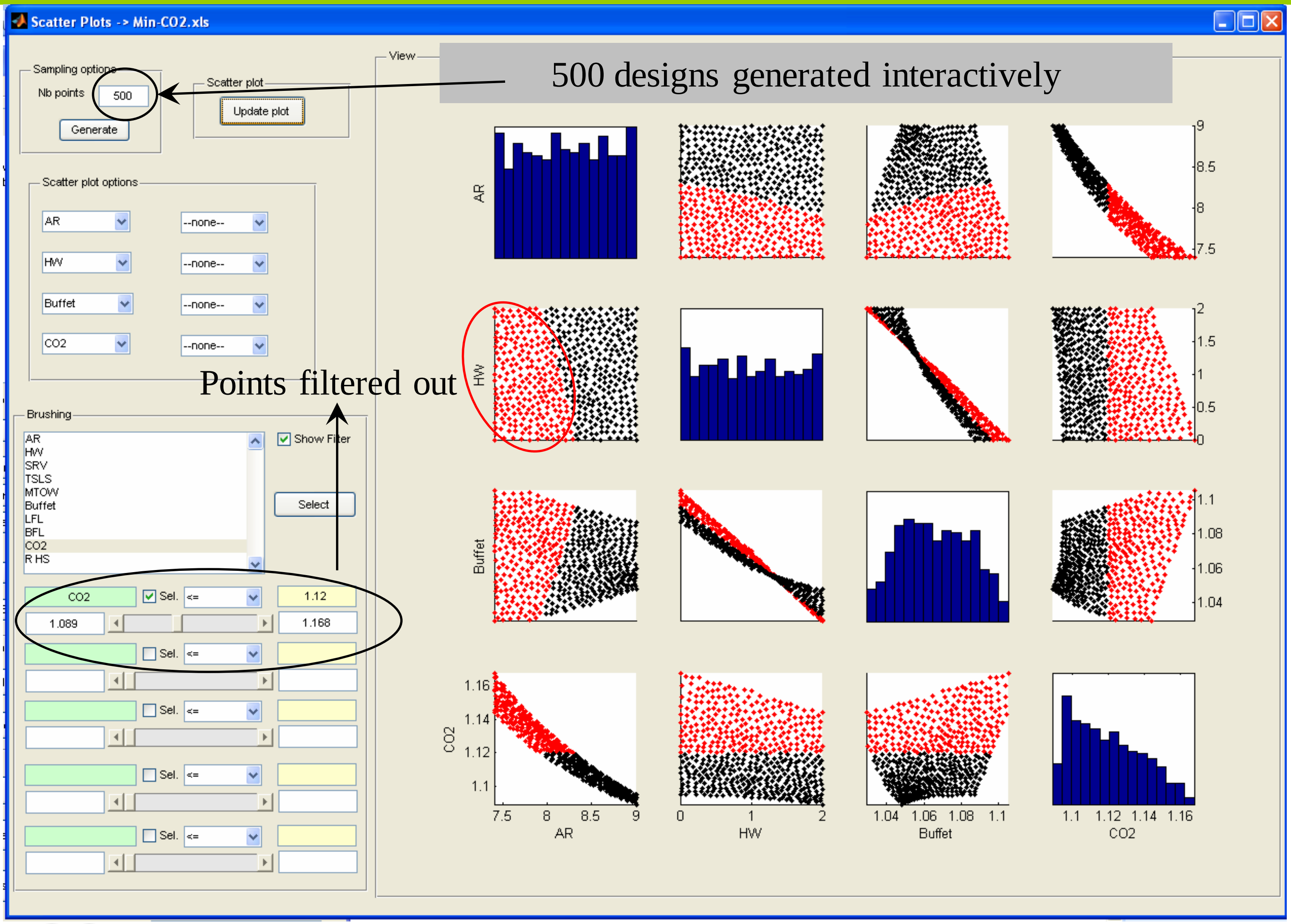
Interactive constraints analysis





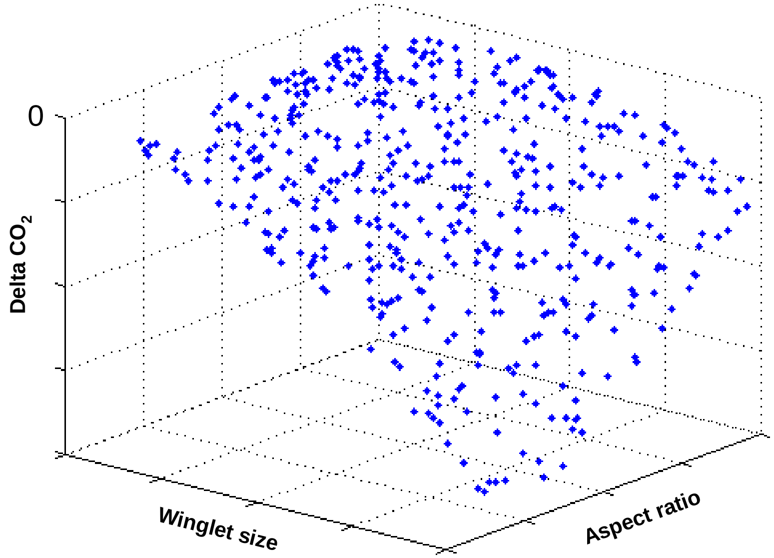
Feasible design space

Filtered scatter plots

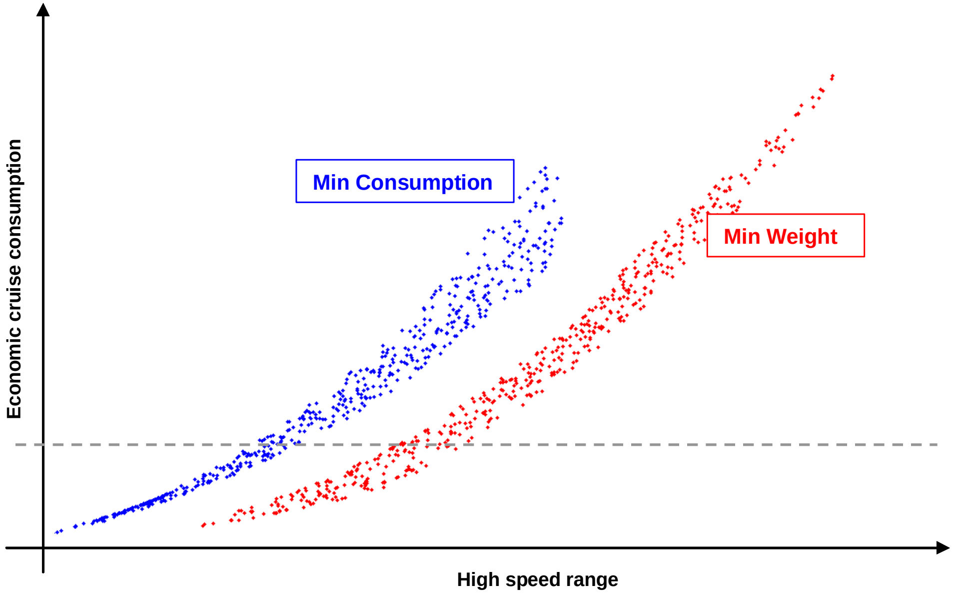


More detailed comparison

500 designs



Delta CO2 "Min CO2 - Min weight"

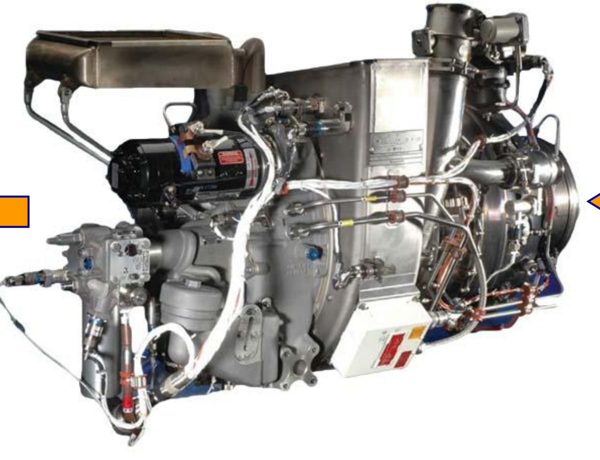


Trade off CO2 vs high speed range

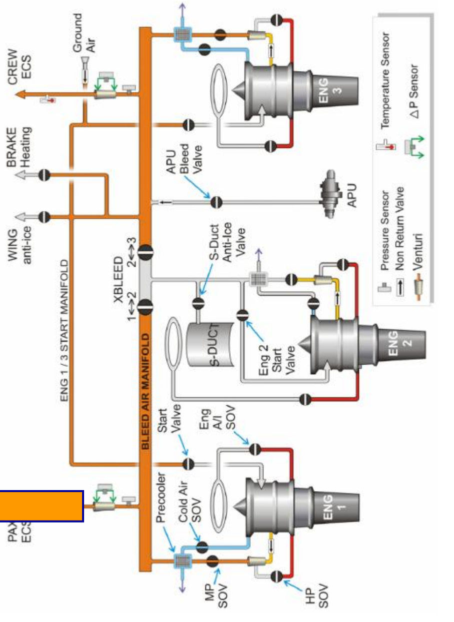
Selected design region must result of a comparative analysis of ***all the performances***

Multicriteria Decision Making

Aircraft Environmental Control System

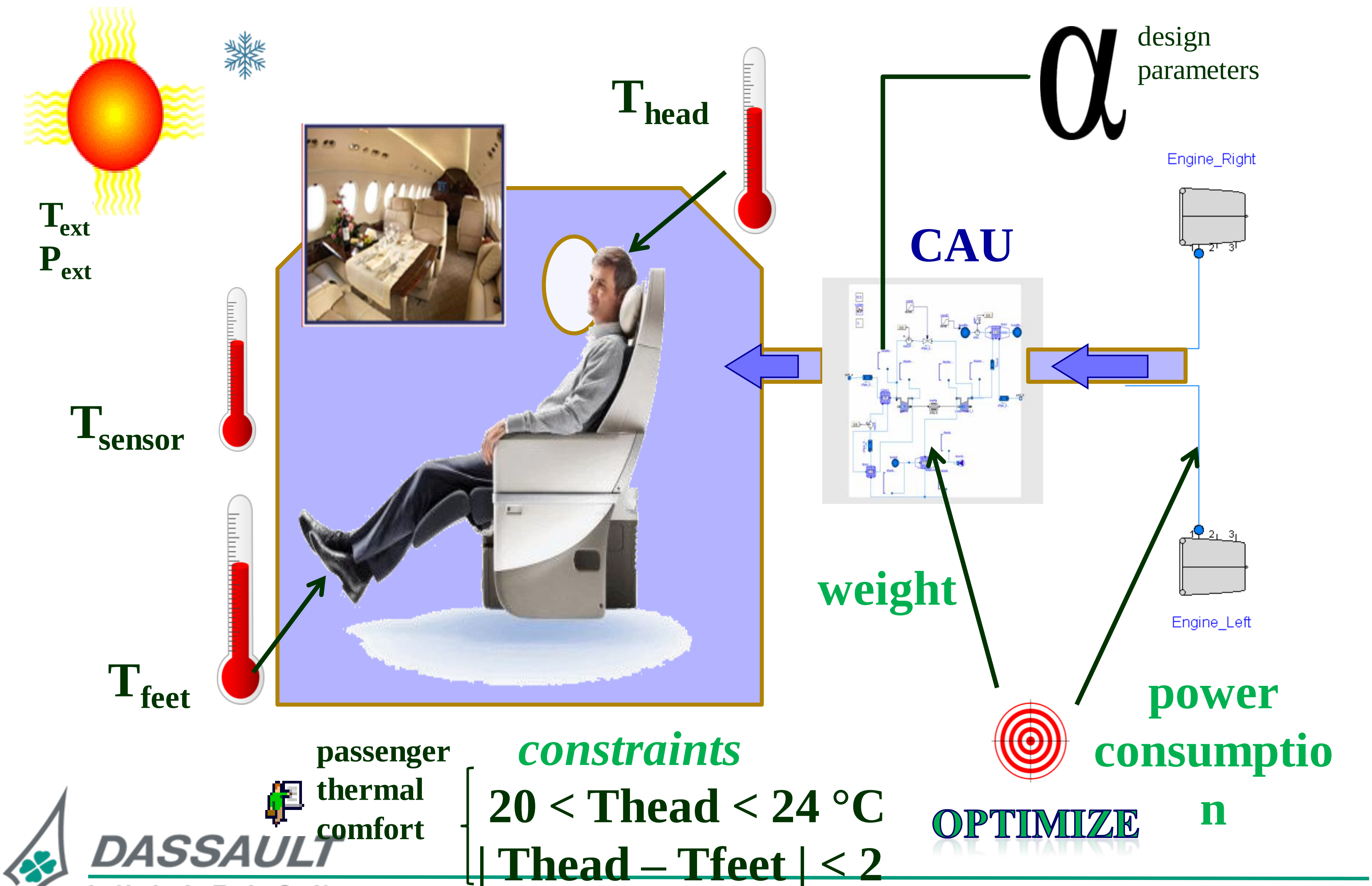


ECS



Engine bleed air

Sizing of the Cold Air Unit



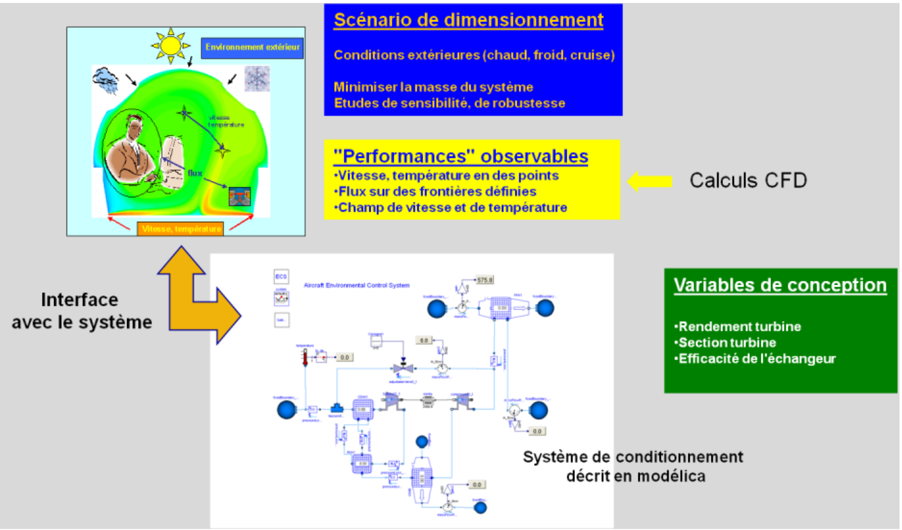
Design of an ECS system

<u>Objective :</u> 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.

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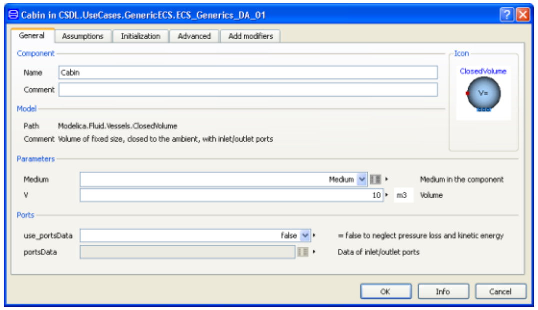
Direction Générale Technique

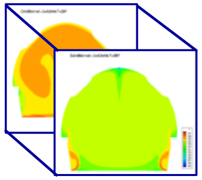
Multi-level models

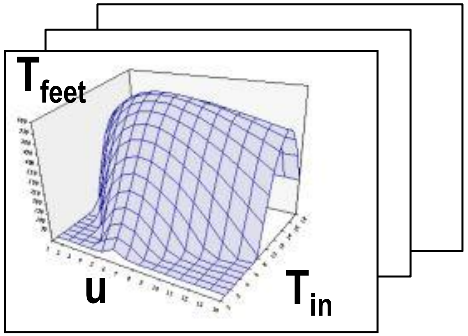
original Modelica component



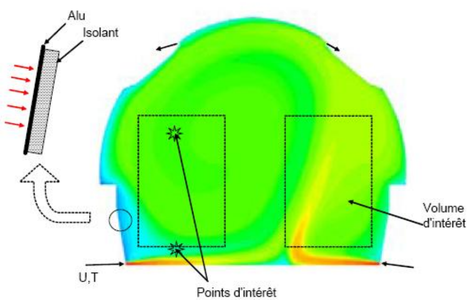
(Modelica.Fluid.Vessels.ClosedVolume)

surrogate models with associated accuracy





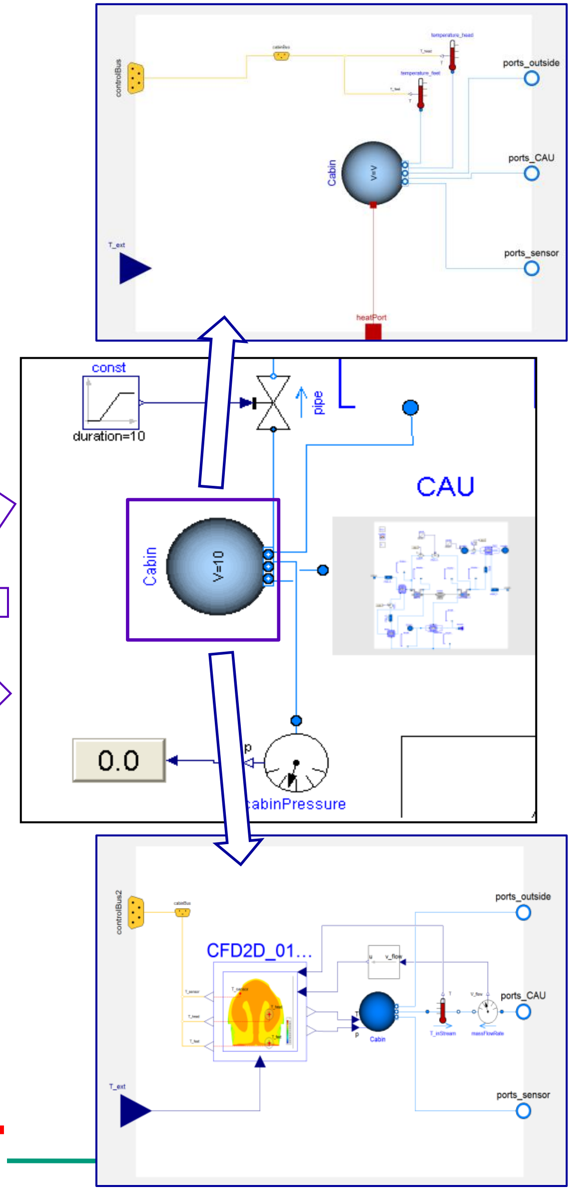
original CFD Model(s)



Low fidelity

Choice of adequate representation

High fidelity



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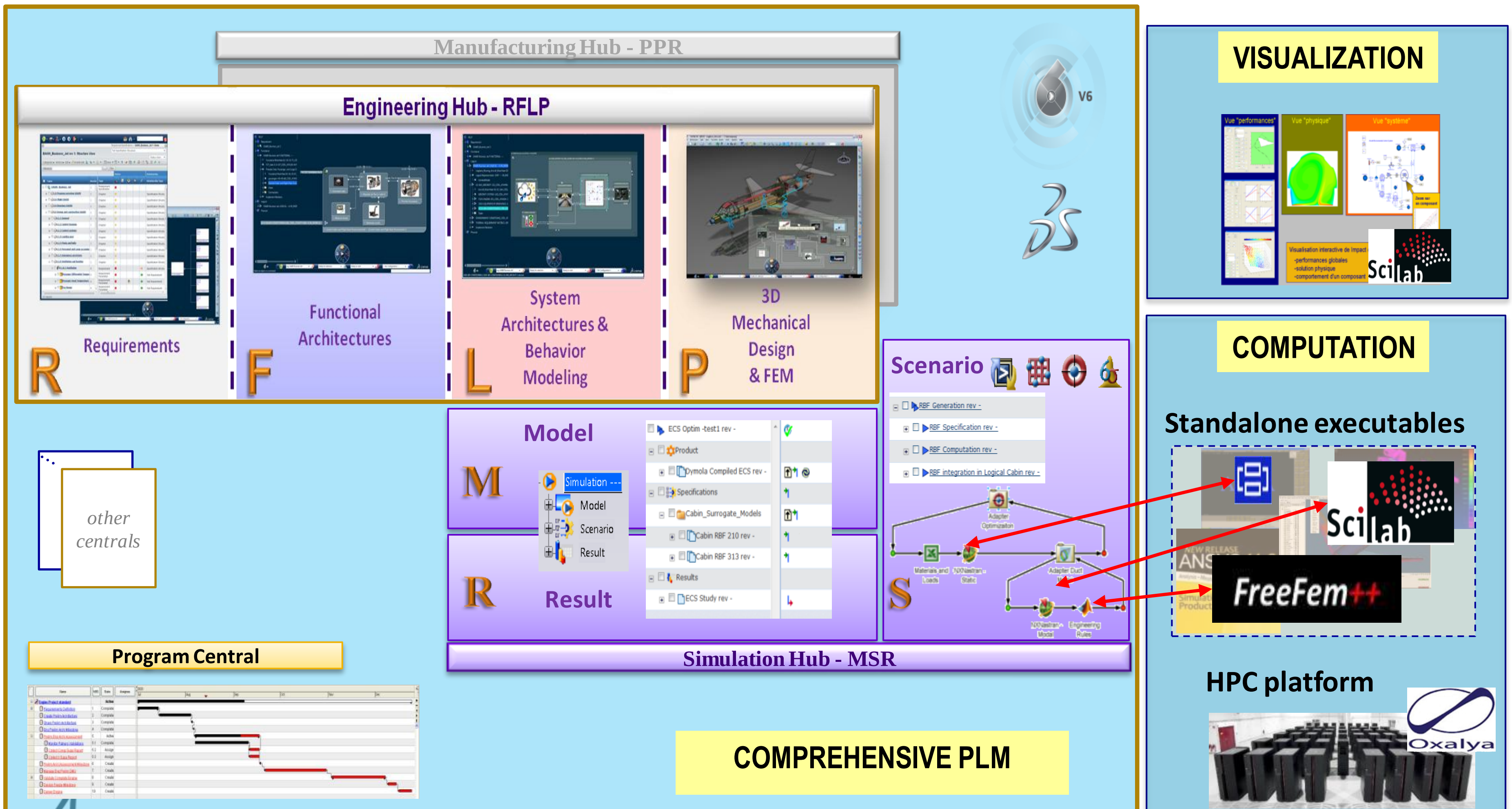
Modelica (www.modelica.org)

Catia V6 Platform component



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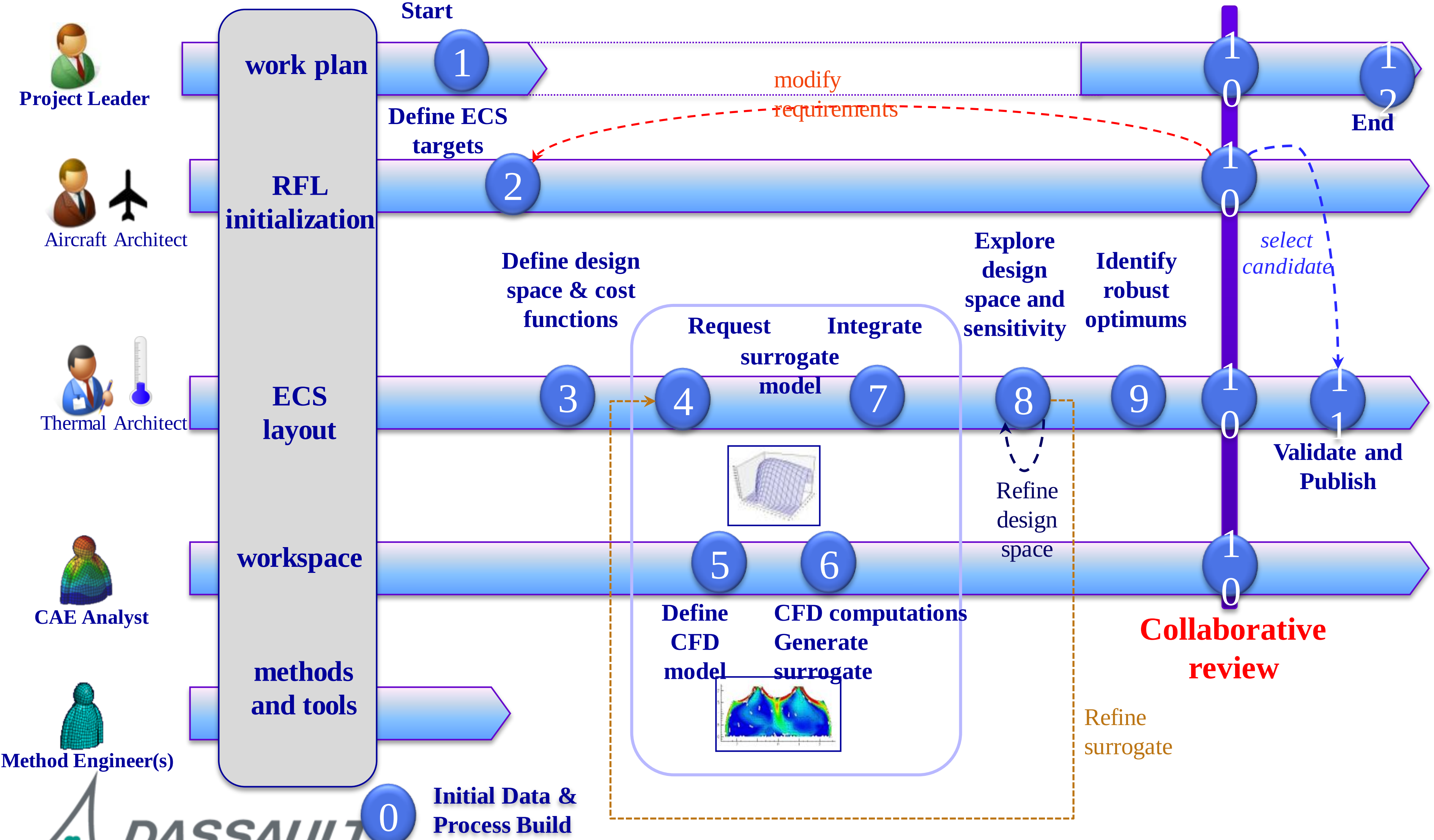
Collaborative process

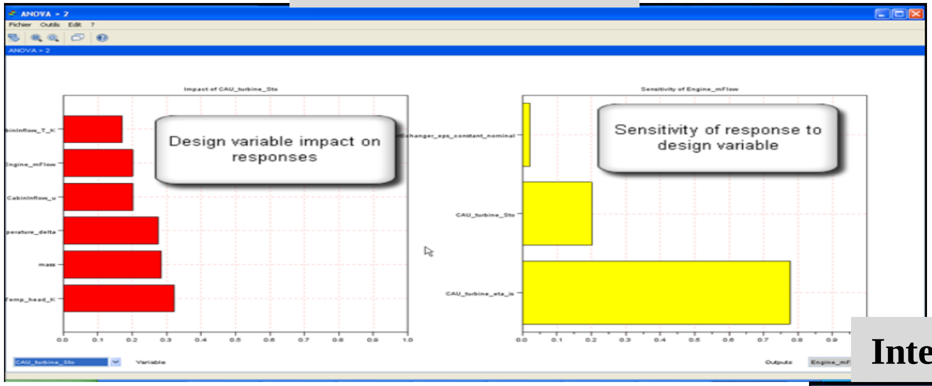


DASSAULT AVIATION

Direction Générale Technique

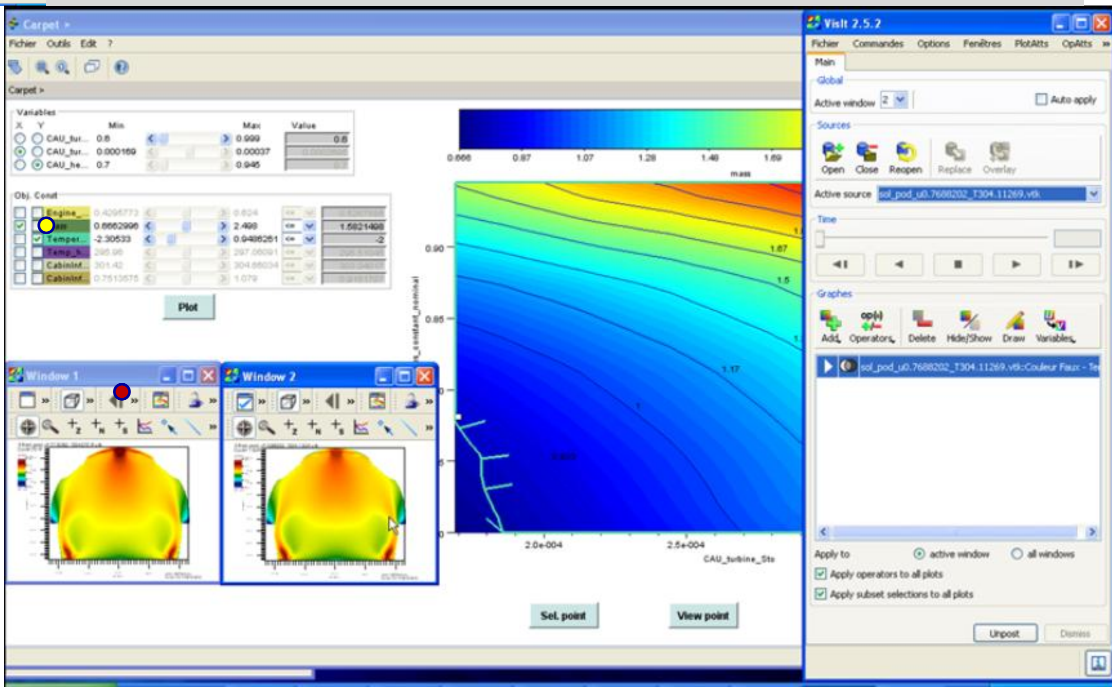
Design review

Sensitivity Analysis



Design space explored using surrogate models

Interactive links between performances and physical behavior



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Conclusions

- **Multi-level strategy based on surrogate models**
  - Enables the reuse of high fidelity simulations in different contexts
  - Allows asynchronous allocation of resources
  - Facilitates exchange of information
- **Improved awareness of the decision making process thanks to**
  - Numerical simulations and data sharing at the earliest stage of development
  - Systematic trade-off studies at all the levels of integration in a collaborative framework
- **Better project management through**
  - The assessment of the design margins on the final performances
  - The allocation of resources to the domains with the highest yield
- **PLM with parametric models**
  - Traceability from cradle to grave
  - Interactive collaborative design review

Exploration efficiency still needs to be improved to better support decision making : towards a collaborative design lab sharing a digital mockup of the design space with all the associated parameterized performance models.