

Infotag ANSA/LS-OPT/META

# Optimization with LS-OPT: Possibilities and new developments in LS-OPT 6.0

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# Outline

- About LS-OPT
- Methodologies
- Applications of LS-OPT
  - Optimization
  - Sensitivity Analysis
  - Robustness Analysis
- New developments in LS-OPT 6.0
  - DIC-based Parameter Identification
  - Interactive Tables
  - Efficient Global Optimization
  - Support Vector Classification
- Outlook

# About LS-OPT

## ■ LS-OPT is a stand alone optimization software

→ can be linked to **any (simulation) code** –

■ Current production version is LS-OPT 5.2

■ Windows and Linux versions available

■ Interface to LS-DYNA, Excel, Matlab

■ Interface to LS-PrePost, ANSA, Hypermorph, ...

→ **shape optimization**

■ Interface to META Post

→ **result extraction**

■ Interface to LS-OPT

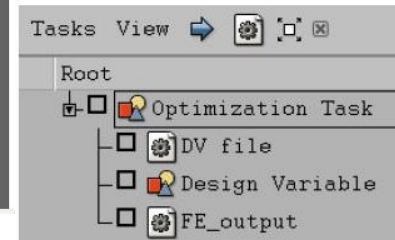
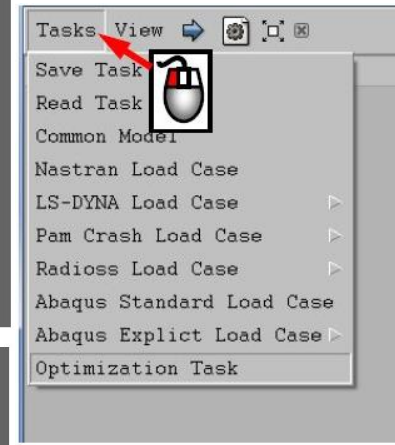
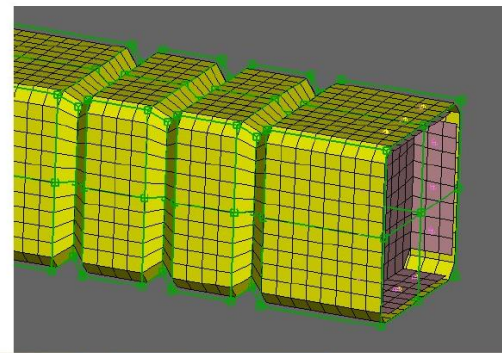
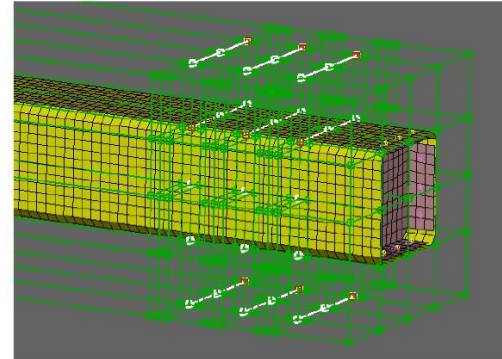
→ **nested optimization**

■ User-defined interface

■ Interface to Queuing Systems

■ PBS, LSF, LoadLeveler, SLURM, AQS, User-defined, ...

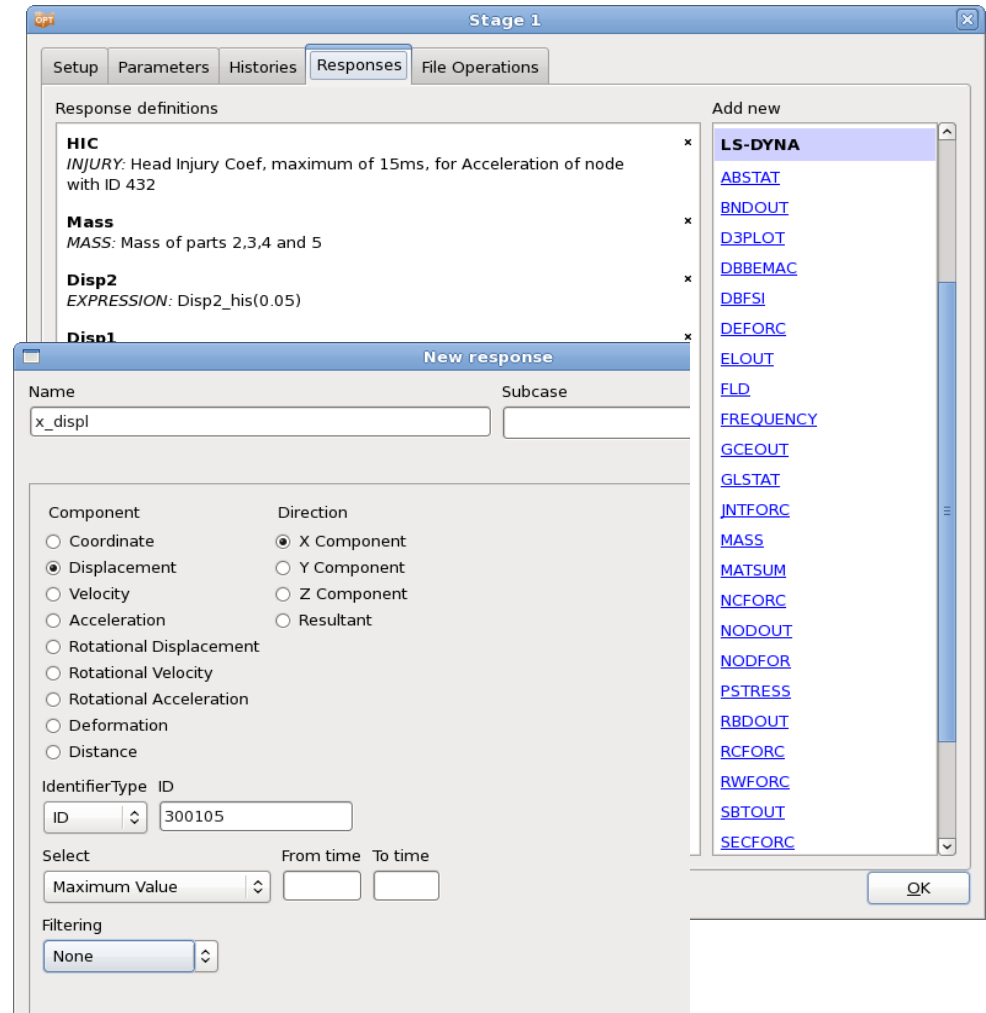
→ **LS-OPT as process manager**



# About LS-OPT

## ■ LS-DYNA integration

- Importation of design parameters from LS-DYNA keyword files (\*PARAMETER)
- Support of include files (\*INCLUDE)
- Result extraction of most LS-DYNA response types
- Checking of LS-DYNA keyword files (\*DATABASE\_)
- Monitoring of LS-DYNA progress
- D3plot compression



# Methodologies

## ■ (Sequential) Response Surface Method ((S)RSM)

### → Metamodels

- Polynomials
- Radial Basis Functions (RBF)
- Feedforward Neural Networks (FFNN)

## ■ Genetic Algorithm (MOGA-→NSGA-II)

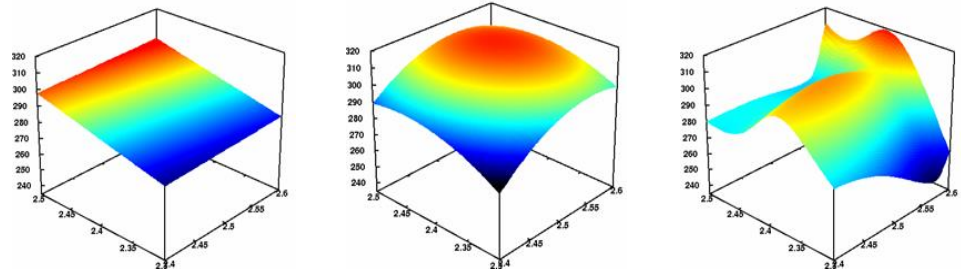
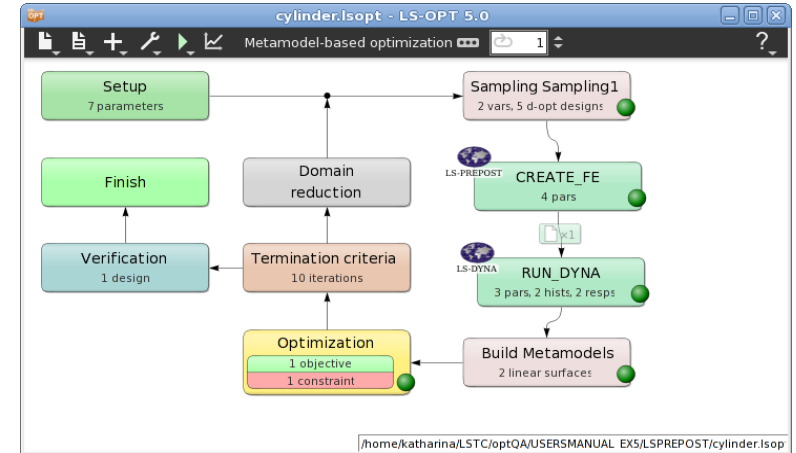
### → Multi-objective Optimization

- Direct
- Metamodel-based

## ■ Monte Carlo Analysis

### → Robustness Analysis

- Direct
- Metamodel-based





# Applications of LS-OPT

## ■ Optimization

- Parameter/System Identification Module:  
Calibration of test and simulation curves  
or scalar values

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

History matching composite

Name: MSE1

Algorithm:  
 Mean Square Error (difference in curve Y values)  
 Curve Mapping (size of area between curves)

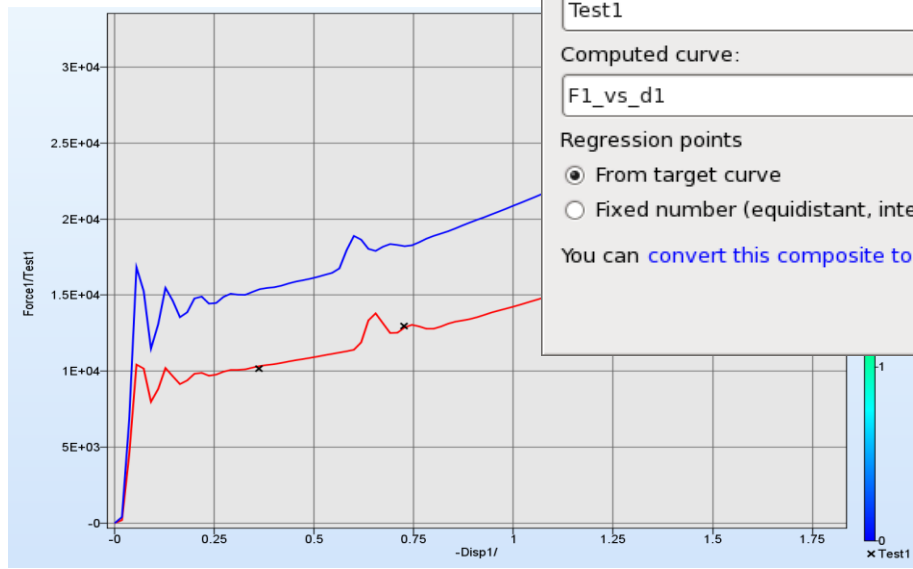
Target curve: Test1 [add new file history](#)

Computed curve: F1\_vs\_d1

Regression points  
 From target curve  
 Fixed number (equidistant, interpolated)

You can [convert this composite to an expression](#) for further fine-tuning.

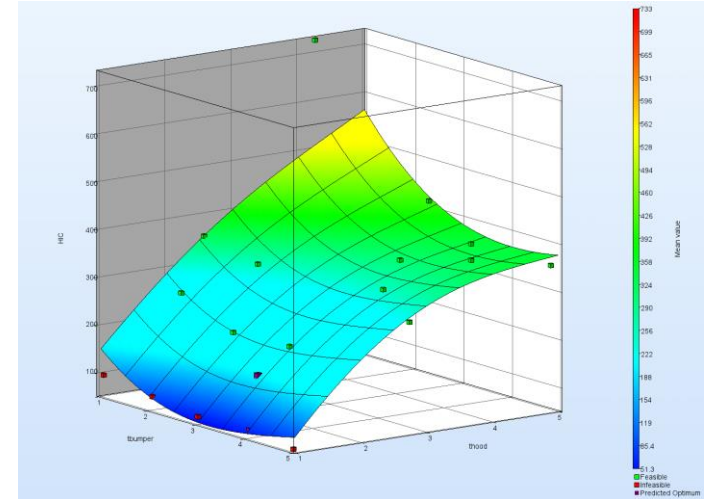
OK



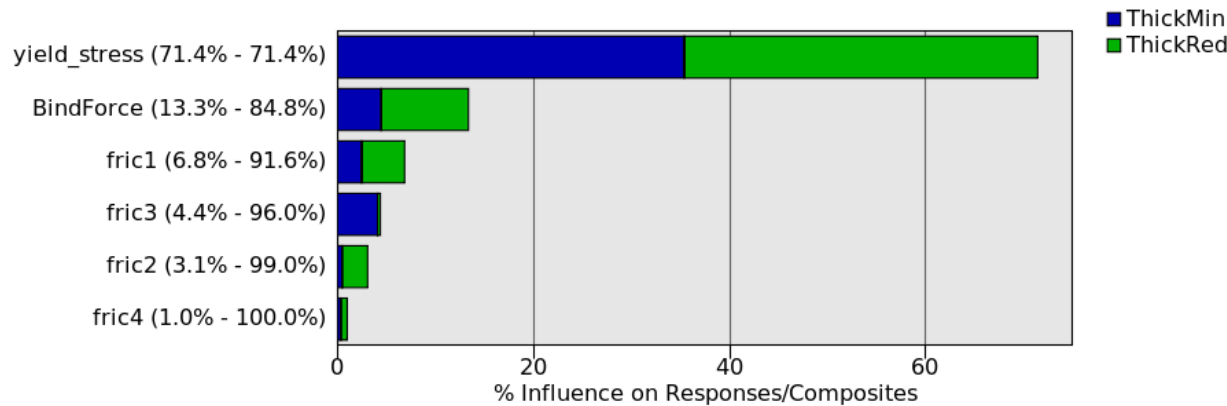
# Applications of LS-OPT

## ■ Sensitivity Analysis

- Design Exploration
- DOE Studies for Variable Screening (ANOVA, Sobol)
  - *Contribution of variables to system performance*
  - *Identification of significant and insignificant variables*
  - *Ranking of importance*



Global Sensitivities Plot





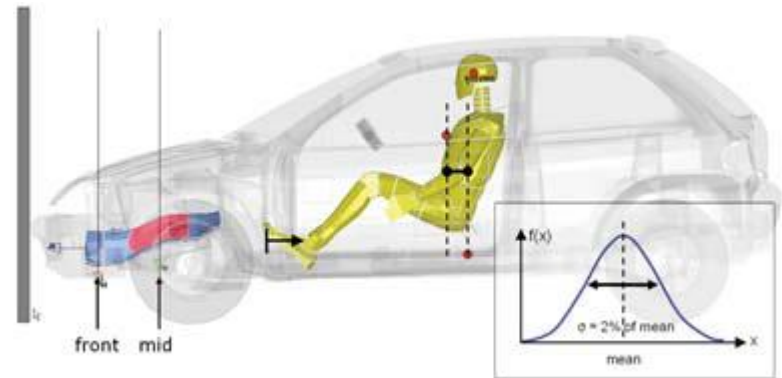
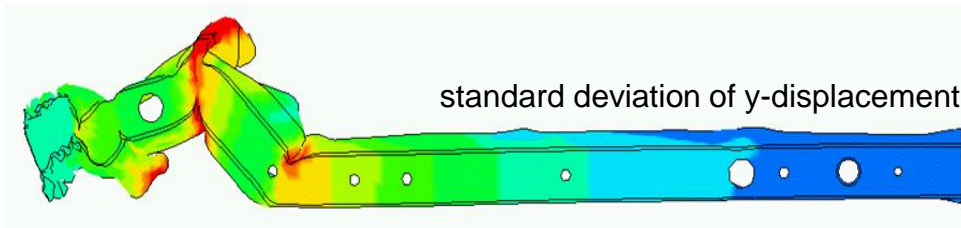
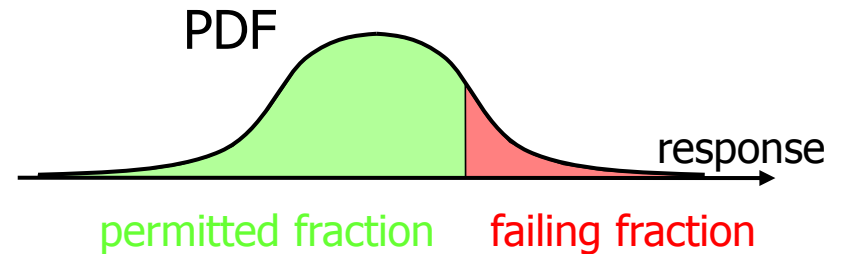
# Applications of LS-OPT

## ■ Stochastic/Probabilistic Analysis: Consideration of uncertainties

- Test of Model Robustness
  - Statistics (mean, standard deviation)
  - Correlation Analysis
- Reliability (Probability of Failure)
- Outlier Detection
- Fringe statistical results on FE model

## ■ Methodology

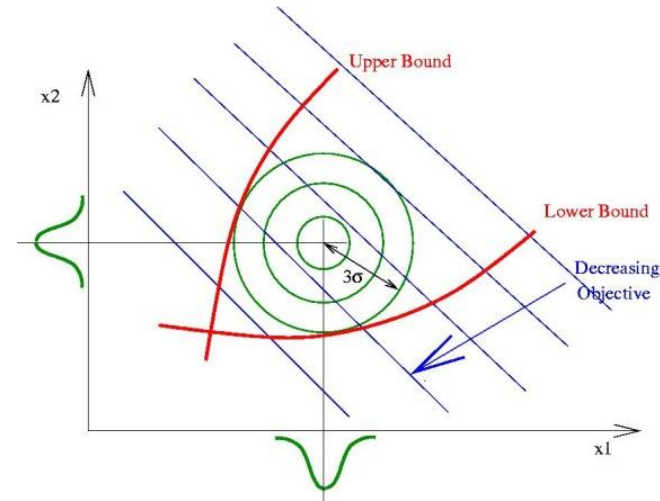
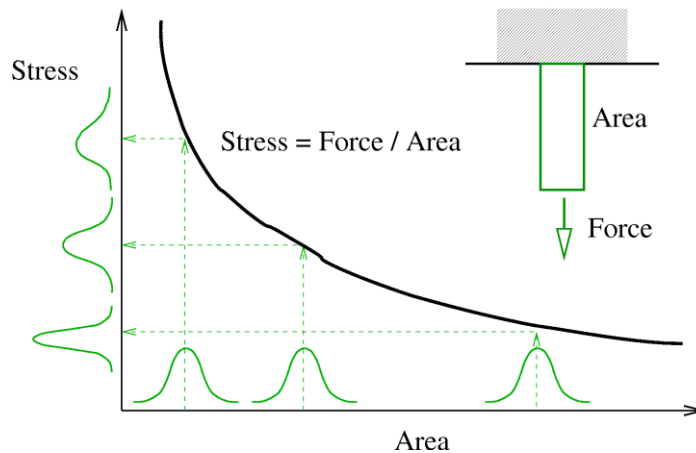
- Monte Carlo Analysis
  - Direct
  - Metamodel-based



# Applications of LS-OPT

## ■ Optimization incorporating uncertainties

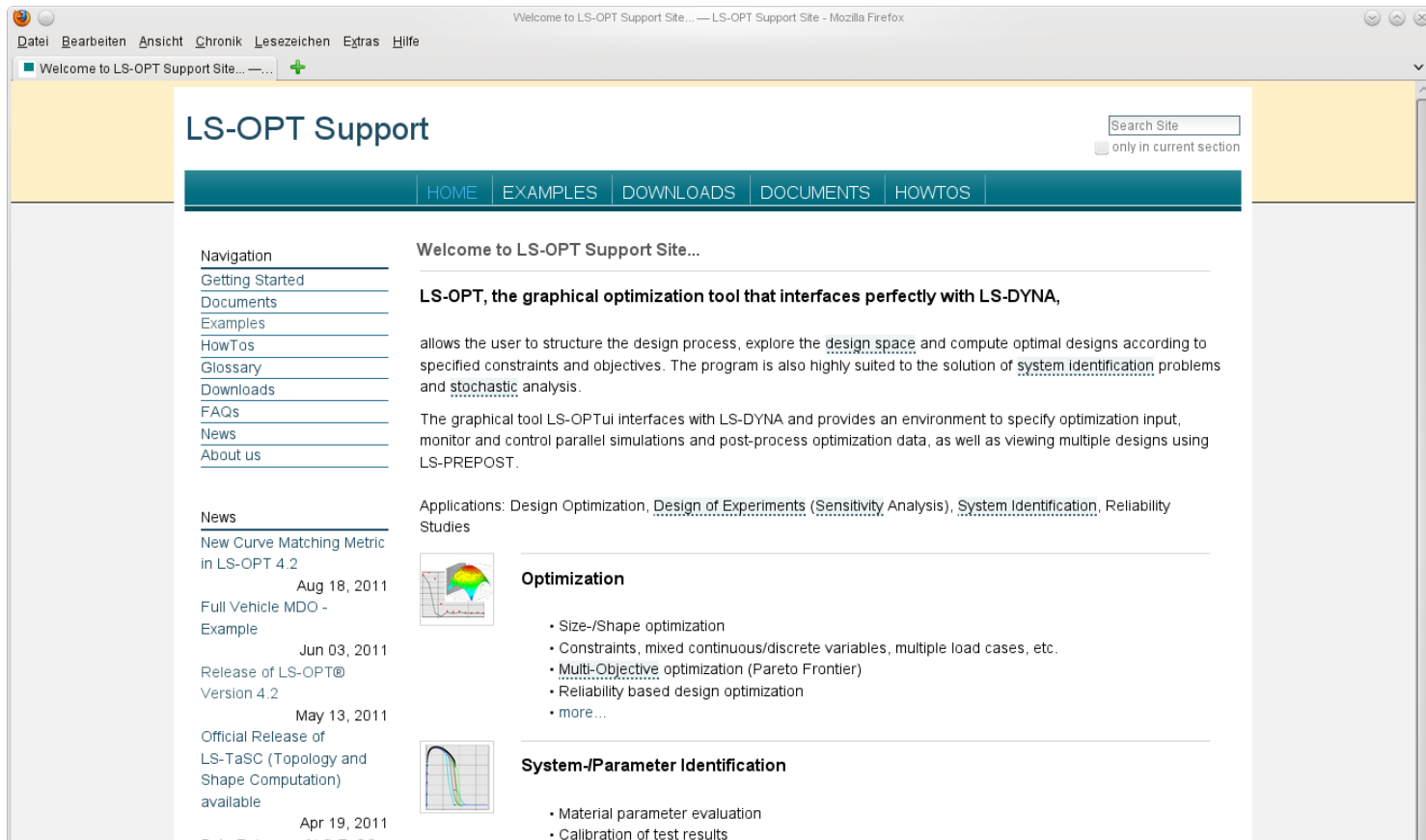
- Robust Parameter Design (RDO)
  - Improve/Maximize the robustness of the optimum
- Reliability Based Design Optimization (RBDO)
  - Improve failure probability of optimum



# LS-OPT Support webpage

## ■ www.lsoptsupport.com

- Many examples, tutorials, FAQs, HowTos...
- Download LS-OPT



The screenshot shows a Mozilla Firefox browser window displaying the LS-OPT Support website. The browser's address bar shows the URL "Welcome to LS-OPT Support Site...". The website has a yellow header with the title "LS-OPT Support" and a search bar. Below the header is a dark blue navigation bar with links for HOME, EXAMPLES, DOWNLOADS, DOCUMENTS, and HOWTOS. The main content area is divided into two columns. The left column contains a "Navigation" menu with links to Getting Started, Documents, Examples, HowTos, Glossary, Downloads, FAQs, News, and About us. Below this is a "News" section with several entries, including "New Curve Matching Metric in LS-OPT 4.2" dated Aug 18, 2011, "Full Vehicle MDO - Example" dated Jun 03, 2011, "Release of LS-OPT@ Version 4.2" dated May 13, 2011, and "Official Release of LS-TaSC (Topology and Shape Computation) available" dated Apr 19, 2011. The right column features a "Welcome to LS-OPT Support Site..." message, followed by a section titled "LS-OPT, the graphical optimization tool that interfaces perfectly with LS-DYNA," which describes the tool's capabilities. Below this is a section for "Applications" listing Design Optimization, Design of Experiments (Sensitivity Analysis), System Identification, and Reliability Studies. The "Optimization" section lists features such as Size-/Shape optimization, Constraints, mixed continuous/discrete variables, multiple load cases, etc., Multi-Objective optimization (Pareto Frontier), and Reliability based design optimization. The "System-/Parameter Identification" section lists Material parameter evaluation and Calibration of test results. Small icons representing optimization results and system identification plots are placed next to their respective sections.

# New features in LS-OPT 6.0

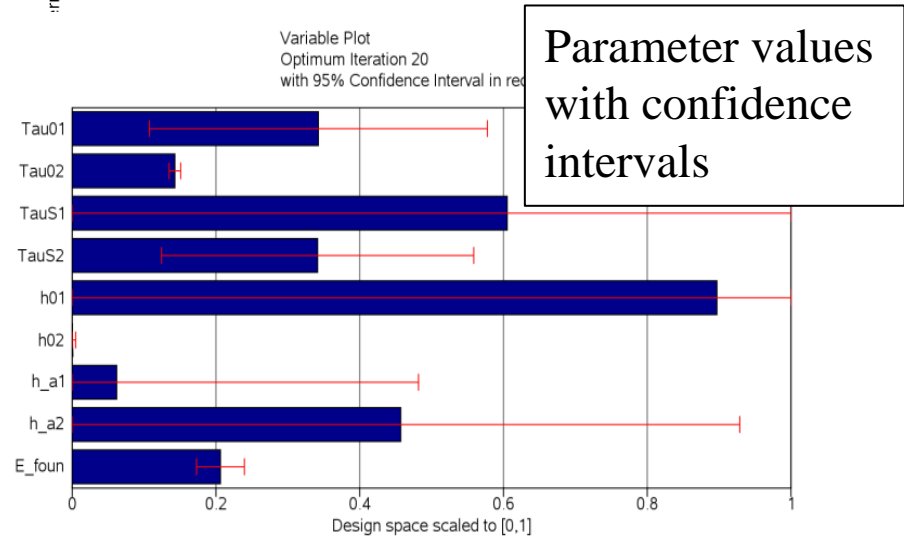
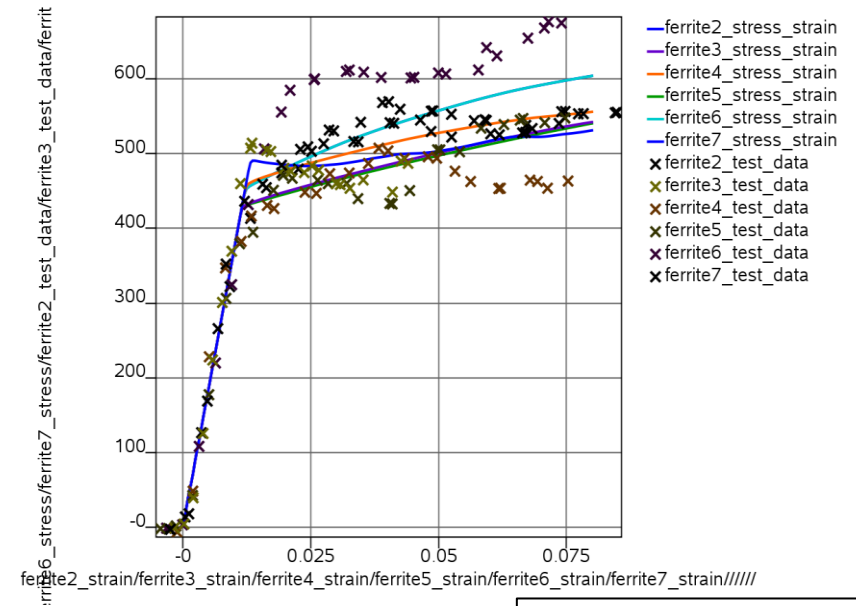
# Overview

- New features for LS-OPT 6
  - DIC-based parameter identification
  - Interactive tables
  - Efficient Global Optimization (EGO)
  - Support Vector Classification
- Other new features
- Outlook

# DIC-based Parameter Identification

- Uniaxial experiments do not necessarily predict non-uniform deformations
- Local phenomena such as coupon necking/barreling missed
- Instability is typical in inverse problems of this nature
- Spatially distributed (full field) data can provide more information than values at individual points
- See e.g. work by Mahnken and Stein, U. Hannover (1997-2001)

**Ferrite single crystal calibration**



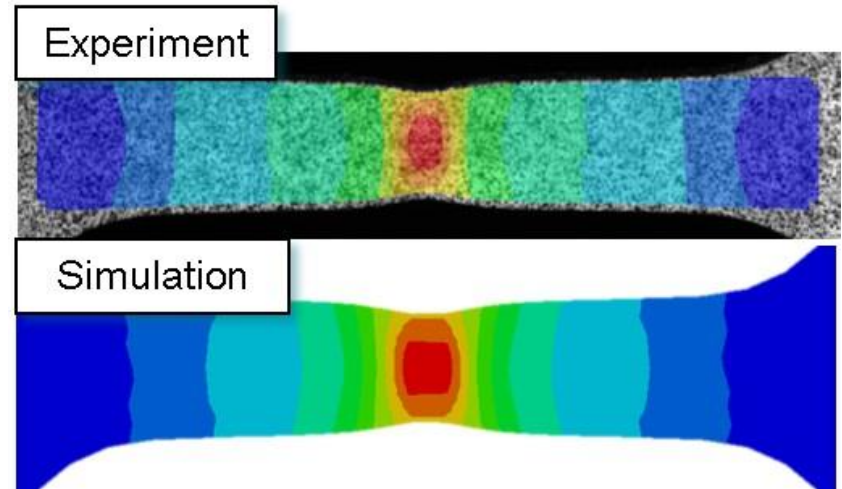
# DIC-based Parameter Identification

- Digital Image Correlation - Optical method for tracking changes in images



Tensile testing equipment

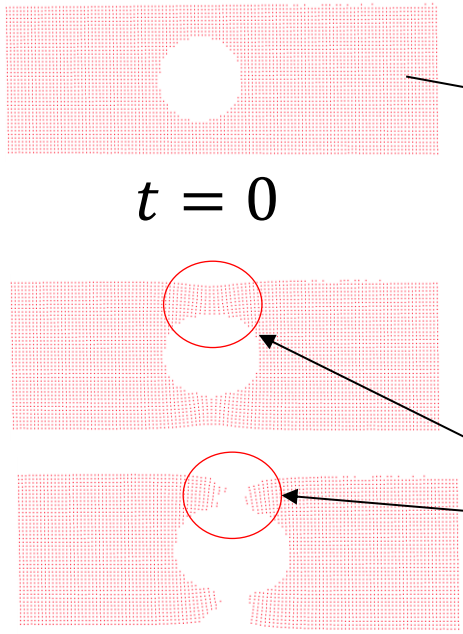
Measurement system



gom/ARAMIS setup at DYNAmore GmbH

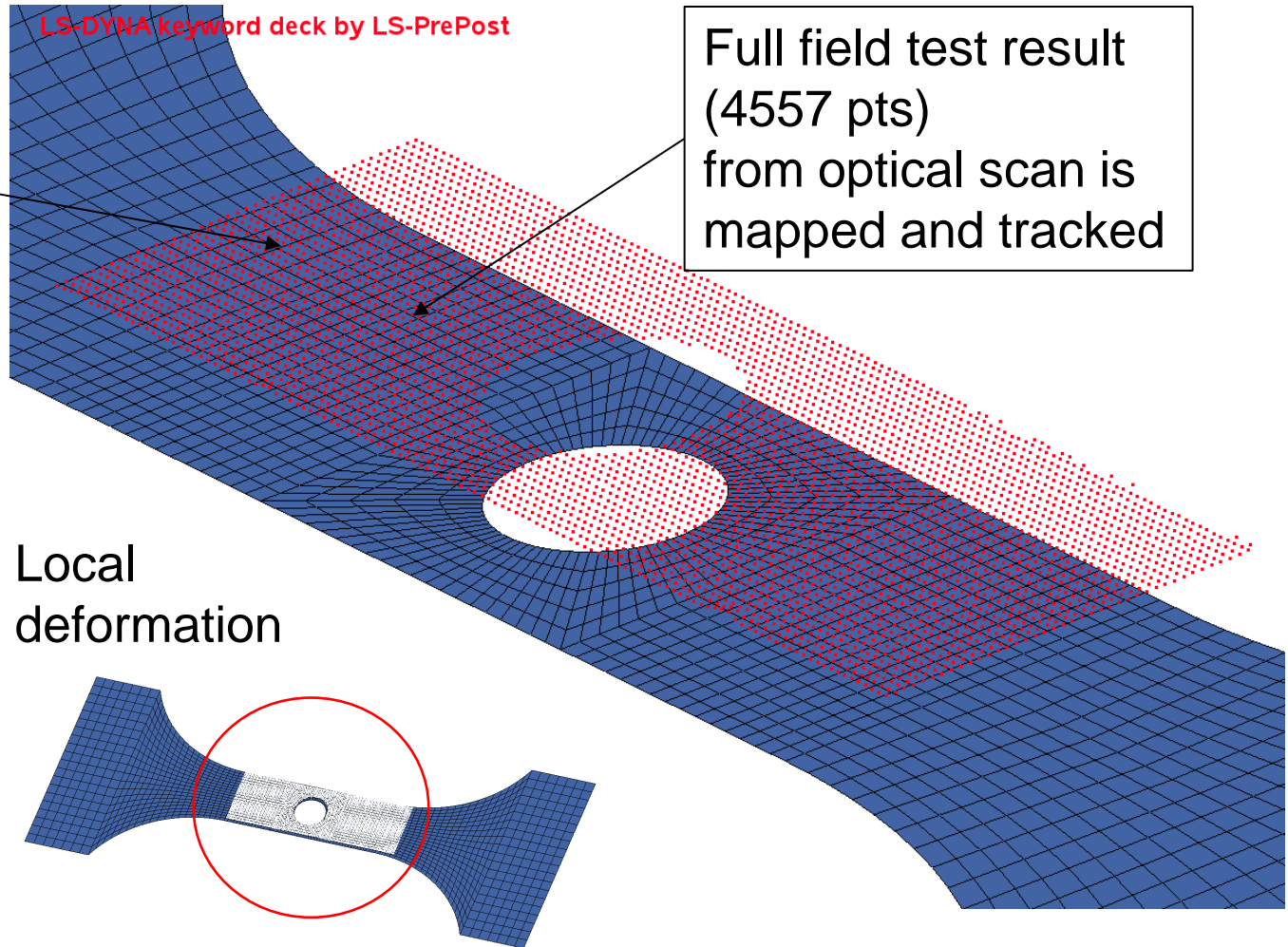
# DIC-based Parameter Identification

## ■ Matching in time and space: Example (tensile)



$t = 0$

DIC data: deformation states

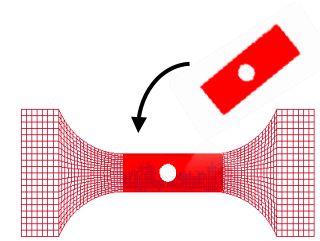




# DIC-based Parameter Identification

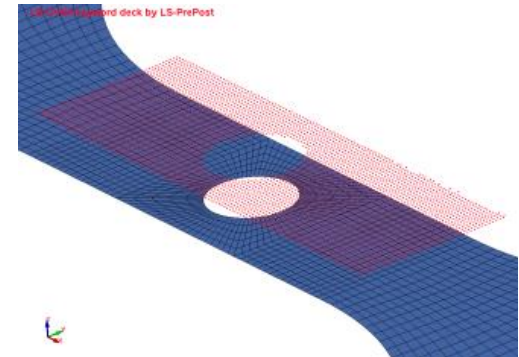
- **Transform:** Align test to FE model. Least Squares solution:

$$\min_{T, \hat{s}} \|\hat{s} X_1 T - X_2\|$$



- $X_1$ : Test pts (subset),  $X_2$ : FE model pts,  $T$ : transform,  $\hat{s}$ : Isotropic scaling
- Linear system (using SVD) if  $\hat{s} = \text{constant}$
- *Alternative:* Pre-processor (e.g. LS-PrePost) to translate, rotate and scale test points
- **Map:** Test  $\rightarrow$  FE mesh: Exact Nearest Neighbor search and element interpolation ( $10^7 \rightarrow 10^7$  pts)
- **Optimization:** Minimize MSE residual

$$\min_x \sum_{j=1}^n \|(\varphi_j(x) - \tilde{\varphi}_j)\|^2$$



# DIC-based Parameter Identification

## ■ Interface to import DIC data

File MultiHistories

Defined file multihistories

- test\_Lochflachzug\_s1

[Add new](#)

MultiHistory Name: test\_Lochflachzug\_s1

gom/ARAMIS  
 GENEX  
 File

Filename Template (wildcard): DATA/SUBSET/example\_data-Stufe-

X-Component: AD-1

Y-Component: Major Strain

Show plot

Preview

strain\_p1-logarithmic

AD-1

OK

# DIC-based Parameter Identification

## ■ Extraction from Simulation: Multipoint histories

- D3plot interface
- Crossplots, Expressions

**Test point source**

**LS-PrePost map**

**Node or element mapping**

**3D Alignment points**

Test x coord	Test y coord	Test z coord	Node ID
-8.47391	.78577	2.02715	495
17.57689	6.08299	2.38169	1435
-8.19484	-6.23842	2.0367	1925
16.96481	-3.20172	2.38046	2771

# DIC-based Parameter Identification

## ■ Multihistory matching

**Edit response**

Name	Subcase	Multiplier	Offset
Residual		n/a	n/a

**Match**

Histories

Multihistories

**Algorithm**

Mean Square Error (difference in curve Y values)

Curve Mapping (area between curves)

Discrete Frechet

Dynamic Time Warping

**Target multihistory**

test\_Lochflachzug\_s1 [Add new file multihistory](#)

**Computed multihistory**

cp\_mh\_first\_principal\_strain

**Regression Points**

From target curve

Fixed number (equidistant, interpolated)

# Interactive Tables

Overall Feasibility    Category    Filter    Constraint Feasibility    Sorting

The interface displays a table of simulation results with columns for Points, Marked, Category, Type, Variables (tbumper, thood), Composites (Intrusion), Constraints (Mass, Acc\_max), Objectives (HIC), Multi-Objective, Max Const Violation, and Success run. A parallel coordinate plot visualizes the data for variables tbumper, thood, Intrusion, Mass, Acc\_max, and HIC. Two dialog boxes are shown: one for defining categories (Design 1, Design 2, Feasible designs, Design 5) and another for defining a description for a design.

Points	Marked	Category	Type	Variables		Composites		Constraints		Objectives			
				tbumper	thood	Intrusion	Intrusion	Mass	Acc_max	HIC	Multi-Objective	Max Const Violation	Success run
1.11	<input type="checkbox"/>	Design 1	Analysis	5	1	573.647	573.647	0.532248	2.64044e+06	57.56	57.56	140940	<input checked="" type="checkbox"/>
1.9	<input type="checkbox"/>	Design 1	Analysis	4.11111	1	570.969	570.969	0.478048	2.63235e+06	57.74	57.74	132354	<input checked="" type="checkbox"/>
1.10	<input checked="" type="checkbox"/>	Design 1	Analysis	4.55556	1	571.191	571.191						
1.21	<input type="checkbox"/>	Design 1	Analysis	5	1.44444	554.096	554.096						
1.8	<input type="checkbox"/>	Design 1	Analysis	3.66667	1	574.76	574.76						
1.20	<input type="checkbox"/>	Design 1	Analysis	4.55556	1.44444	554.918	554.918						
1.3	<input type="checkbox"/>	Design 1	Analysis	1.44444	1	583.545	583.545						
1.5	<input type="checkbox"/>	Design 1	Analysis	2.33333	1	583.455	583.455						
1.4	<input checked="" type="checkbox"/>	Design 1	Analysis	1.88889	1								
1.2	<input type="checkbox"/>	Design 1	Analysis	1	1								
1.6	<input type="checkbox"/>	Design 1	Analysis	2.77778	1								

**Define Categories**

- Design 1 (14 points)
- Design 2 (20 points)
- Feasible designs (1 points)
- Design 5 (16 points)

**Define Description**

Name: Design 1  
Color: [Black]  
Shape: cube  
Description: This is design 1

# Interactive Tables

## ■ Interactive Constraint management

Constraints are only changed for the active tab Reset

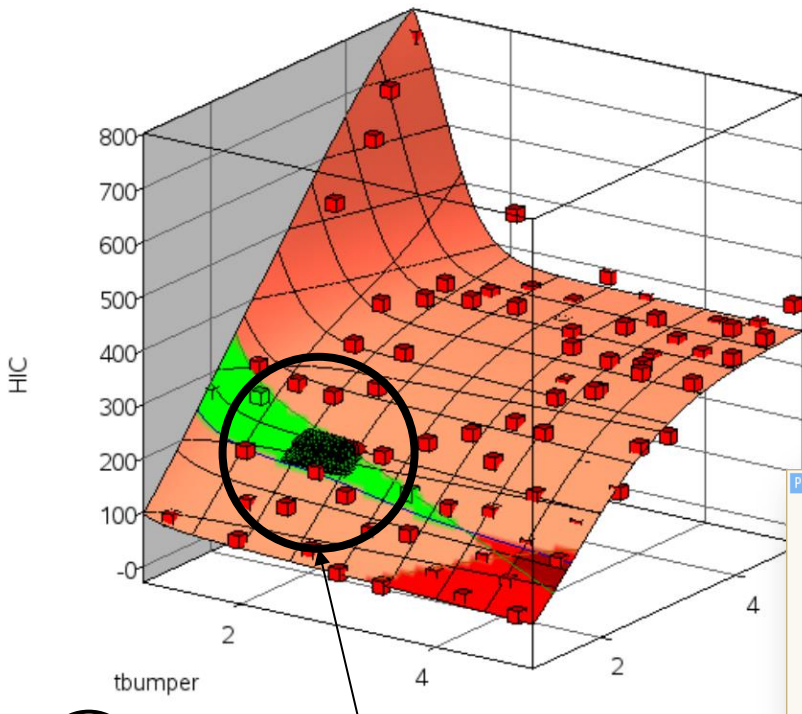
Constraint	Lower Bound	Strict	Upper Bound	Strict
Intrusion	<a href="#">Set lower bound</a>	<input checked="" type="checkbox"/>	<input type="text" value="550"/>	<input type="checkbox"/>
Mass	<a href="#">Set lower bound</a>	<input checked="" type="checkbox"/>	<input type="text" value="0.7"/>	<input type="checkbox"/>
Acc_max	<a href="#">Set lower bound</a>	<input checked="" type="checkbox"/>	<input type="text" value="2.5e+06"/>	<input type="checkbox"/>

## ■ Statistics of selected point

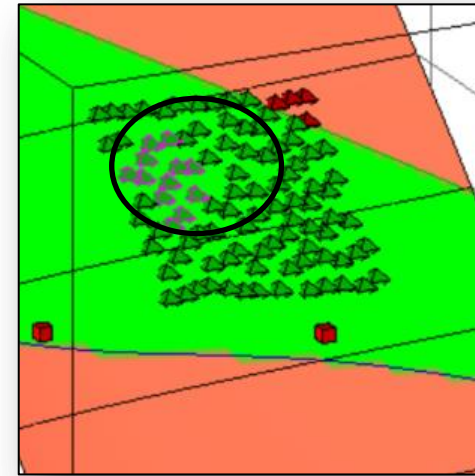
Points	Variables		Composites	Constraints			Objectives	Multi-Objective	Max Constr. Violation
	tbumper	thood	Intrusion	Intrusion	Mass	Acc_max	HIC		
Nominal	0	0	0	0	0	0	0	0	0
Mean	2.97523	2.93732	521.056	521.056	0.849357	1.99565e+06	286.893	286.893	5503.76
StdDev	1.27034	1.29872	33.3185	33.3185	0.306708	288499	143.974	143.974	23963.3
SS	1086.83	1071.02	2.83503e+07	2.83503e+07	84.7155	4.22765e+14	1.0695e+07	1.0695e+07	6.2297e+10
Min	1	1	450.81	450.81	0.288374	1.4871e+06	51.52	51.52	0
Max	5	5	583.545	583.545	1.44187	2.64094e+06	773.8	773.8	140940
Lower Constraint	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lower Exceeded	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prob. Exceed Lower	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Upper Constraint	N/A	N/A	N/A	550	0.5	2.5e+06	N/A	N/A	N/A
Upper Exceeded	N/A	N/A	N/A	24	88	6	N/A	N/A	N/A
Prob. Exceed Upper	N/A	N/A	N/A	0.230769	0.846154	0.0576923	N/A	N/A	N/A
Num. Values	104	104	104	104	104	104	104	104	104

# Interactive Tables

## Virtual points



2 Select



Virtual points Run simulations

Point selection

Points	Marked	Type	Variables		Constraints			Objectives	Ma	V
			tbumper	thood	Intrusion	Mass	Acc_max	HIC ▲		
vo1.109	<input checked="" type="checkbox"/>	Virtual	2.25259	1.86465	544.755	0.561377	1.88095e+06	200.142		
vo1.144	<input checked="" type="checkbox"/>	Virtual	2.19286	1.87575	544.488	0.560259	1.85526e+06	202.227		
vo1.149	<input checked="" type="checkbox"/>	Virtual	2.23566	1.9226	542.64	0.573522	1.85635e+06	208.534		
vo1.167	<input checked="" type="checkbox"/>	Virtual	2.16694	1.93914	542.235	0.573095	1.82604e+06	211.42		
vo1.182	<input checked="" type="checkbox"/>	Virtual	2.3141	1.89203	543.545	0.571354	1.89467e+06	203.571		
vo1.196	<input checked="" type="checkbox"/>	Virtual	2.12216	1.88888	544.171	0.558934	1.82481e+06	204.703		
vo1.200	<input checked="" type="checkbox"/>	Virtual	2.3527	1.84454	545.248	0.562909	1.92413e+06	196.428		

Output Table1

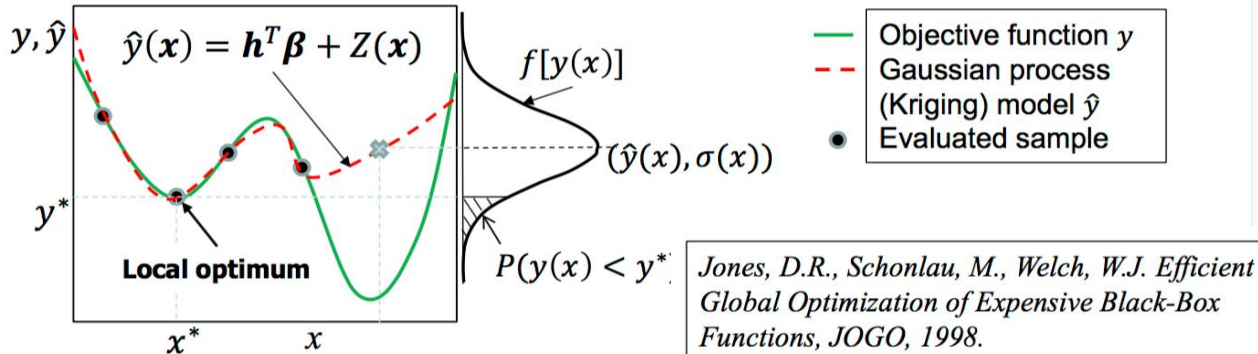
1 Generate in Viewer

3 Evaluate & Simulate

# Efficient Global Optimization (EGO)

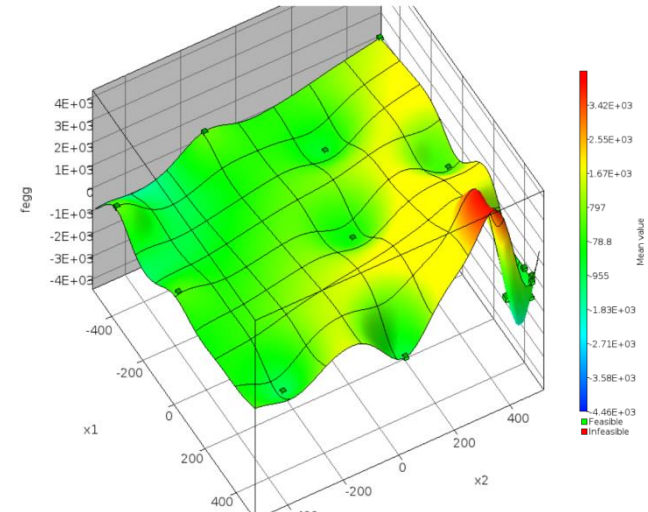
## Basic Idea

- Balances local and global search through compromise between good objective function value and high prediction uncertainty
- Needs Kriging metamodel for objective function
- Limited to small variable sets (e.g. 10)
- Useful for parameter identification

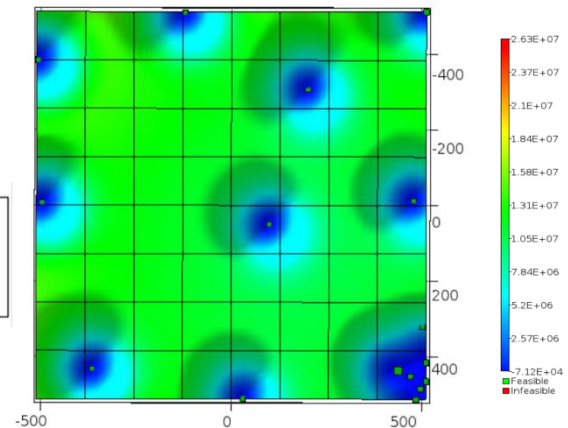


Expected improvement of the objective function:

$$E[I(x)] = \int_{-\infty}^{y^*} (y^* - y(x)) f[y(x)] dy = (y^* - \hat{y}) \Phi\left(\frac{y^* - \hat{y}}{\sigma}\right) + \sigma \phi\left(\frac{y^* - \hat{y}}{\sigma}\right) \rightarrow \max_x$$



Minimize mean function value (exploitation)



Maximize standard deviation (exploration)

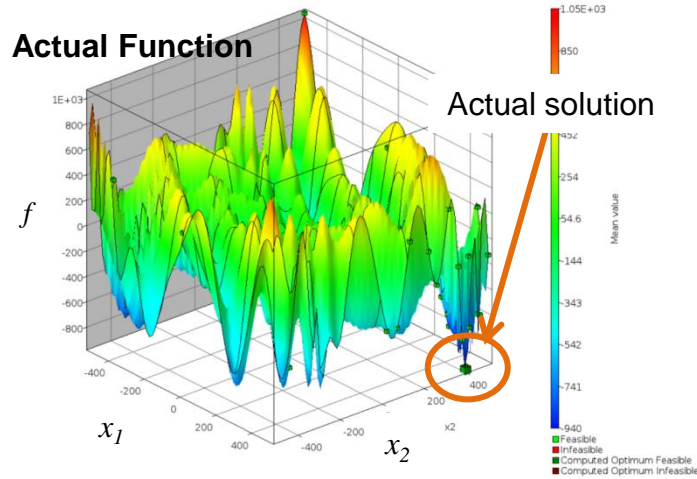


# Efficient Global Optimization (EGO)

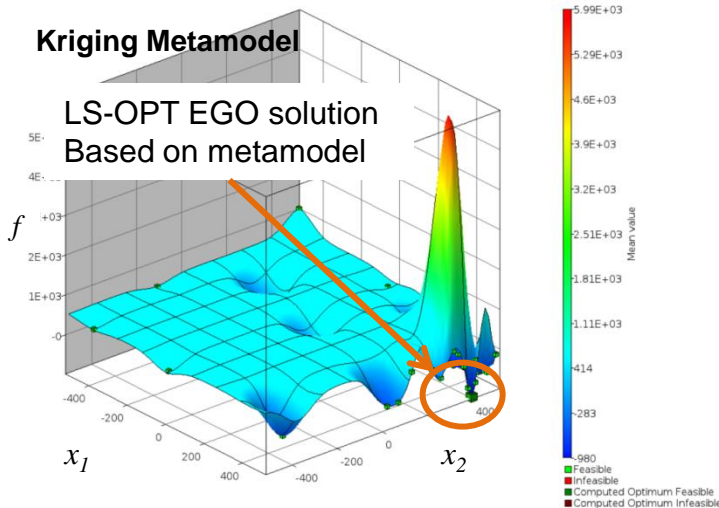
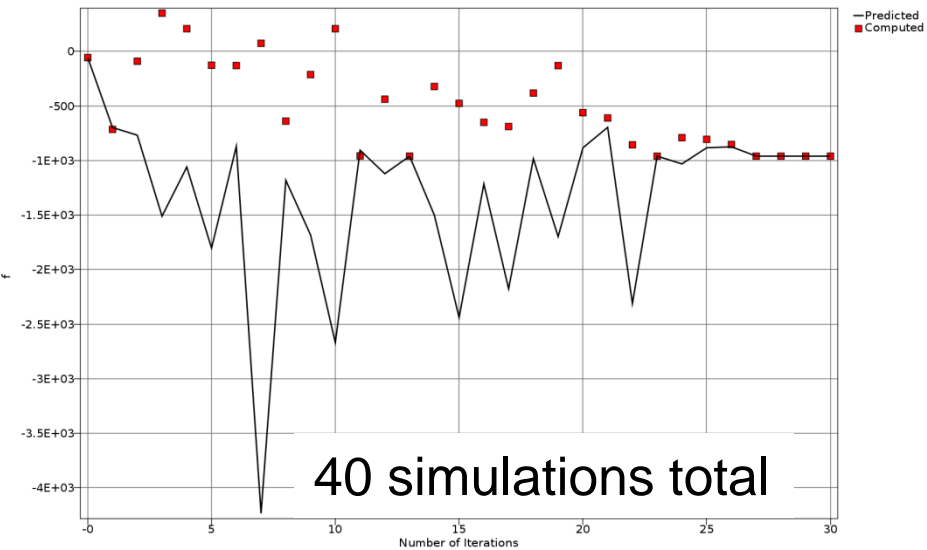
## Example and comparison to GA

$$f(x_1, x_2) = -(x_2 + 47) \sin\left(\sqrt{\left|\frac{x_1}{2} + (x_2 + 47)\right|}\right) - x_1 \sin\left(\sqrt{|x_1 - (x_2 + 47)|}\right)$$

$$-512 \leq x_1, x_2 \leq 512$$



Optimization History of objective function



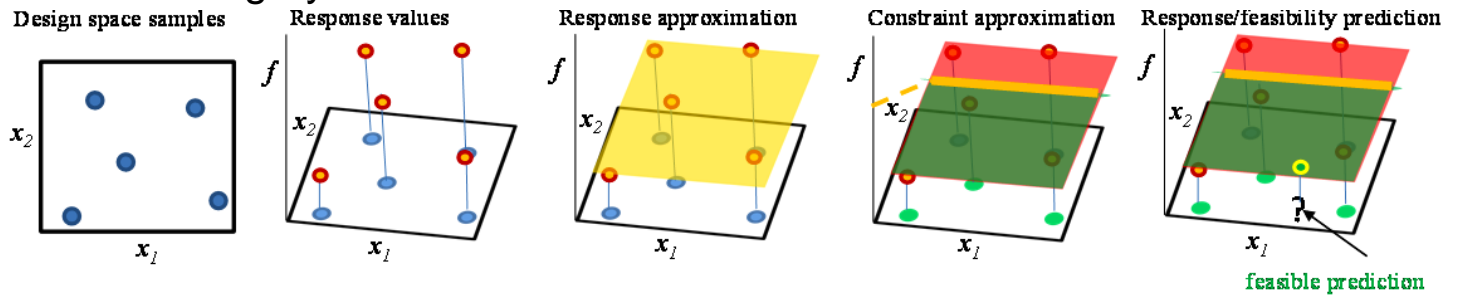
Algorithm	Cost	Objective
GA	300	-718
GA	600	-889
<b>EGO</b>	<b>40</b>	<b>-960</b>

# Support Vector Classification

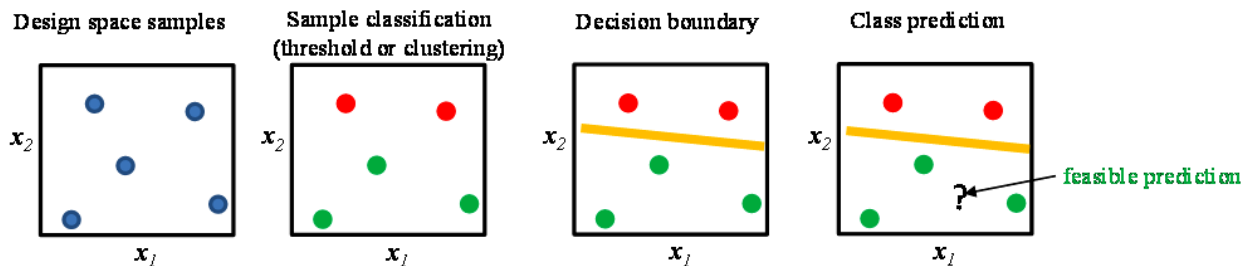
- Discontinuous and binary responses

- Map input data to category

## Metamodeling



## Basic classification method



- Adaptive multi-objective optimization

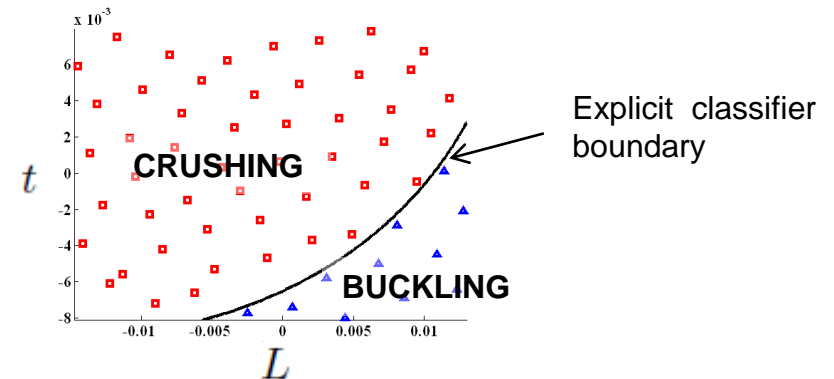
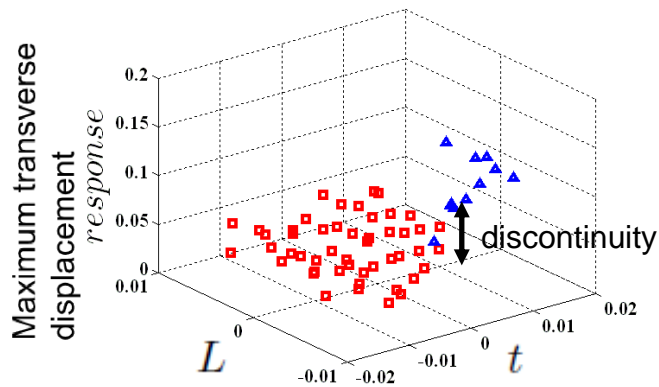
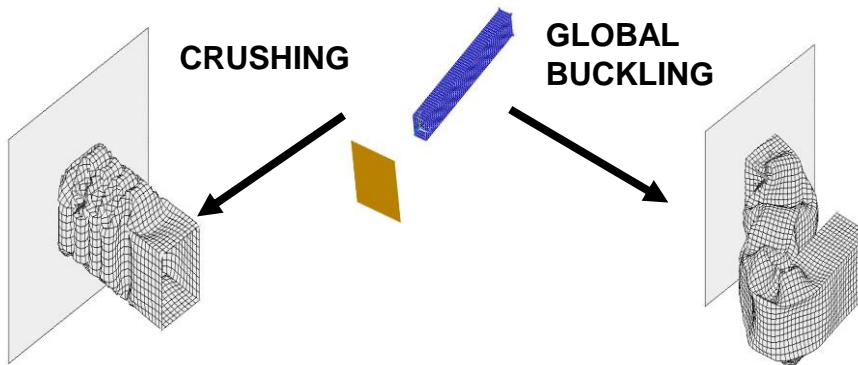
- classifier defines the boundary of the Pareto optimal designs

*Basudhar, A. (2015). Multi-objective Optimization Using Adaptive Explicit Non-Dominated Region Sampling. In 11th World Congress on Structural and Multidisciplinary Optimization.*

- Statistical Classification together with established features (e.g. multi-layer Feedforward Neural Networks) is progression towards building a Statistical Learning tool based on the current Viewer

# Support Vector Classification

## ■ Example: Tube impact

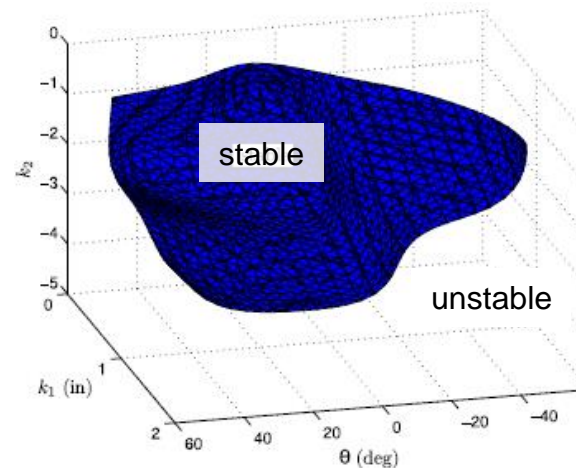
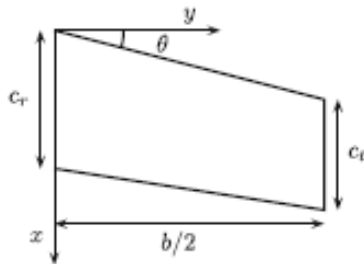


Design Space (length and thickness)

# Support Vector Classification

- Example: Wing Aeroelasticity
- Binary constraints
  - Divergence instability
    - Zero vs Non-zero Modal Frequency
  - Flutter instability
    - Positive vs Negative damping coefficient

*Basudhar, Anirban, et al. "Constrained efficient global optimization with support vector machines." Structural and Multidisciplinary Optimization 46.2 (2012): 201-221.*



**Decision Surface  
in Design Space**

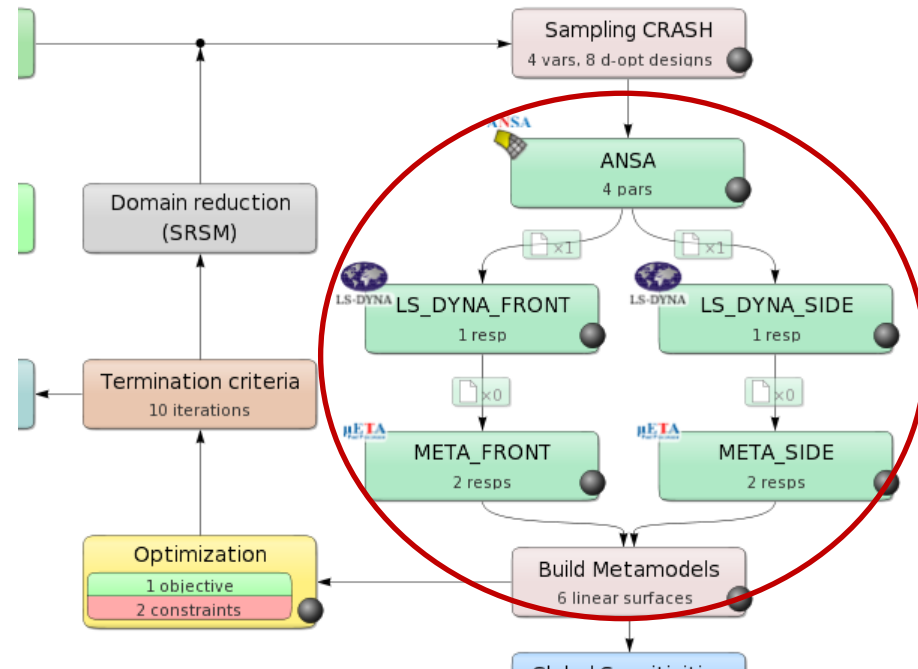
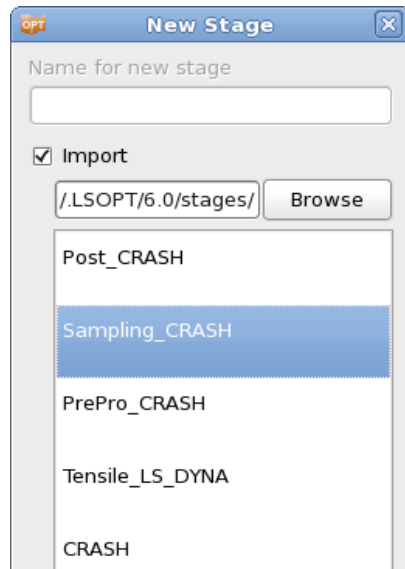
## Other new Feature

### ■ Taguchi method

- Classical robust design approach using Orthogonal Arrays

### ■ Export and import of stages

- Individually
- Full case-based process
  - E.g. Frontal Crash including its pre- and post-processing could be imported/exported as a unit with a given name



# Outlook

## ■ Full-Field Calibration (DIC)

- Pre-viewing, editing and Pre-processing tools
  - Edit test data using filtering, truncation, reduction, etc.
  - Includes editing of full-field data
- Curve similarity criteria
  - Others in addition to MSE, PCM, DF, DTW

## ■ Statistical Learning Tools

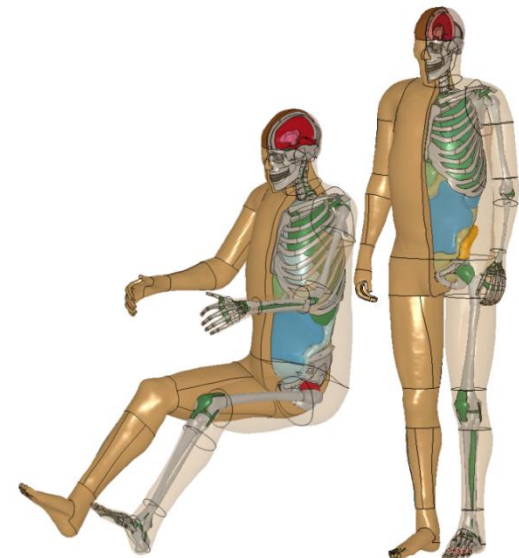
- Incorporation of metamodeling into Viewer so it becomes an independent Statistical Learning Tool
- Tools: Classification, Neural Networks, Principle Component Analysis (existing or under development)

## ■ Job distribution

- Graphical Interface for Blackbox option

# More Information on the LSTC Product Suite

- Livermore Software Technology Corp. (LSTC)  
[www.lstc.com](http://www.lstc.com)
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[www.dynasupport.com](http://www.dynasupport.com)
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