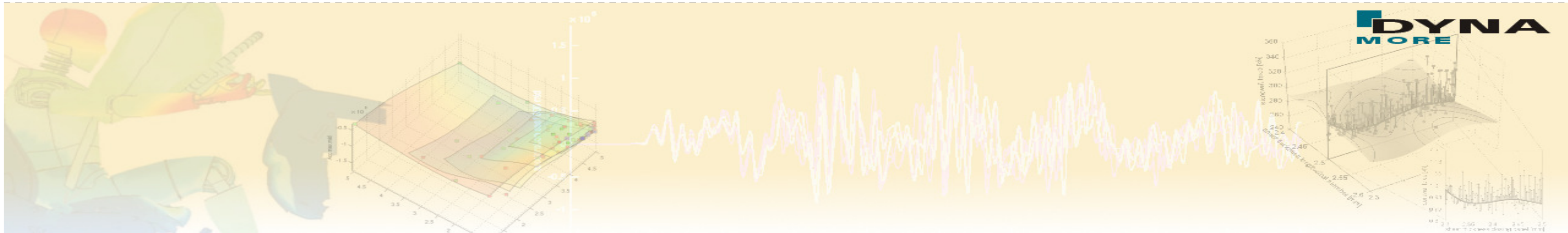

Optimization and Robustness Studies with LS-OPT - New Developments in V4.1

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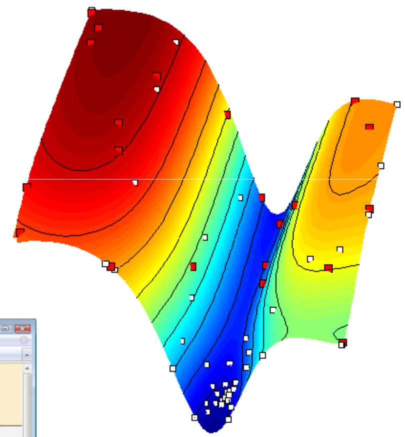
DYNAmore GmbH
Germany
http://www.dynamore.de

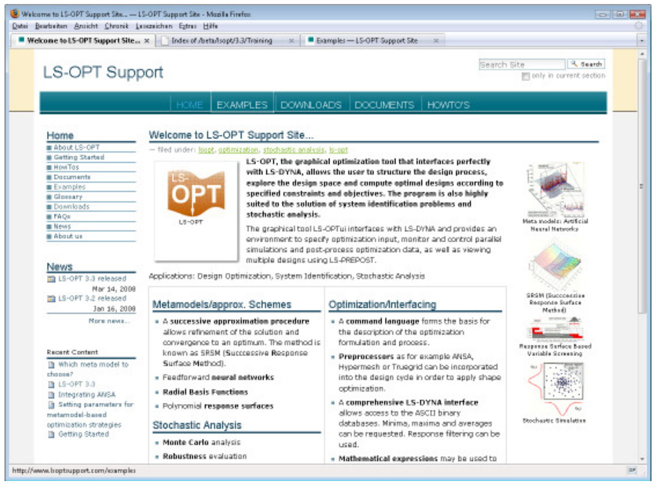
Overview

- Introduction to LS-OPT
- Application Examples of Automotive Industry
  - *Multi-Load Case Optimization of an Adaptive Restraint System*
  - *Multi-Objective Optimization of a Crash Management System*
  - *Reliability Optimization of a Metal Forming Process*
- New Features in Version 4.1

➔ About LS-OPT

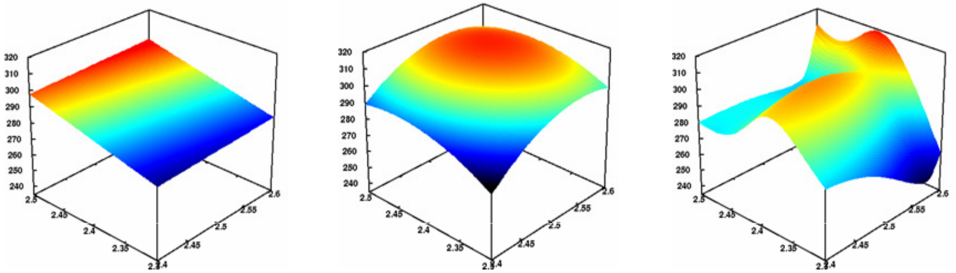
- LS-OPT can be linked to any simulation code – stand alone optimization software, but perfect suitable with LS-DYNA
- Two main products LS-OPT and LS-OPT/Topology
- Current production version is LS-OPT 4.0 – Version 4.1 beta is available
- LS-OPT Support web page -> www.lsoptsupport.com
  - *Download of Executables*
  - *Tutorials*
  - *HowTos / FAQs*
  - *Documents*
  - *....*



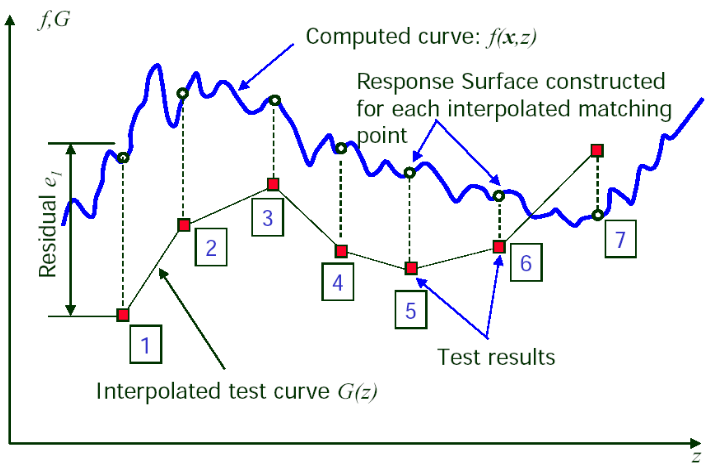


➔ LS-OPT – Overview Methodologies

- Response Surface Methodologies
- Meta-Models
  - *Polynomials*
  - *Radial Basis Functions*
  - *Neural Nets (FFNN)*



- Multidisciplinary Optimization (MDO)
- Design of Experiments (DOE) Studies
- Shape Optimization – Interfaces to ANSA, Hypermesh,…
- Parameter/System Identification Module



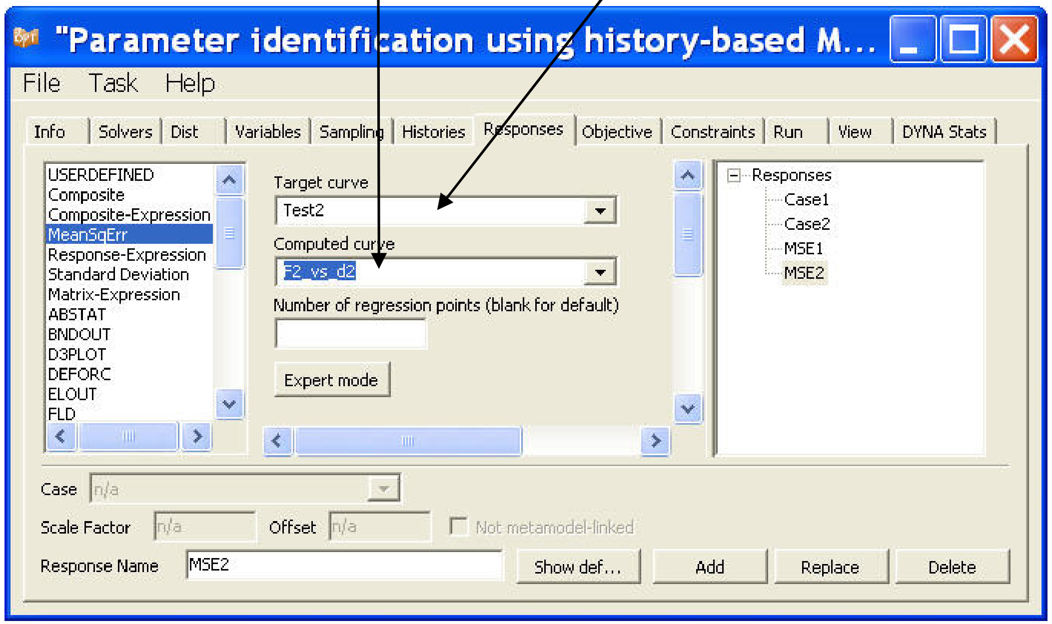
➔ Parameter Identification with Test Curves

$$MSE(\mathbf{x}) = \frac{1}{P}\sum_{i=1}^{P} W_i \left(\frac{F_i(\mathbf{x}) - G_i}{s_i} \right)^2 \rightarrow \min$$

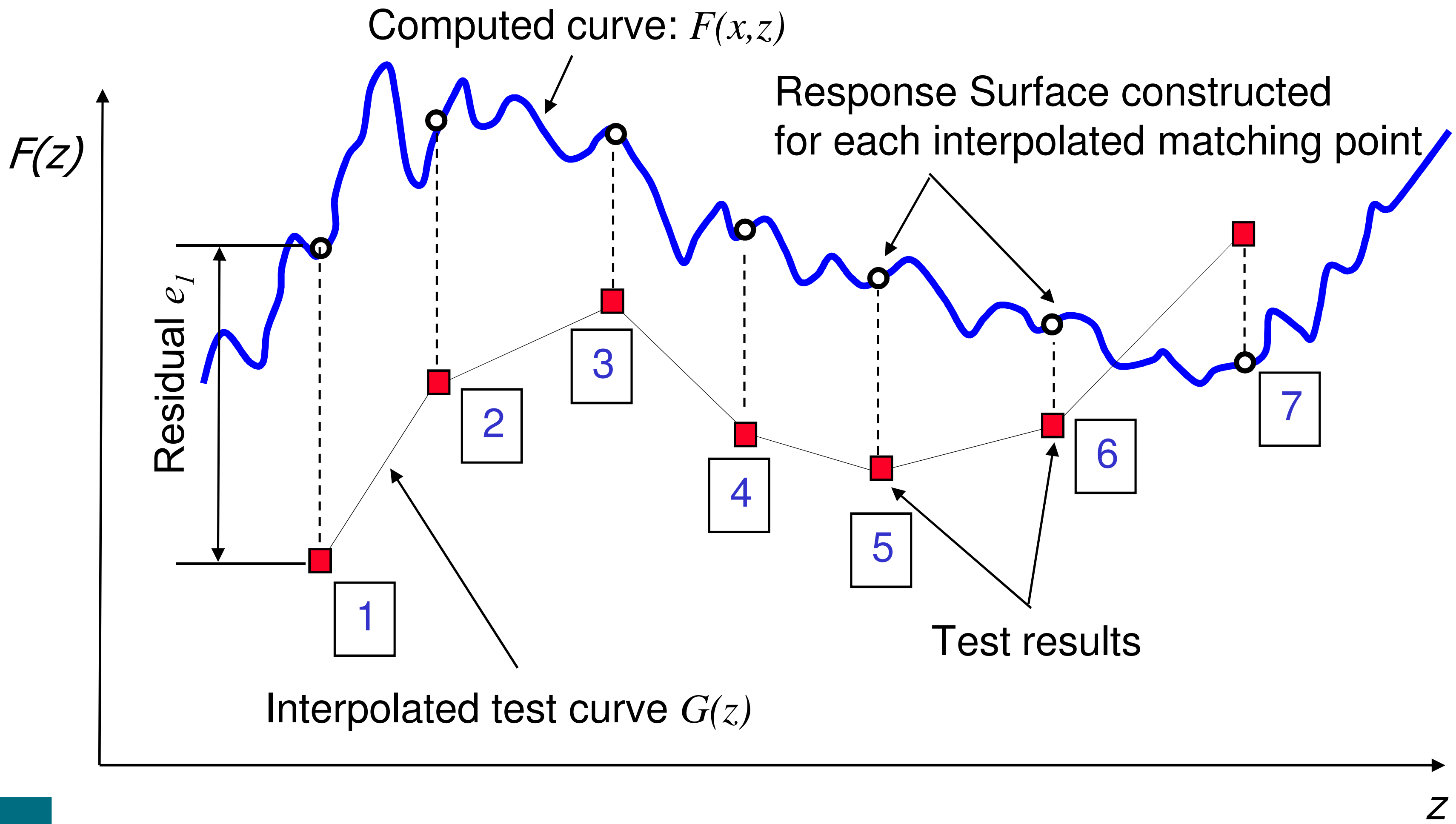
Test curve

Simulation curve

- Reads test curve files directly
- Options: number of points, start point, end points, weighting/scaling options
- Crossplots can be defined, e.g. Stress vs. strain, Force vs. deformation …

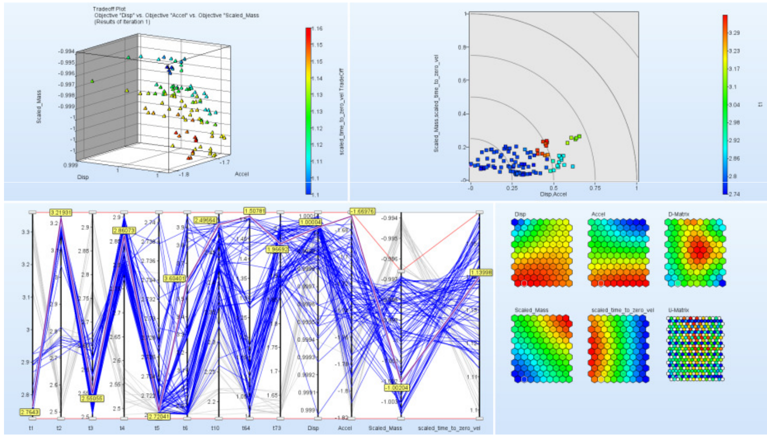


➔ Parameter Identification with Test Curves

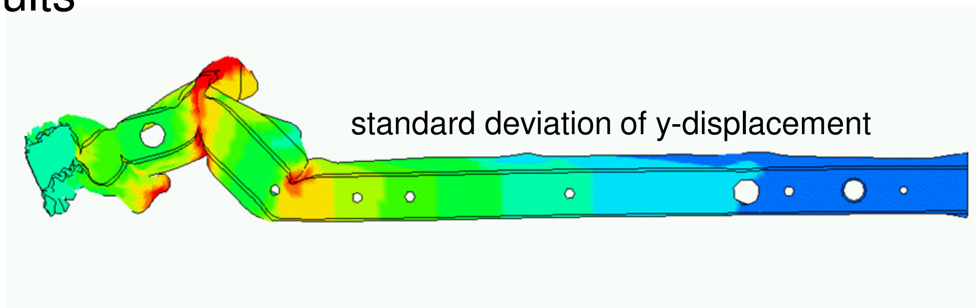


➔LS-OPT – Overview Methodologies

- Genetic Algorithm (MOGA->NSGA-II) for Multi Objective Optimization (Pareto Frontiers)
- Visualization Strategies for Pareto Optimal Data
  - Parallel Coordinate Plots
  - Hyper-Radial Visualization
  - Self Organizing Maps

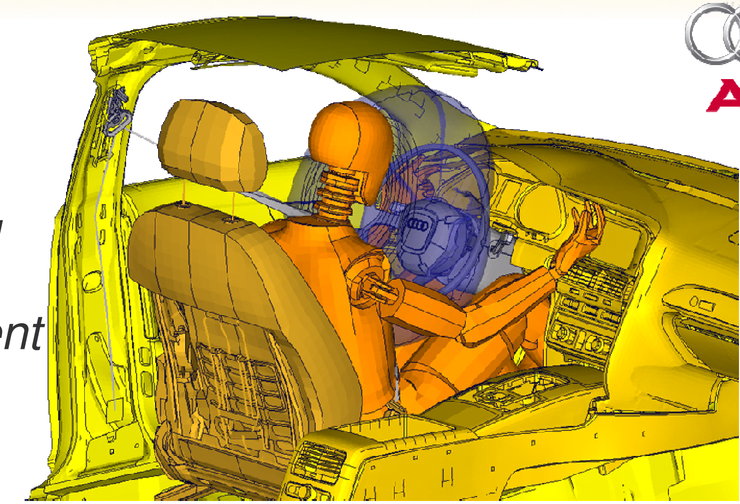


- Stochastic/Probabilistic Analysis
- Reliability based Design Optimization (RBDO and RDO)
- Visualization of Stochastic Results
  - *Fringe of statistic results on the FE-Model*



Example – Optimization of a Front-Crash Restraint System at AUDI

→ Load Cases / Model



- Adaptive Restraint System
  - *Trigger time for seatbelt, airbag and steering column can be specified individually for different load cases*
- Four Front-Crash Load Cases (FMVSS 208)

Dummy	56 km/h – belted	40 km/h – not belted
Hybrid III 5th Female	**H305a**(ctive)	**H305p**(assive)
Hybrid III 50th Male	**H350a**(ctive)	**H350p**(assive)

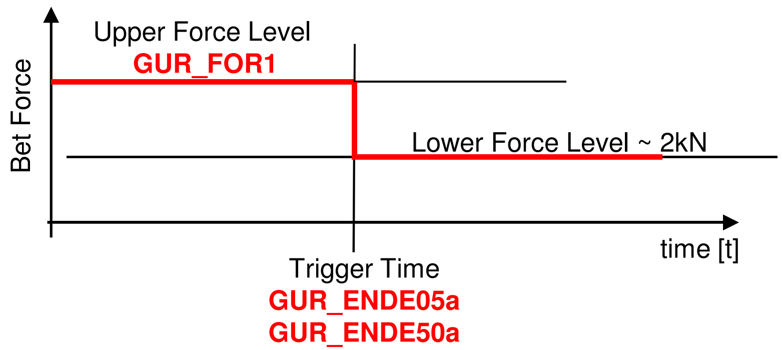
- Objective
  - *Fulfill injury criteria of dummies for all load cases (starting design violates several criteria)*

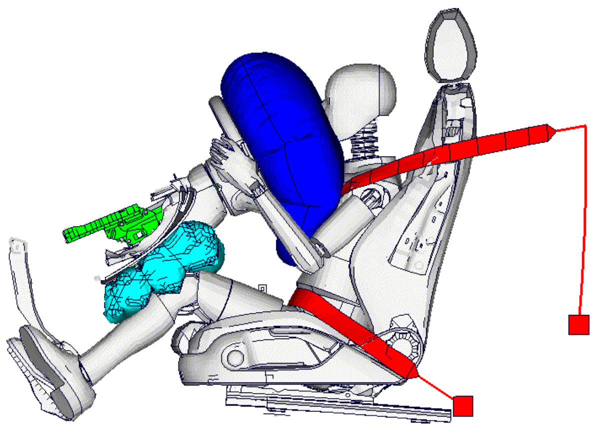
Example – Optimization of a Front-Crash Restraint System at AUDI

➔ Design Variables

- Adaptive Seat Belt System (3 Variables)

	H305a 5%-dummy, belted	H305p 5%-dummy, not belted	H350a 50%-dummy, belted	H350p 50%-dummy, not belted
Upper Force Level	GUR_FOR1		GUR_FOR1	
Trigger Time	GUR_ENDE05a		GUR_ENDE50a	



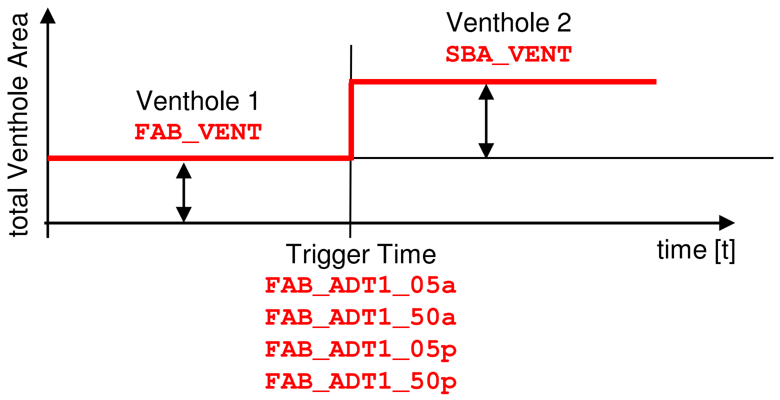


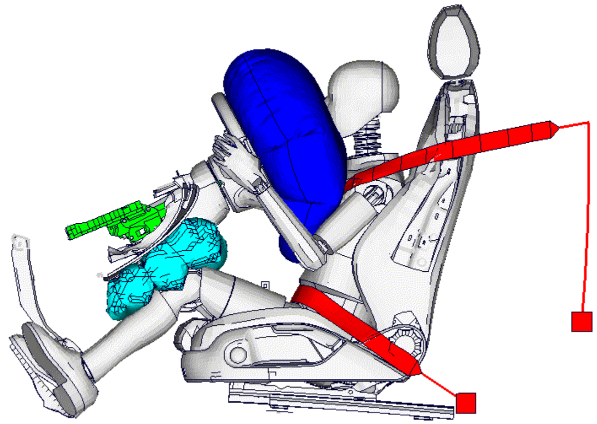
Example – Optimization of a Front-Crash Restraint System at AUDI

➔ Design Variables

- Adaptive Airbag Deployment (6 Variables)

	H305a 5%-dummy, belted	H305p 5%-dummy, not belted	H350a 50%-dummy, belted	H350p 50%-dummy, not belted
Area Venthole1	FAB_VENT	FAB_VENT	FAB_VENT	FAB_VENT
Area Venthole2	SBA_VENT	SBA_VENT	SBA_VENT	SBA_VENT
Trigger Time	FAB_ADT1_05a	FAB_ADT1_05p	FAB_ADT1_50a	FAB_ADT1_50p



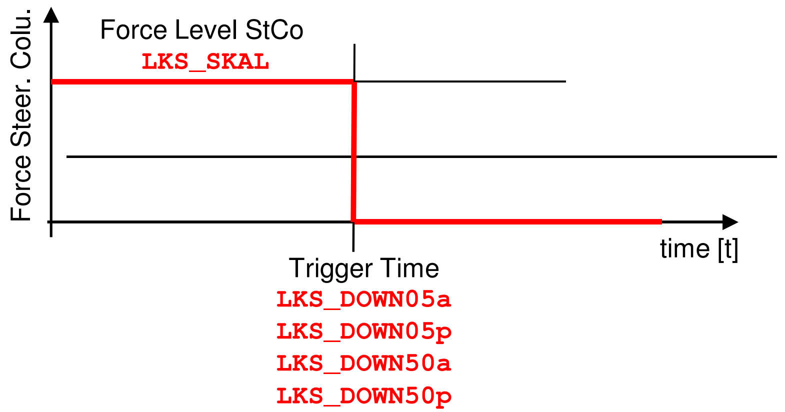


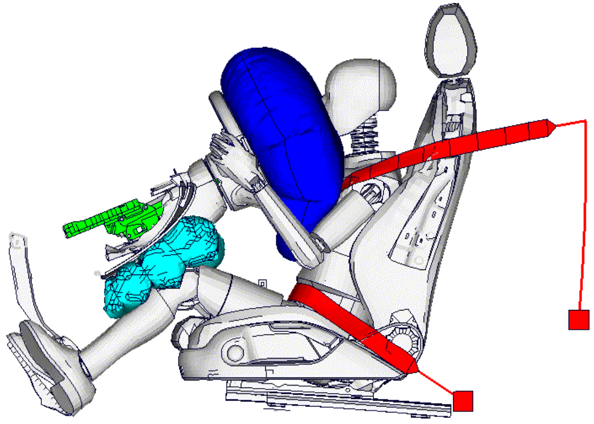
Example – Optimization of a Front-Crash Restraint System at AUDI

➔ Design Variables

- Adaptive Steering Column (5 Variables)

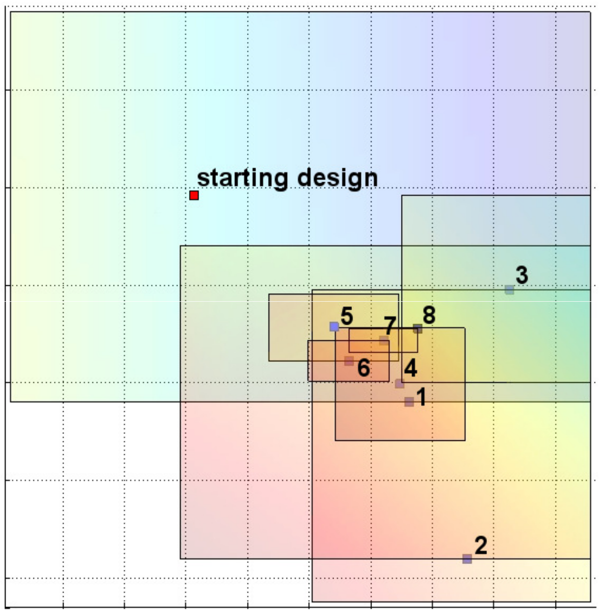
	H305a 5%-dummy, belted	H305p 5%-dummy, not belted	H350a 50%-dummy, belted	H350p 50%-dummy, not belted
Force Level StCo	LKS_SKAL	LKS_SKAL	LKS_SKAL	LKS_SKAL
Trigger Time	LKS_DOWN05a	LKS_DOWN50a	LKS_DOWN05p	LKS_DOWN50p

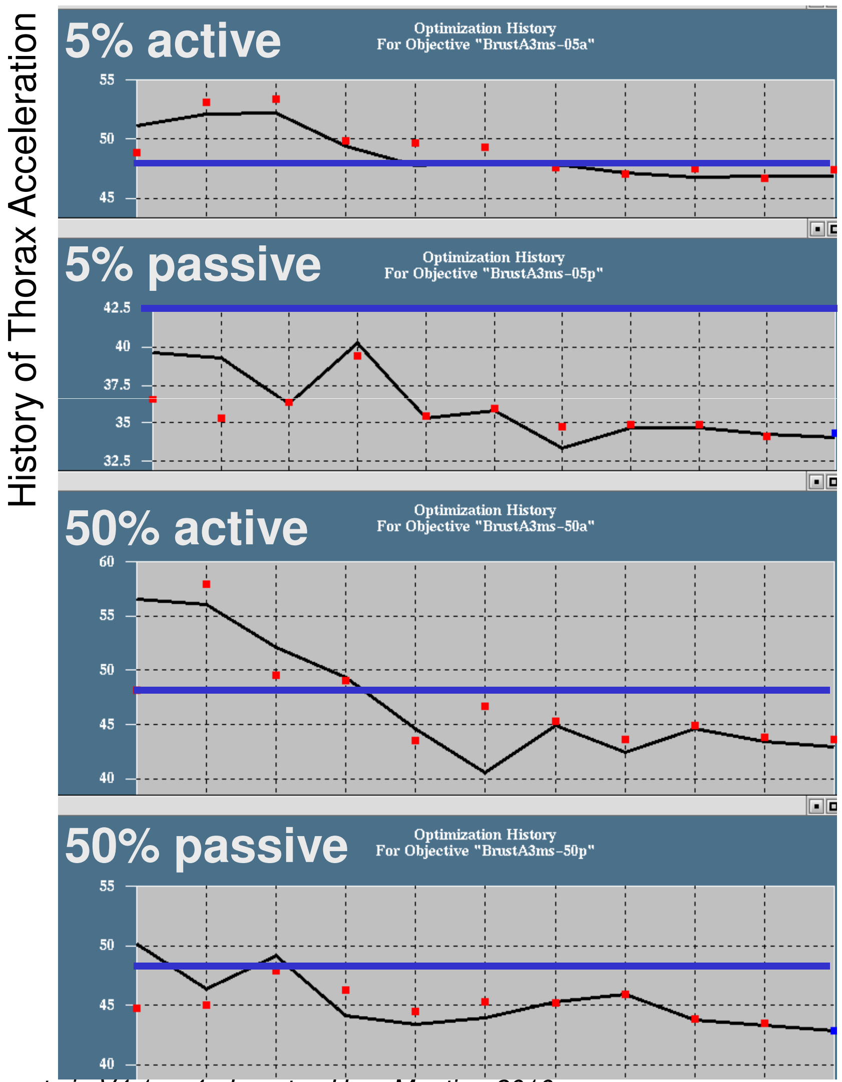




Example – Optimization of a Front-Crash Restraint System at AUDI

➔ Optimization Progress

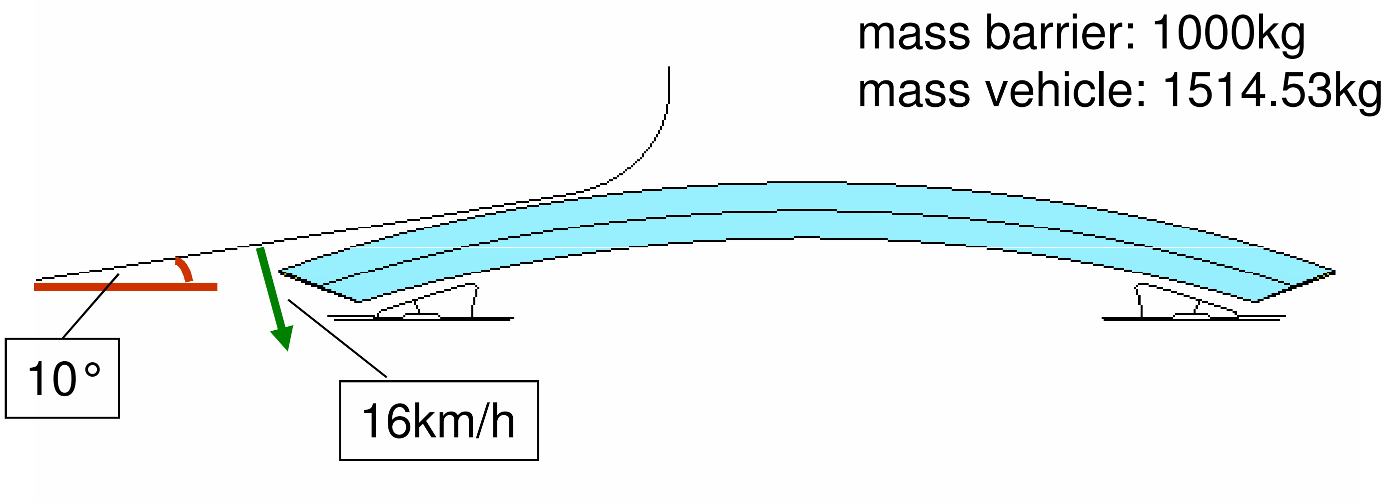




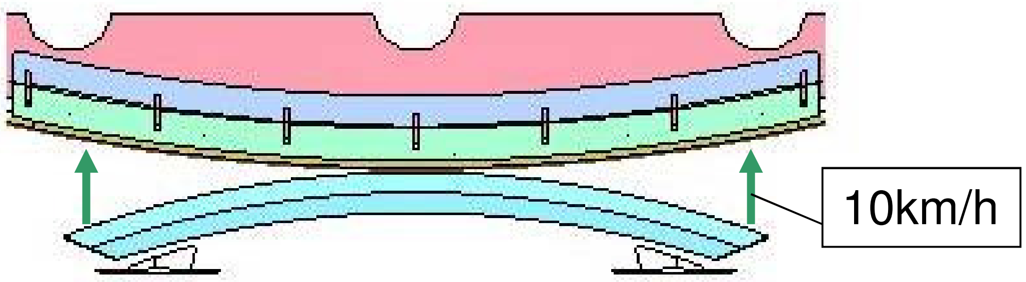
A result which meets all requirements is gained in 8 iterations, each with 34 shots

➔ Problem Description

- Load Case 1: AZT crash repair test



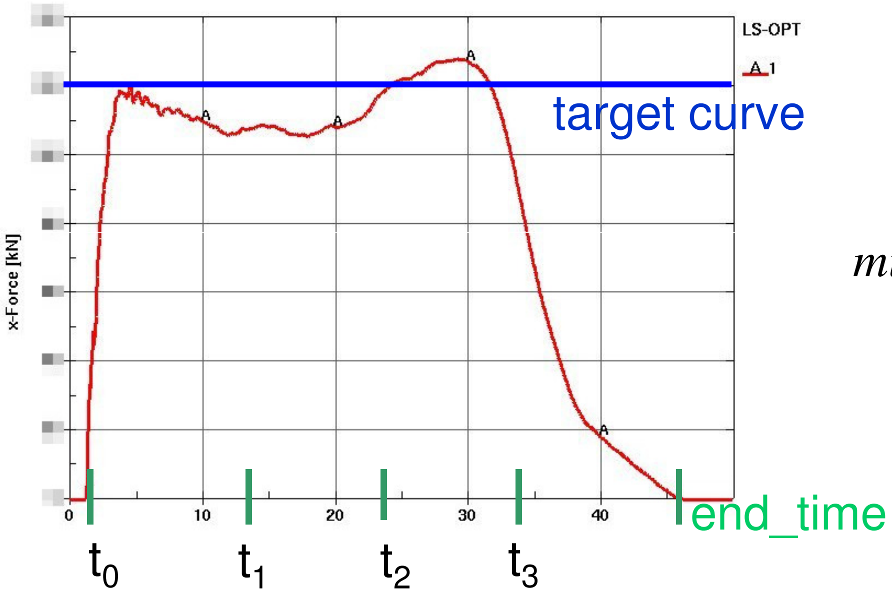
- Load Case 2: RCAR test

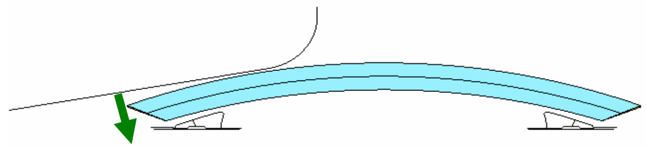


Example – Optimization of a Crash Management System

➔3 Objectives

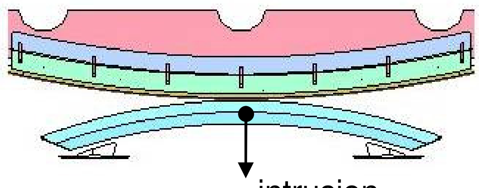
- Homogeneous Energy Absorption (AZT Load Case)



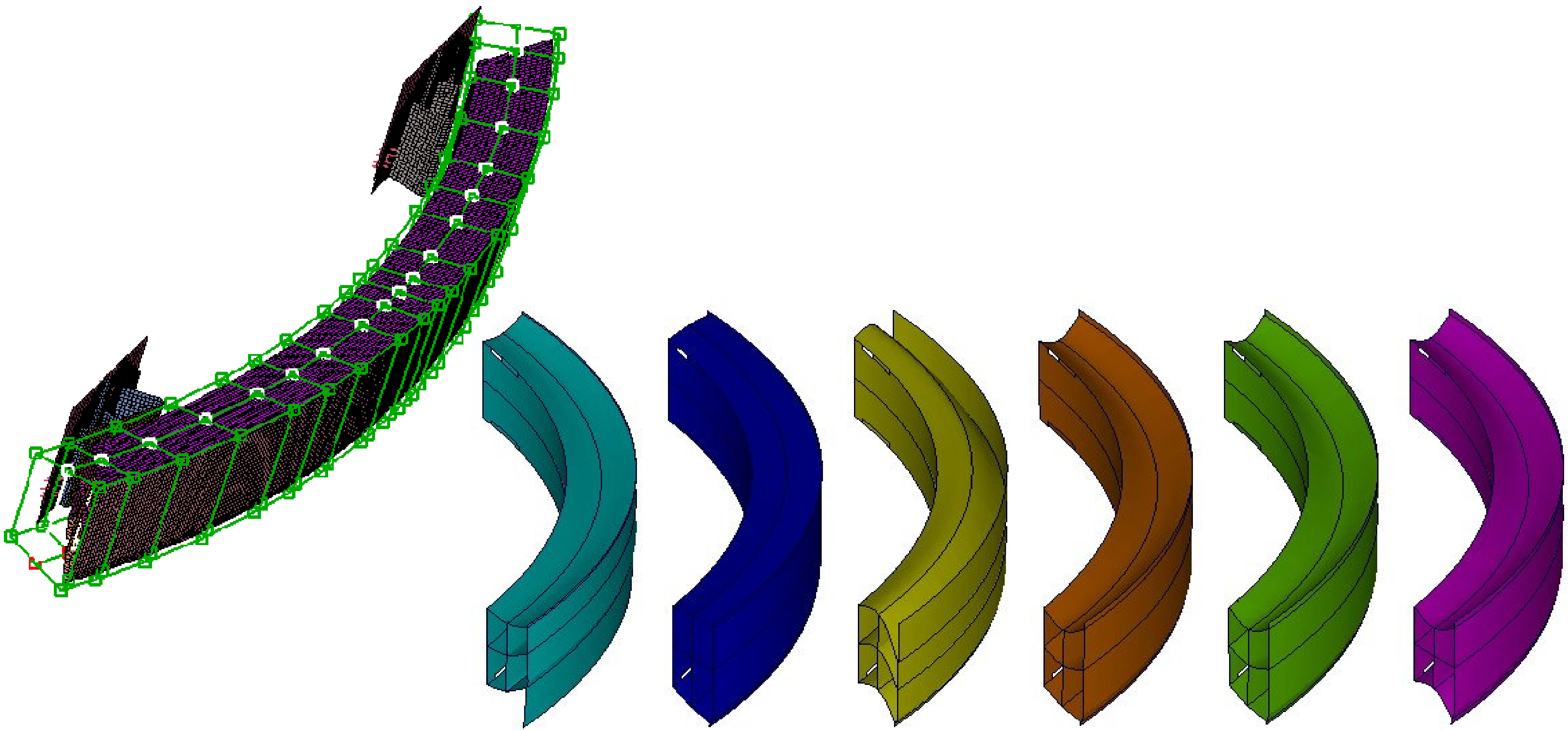


$$\min \mathrm{MSE\_Force} = \sqrt{\sum_{i=0}^{3}\left(F(t_i)-tc\right)^2}$$

- Minimize Intrusion (RCAR Test)
- Minimize Total Mass of the Bumper



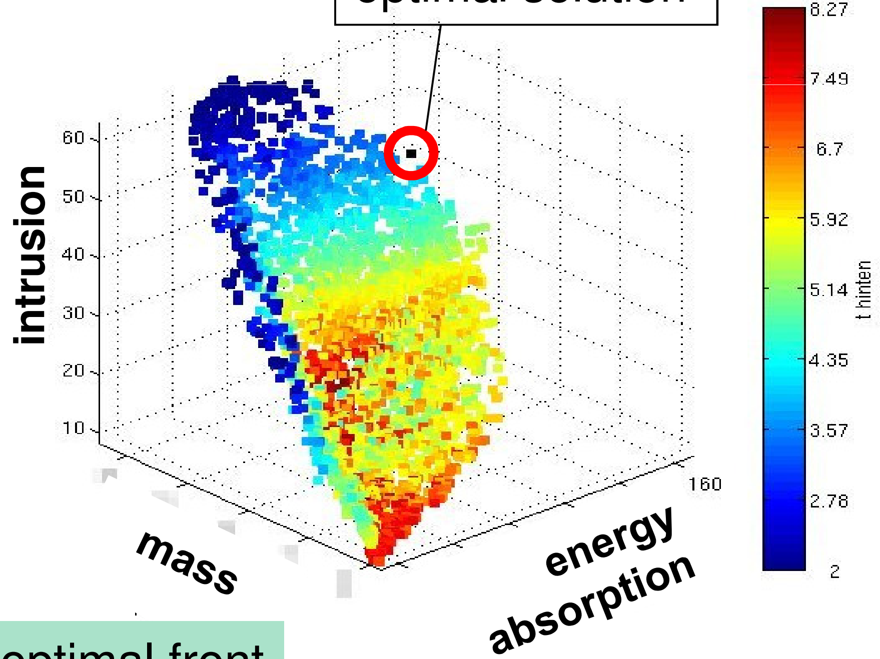
➔ Application of Morphing for Shape Optimization using ANSA

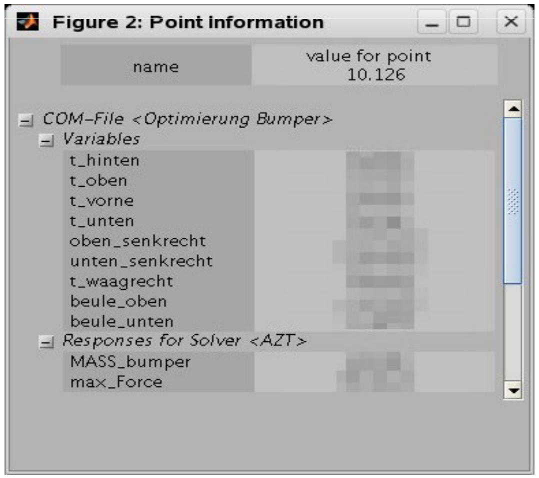


→ Pareto Optimal Solutions

- Optimal solutions considering all objectives

Selected Pareto optimal solution



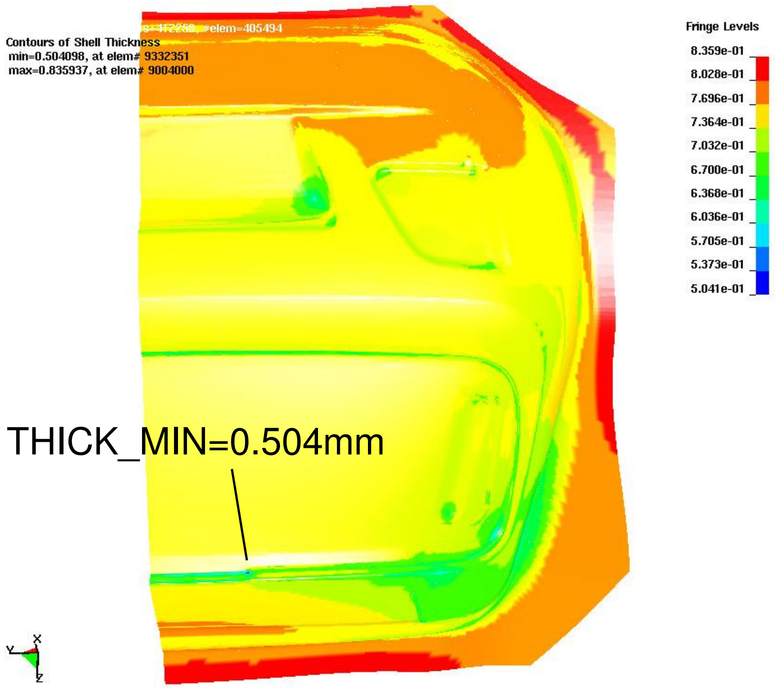


3D Pareto optimal front

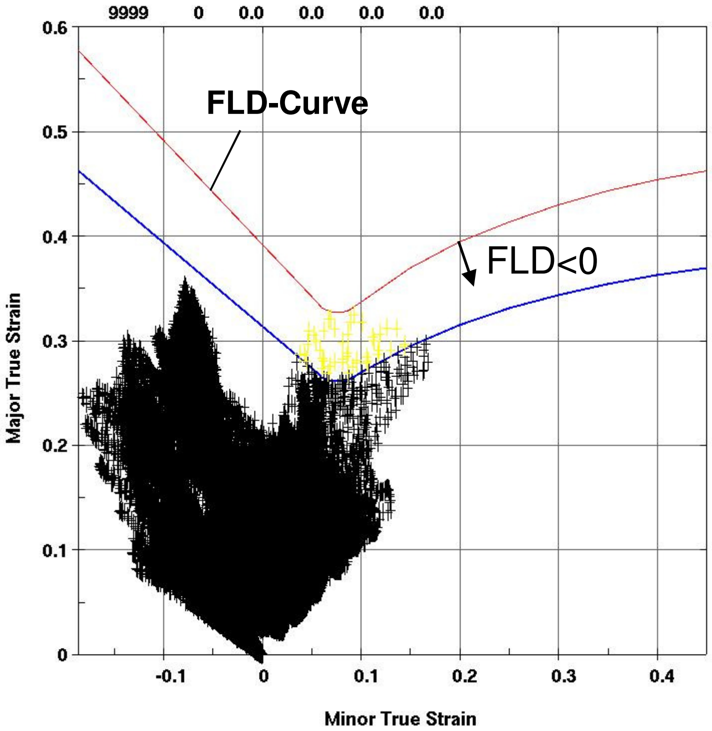
Example – Reliability Optimization of a Metal Forming Process

➔ FE-Simulation of Starting Design

- Consideration of two response criteria: THICK_MIN>0.5mm, FLD<0
- Result is feasible, but fairly close to infeasible region



sheet thickness distribution after forming simulation (initial=0.8mm)



major vs. minor strain of each element after forming simulation

➔ Considered Uncertainties – Material Properties

Variable	Description	Distribution		
σ	Swift Law Parameter – Yield Strain	**uniform**	lower: 120 MPa	upper: 160 MPa
K	Swift Law Parameter	**uniform**	lower: 440 MPa	upper: 660 MPa
N	Swift Law Parameter	**uniform**	lower: 0.23	upper: 0.3
r0	Lankford Anisotropy Coefficient 0°	**uniform**	lower: 2.0	upper: 2.5
r45	Lankford Anisotropy Coefficient 45°	**uniform**	lower: 1.4	upper: 2.0
r90	Lankford Anisotropy Coefficient 90°	**uniform**	lower: 2.5	upper: 3.2

Example – Reliability Optimization of a Metal Forming Process

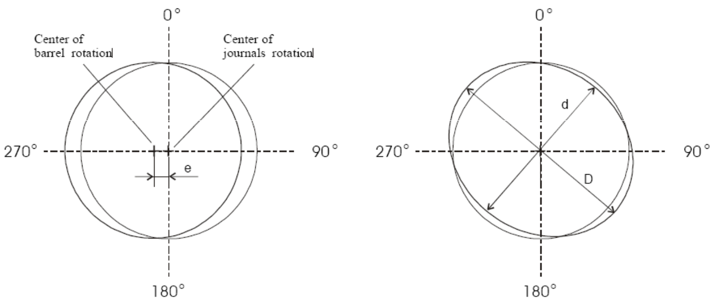
➔ Considered Uncertainties – Process Parameters

Variable	Description	Distribution		
		type	**lower**	**upper**
μ	Friction – Punch/Blank	uniform	0.05	0.1
			Mean	**Std**
BF	Binder Force	normal	1910 kN	50 kN
DBF1	Draw Bead Force #1	normal	70 kN	5 kN
DBF2	Draw Bead Force #2	normal	20 kN	5 kN
DBF3	Draw Bead Force #3	normal	80 kN	5 kN
DBF4	Draw Bead Force #4	normal	90 kN	5 kN
DBF5	Draw Bead Force #5	normal	100 kN	5 kN
DBF6	Draw Bead Force #6	normal	140 kN	5 kN
Pert1	Perturbation amplitude in rolling direction	normal	0	0.005mm
Pert2	Perturbation amplitude perpendicular to rolling direction	normal	0	0.005mm

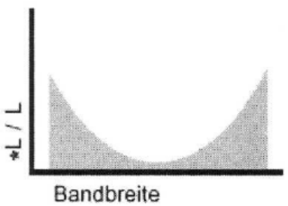
Example – Reliability Optimization of a Metal Forming Process

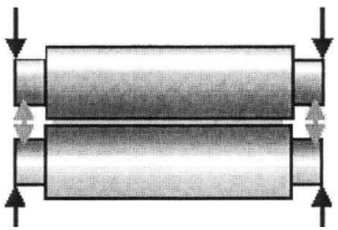
→ Perturbation of blank thickness

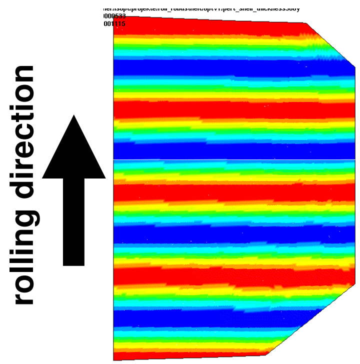
- Sheet thickness variation due to rolling process
  - *Possible slight eccentric suspension can lead to "mill chatter"*

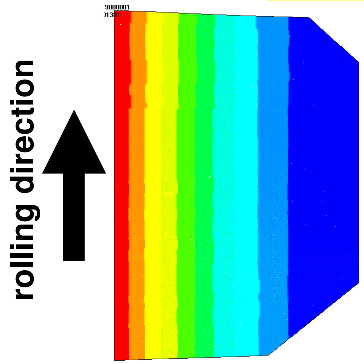


  - *Non-uniform contact pressure*



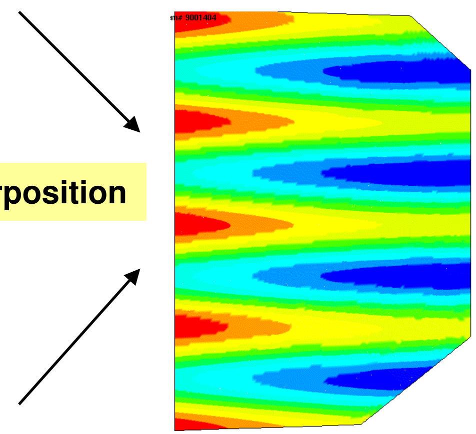






sheet thickness variation by a harmonic random field, amplitude: $\mu=0, \sigma=0.005$mm in both directions

superposition



Keyword
`*PERTURBATION`

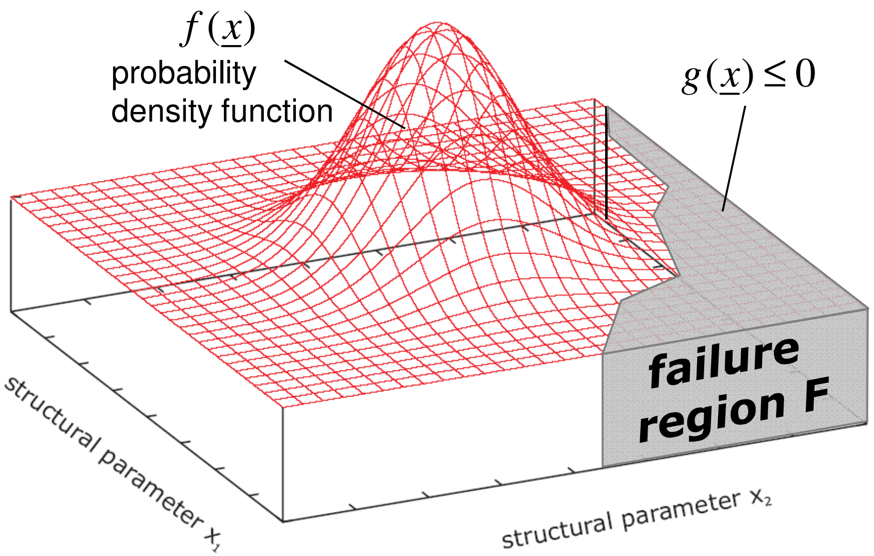
Example – Reliability Optimization of a Metal Forming Process

➔ Conclusions after Monte Carlo Simulations

- Considering the chosen baseline design, the FE-simulation is very sensitive regarding the assumed variations of the uncertain process and material parameters
- The failure probability is very high and the baseline configuration must be declared as non-robust

➔ Next Step

- Investigation of reliability based design optimization
- Objective is to minimize the failure probability



Example – Reliability Optimization of a Metal Forming Process

➔ Reliability Based Design Optimization (RBDO)

- Introduction of “control” and “noise” variables
  - *“control variables” drive optimization process*
  - *“noise variables” for consideration of uncertainties*

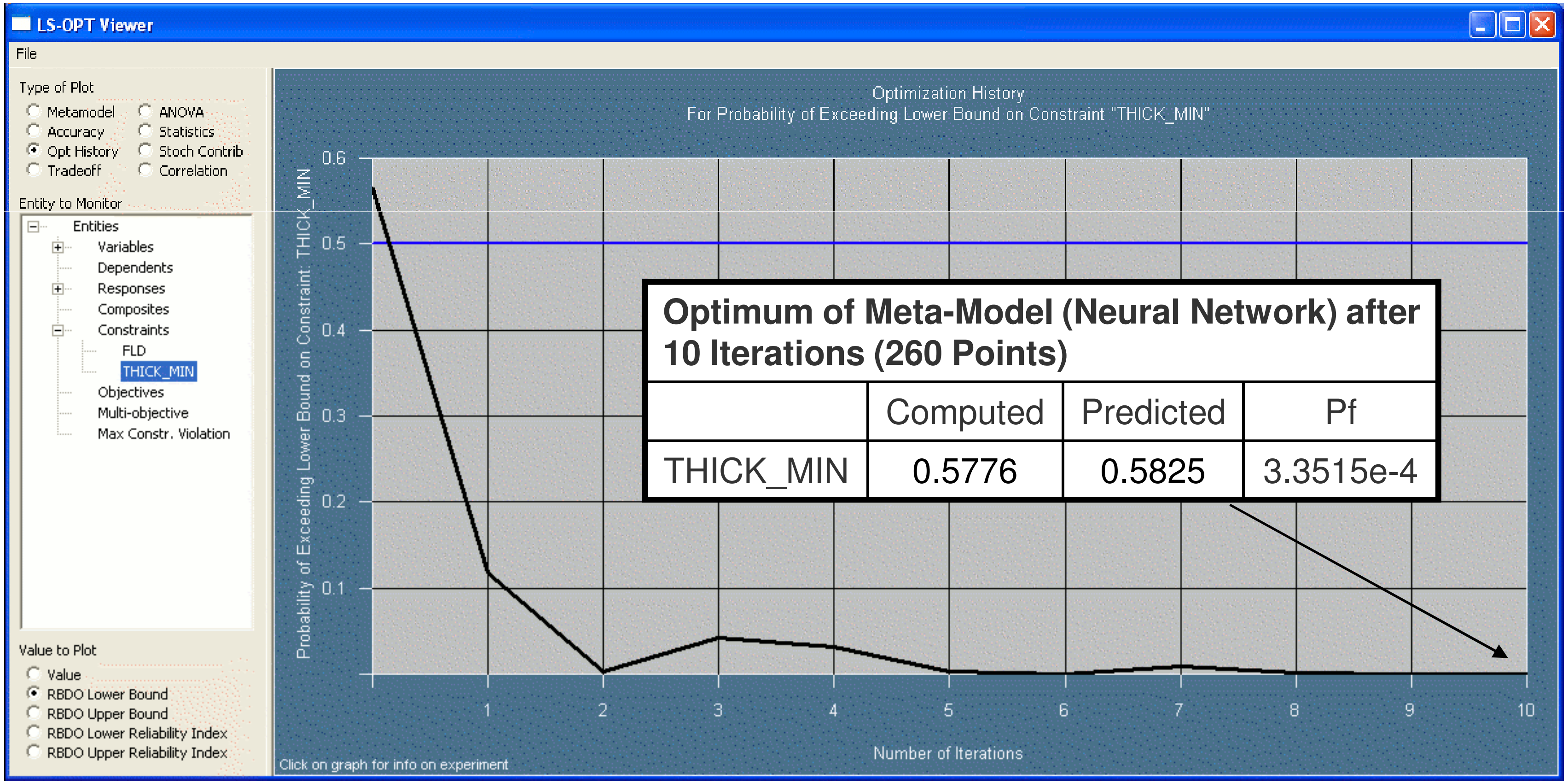
control and noise variables

Variable	Description	Distribution ”noise variable”			Range “control variable”	
		Type	mean	std	min	max
DBF1	Draw Bead Force #1	normal	70	5 kN	20 kN	200 kN
DBF2	Draw Bead Force #2	normal	20	5 kN	20 kN	200 kN
DBF3	Draw Bead Force #3	normal	80	5 kN	50 kN	120 kN
DBF4	Draw Bead Force #4	normal	90	5 kN	60 kN	120 kN
DBF5	Draw Bead Force #5	normal	100	5 kN	70 kN	130 kN
DBF6	Draw Bead Force #6	normal	140	5 kN	20 kN	200 kN
FORCFN	Binder Force	normal	1910	50 kN	1400 kN	2400 kN

- All other variables remain noise variables

➔ Reliability Based Design Optimization (RBDO)

- Optimization history of probabilty of exceeding bound for THICK_MIN



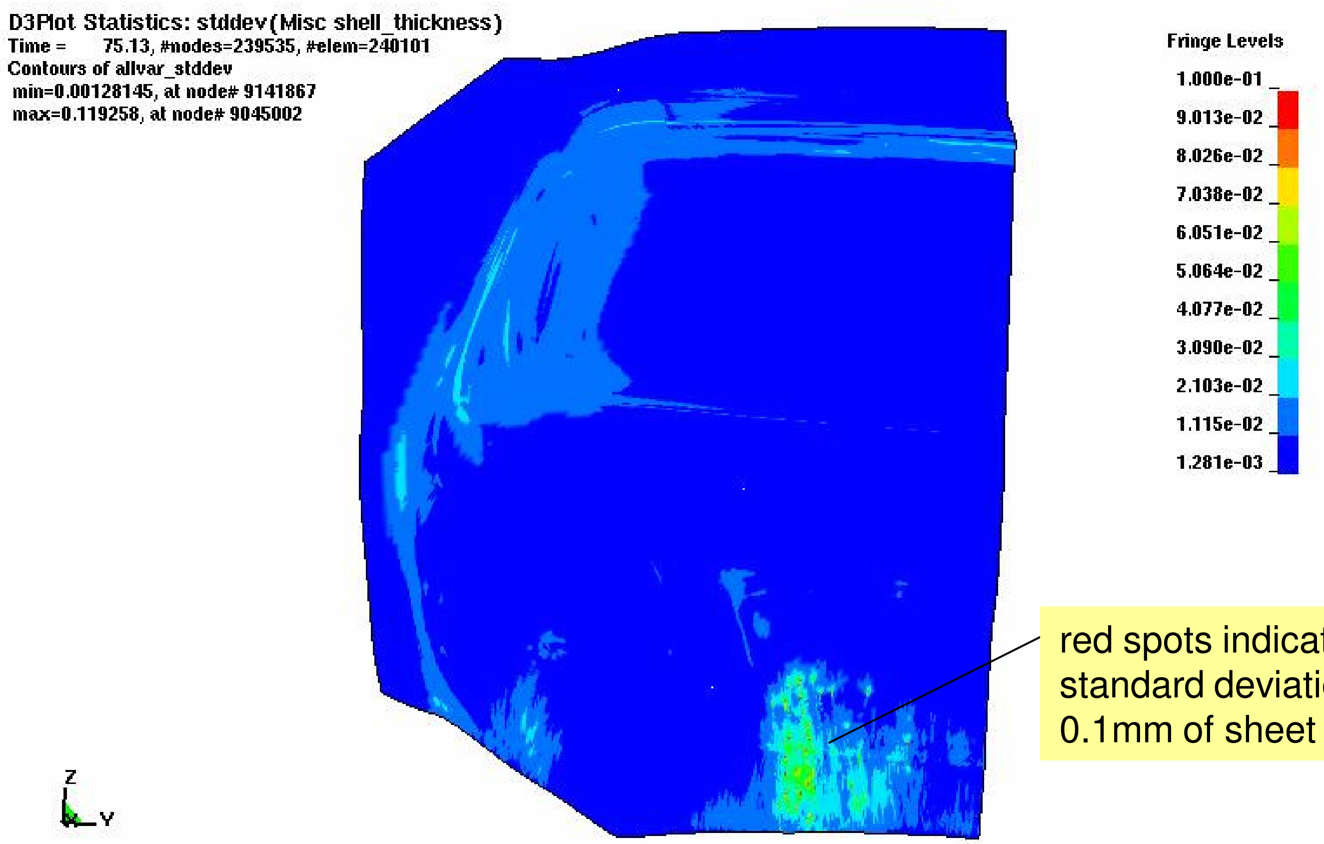
Optimum of Meta-Model (Neural Network) after 10 Iterations (260 Points)

	Computed	Predicted	Pf
THICK_MIN	0.5776	0.5825	3.3515e-4

Example – Reliability Optimization of a Metal Forming Process

➔ Visualization of Statistical Results on the FE-Model with LS-OPT

- Scatter of minumum sheet thickness due to considered uncertainties based on 160 simulations



red spots indicate a total standard deviation of 0.1mm of sheet thickness

➔ New Features in LS-OPT V4.1

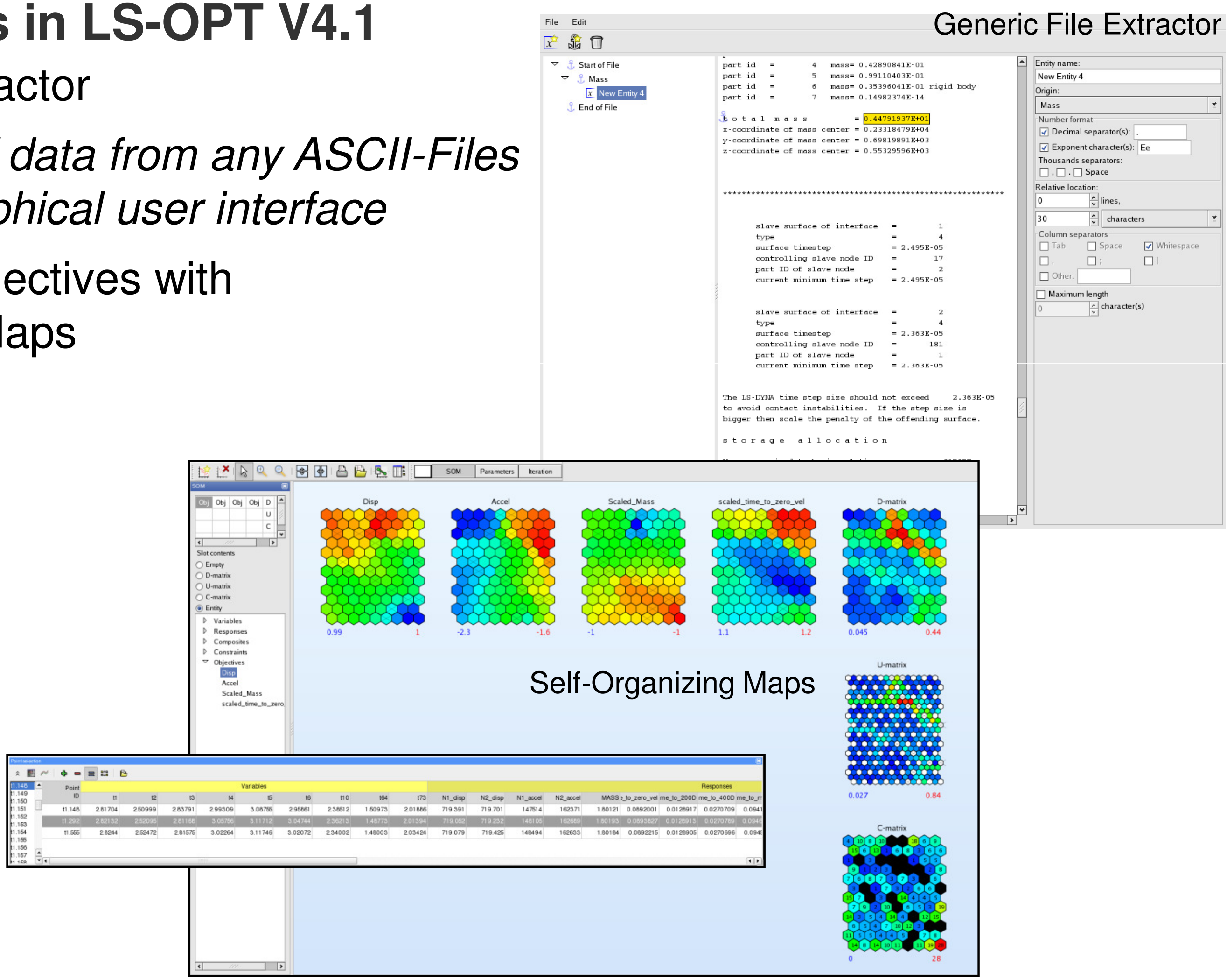
- Frequency/Mode Tracking
  - *NASTRAN Frequency with Mode tracking added*
  - *Previously existed only for LS-DYNA*
  - *Industry tested in an automotive multidisciplinary setting*

$$\boxed{\max_i[(\boldsymbol{\varphi}_r{}^T\mathbf{M}_r)\boldsymbol{\varphi}_i]}$$

- Additional Injury Criteria
  - *VC (Viscous Criterion)*
  - *Chest Compression*
  - *A3ms (Acceleration level for 3ms)*
  - *More added in V4.2*
- Additional Result Interfaces for LS-DYNA
  - *SPH: Strains, Stresses*
  - *Acoustics binary database: DBBEMAC*
  - *LS-DYNA *CASE supported*

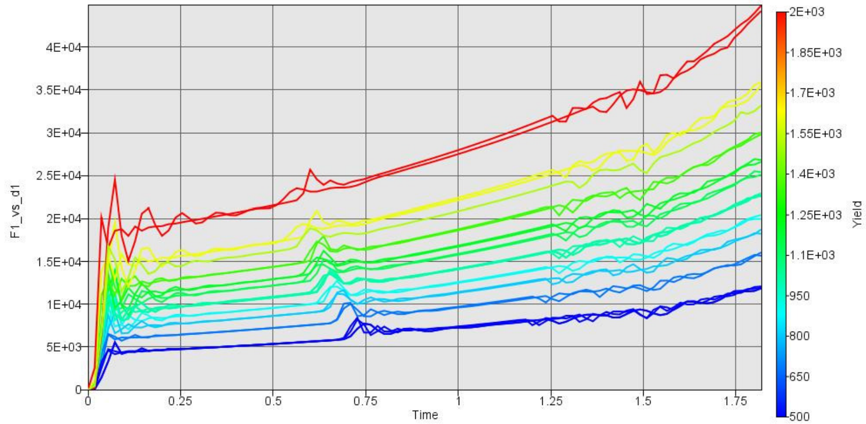
➔ New Features in LS-OPT V4.1

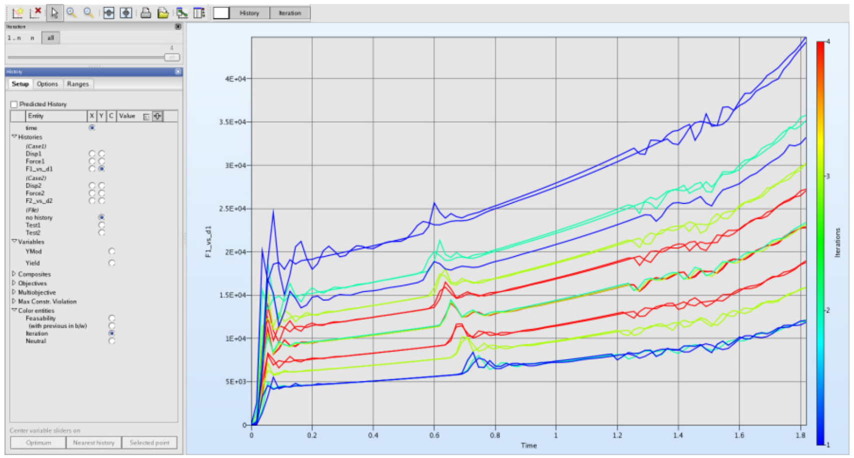
- Generic File Extractor
  - *Extraction of data from any ASCII-Files within the graphical user interface*
- View Multiple Objectives with Self-Organizing Maps

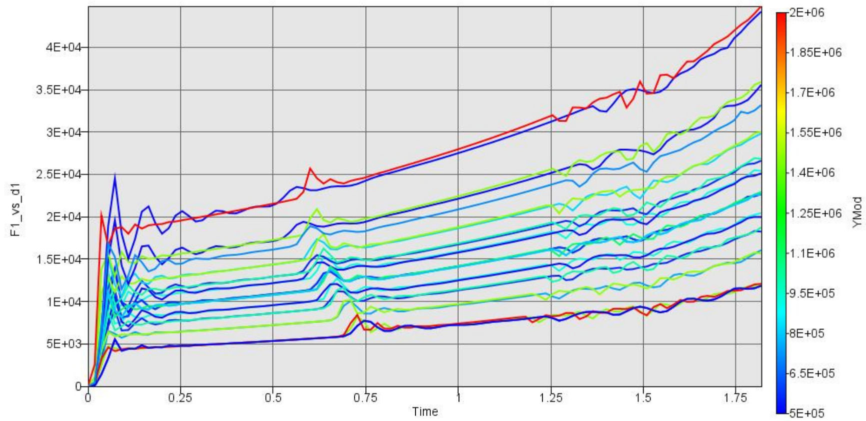


➔ New Features in LS-OPT V4.1

- History Curves
  - *View of histories of all design points*
  - *Color selection*
    - *Feasibility*
    - *Iteration*
    - *Variables, Responses, …*

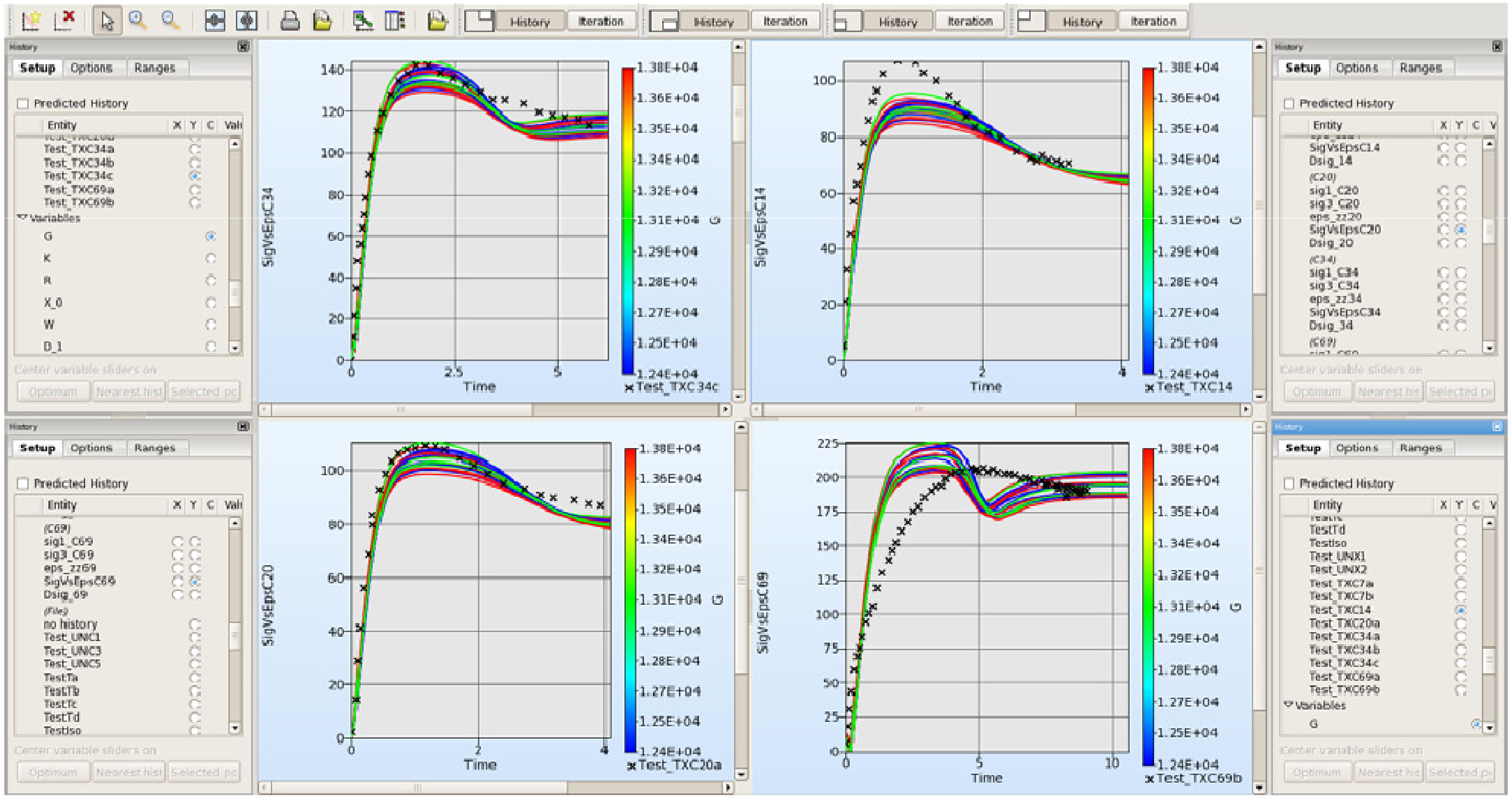






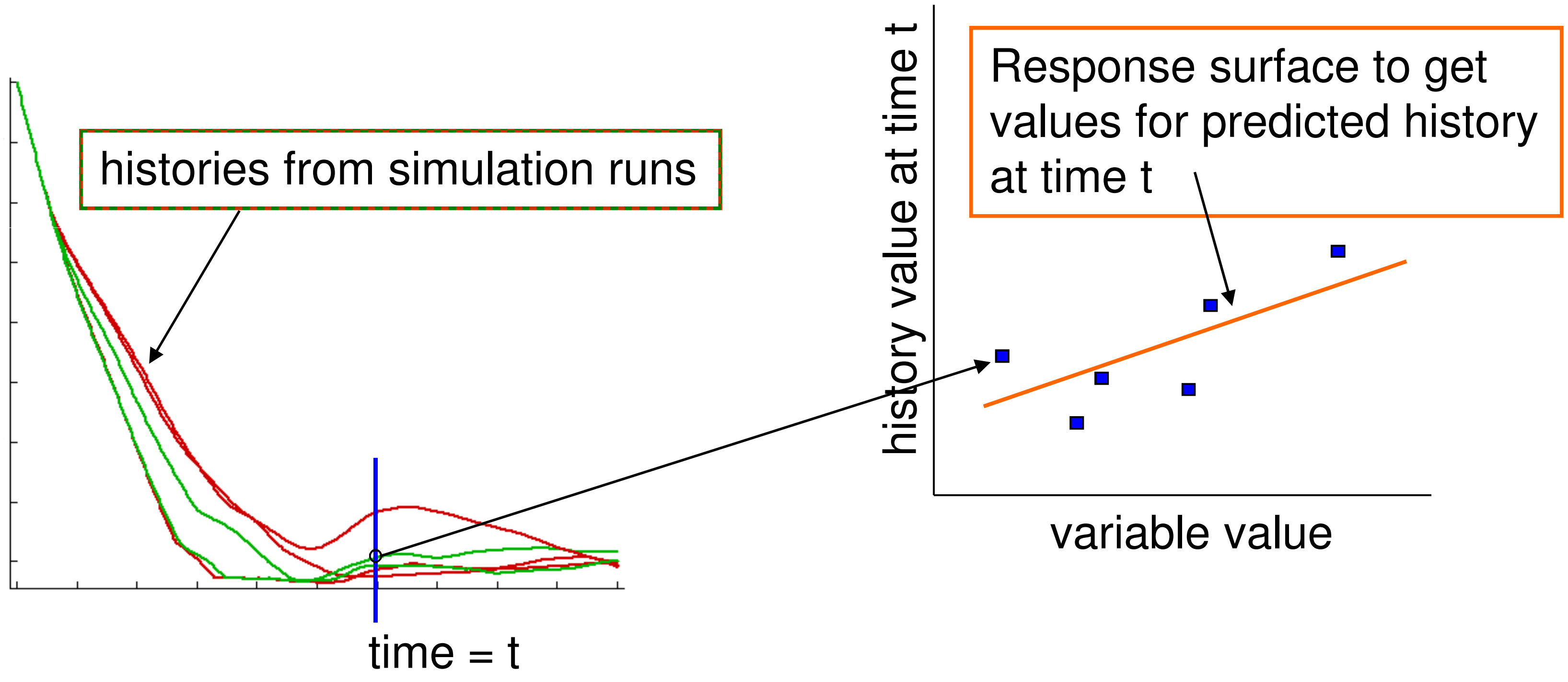
➔ New Features in LS-OPT V4.1

- Computed history curves vs. Target curves



➔ New Features in LS-OPT V4.1

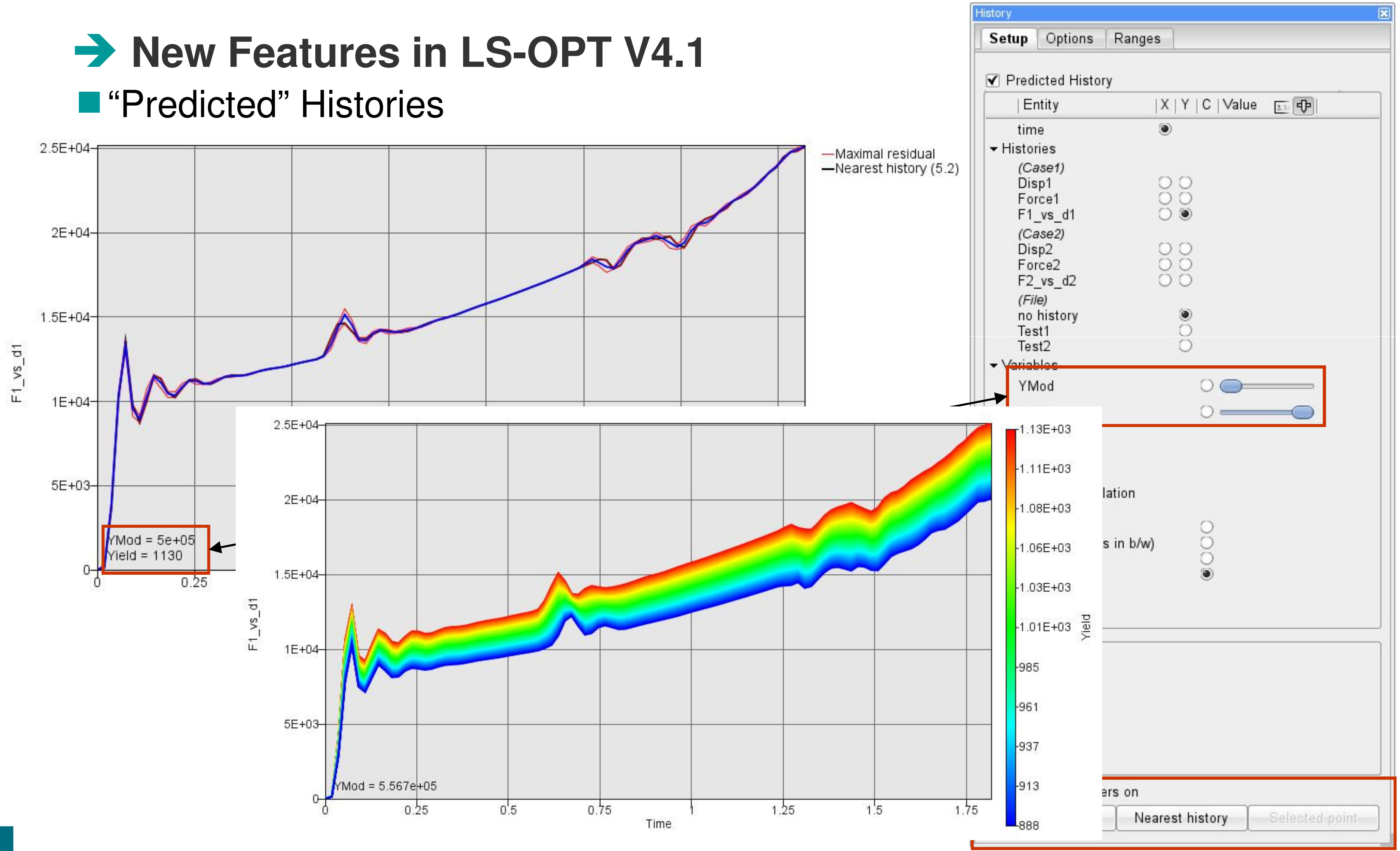
- "Predicted" Histories



LS-OPT V4.1

➔ New Features in LS-OPT V4.1

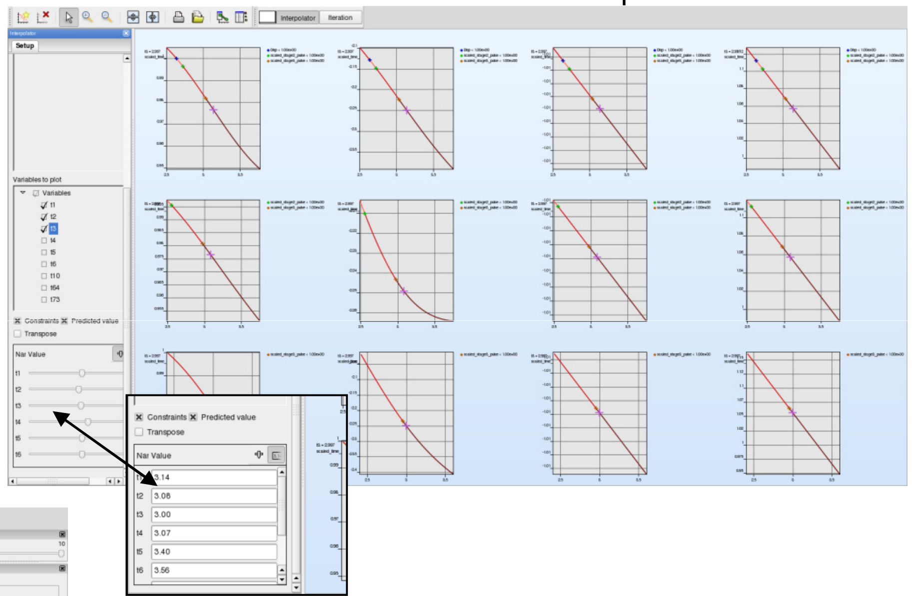
- "Predicted" Histories

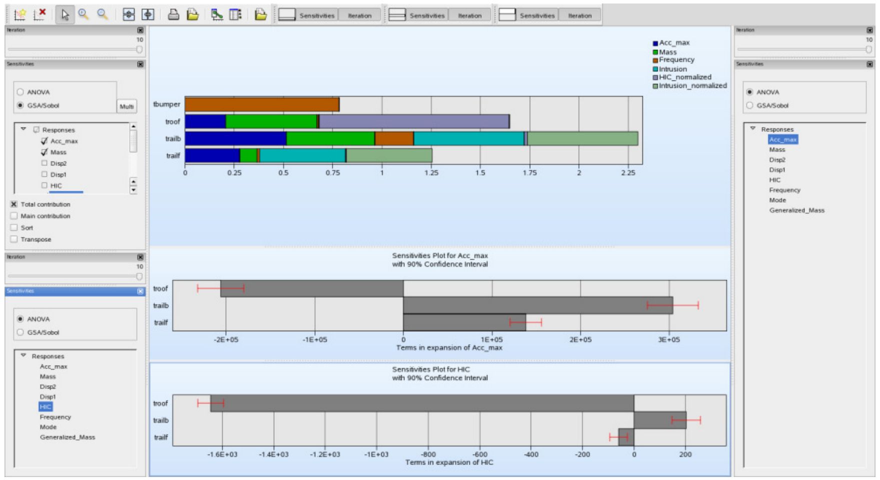


➔ New Features in LS-OPT V4.1

- Multiple Meta Model Plot
  - *Compare meta models of different responses even for different load cases*
- Global (nonlinear) Sensitivity Analysis
  - *Evaluation of Sobol Indices*

Multiple Meta Model Plot





Thanks for your attention!