"CAD-based optimization methods with application to the automotive industry"

In parallel to the current development of adjoint-based optimization methods in the scope of FLOWHEAD, the automobile industry is actively searching for reduction of greenhouse effect gas emissions through numerical simulation. The aim of the presentation is to draw up the work in progress in the field of the CAD-based shape optimization methods and to shown some recents results around the powertrain and the external aerodynamic optimization

Nowadays, the entire automotive CFD Product Development Process is only relying on CAD models. All the models contain native manufacturing parameters. But these parameters are not often the geometric variables we want to optimize. Either they are architectural parameters, or they are a bad combination of optimization variables. Taking into account these amount of parameters, moreover, requires a lot of computer resources and to know how to manage the global optimization problem. Hence the two main drawbacks of the CAD-based optimization are : suitable computer resources and the availability of a goal-oriented parametrization of the initial shape.

FLOWHEAD fulfills these requirements : the adjoint sensibilities trace the path to the one-shot optimization on paramete-free geometries. In parallel to the current development in the scope of FLOWHEAD, Renault keeps going to improve the classical CAD-based optimization process. Either on a CAD model directly provided by the project, ie. the optimization result is also directly integrated in the final vehicle, or on a "home made" template, simplified for now, built on the optimization purpose. These specific models integrate all the necessary optimization variables, defined by the CFD engineer . The optimization result is not a geometry, but some new conception rules (pareto, interactions plot, statistical surrogates) reused later in the project to manually perform an optimization (radiator grill,car roof, car sides, ...)

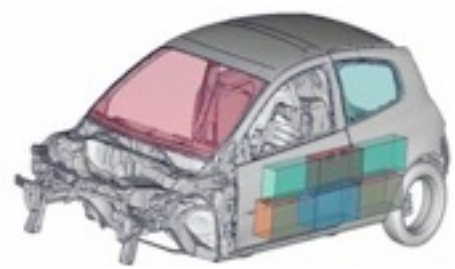
The aim of the presentation is to draw up the 2 approaches and to illustrate them with examples from the powertrain field (internal aerodynamic) and the external field (side mirror and vehicle).

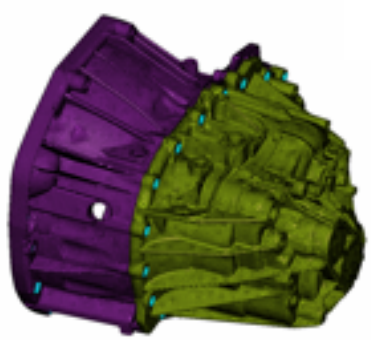
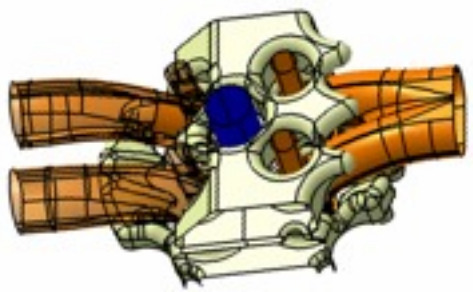
CAD-based optimisation methods with application to the automotive industry

Maryan Sidorkiewicz
RENAULT / DREAM / DTAA / Groupe Optimisation

THE OPTIMISATION TEAM IN RENAULT

- **10 engineers within the «DREAM»**
  - Direction de la Recherche, Etudes Avancées, Matériaux
  - 742 people
  - 203 patents/year
  - 5 stategic axes : environment, security, life on board, dynamic performance, competitivity
- **Main missions**
  - to develop new numerical optimisation methodologies
  - to integrate them into the Product Development Process (PDP)



SCIENTIFIC PARTNERSHIP

- **DICE 2009**
  - Deep Inside Computer Experiment
  - Mines de St-Etienne, TOTAL, Renault, EDF, ONERA
- **OMD 2009**
  - Optimisation Multi-disciplinaire
  - Dassault Aviation, Astrium, Renault, ENSM-SE, ECP, INRIA, etc ...
- **OPSIM 2010**
  - Optimisation de SIMulations pour la conception
  - ALSTOM, Renault, BULL,ESI, ECP, Eurodecision, ...
- **FLOWHEAD 2011**
  - Fluid Optimisation Workflows for Hightly Effective Auto. Dev. Processes
  - VW, Renault, Univ QM London, ICON, ESI, CD-adapco, TUB, TUM, ...
- **OMD² 2012**
  - Optimisation Multi-Disciplinaire Distribuée
  - Renault, DIGITEO, CD-adapco, Sirehna, Activeeon, INRIA, UTC, ...
- **CSDL 2012**
  - Complex System Design Lab
  - Dassault, Renault, EADS, CS, BULL, Alcatel, ESI, Eurodecision, ...

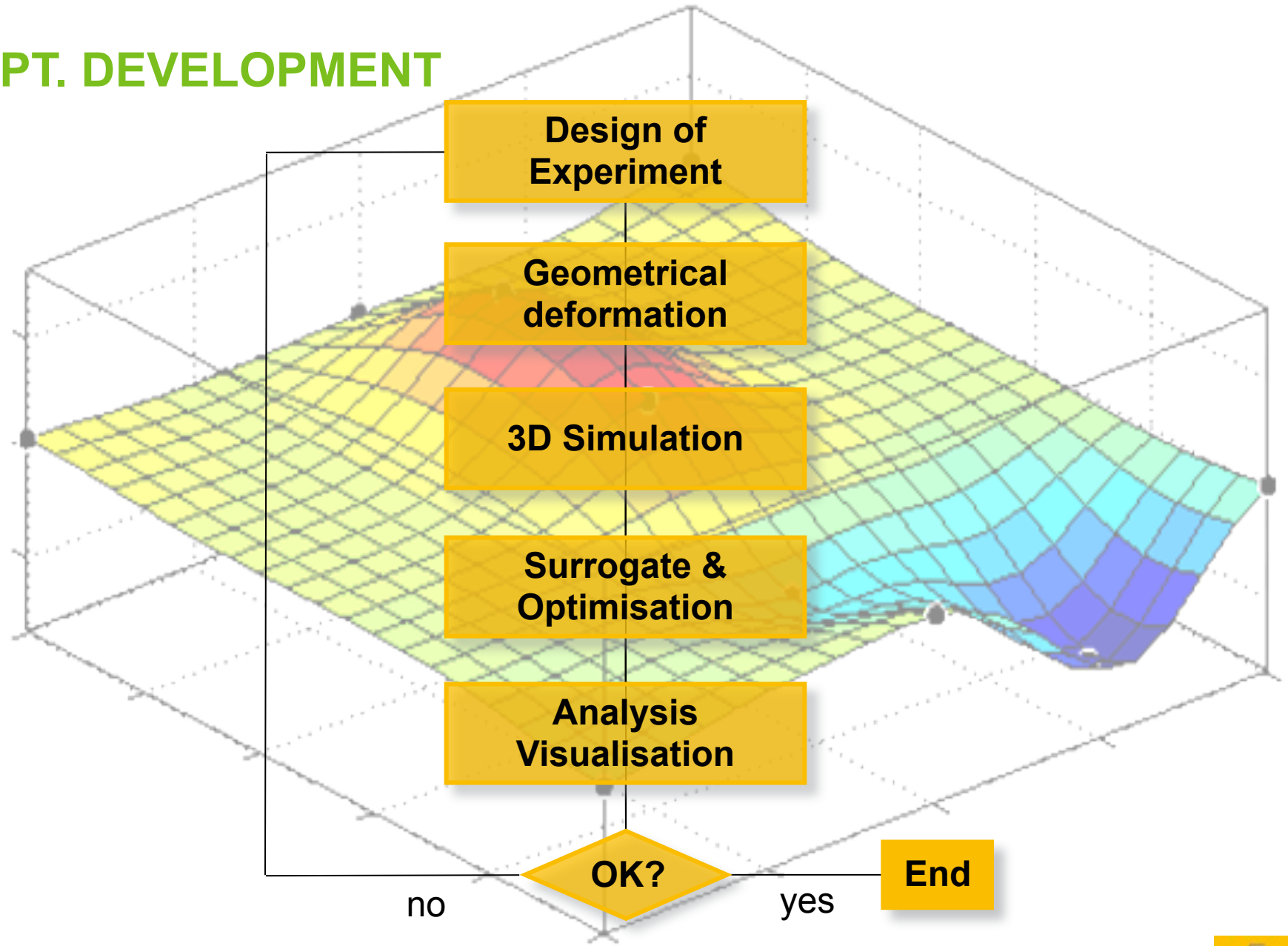
MOTIVATIONS

- **Economical / Environmental context**
  - Growth of Low Cost Countries
  - CO2 and EURO VI regulation

- **Role of the numerical optimisation**
  - To accelerate the developments / reduce the costs (testbed suppression)
  - To provide a Decision Support (Multidisciplinarity Optimisation)
  - To innovate by improving the benefit for the custumer (mass, emissions , security, comfort)

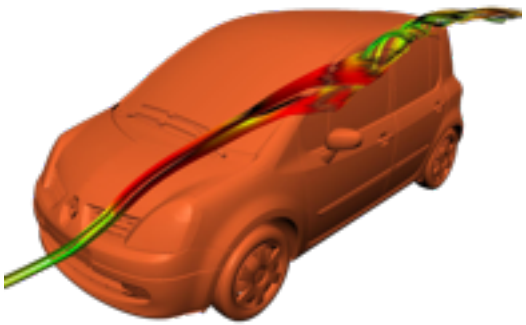
⇒ Improve the competitiveness of the industry

OPT. DEVELOPMENT

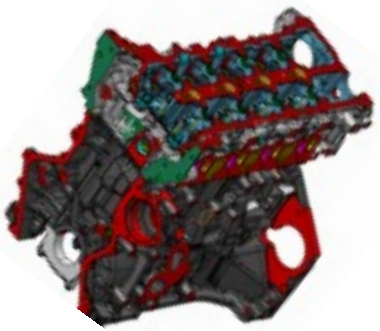


OVERVIEW OF APPLICATIONS

crash
(1j / 16CPU / 5Mcells)



aerodynamic
(3j / 128CPU / 50Mcells)

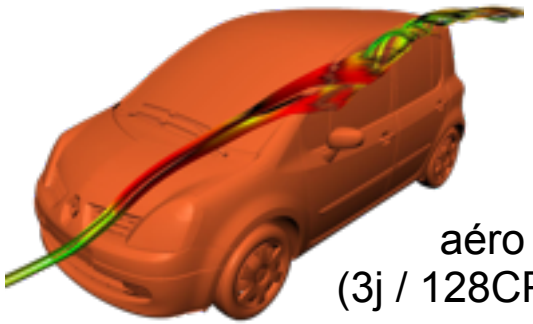


powertrain
(1j / 16CPU / 2Mcells)

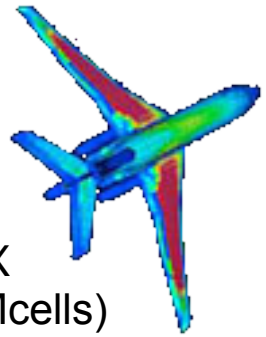
- **25% of the HPC Renault devoted to the numerical optimisation**

CFD AND HPC

- **Computation models not as heavy as the aeronautic, climatology, ... fields**



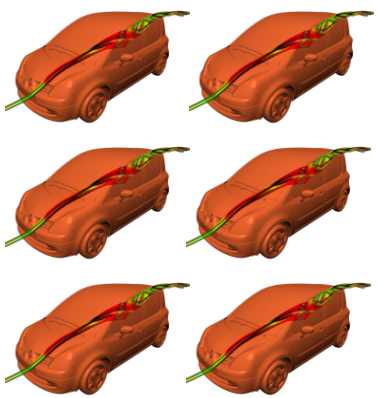
aéro MODUS
(3j / 128CPU / 50Mcells)

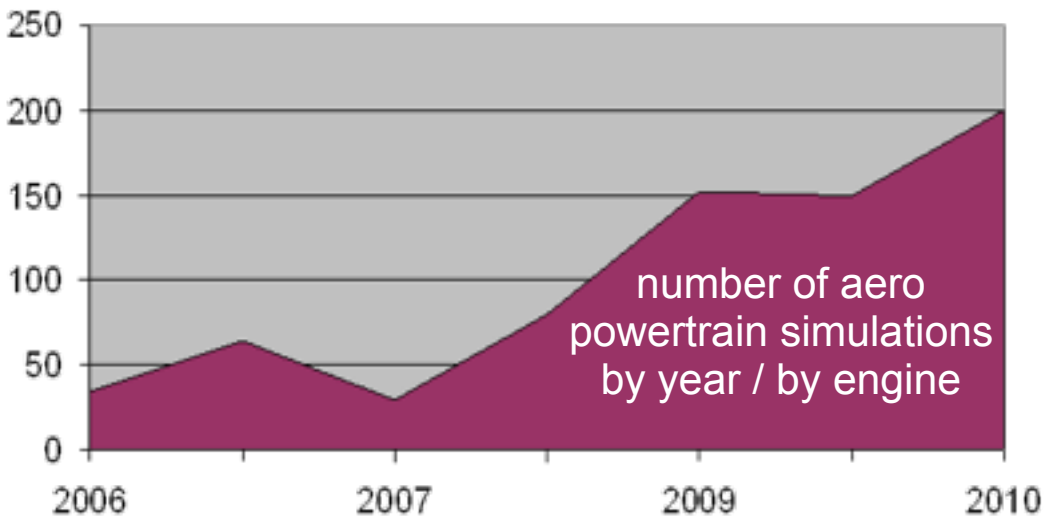


aéro Falcon 7X
(8j / 200CPU / 115Mcells)

Dassault Aviation courtesy

- **But the HPC need increases with optimisation loops**





M.Sidorkiewicz - Bulgaria, Varna Workshop 22/24 Sept. 2010

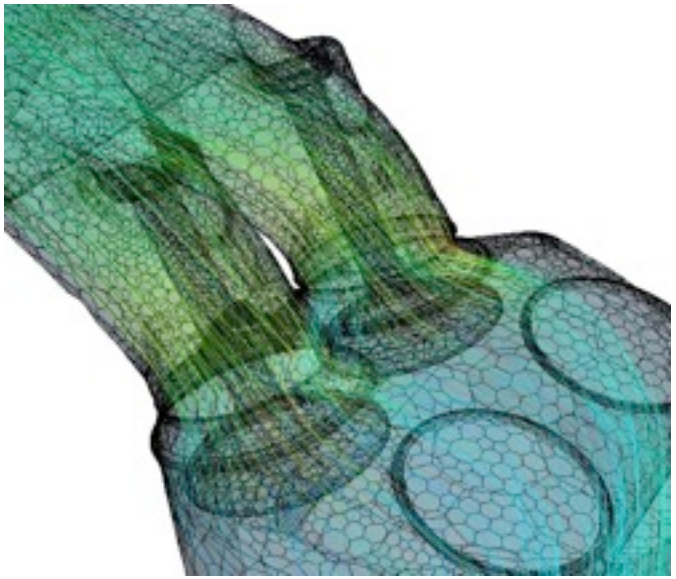
FOCUS ON THE CFD OPTIMISATION (1/2)

- **Environmental issues**
  - Reduce the CO2 emissions and fuel consumption
  - Preserve the quality of the cabin air

- **What fields of application**
  - external aerodynamic
  - engine
  - exhaust line
  - HVAC

- **Some figures**
  - -3% SCX ⇒ -1g CO_2 / km
  - +/-1mm of manufacturing dispersion of the cylinderhead ⇒ -20% of performance (worst case)

FOCUS ON THE CFD OPTIMISATION (2/2)



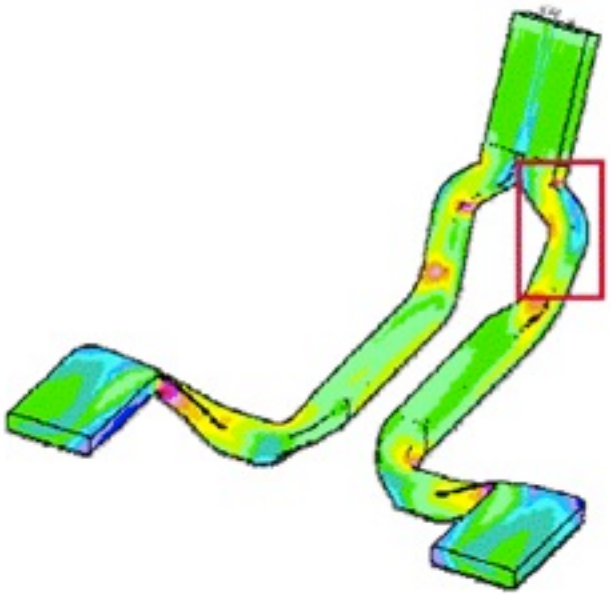
- **Main difficulties**
  - Lack of precision of the CFD simulation
  - Lack of automation
  - Expensive cost of HPC licences
  - Lack of CAD-based geometries
  - Mainly local optimization

- **Research area**
  - Development of optimisation technics with large number of parameters
  - Topological / Shape Optimisation
  - Commercial / Open Source benchmarking
  - Cloud computing

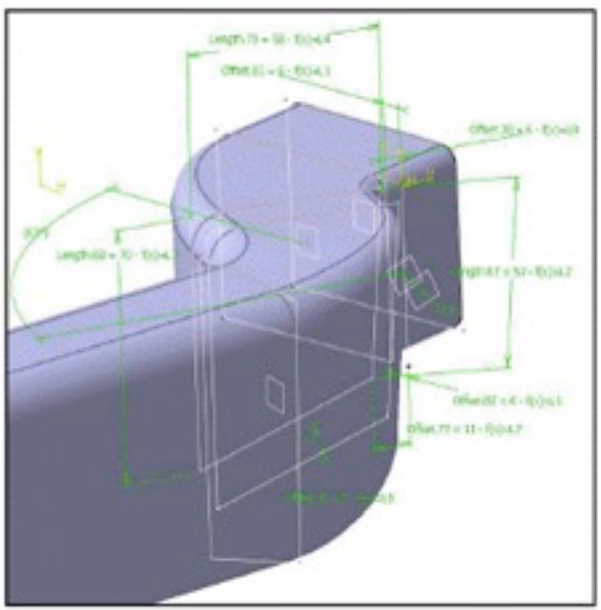
⇒ **collaborative projects : FLOWHEAD, OMD²,...**

WHY CAD-BASED OPTIMISATION

- **Improvement of the CAD sotfwares (reliability, parametrization)**
- **Improvement/automation of the interface CAD/CAE**
- **Seamless integration of the opt. workflow into the PDP (compared to morphing tools)**



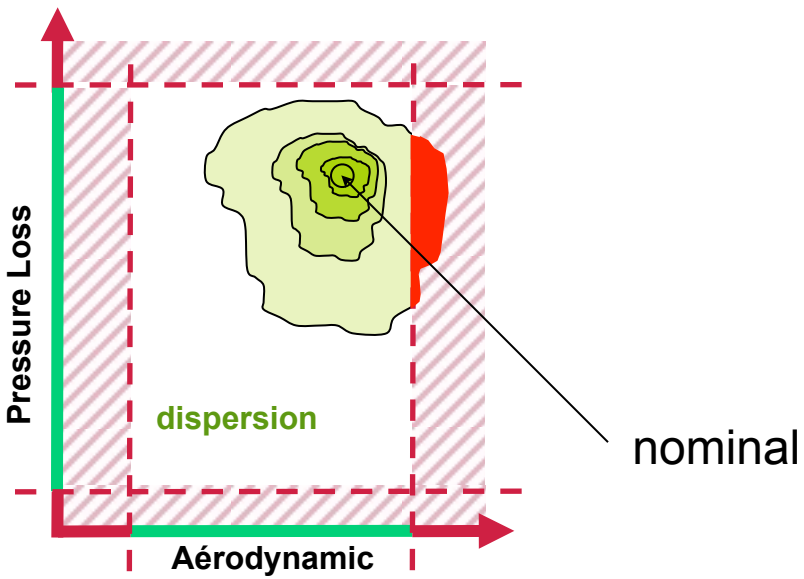
airduct - VW courtesy
FLOWHEAD testcase

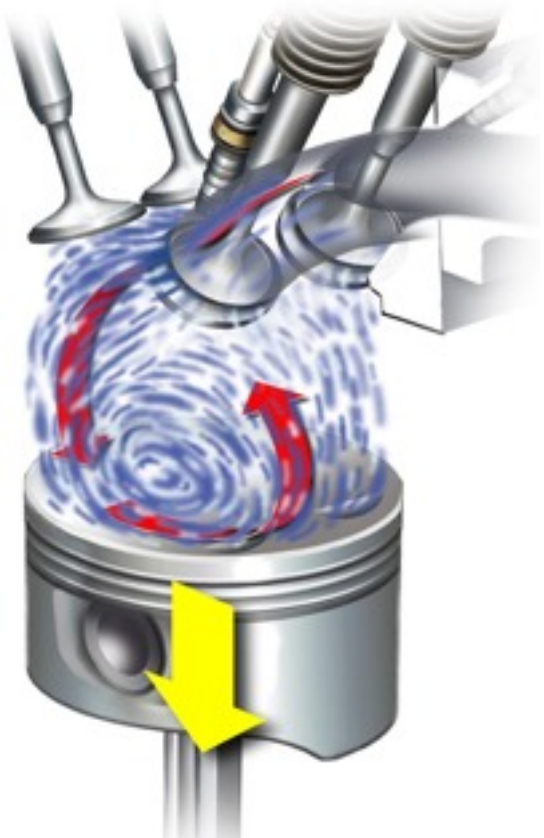


parametric version of the airduct

EXAMPLES OF CURRENT CAD-BASED OPTIMISATION WORKFLOW

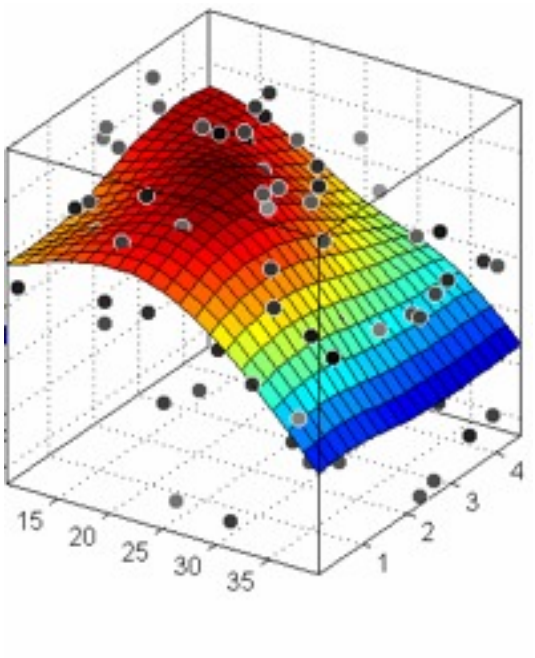
- **Multiobjective and Robust Optimisation of an intake port**
  - Specification of conception for the pressure loss and the turbulence level
  - Aerodynamic robustness evaluation to take into account some manufacturing dispersions
  - Impact on emissions, performances, consumption

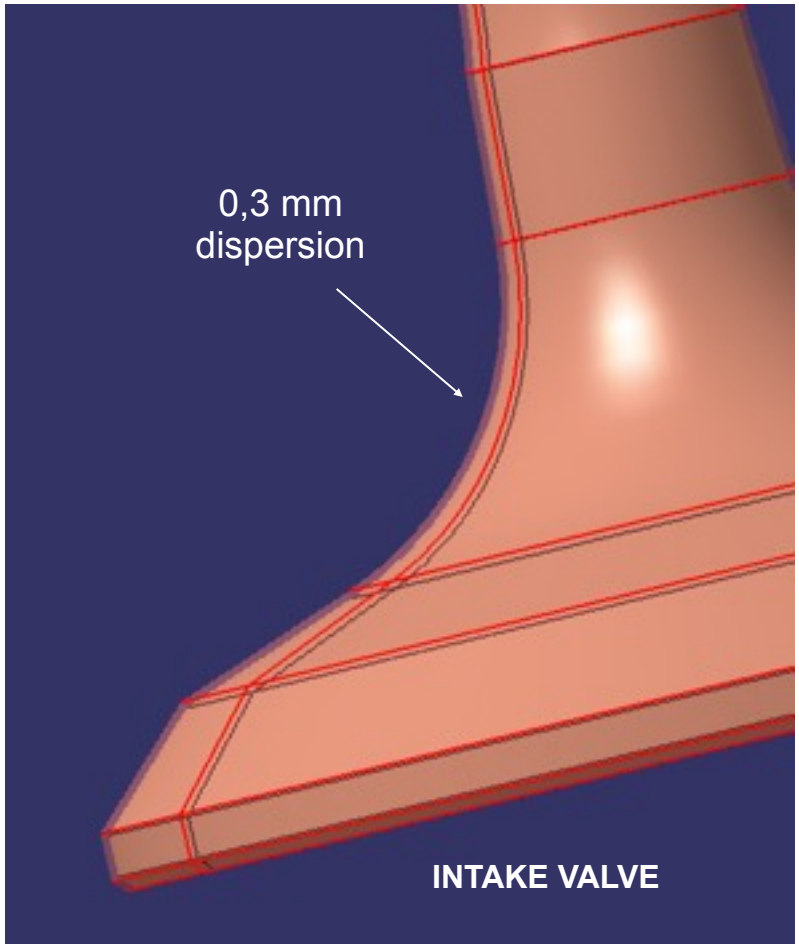




EXAMPLES OF CURRENT CAD-BASED OPTIMISATION WORKFLOW

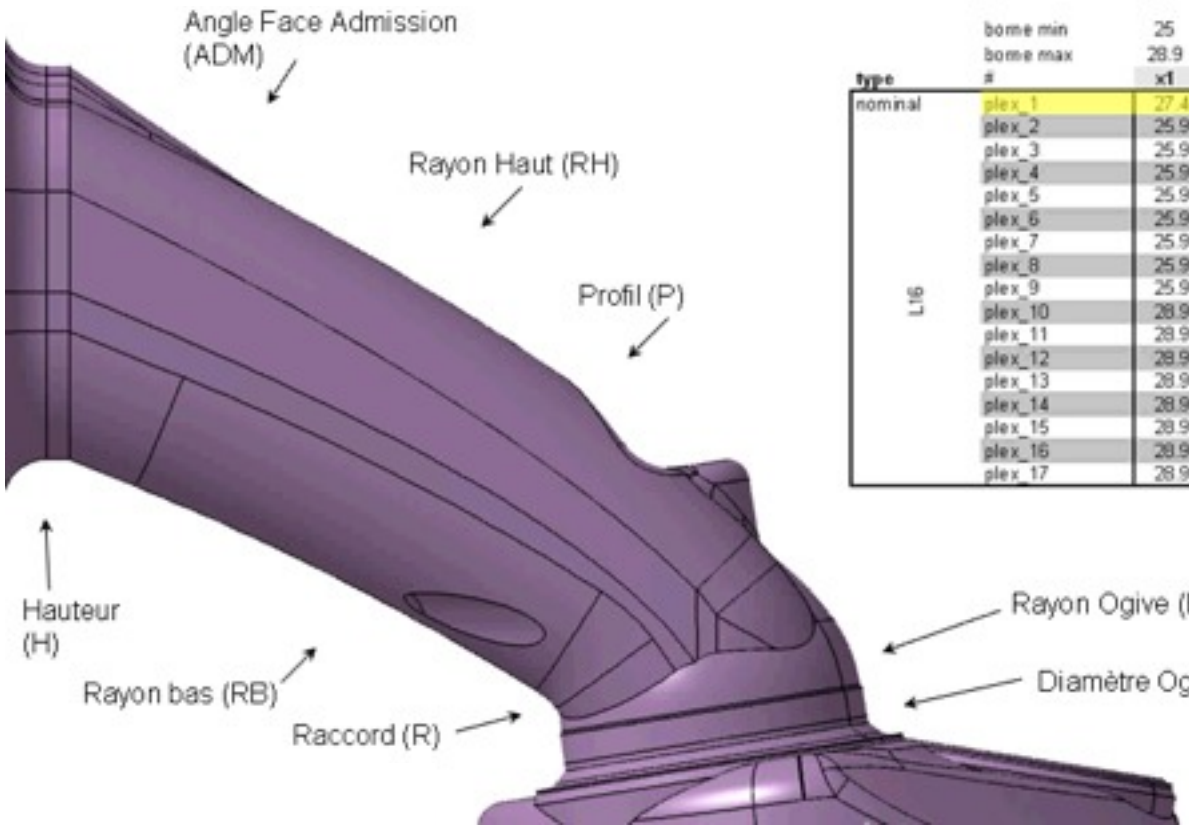
- **Why robust Optimization ?**
  - Very small manufacturing dispersions provide large effects on objectives functions
  - Non linear behavior explains why robust optimization is relevant.





EXAMPLES OF CURRENT CAD-BASED OPTIMISATION WORKFLOW

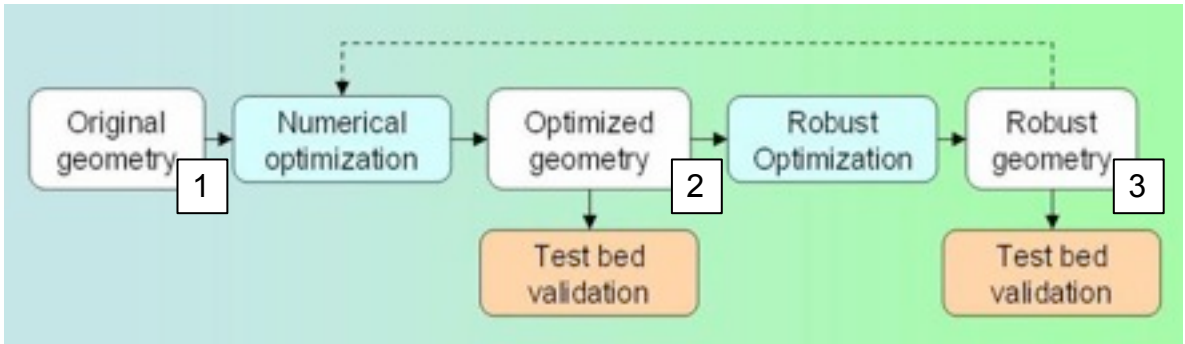
- **Parametric CAD respecting all manufacturing contraints (demolding, curvature, foundry,...)**



type	id.	DO	RO	RH	RB	H	ADM	P	R
	borne min	25	8	1	9.5	68	57	12	15
	borne max	28.9	20	12	13.5	72	90	25	41.5
	#	x1	x2	x3	x4	x5	x6	x7	x8
nominal	plex_1	27.4	14	8	11.25	70	73.5	18.5	28.25
L16	plex_2	25.9	8	4	9.5	68	57	12	15
	plex_3	25.9	8	4	9.5	72	90	25	41.5
	plex_4	25.9	8	12	13	68	57	25	41.5
	plex_5	25.9	8	12	13	72	90	12	15
	plex_6	25.9	20	4	13	68	90	12	41.5
	plex_7	25.9	20	4	13	72	57	25	15
	plex_8	25.9	20	12	9.5	68	90	25	15
	plex_9	25.9	20	12	9.5	72	57	12	41.5
	plex_10	28.9	8	4	13	68	90	25	15
	plex_11	28.9	8	4	13	72	57	12	41.5
	plex_12	28.9	8	12	9.5	68	90	12	41.5
	plex_13	28.9	8	12	9.5	72	57	25	15
	plex_14	28.9	20	4	9.5	68	57	25	41.5
	plex_15	28.9	20	4	9.5	72	90	12	15
	plex_16	28.9	20	12	13	68	57	12	15
	plex_17	28.9	20	12	13	72	90	25	41.5

EXAMPLES OF CURRENT CAD-BASED OPTIMISATION WORKFLOW

- **3 steps : First design input / Project iterations / Final validation**



- **Full automated pre/post-treatment, mesh, calculation**

EXAMPLES OF CURRENT CAD-BASED OPTIMISATION WORKFLOW

- **External Aerodynamic Optimisation**
  - drag ⇒CO2
  - brake and engine cooling
  - aerodynamics forces
  - dynamic stability of the vehicle

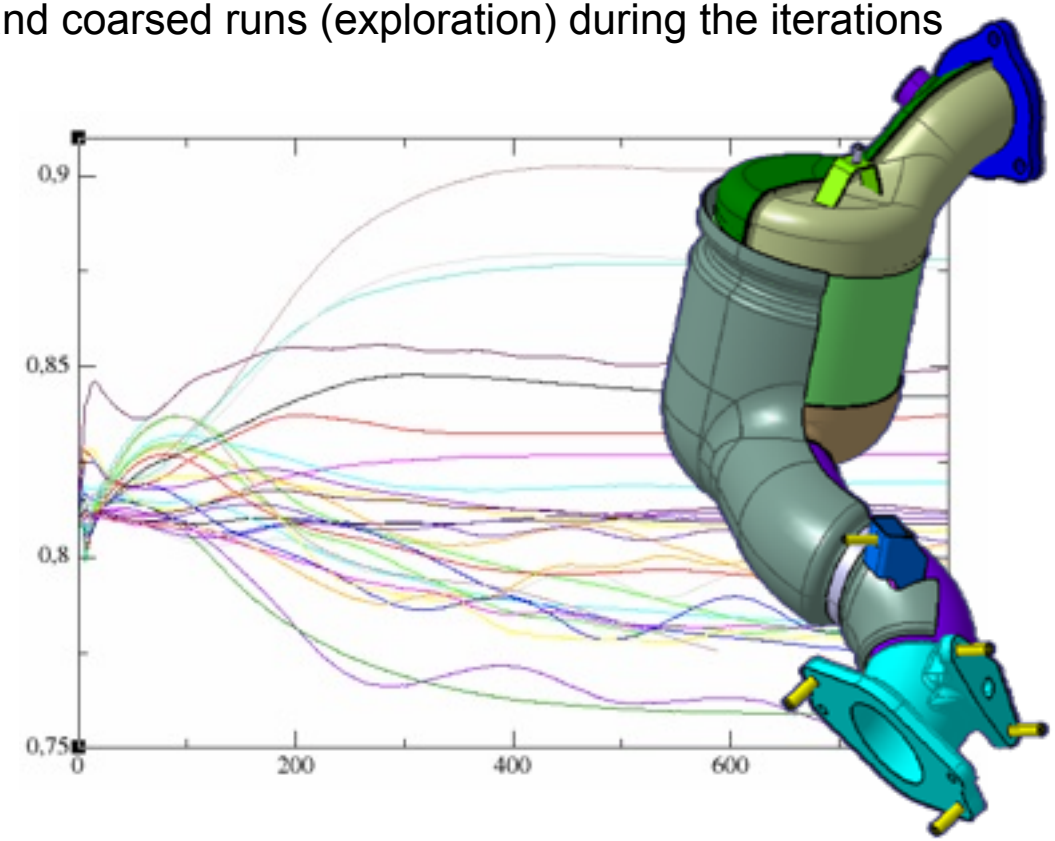
- **Numerical challenges**
  - Sensibilities and interactions between CAD parameters (roller, wing, wheels, etc) by DoE
  - DES simulation : Target = 0,2% of difference between wind tunnel and simulation
  - Global optimisation on a complete vehicle

- **⇒ Petaflop requirement if no Adj.-based optimisation is available**

EXAMPLES OF CURRENT CAD-BASED OPTIMISATION WORKFLOW

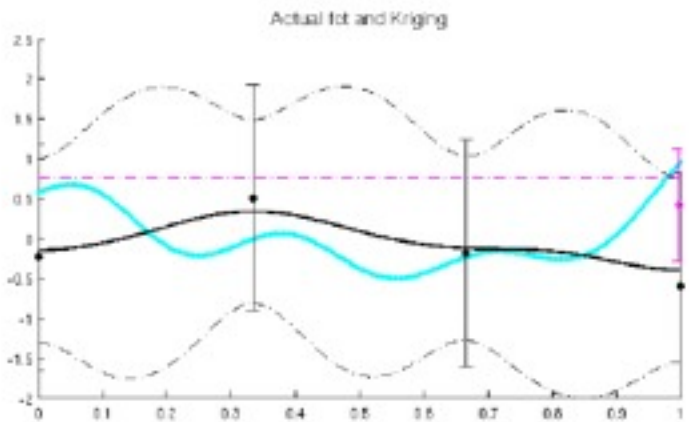
- **Global optimisation algorithm with partially converged simulations**
  - To reduce the calculation time in order to explore the global design space
  - To mix fine runs (optimisation) and coarsed runs (exploration) during the iterations
  - Better use of HPC

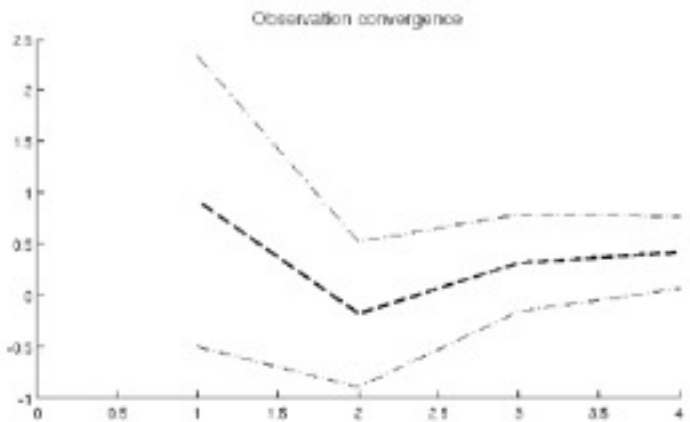
- **References**
  - 2-levels multifidelity opt (DAKOTA, Alexandrov)
  - Global optimisation based on noisy evaluations (EGO, J.Ville-monteix)
  - Partial Convergence Strategies (Forrester)

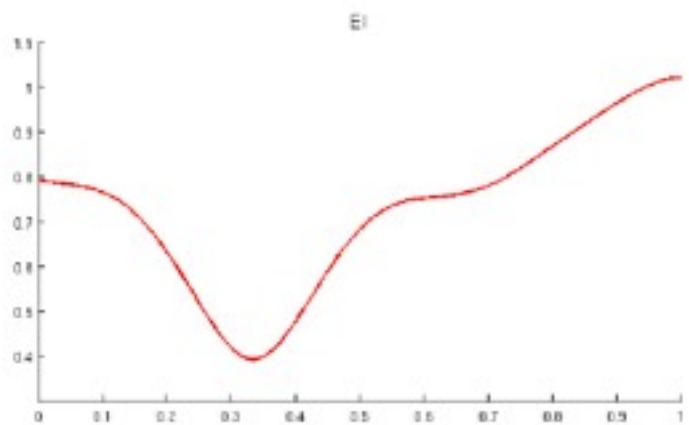


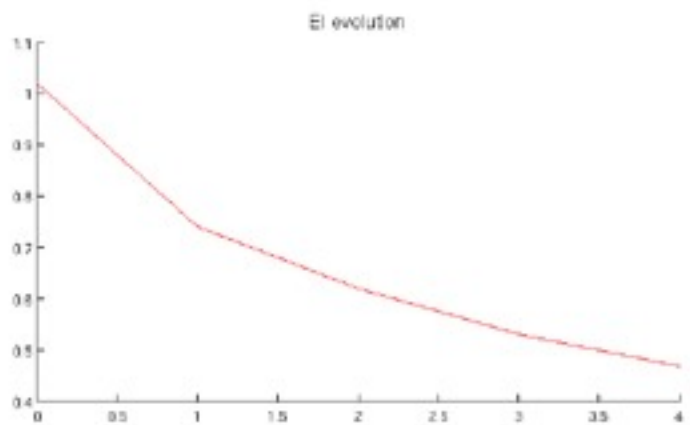
Iteration 1

4 steps used / 92 remaining



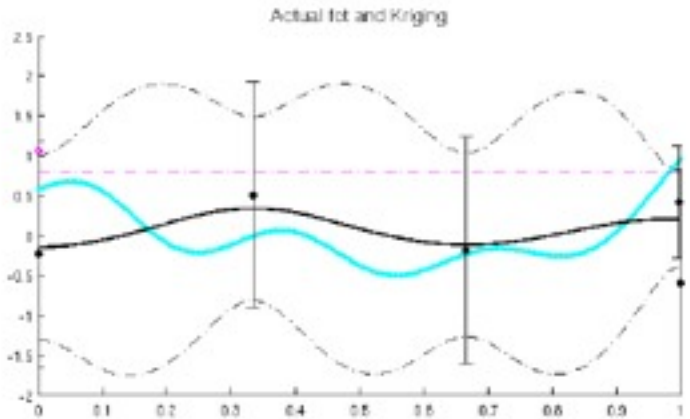


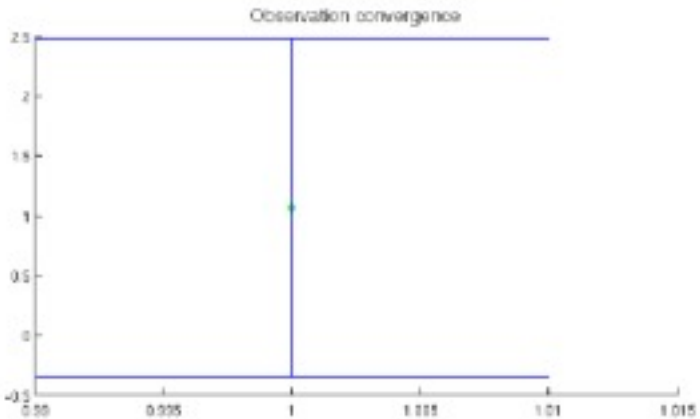


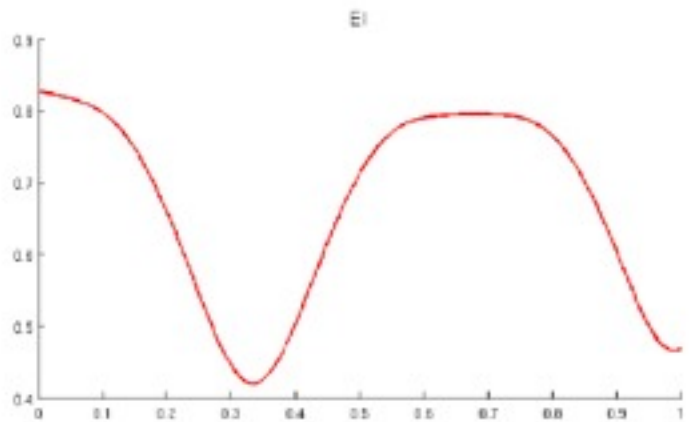


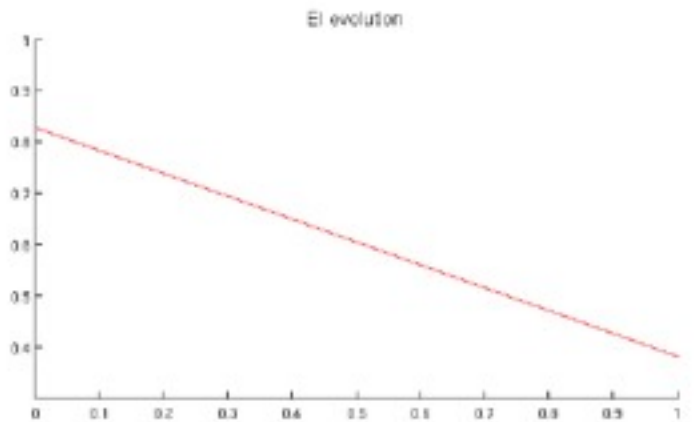
Iteration 2

1 step used / 91 remaining



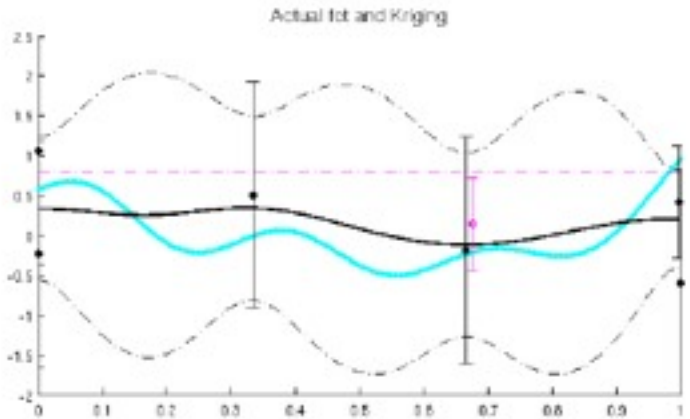


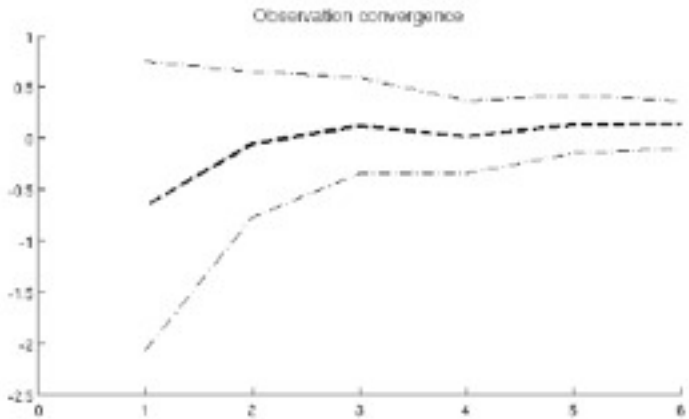


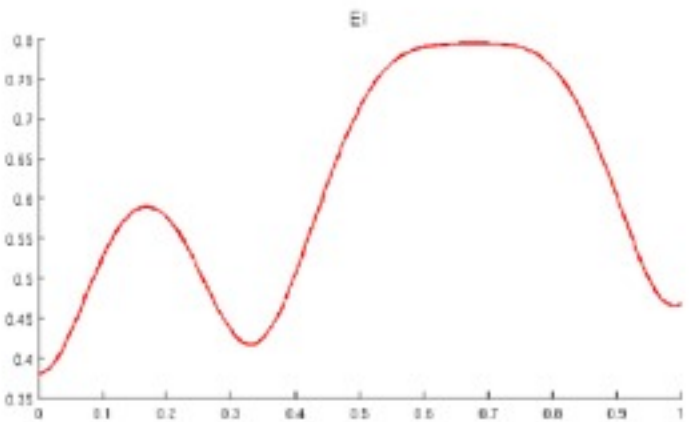


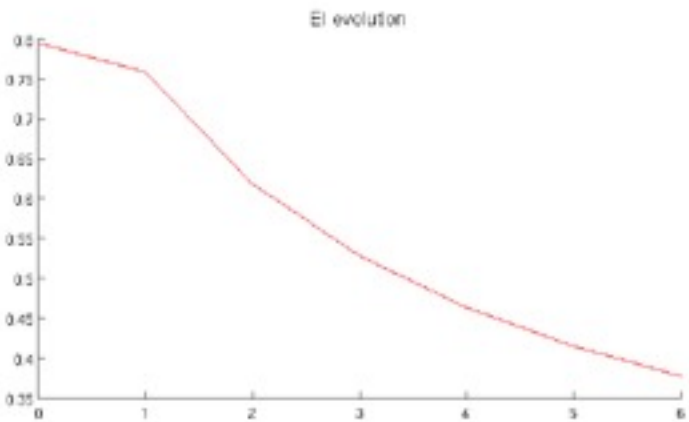
Iteration 3

6 steps used / 85 remaining



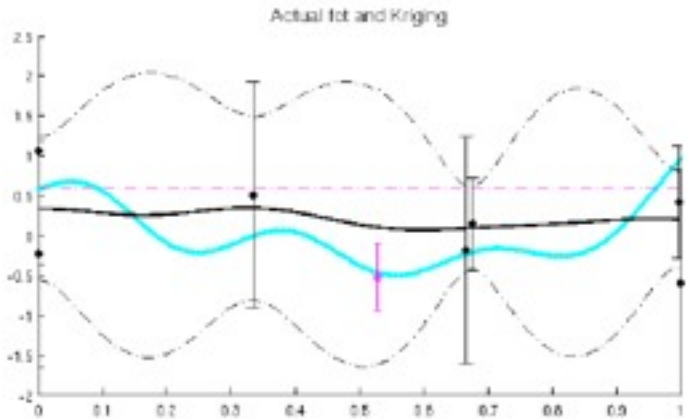


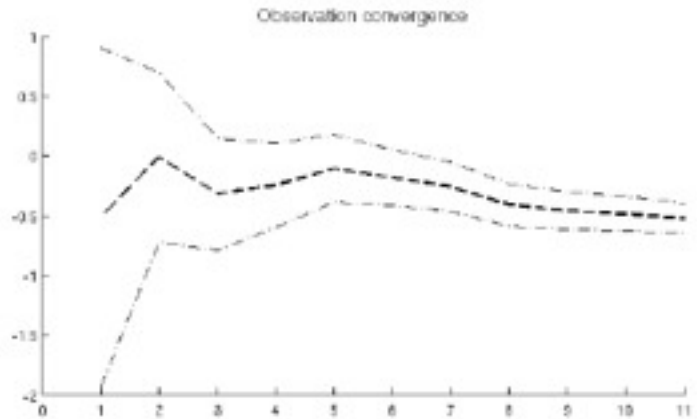


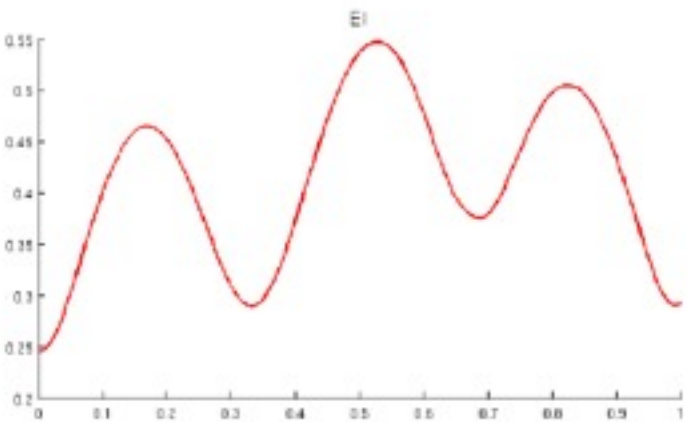


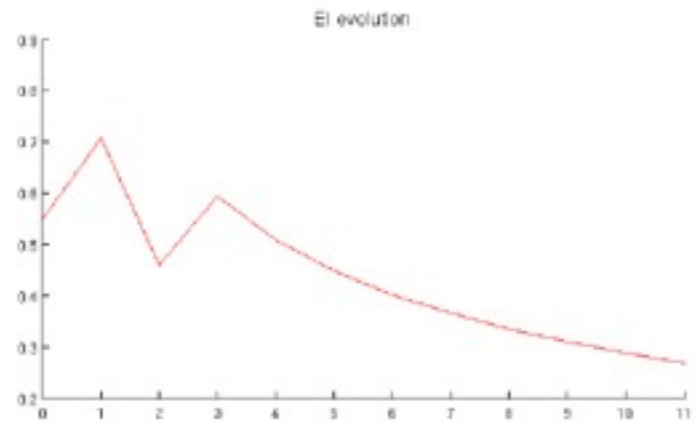
Iteration 4

11 steps used / 74 remaining



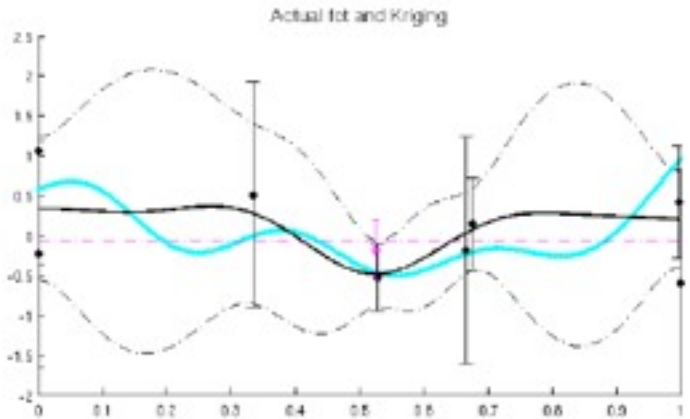


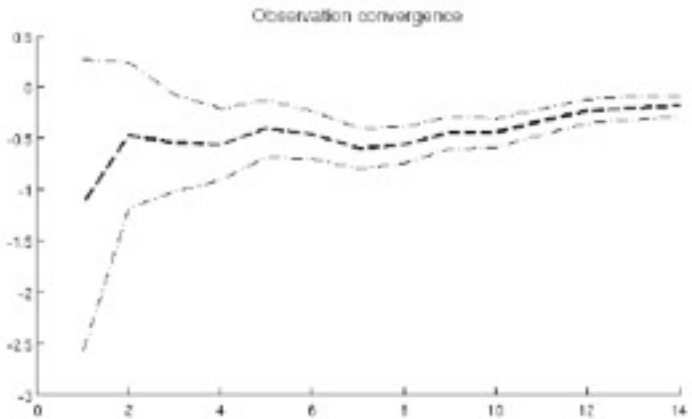


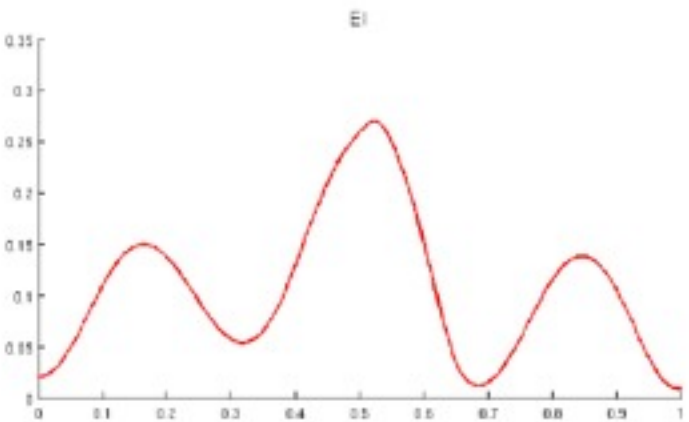


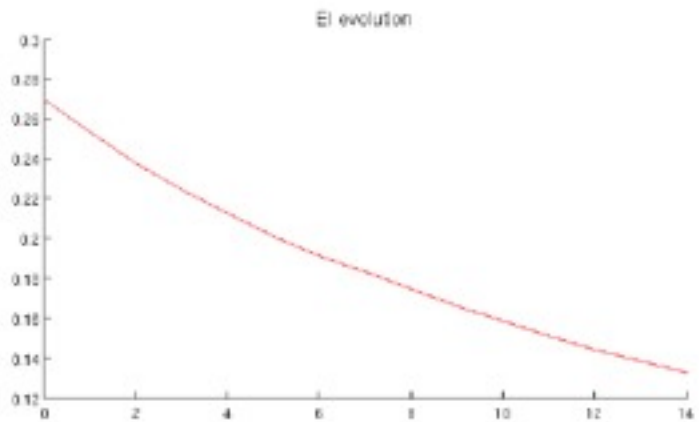
Iteration 5

14 steps used / 60 remaining



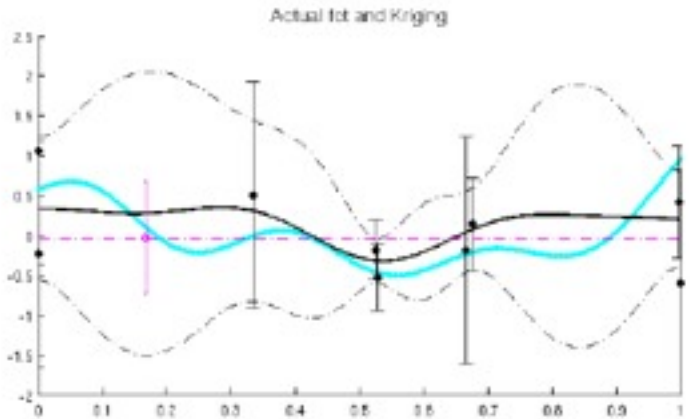


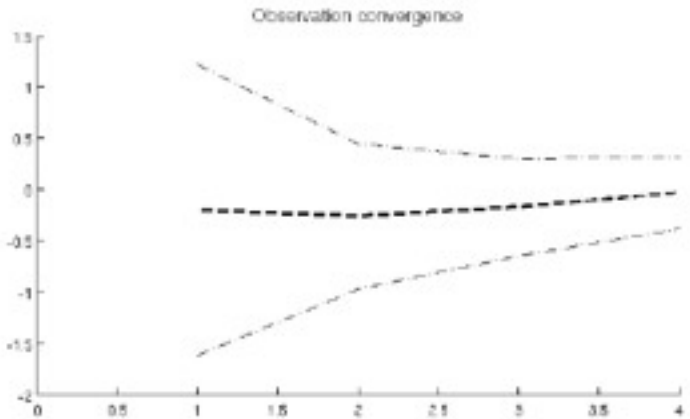


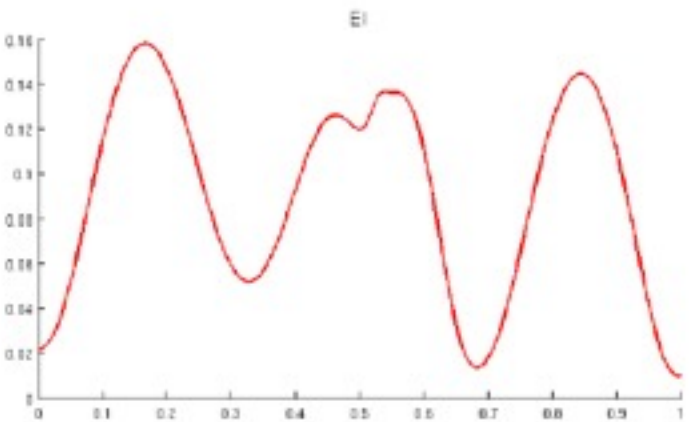


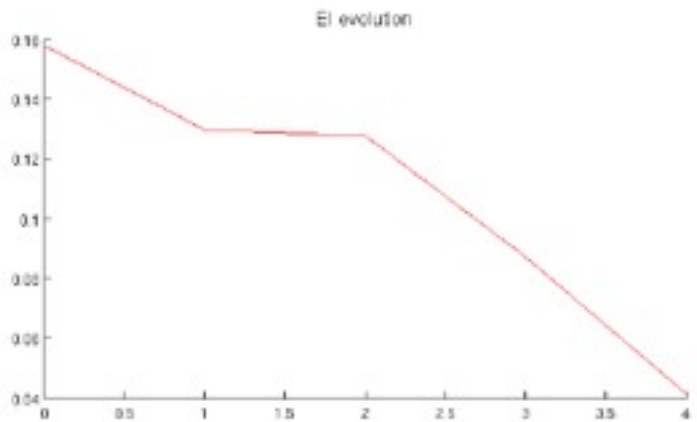
Iteration 6

4 steps used / 56 remaining



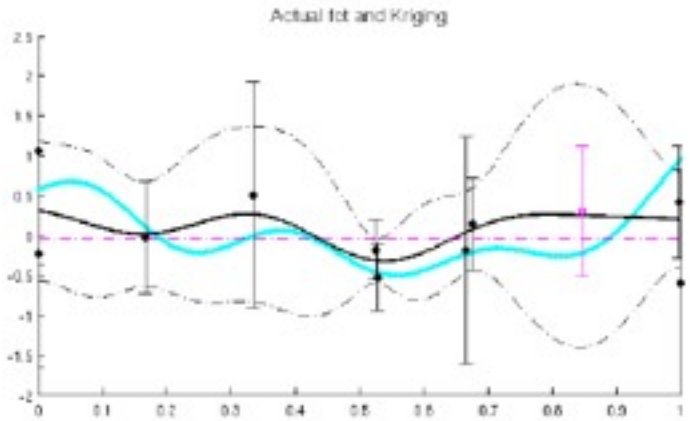


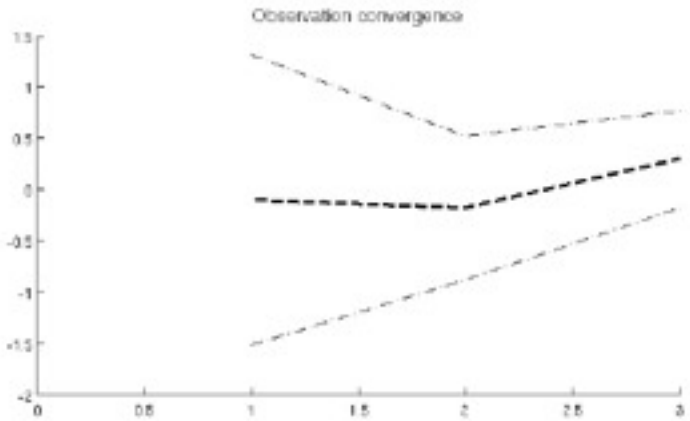


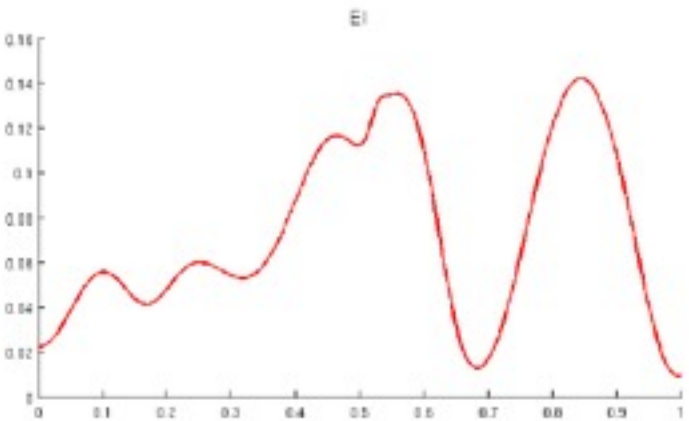


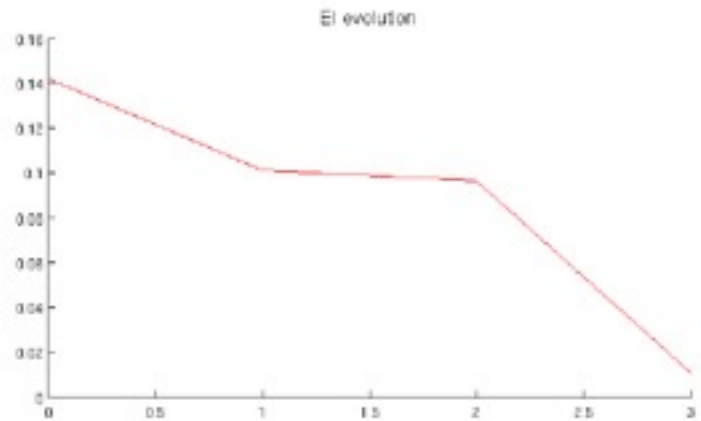
Iteration 7

3 steps used / 53 remaining



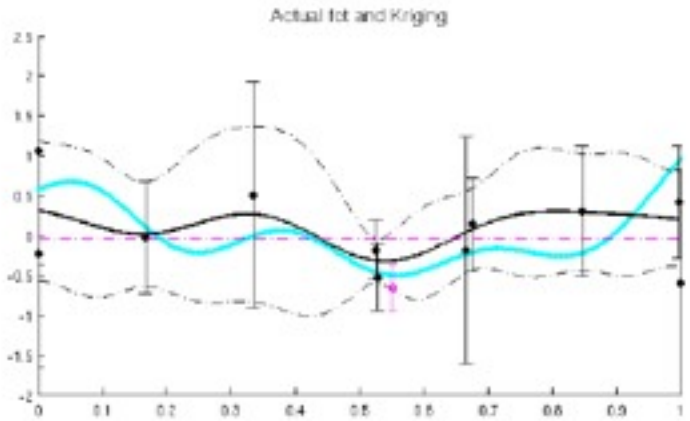


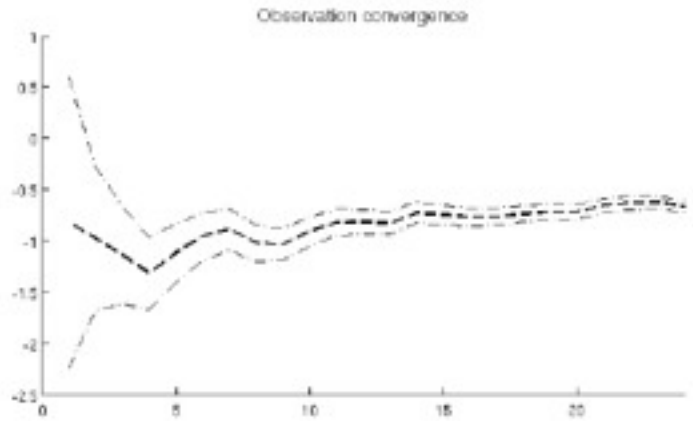


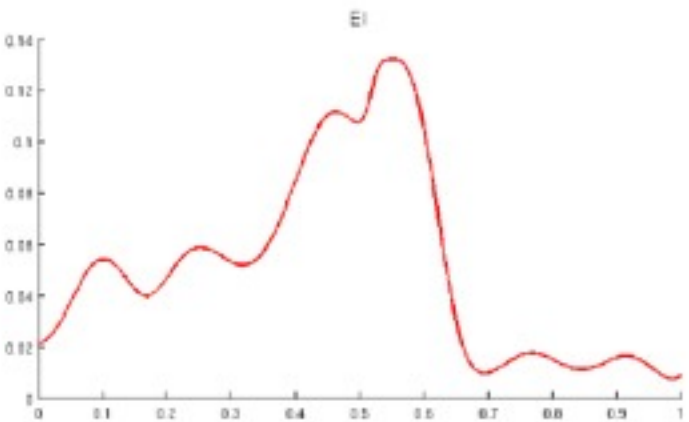


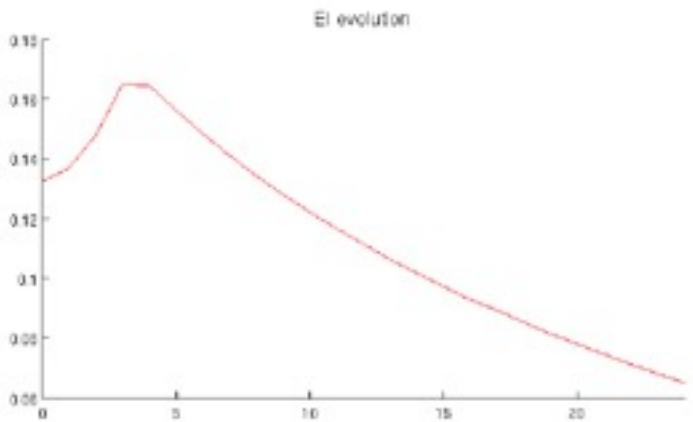
Iteration 8

22 steps used / 29 remaining



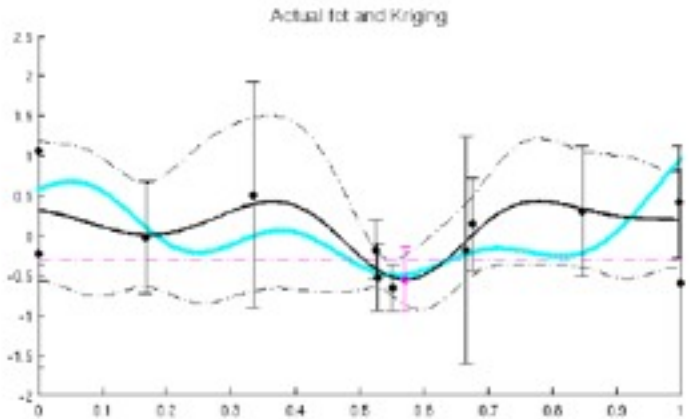


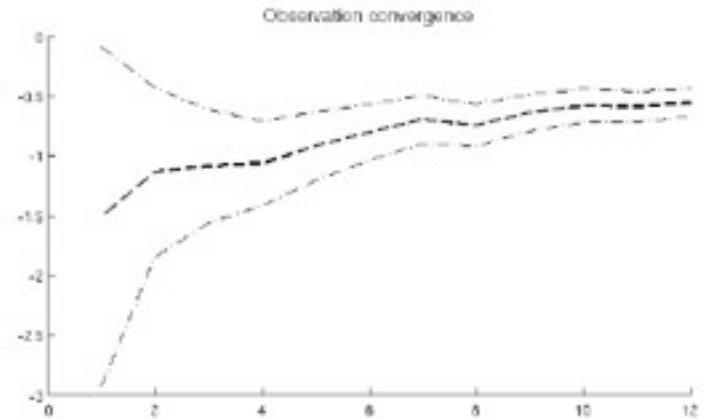


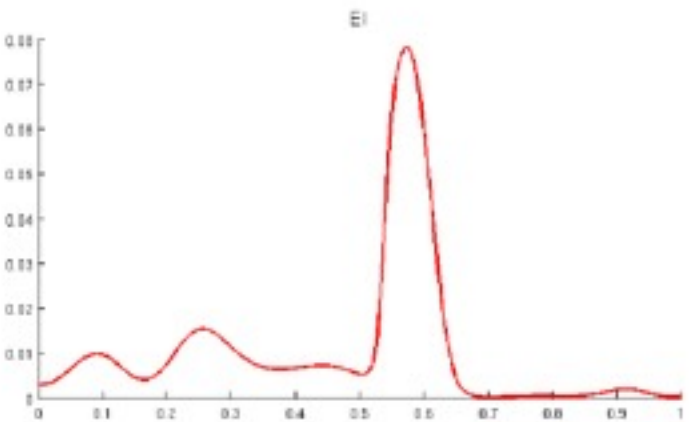


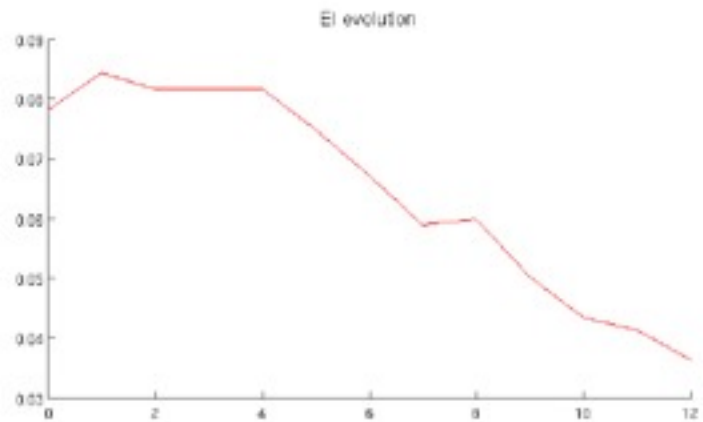
Iteration 9

12 steps used / 17 remaining



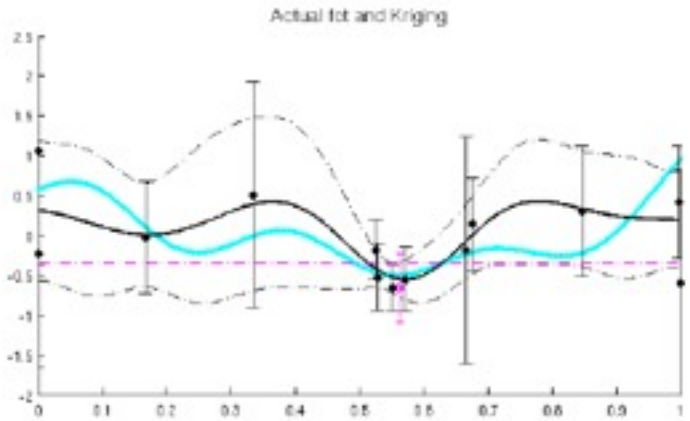


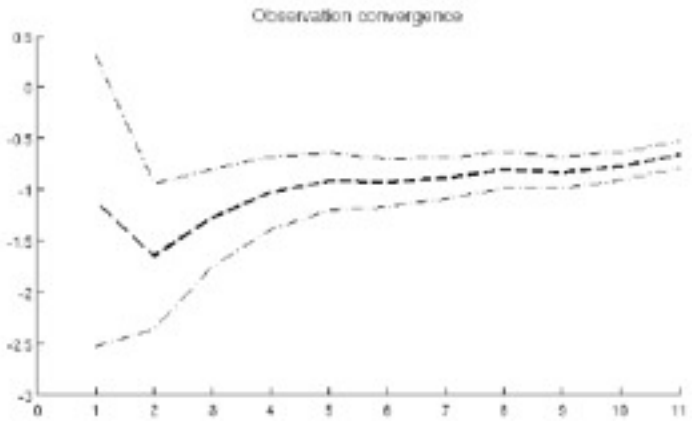


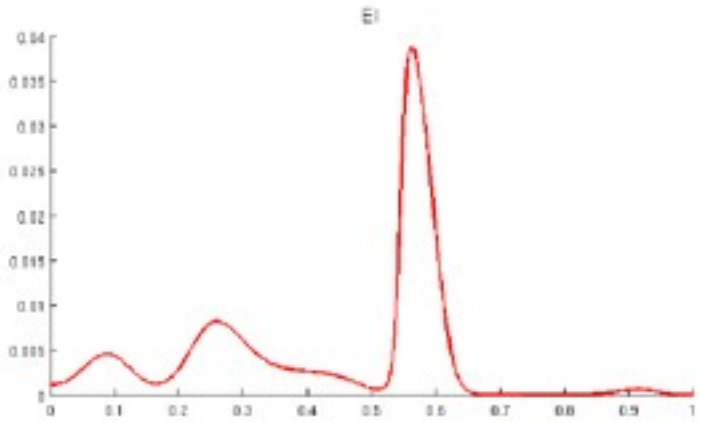


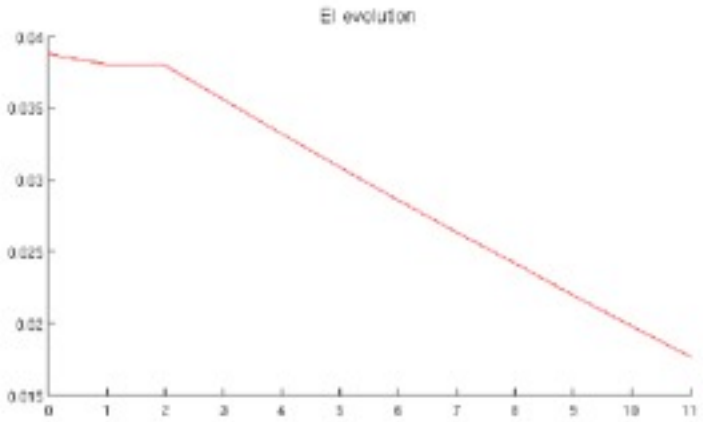
Iteration 10

11 steps used / 6 remaining



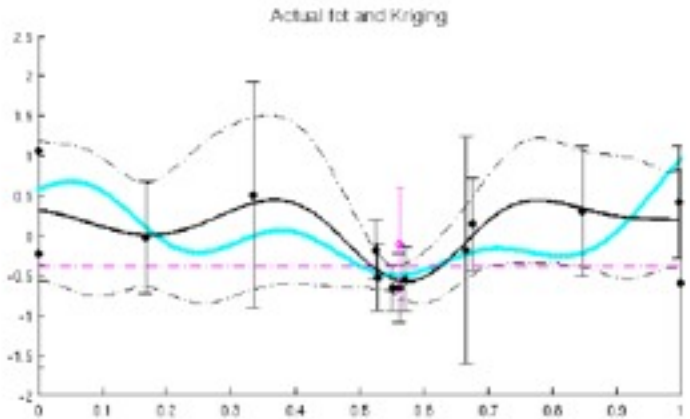


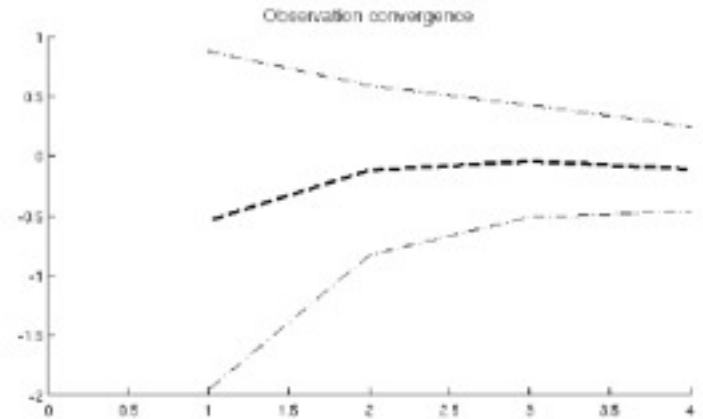


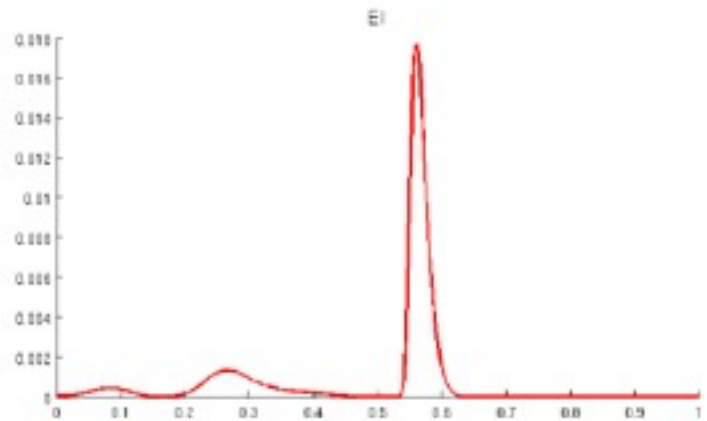


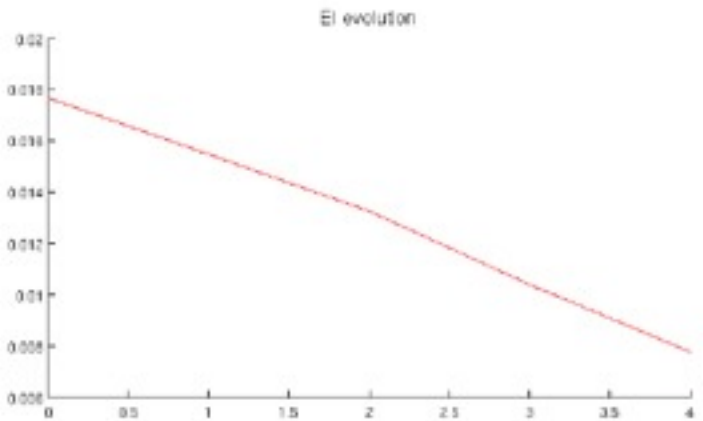
Iteration 11

4 steps used / 2 remaining



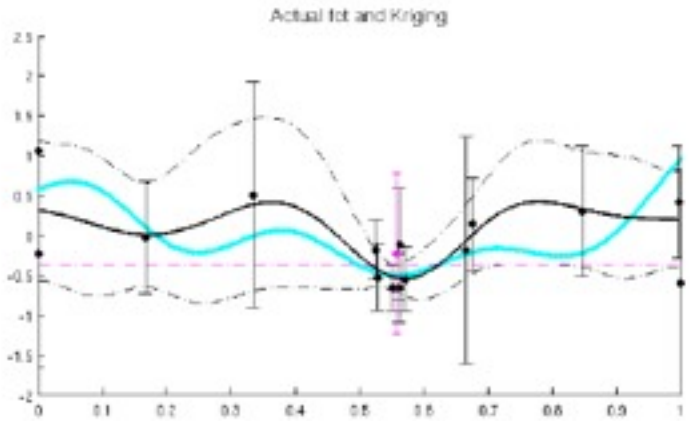


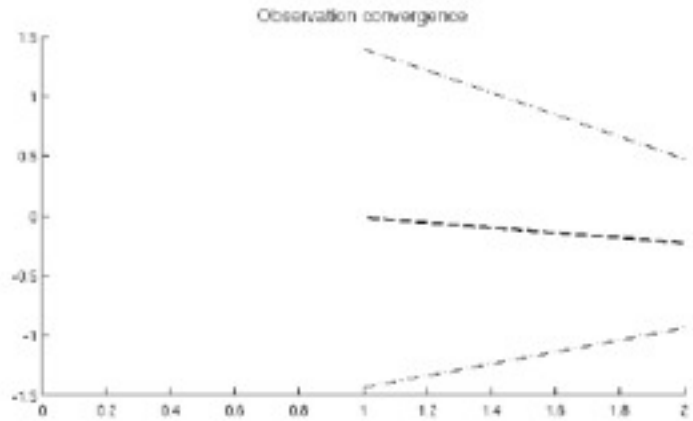


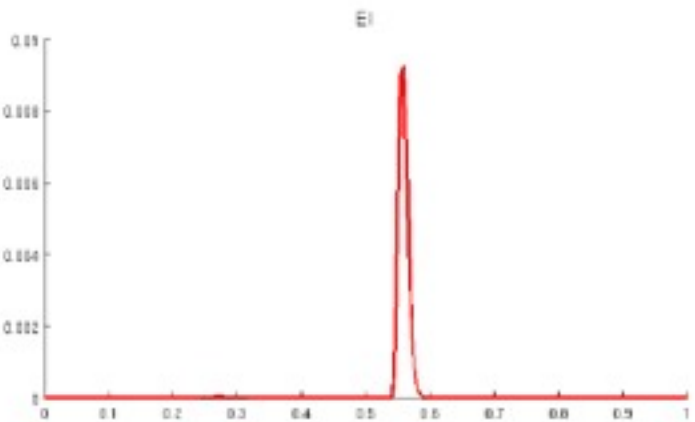


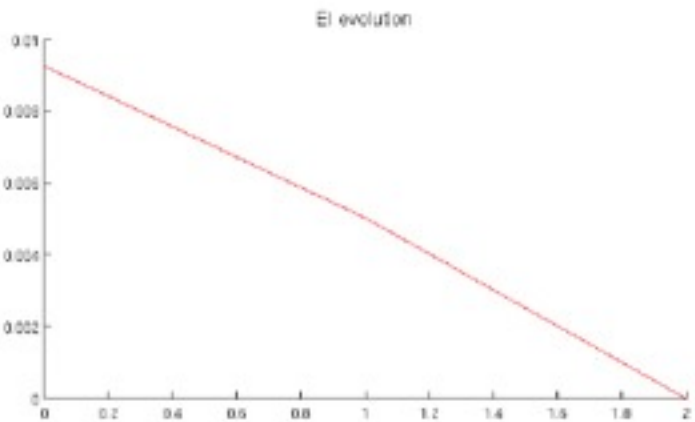
Iteration 12

2 steps used / 0 remaining

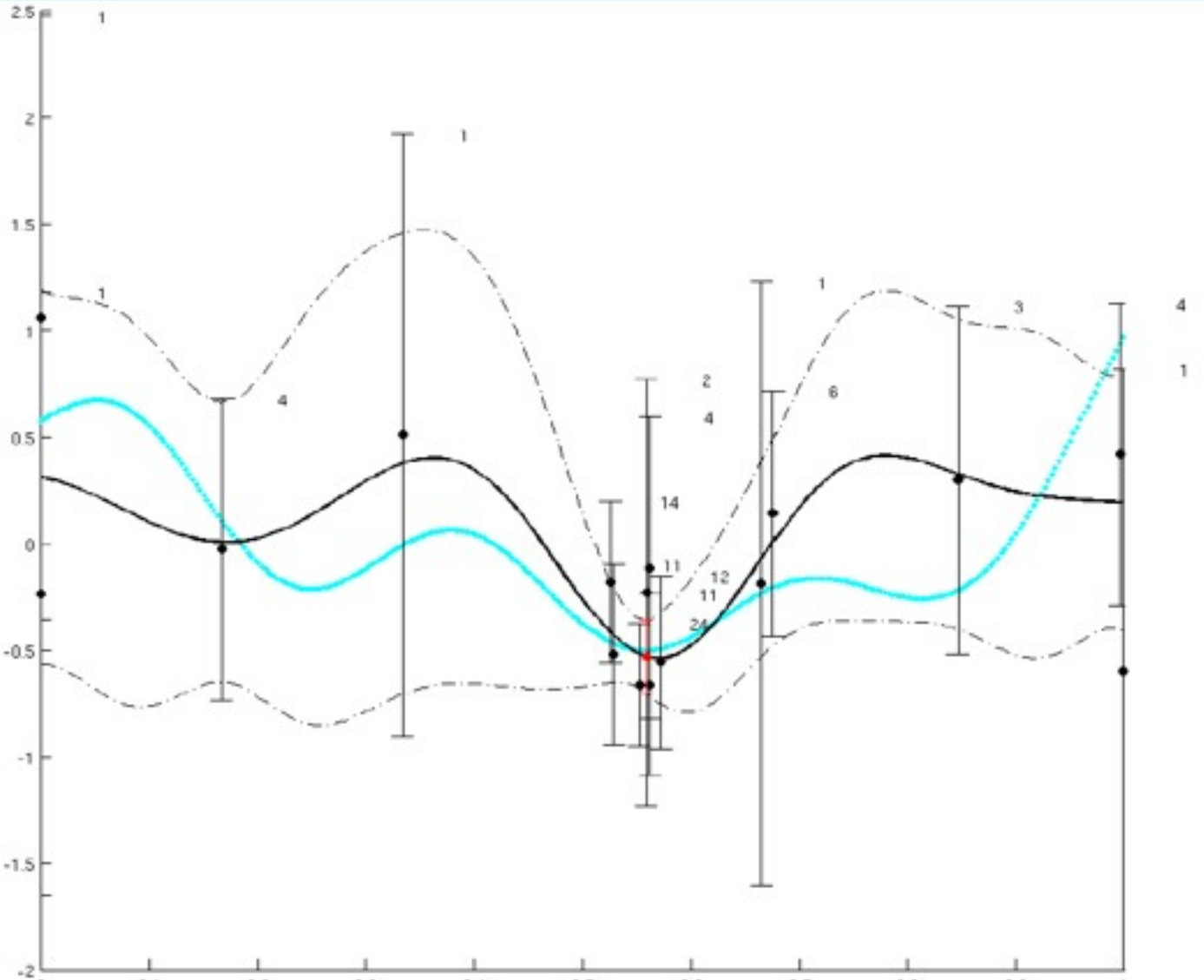








Final DOE and best point



CONCLUSION AND OUTLOOK

- **HPC generalization**
  - To improve performance and precision
  - To reduce the industrial development time

- **Focus of research**
  - 3D CAD parametric modelling
  - Distributed Optimisation
  - Automation of the numerical workflow

- **Outlook**
  - Assessment of adjoint-based optimisation on industrial testcases
  - Integration of the CFD optimisation workflow into the CAD-oriented PDP