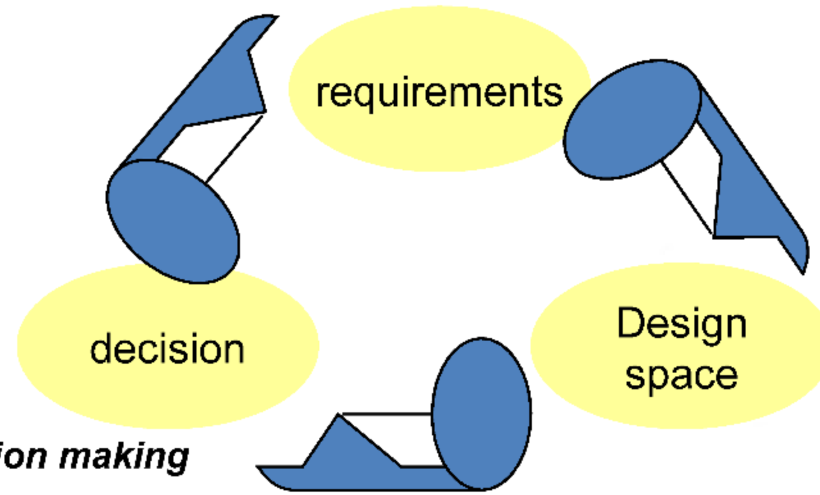
Complex Systems Design Lab

Reasons why, Challenges, Results

Decision Loop in design

Evaluate impact of requirements



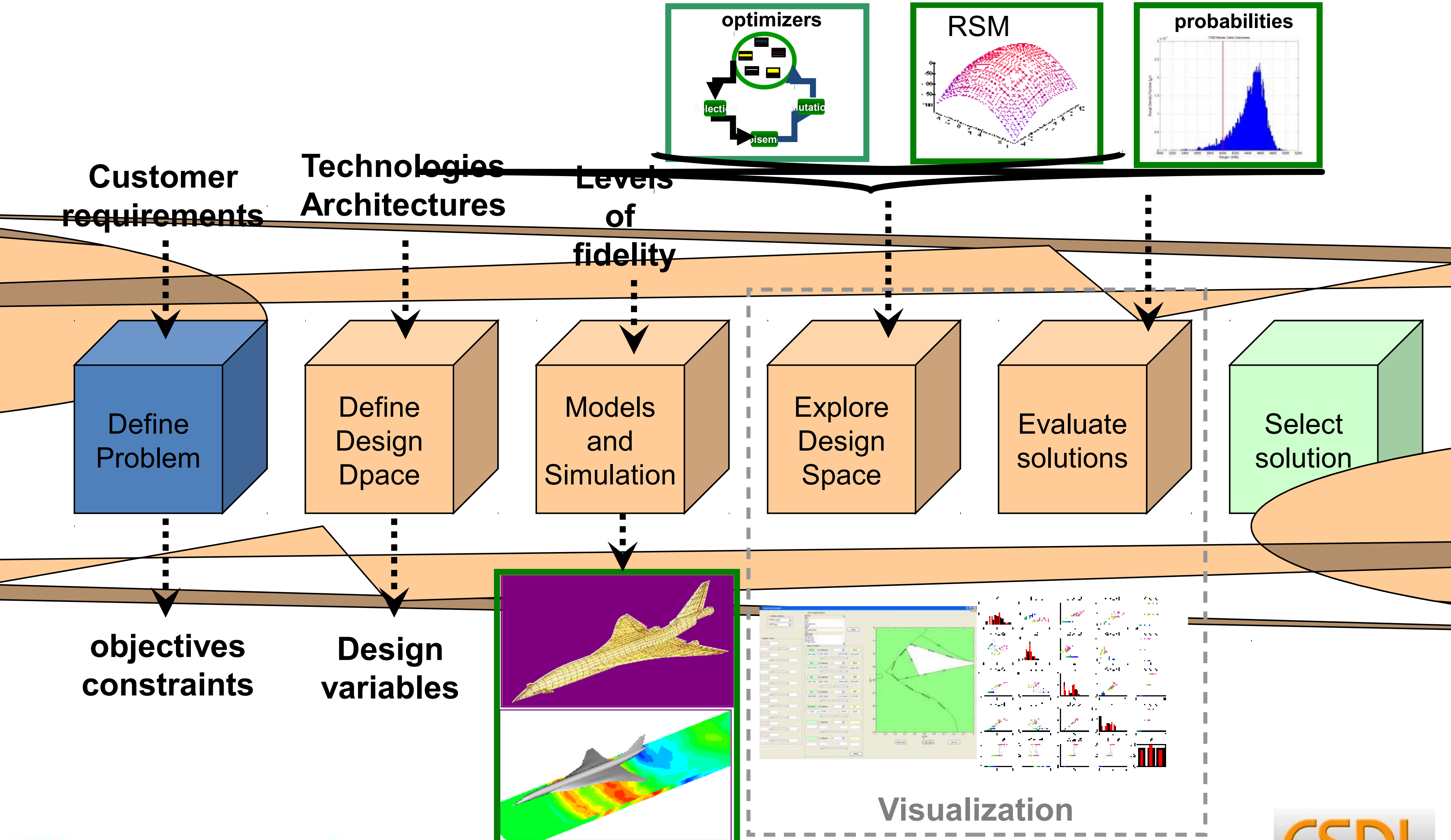
Synthesis to support decision making

- 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



SYSTEMATIC

CSDL Complex System Design Lab

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

Industrial Use Cases

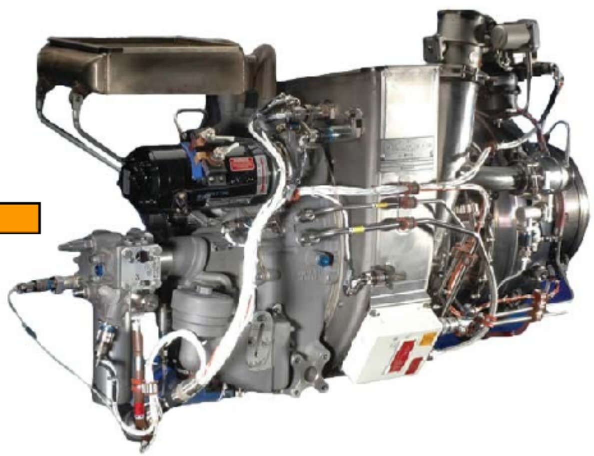
Objective : Provide actual design processes

- 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

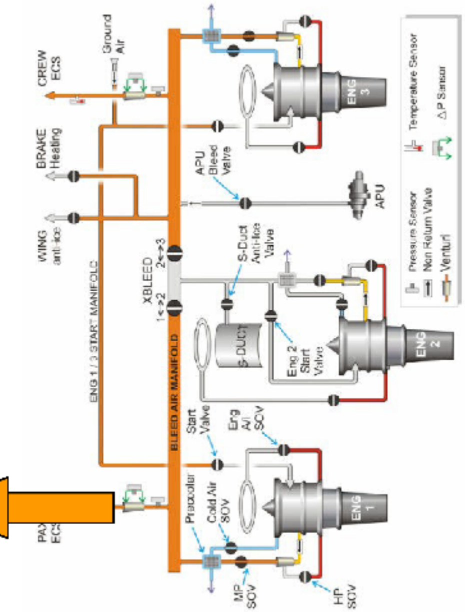
5 industrial use cases

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

Aircraft Environmental Control System



ECS



Engine bleed air

Design of an Aircraft ECS

<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.

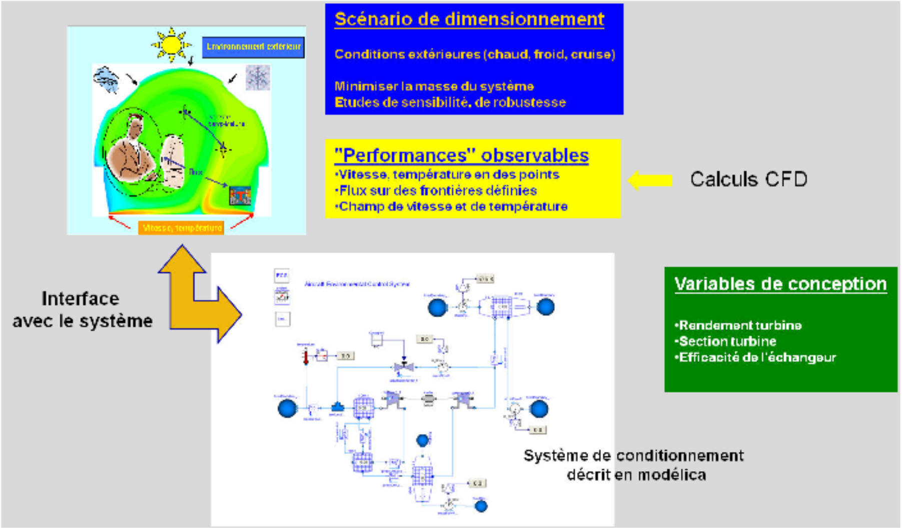
CFD computations in the cabin:
- air flow
- temperature

The boundary conditions are specified by the ECS.

The ECS is modeled using the Modelica language.

CFD computations : batch on HPC Clusters

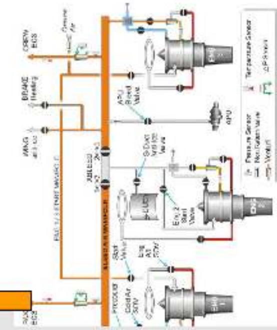
System simulation : interactive on PC (windows)

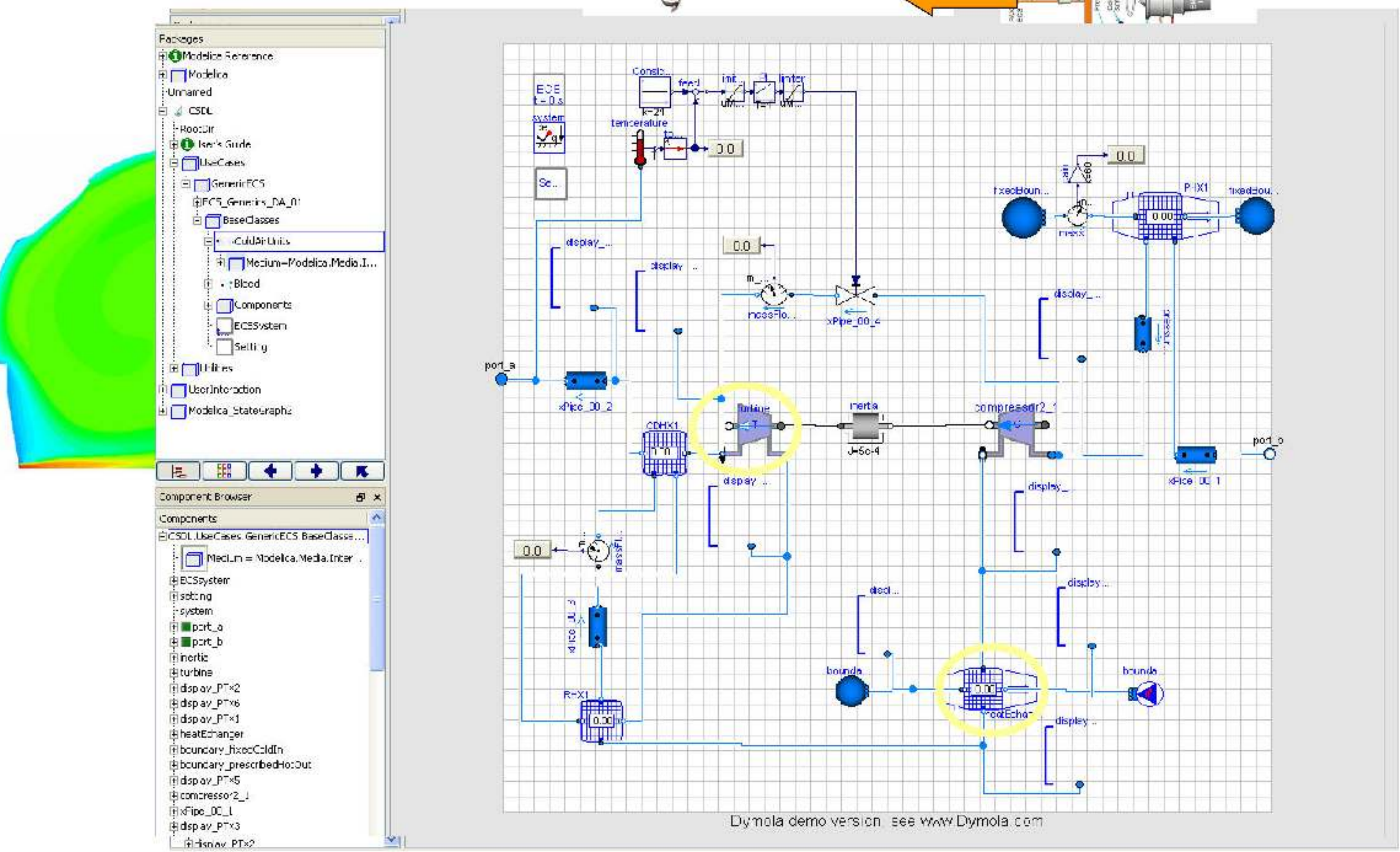


==> Methodology and process to
- perform each simulation in its native environment
- couple the different simulation to explore efficiently explore the design space
- synthesize the results and support decision making

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

ECS Model

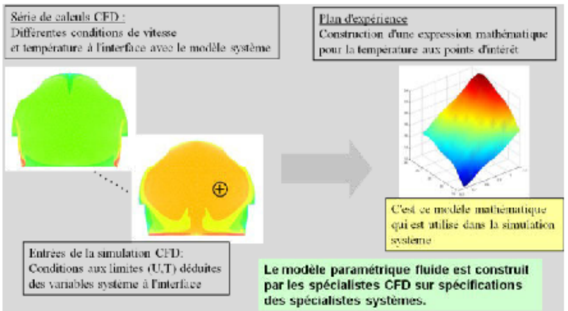



Packages
Modelica Reference
Modelica
CSDL
UseCases
GenericECS
BaseClasses
Components
ECSSystem
Component Browser
Components
port_a
port_b
inertia
turbine
compressor2_1
Dymola demo version, see www.Dymola.com

Challenges

Surrogate model for the CFD results	Integrate the surrogate model In the modelica model	Design the ECS

Surrogate model for the CFD results

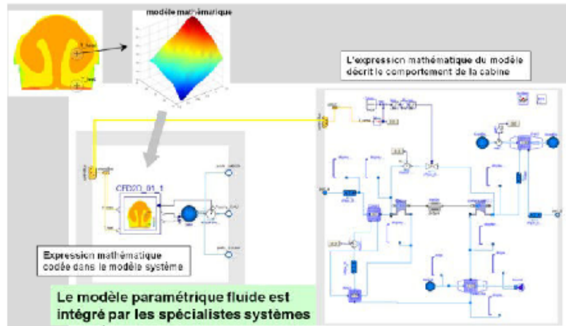


Surrogate constructed
BY the CFD specialist
FOR the ECS specialist

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

autonomy

Integrate the surrogate model In the modelica model

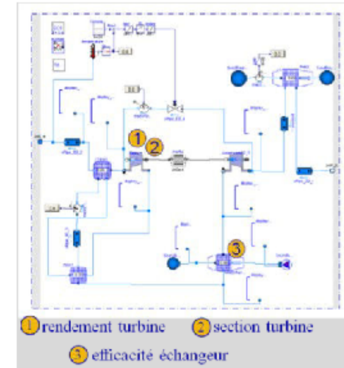


Surrogate model integrated
BY the system specialist

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

interoperability

Design the ECS

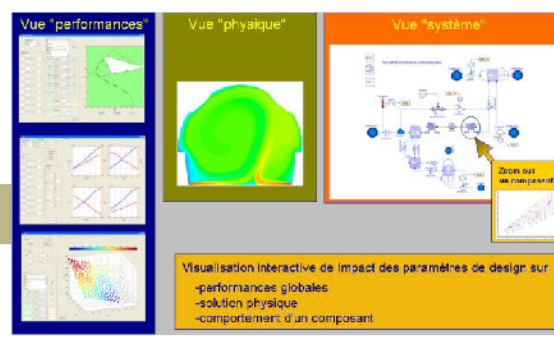


Surrogate model used BY the system specialist

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

autonomy

Synthesis for decision



Collaborative Visualization

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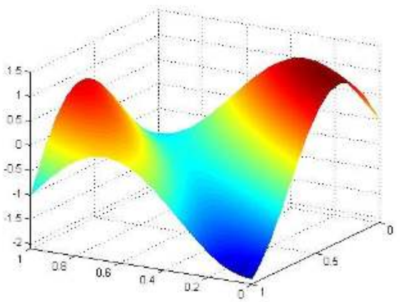
Key Elements in this problem

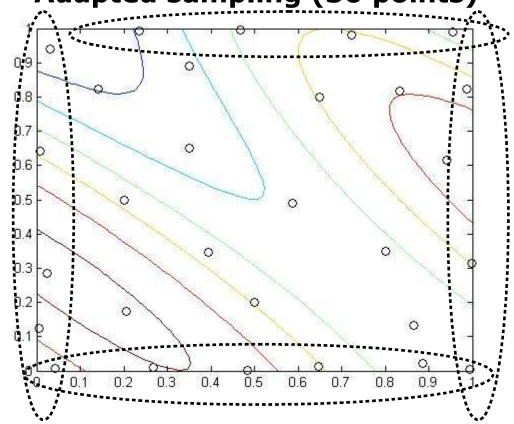
- Coupling between physical and system simulations
  - Surrogate models
- Design of parts of ECS
  - Optimization methods
  - Sensitivity Analysis
  - Uncertainties propagation (robust design)
- Process
  - Integration of the different elements in a workflow to explore efficiently the design space.
-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

DOE using Kring MSE

True Surface

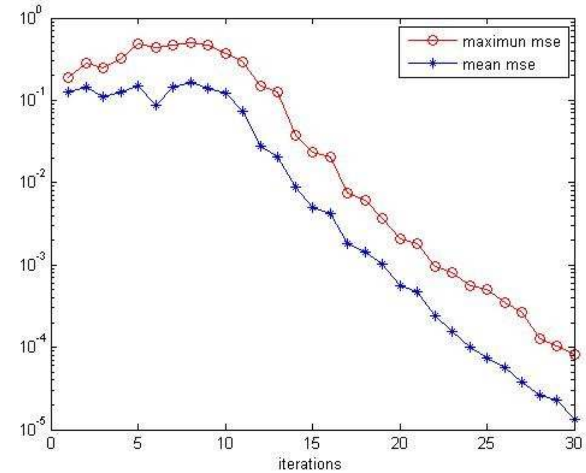


Adapted sampling (30 points)

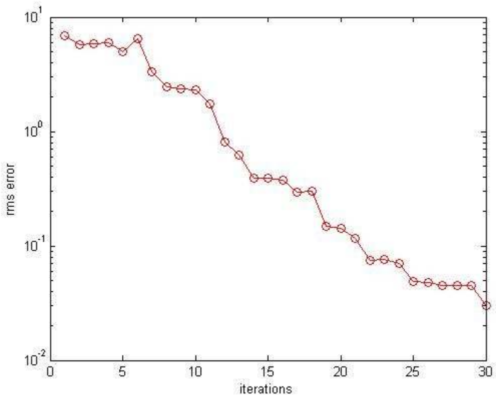


Points on the border of the domain

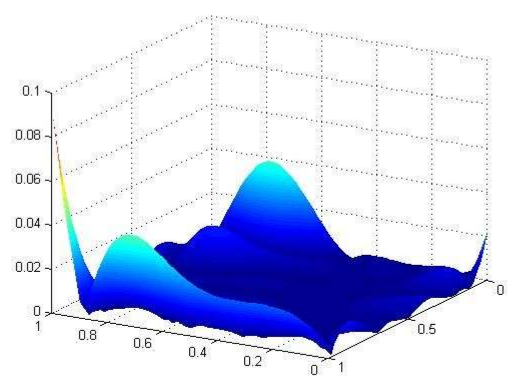
Sampling convergence (mse)



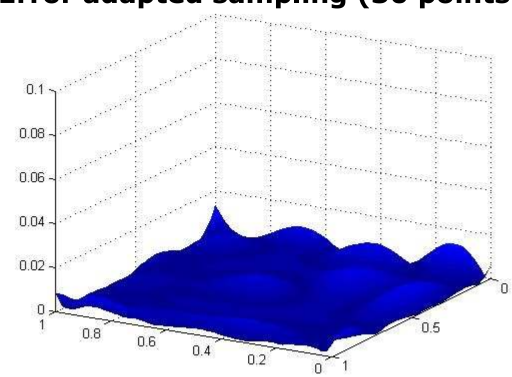
Sampling convergence (rms)



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

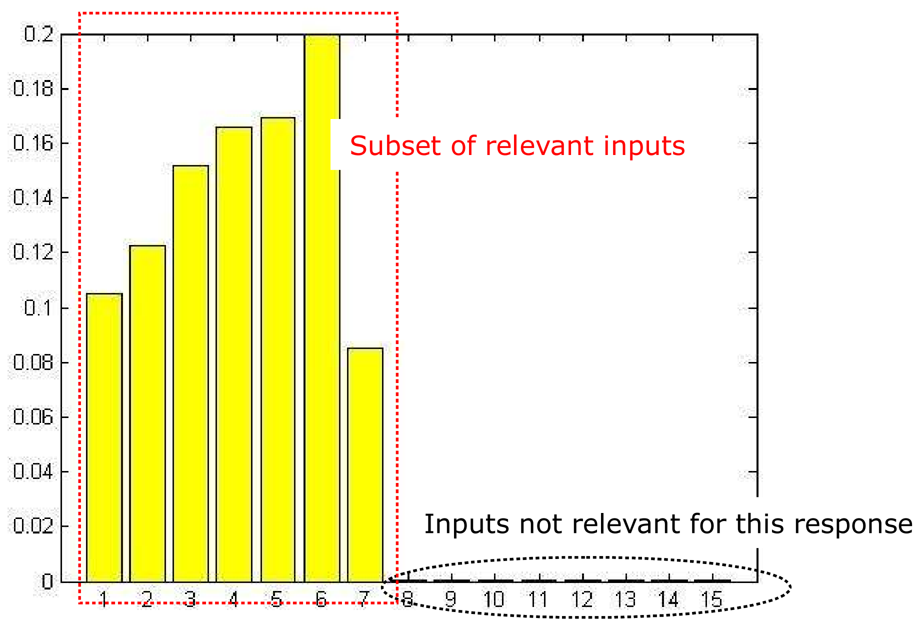
Extension to multiple objectives: work in progress

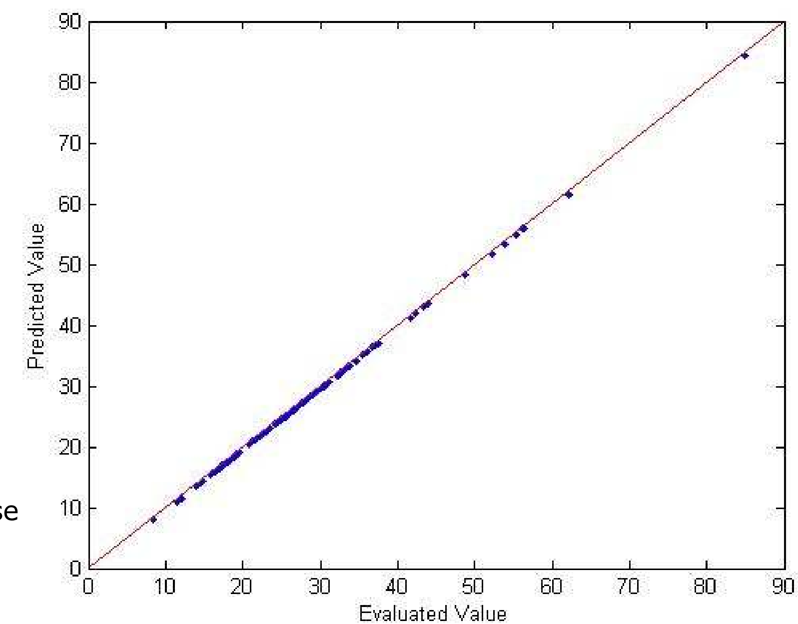
DOE: Reduction of dimension

<u>Problem :</u> Black Box with 15 inputs and 3 outputs
Find the relevant parameters for each output to
Construct a surrogate model

<u>Algo:</u>
1. Build a coarse surrogate
2. ANOVA with coarse surrogate (Sobol)
3. Perfom fine DOE on relevant inputs
4. Build surrogate on the reduced space
5. Estimate error using coarse DOE

Sobol analysis using coarse surrogate





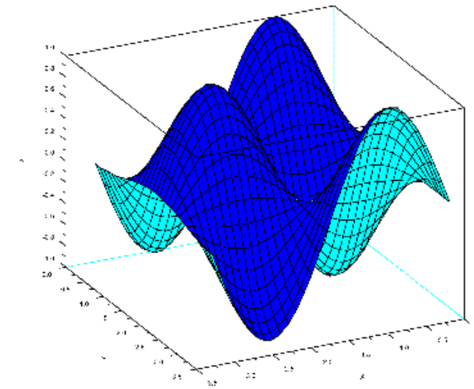
Comparison actual value / predicted value

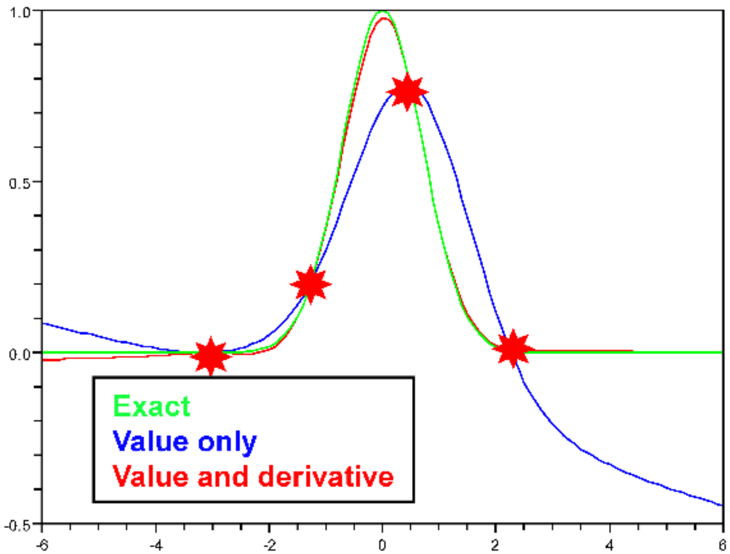
Surrogate models using derivatives

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

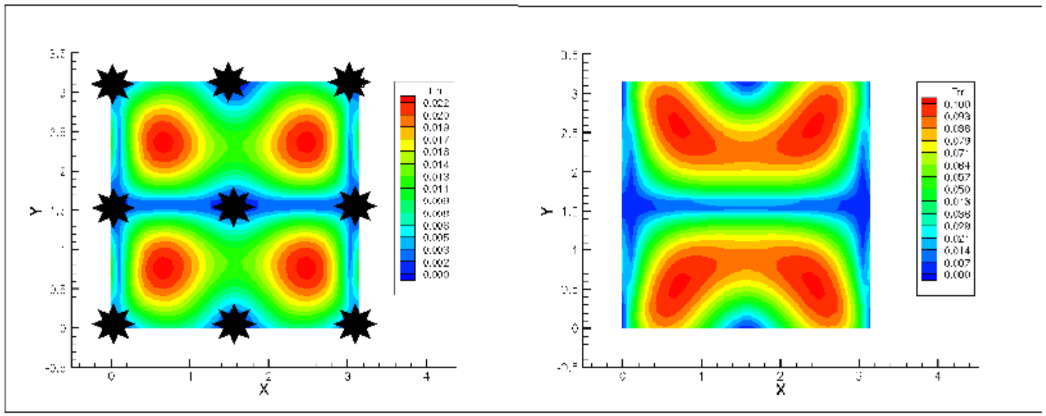
$$s(x) = f(x), x \in \{x_i\}_{i=1}^{n_s}$$

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





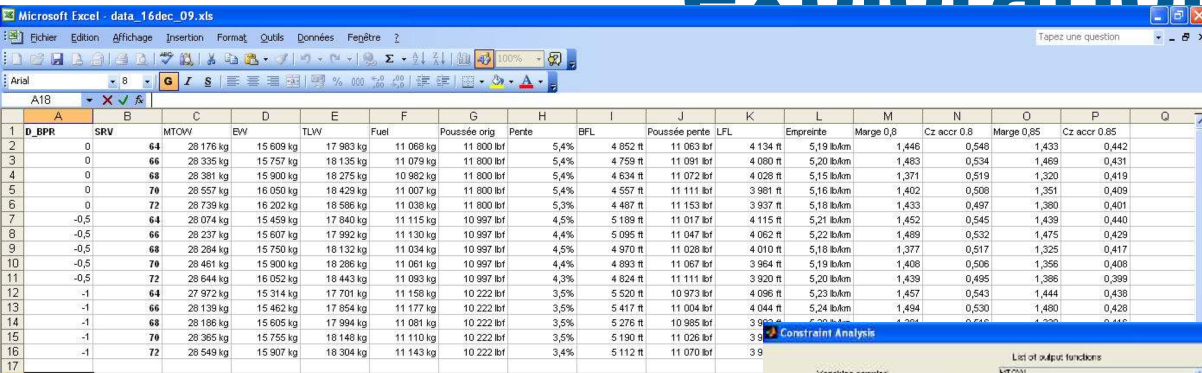
1D example



with gradients errmax=2.2%

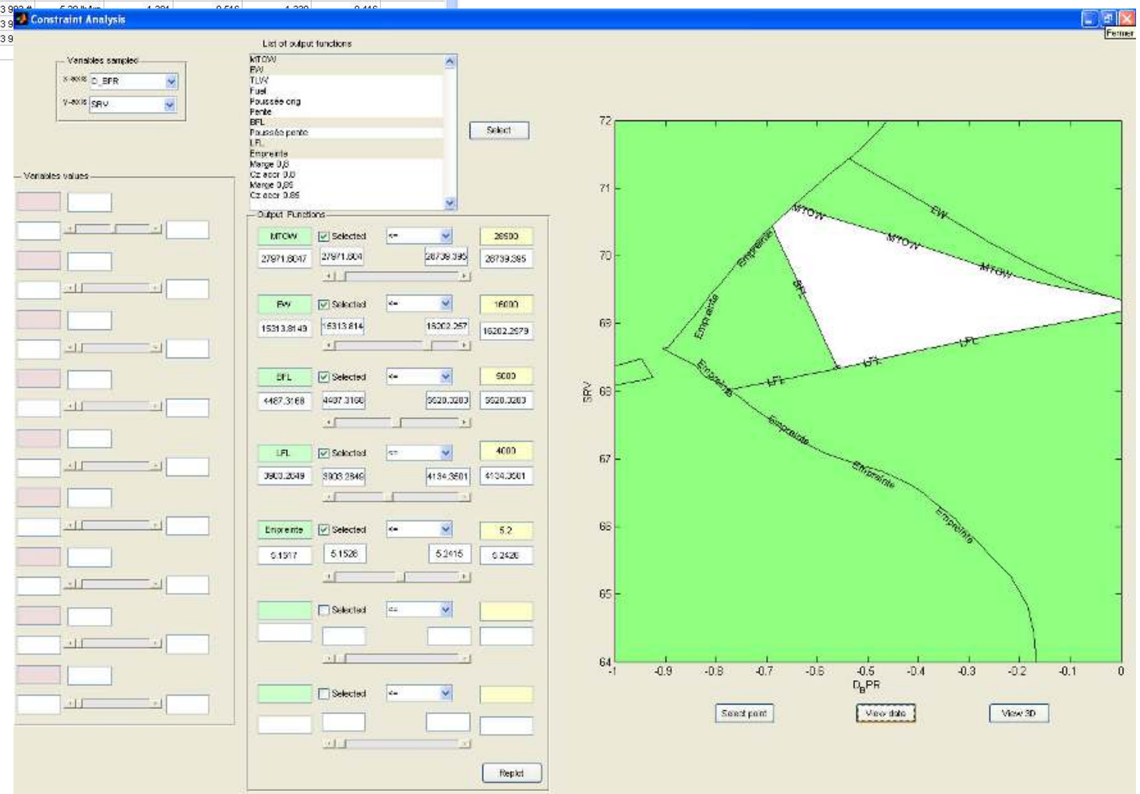
without gradient errmax=10%

Interactive design space exploration



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	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]	[illegible]	[illegible]	[illegible]	[illegible]	[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]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17																

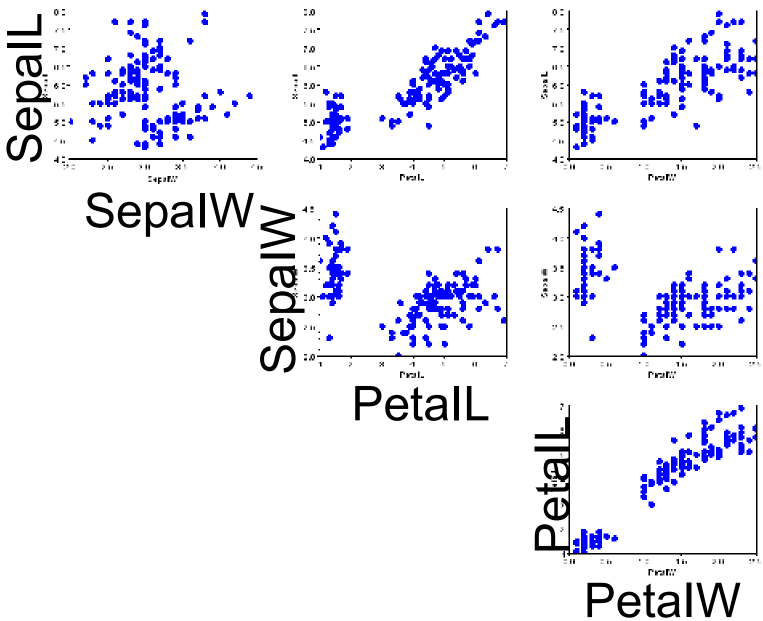
before



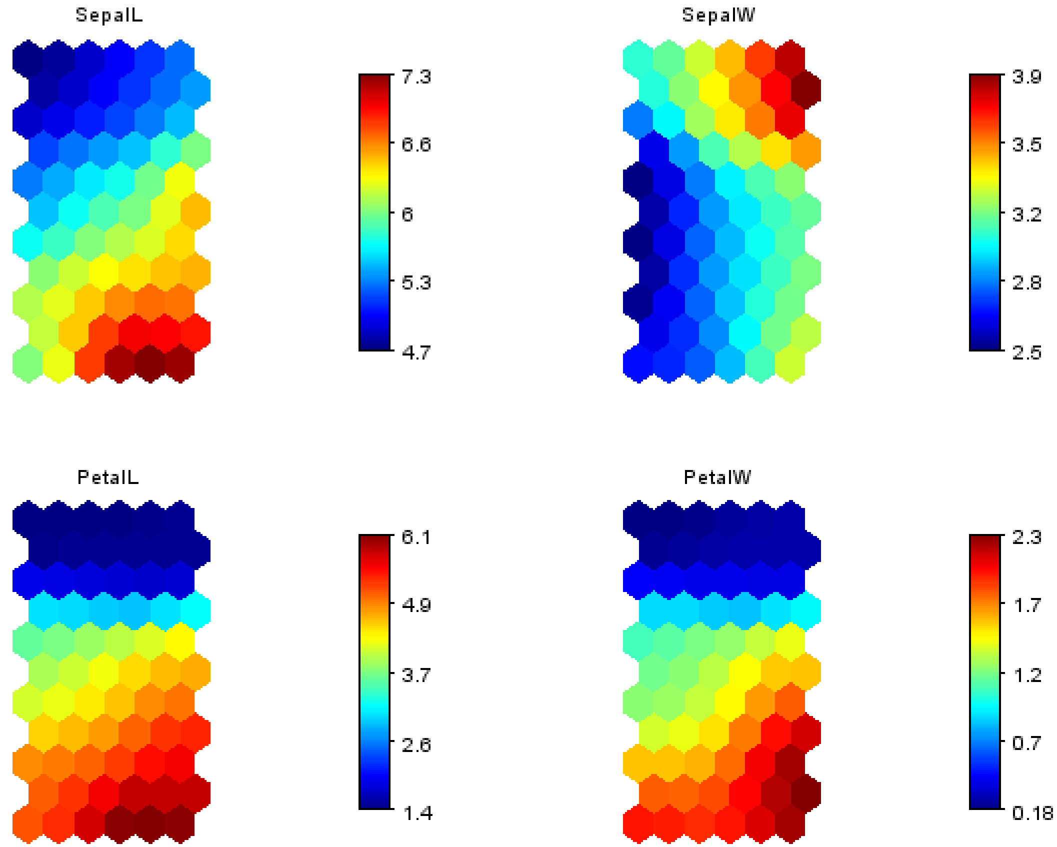
now

Self Organizing Maps

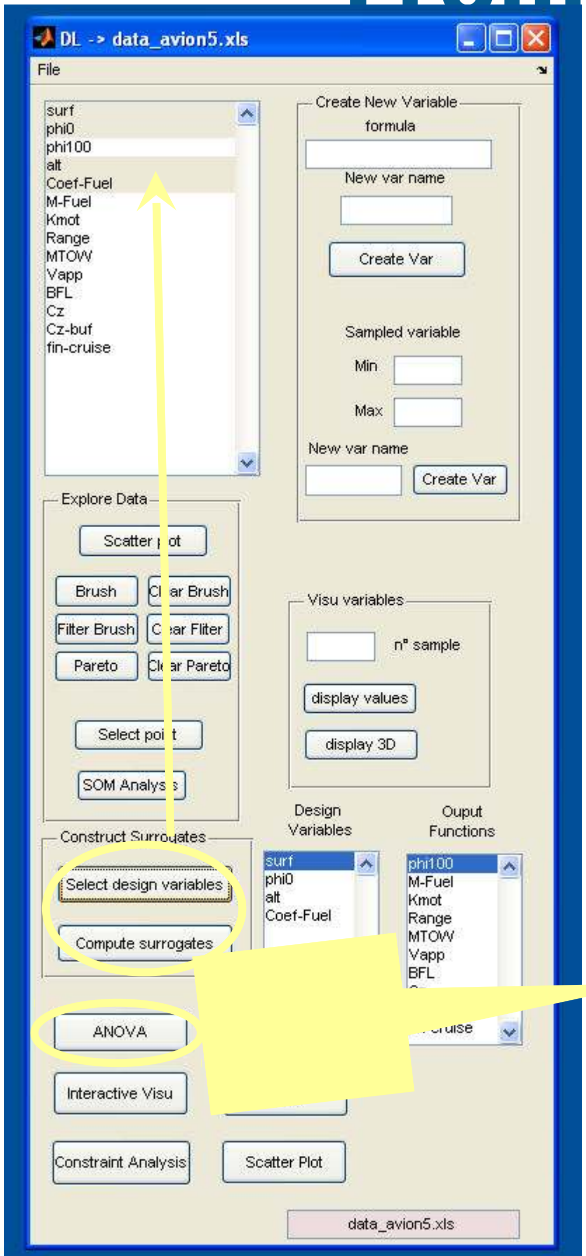
scatterplot

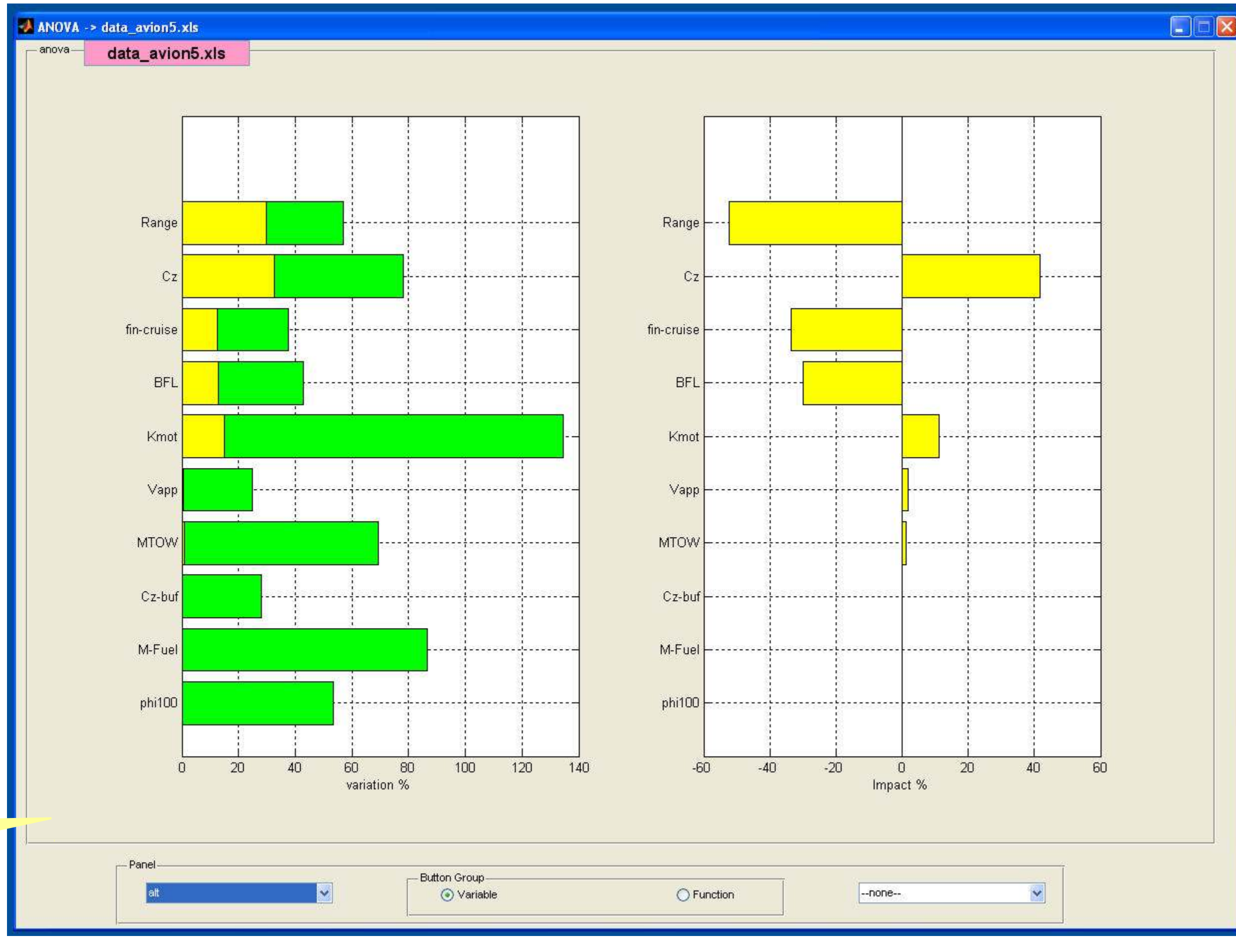


SOM



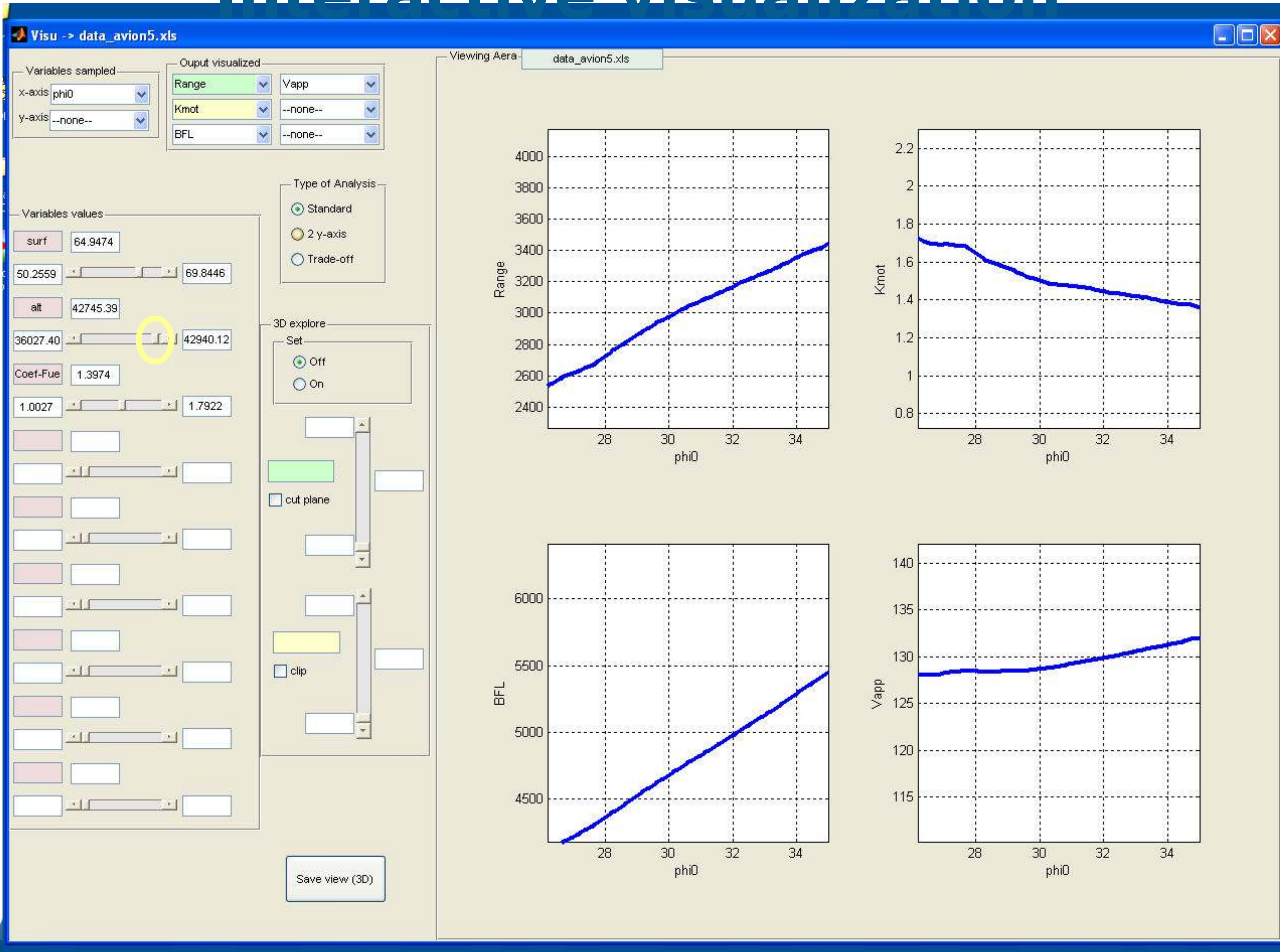
From Static to Dynamic

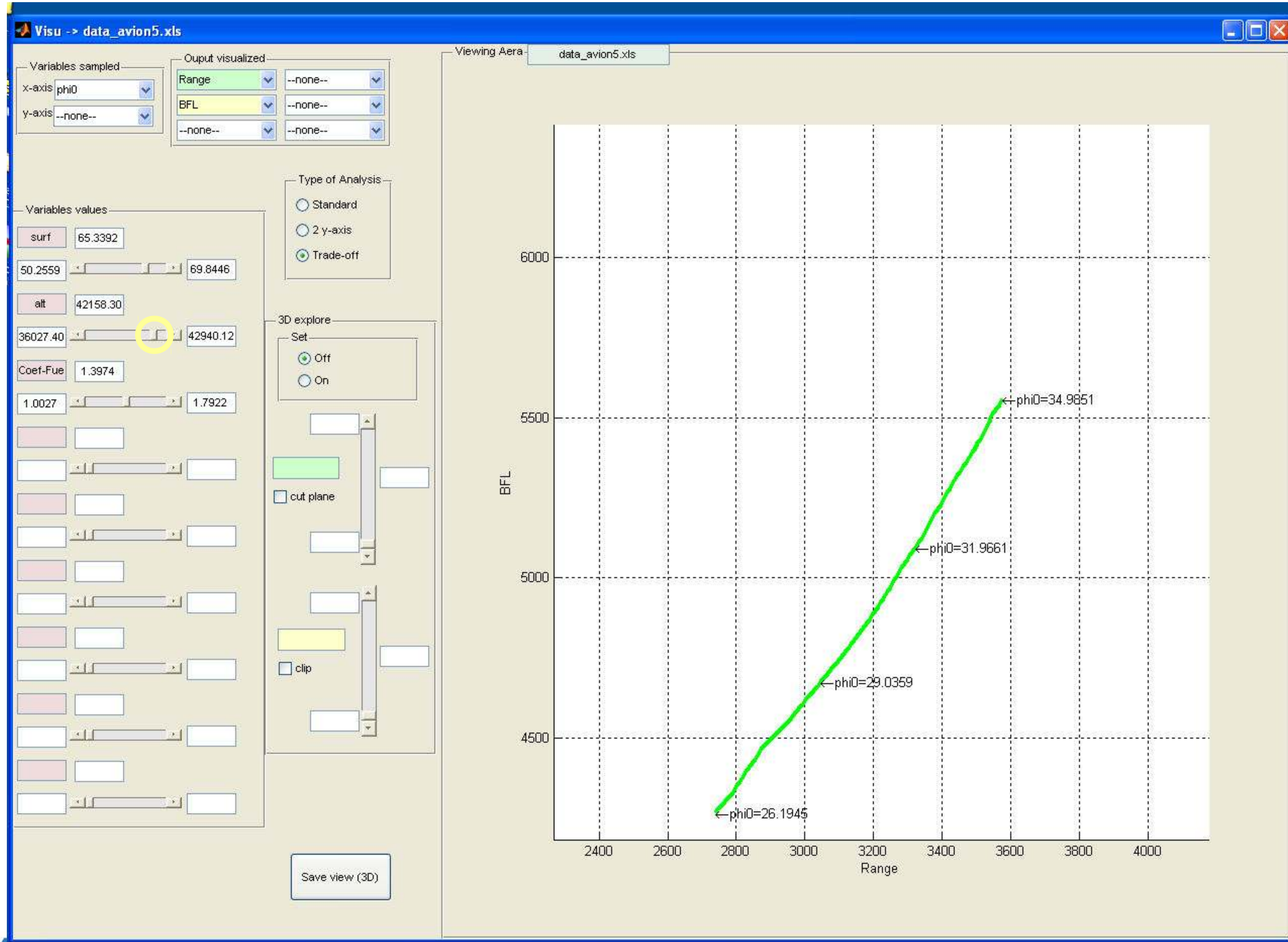


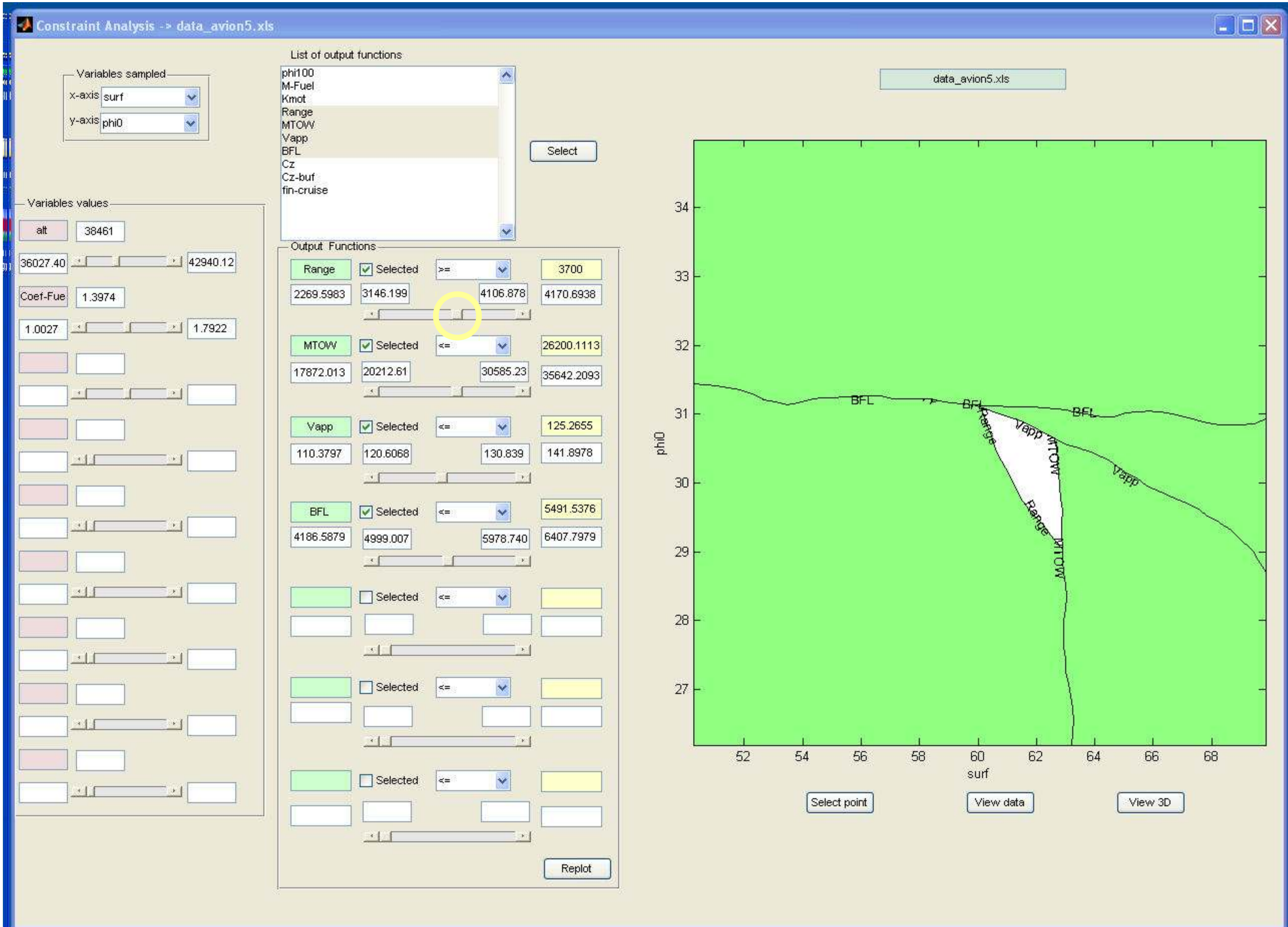


Analysis of variance

Interactive visualization




Visu -> data_avion5.xls
Variables sampled
x-axis phi0
y-axis --none--
Ouput visualized
Range
BFL
--none--
Type of Analysis
Standard
2 y-axis
Trade-off
Variables values
surf 65.3392
50.2559 69.8446
alt 42158.30
36027.40 42940.12
Coef-Fue 1.3974
1.0027 1.7922
3D explore
Set
Off
On
cut plane
clip
Save view (3D)
Viewing Aera
data_avion5.xls
BFL
Range
phi0=34.9851
phi0=31.9661
phi0=29.0359
phi0=26.1945


Constraint Analysis -> data_avion5.xls
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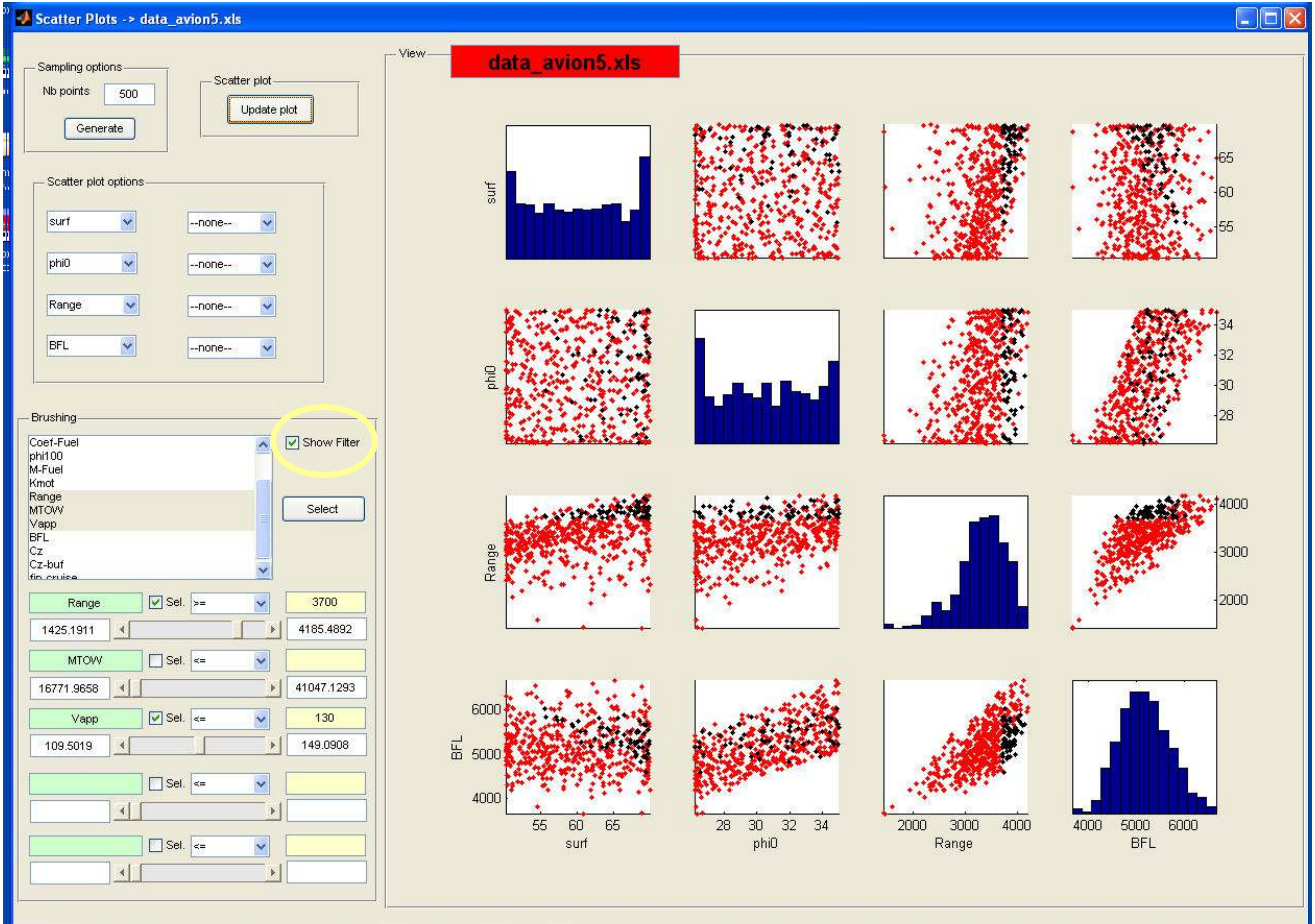
y-axis phi0
Variables values
alt 38461
36027.40 42940.12
Coef-Fue 1.3974
1.0027 1.7922
List of output functions
phi100
M-Fuel
Kmot
Range
MTOW
Vapp
BFL
Cz
Cz-buf
fin-cruise
Select
Output Functions
Range Selected >= 3700
2269.5983 3146.199 4106.878 4170.6938
MTOW Selected <= 26200.1113
17872.013 20212.61 30585.23 35642.2093
Vapp Selected <= 125.2655
110.3797 120.6068 130.839 141.8978
BFL Selected <= 5491.5376
4186.5879 4999.007 5978.740 6407.7979
Selected <=
Selected <=
Selected <=
Replot
data_avion5.xls
BFL
Range
Vapp
MTOW
phi0
surf
Select point
View data
View 3D


Scatter Plots -> data_avion5.xls
Sampling options
Nb points
500
Generate
Scatter plot
Update plot
Scatter plot options
surf
phi0
Range
BFL
--none--
Brushing
Coef-Fuel
phi100
M-Fuel
Kmot
Range
MTOW
Vapp
BFL
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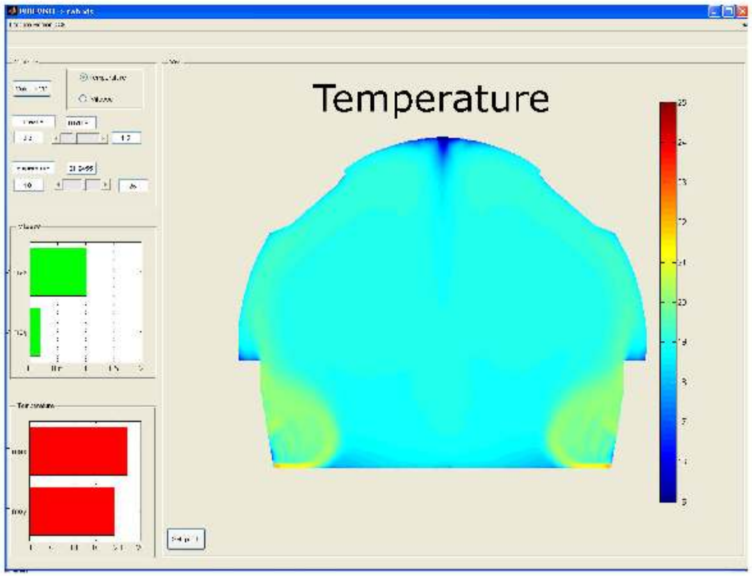
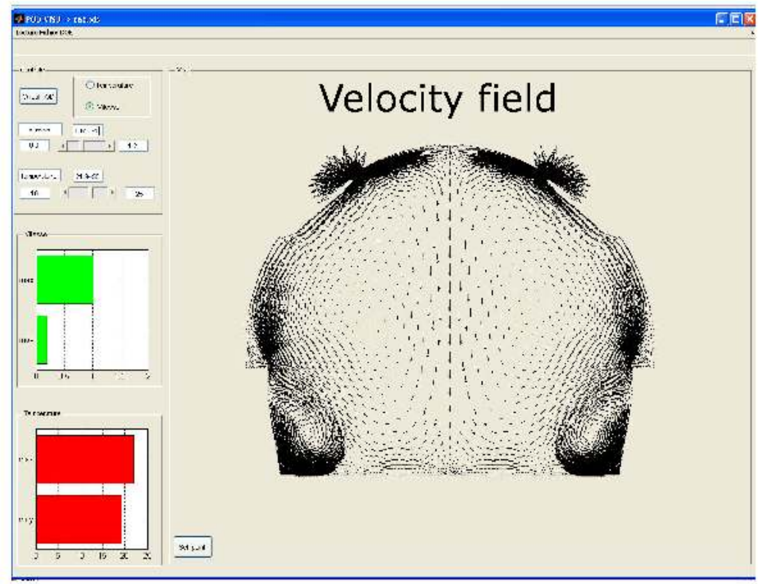
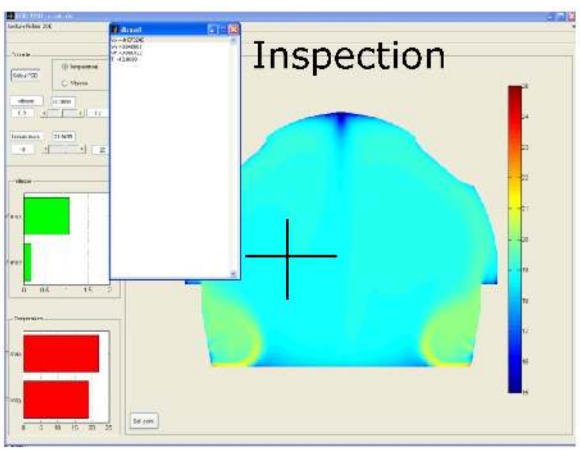
>=
3700
1425.1911
4185.4892
MTOW
<=
16771.9658
41047.1293
Vapp
130
109.5019
149.0908
View
data_avion5.xls
surf
phi0
Range
BFL

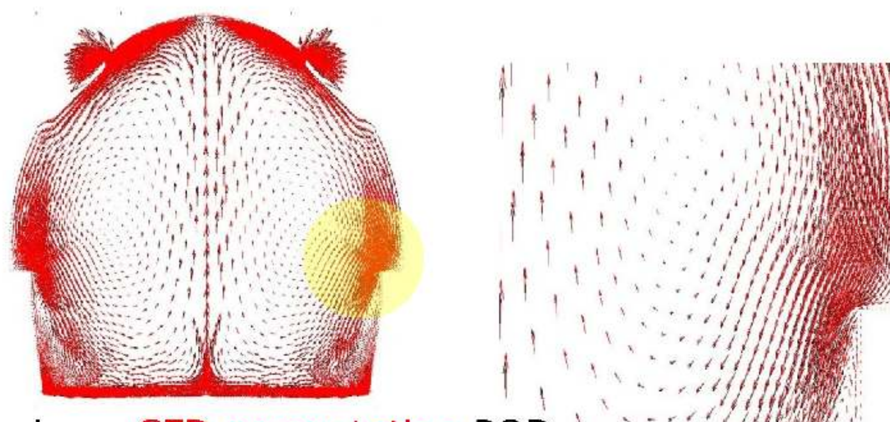
Interactive reconstruction of physical solutions

Matlab prototype based on POD









Comparison CFD computation POD reconstruction

Shortcomings

- 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 constraint 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

Conclusion

- 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 softwares
- …. But this should be a considered as a beginning
  - Real scientific challenges have to be tackled
    - Support from scientific community indispensable

Thank you for your attention !

Questions ?

The cluster and its projects are sponsored by:

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