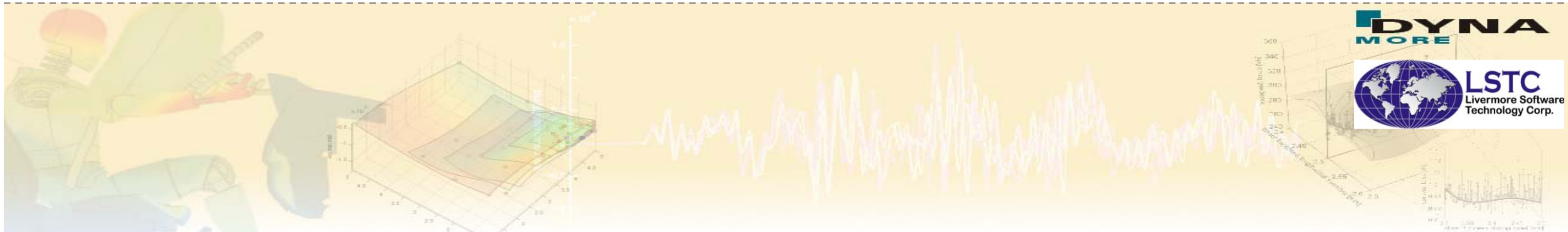

New Developments on Identification of Material and System Parameters with LS-OPT®

Katharina Witowski (DYNAmore GmbH)
Markus Feucht (Daimler AG)
Nielen Stander (LSTC)

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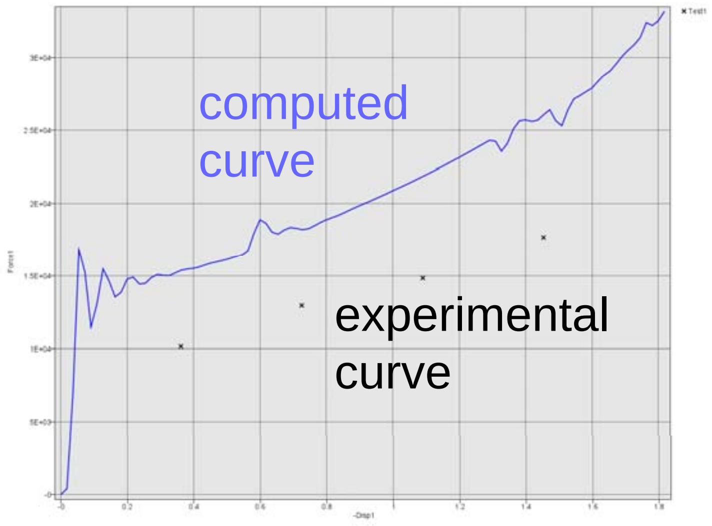
- Introduction: Problem statement
- Example: Current ordinate-based curve matching metric
- Motivation and theory of new curve matching metric
- Examples
- Conclusions

Parameter identification: Objectives

- Parameter Identification problems are non-linear inverse problems solved using optimization
- A computed curve (from LS-DYNA®), dependent on parameters, is matched to an experimental curve
- Optimization provides a calibration of the unknown parameters
- An LS-OPT feature dedicated to Parameter Identification (MeanSqErr) has been available since LS-OPT v3
- Principle technologies involved:
  - *Optimization algorithm*
  - *Curve Matching metric*

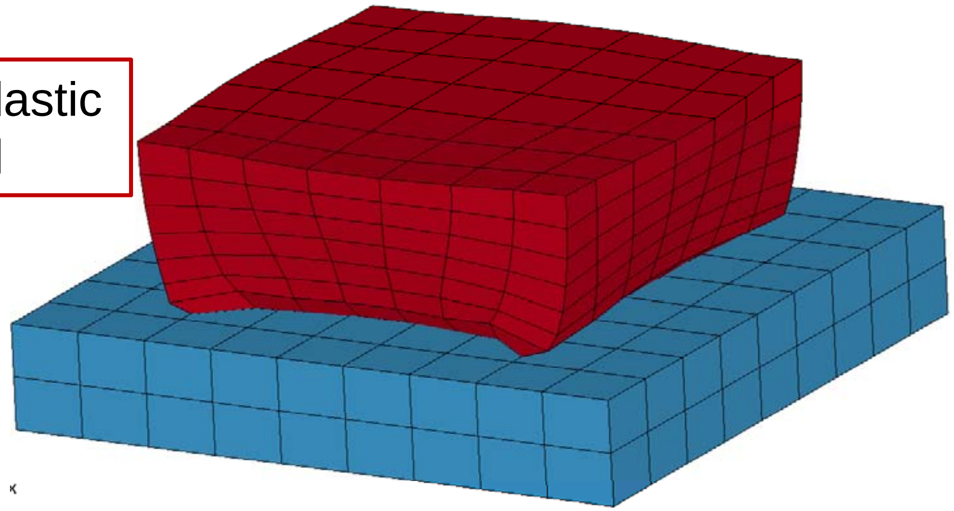


Current Ordinate-based Parameter Identification (MeanSqErr) - Example

- Example: Material properties of a foam

Elastoplastic material

Rigid base



Experiment:

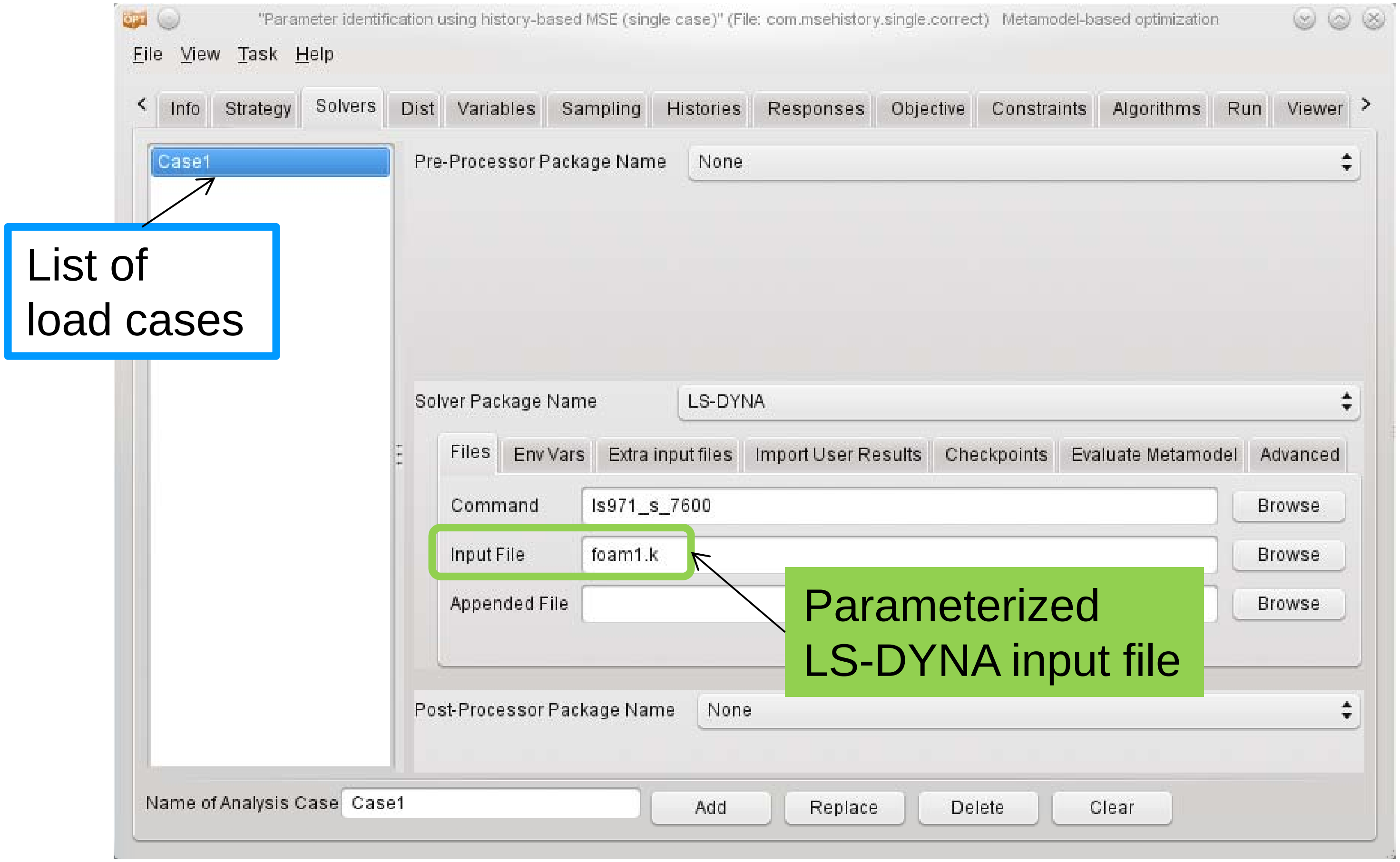
Displ	Force
0.36168	10162
0.72562	12964
1.0903	14840
1.4538	17672

```
*PARAMETER
rYMod,7e5,rYield,15e2
*MAT_PLASTIC_KINEMATIC
       1    1.0E-3&YMod           0.3&Yield         10.0       0.0
     0.0       0.0       0.0       0.0
```

Parameters:
- Young‘s modulus
- Yield stress

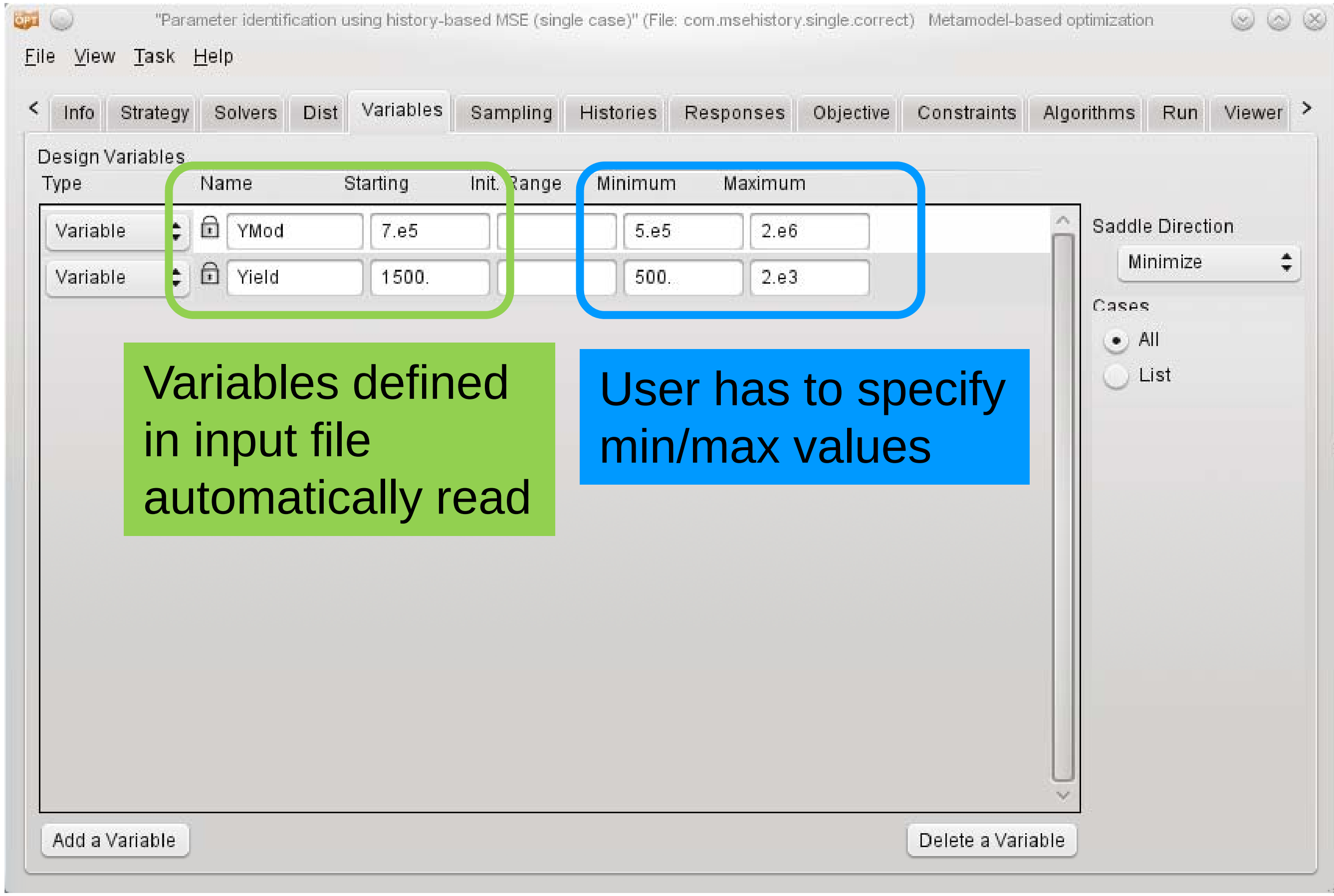
Current Ordinate-based Parameter Identification (MeanSqErr) - Example

- Setup in LS-OPT GUI – Definition of load cases



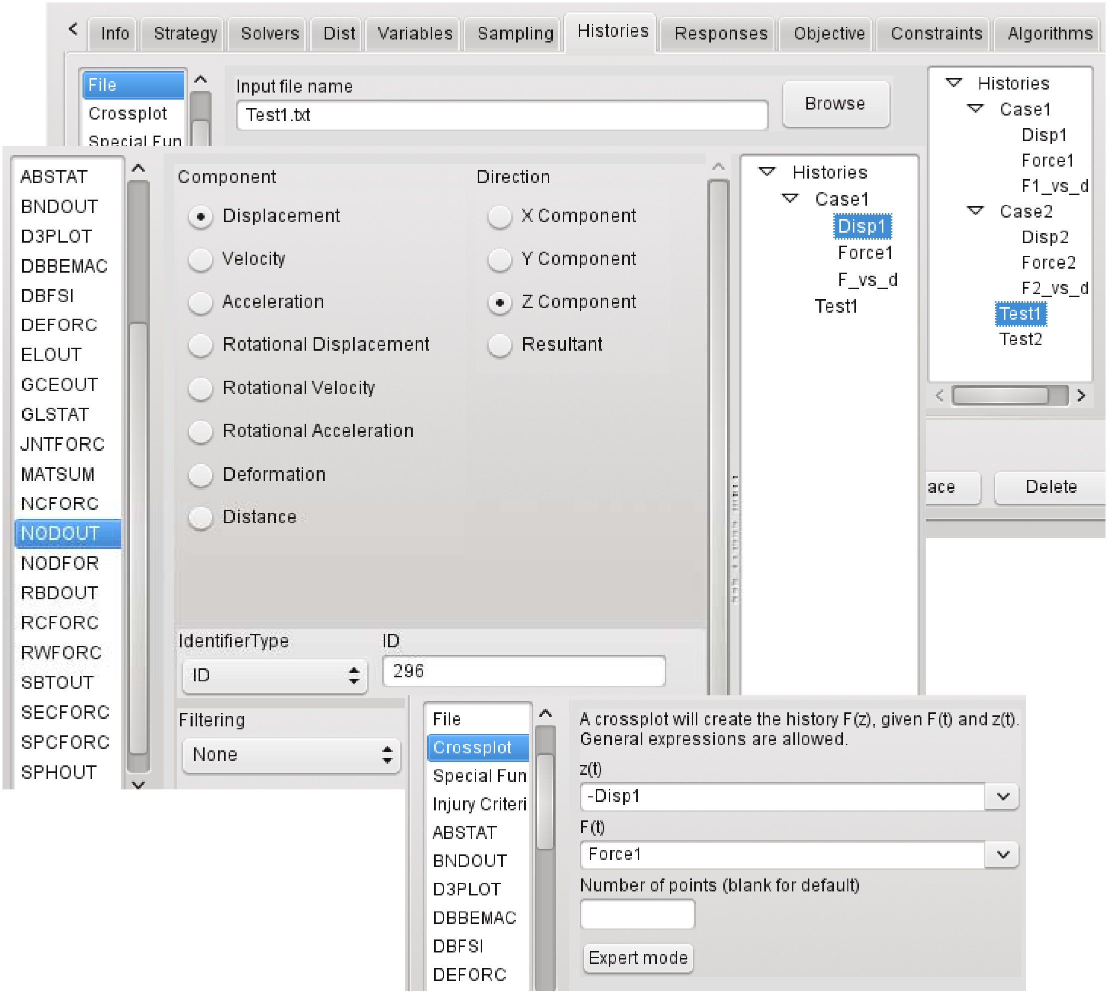
Current Ordinate-based Parameter Identification (MeanSqErr) - Example

- Setup in LS-OPT GUI – Definition of variables

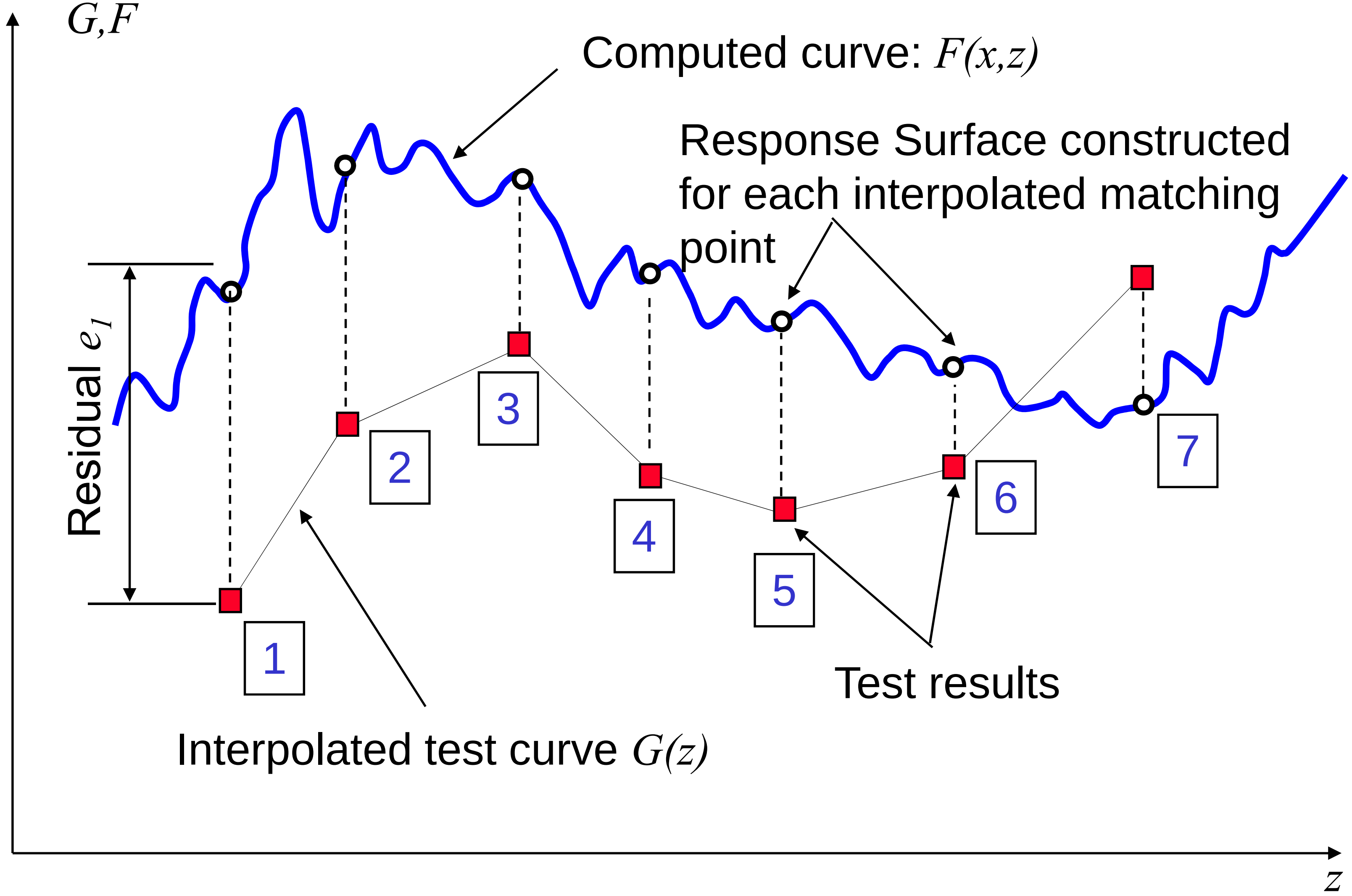


Current Ordinate-based Parameter Identification (MeanSqErr) – Setup in LS-OPT GUI

- Setup in LS-OPT GUI – Definition of test and simulated curves
- Reads test curve files directly
- Interfaces to most LS-DYNA response types
- Crossplots can be defined, e.g. Stress vs. strain, Force vs. deformation …



Current Ordinate-based Parameter Identification (MeanSqErr)

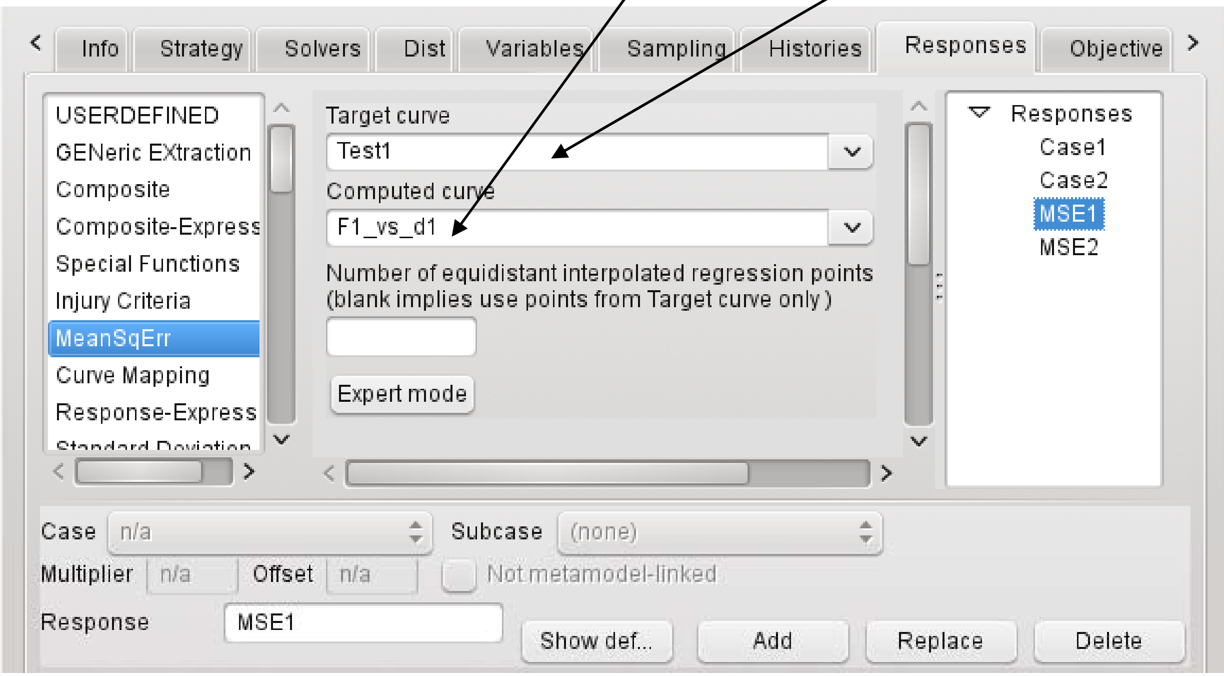


Current Ordinate-based Parameter Identification (MeanSqErr) – Setup in LS-OPT GUI

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

Test curve

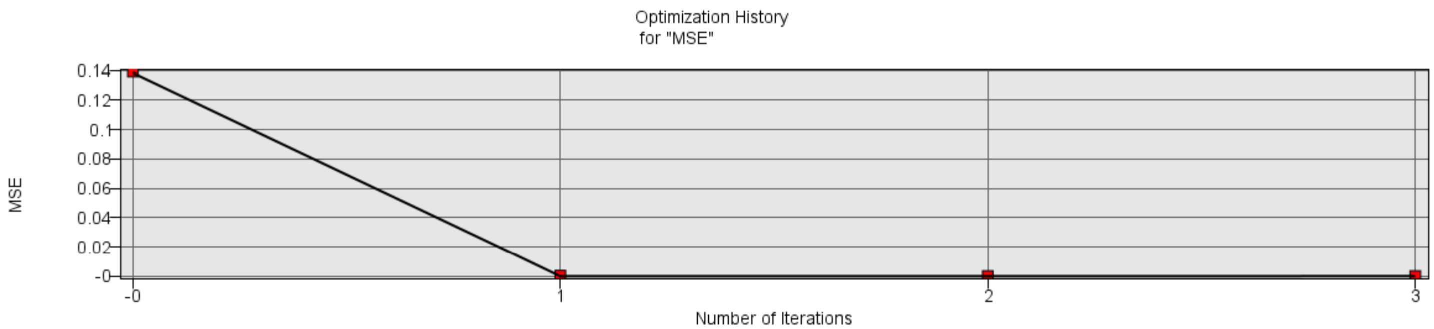
Simulation curve



- Advanced options: number of points, start point, end points, weighting/scaling options

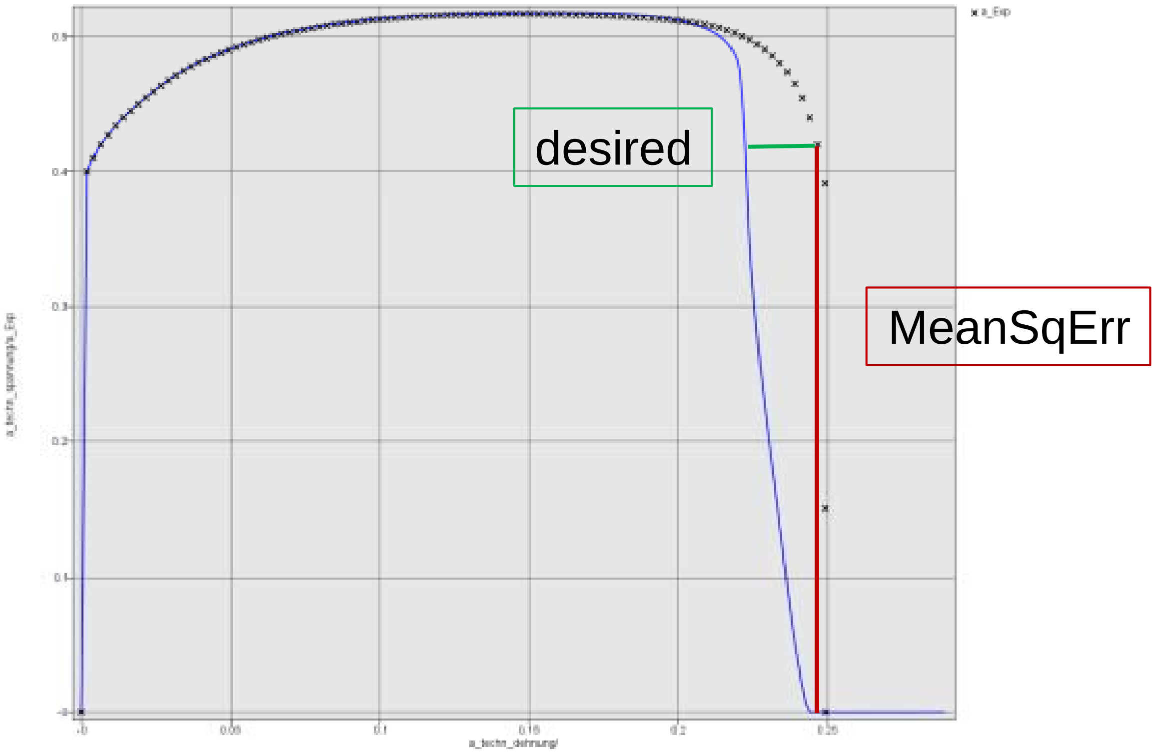
Current Ordinate-based Parameter Identification (MeanSqErr) - Example

- Results



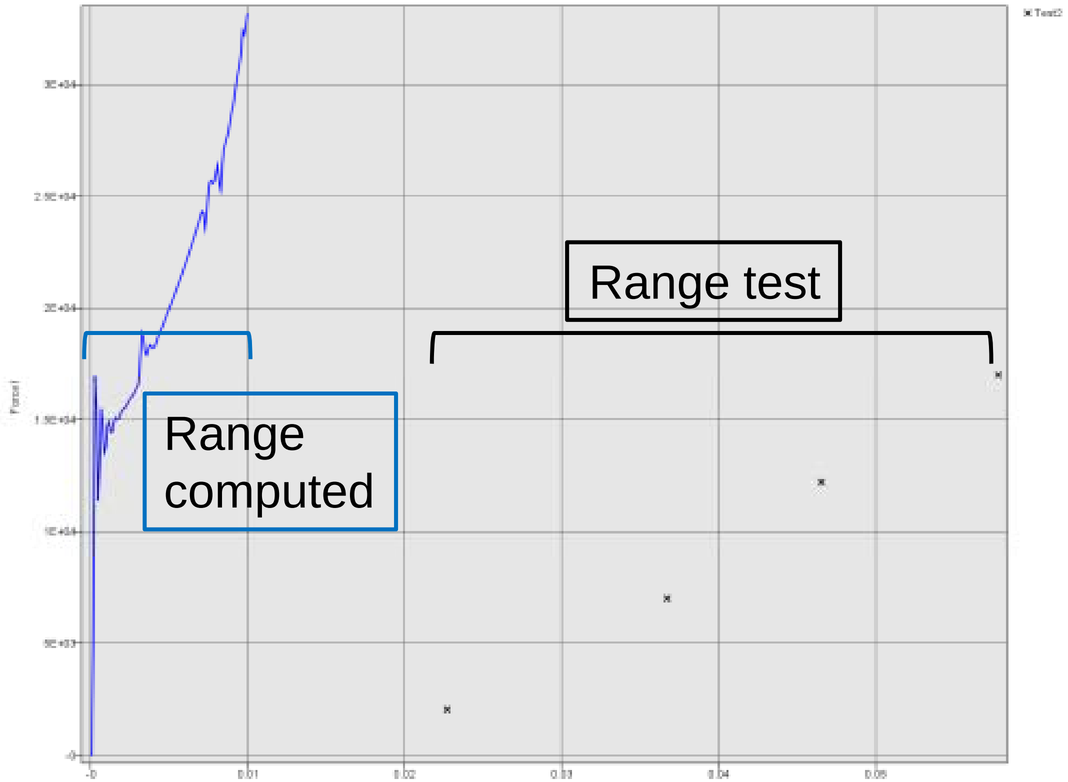
Problems with ordinate-based curve matching

- Steep parts of the response are difficult or impossible to incorporate, e.g. linear elastic range or failure (damage models such as the GISSMO model in LS-DYNA®)



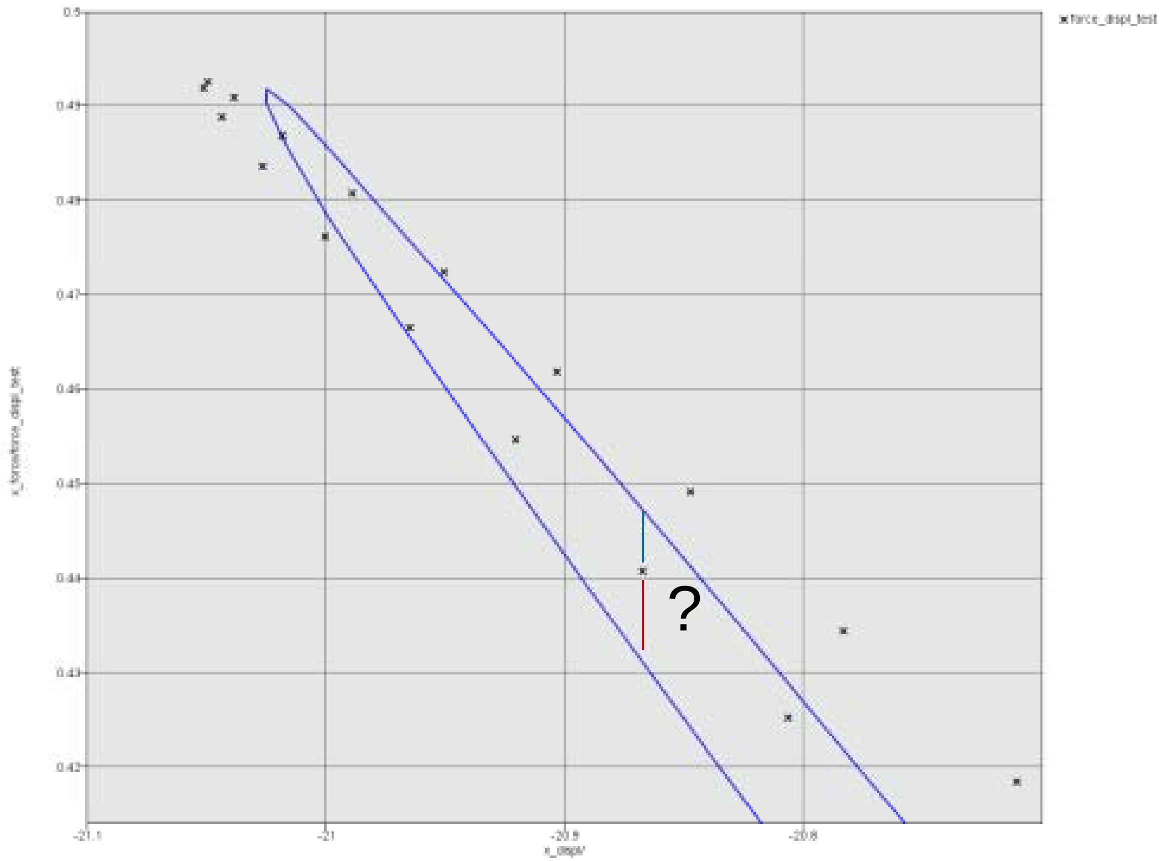
Problems with ordinate-based curve matching

- Ranges of the computed and test curves do not coincide in the abscissa at an interim stage of the optimization resulting in instability



Problems with ordinate-based curve matching

- <u>Hysteretic</u> test curves or <u>springback</u> cannot be matched since the ordinate values are non-unique

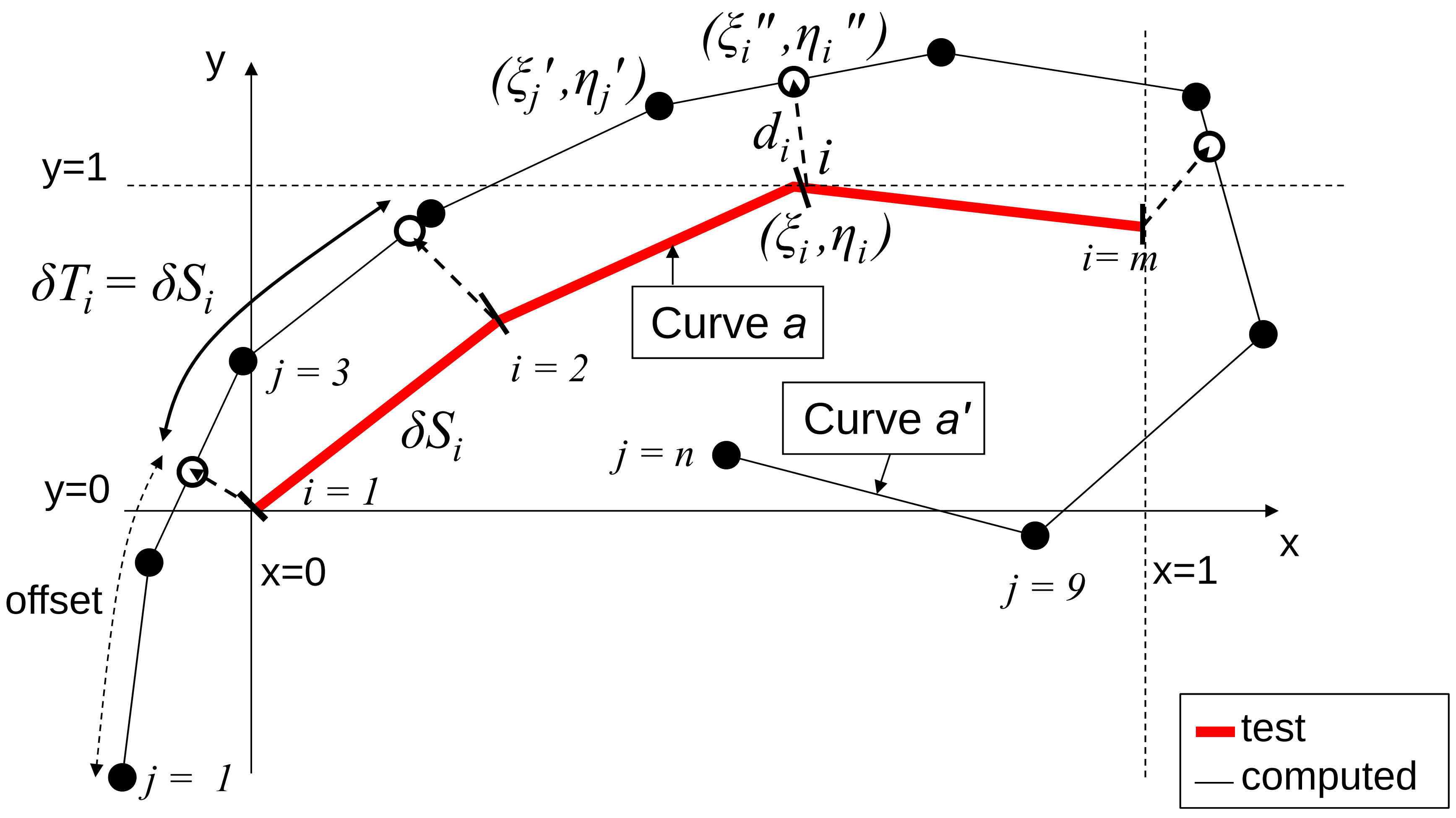


Problems with ordinate-based curve matching

- Partial matching is not robust, i.e. where only a part of the test curve or a part of the computed curve is available

→ Requires Curve Mapping

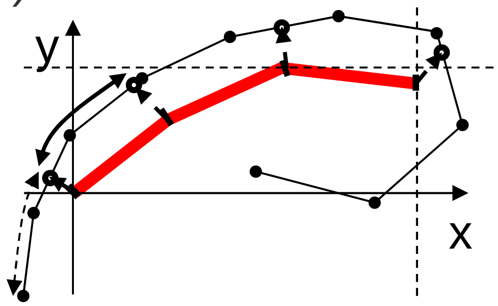
Partial Curve Mapping



Partial Curve Mapping algorithm

- Normalize the curves to the test (experimental) curve
  - *Avoids problems with different magnitudes for abscissa and ordinate*
  - *Unit independent*
- Map the short curve onto the long curve so that the lengths are equal (mild filtering of curves by user is recommended)
- The distance is defined by the area between the short curve and the mapping
- Optimize the offset to find the smallest distance between the curves
- Implemented into LS-OPT as

  CurveMapSegment ("testcurve", "computed_curve")

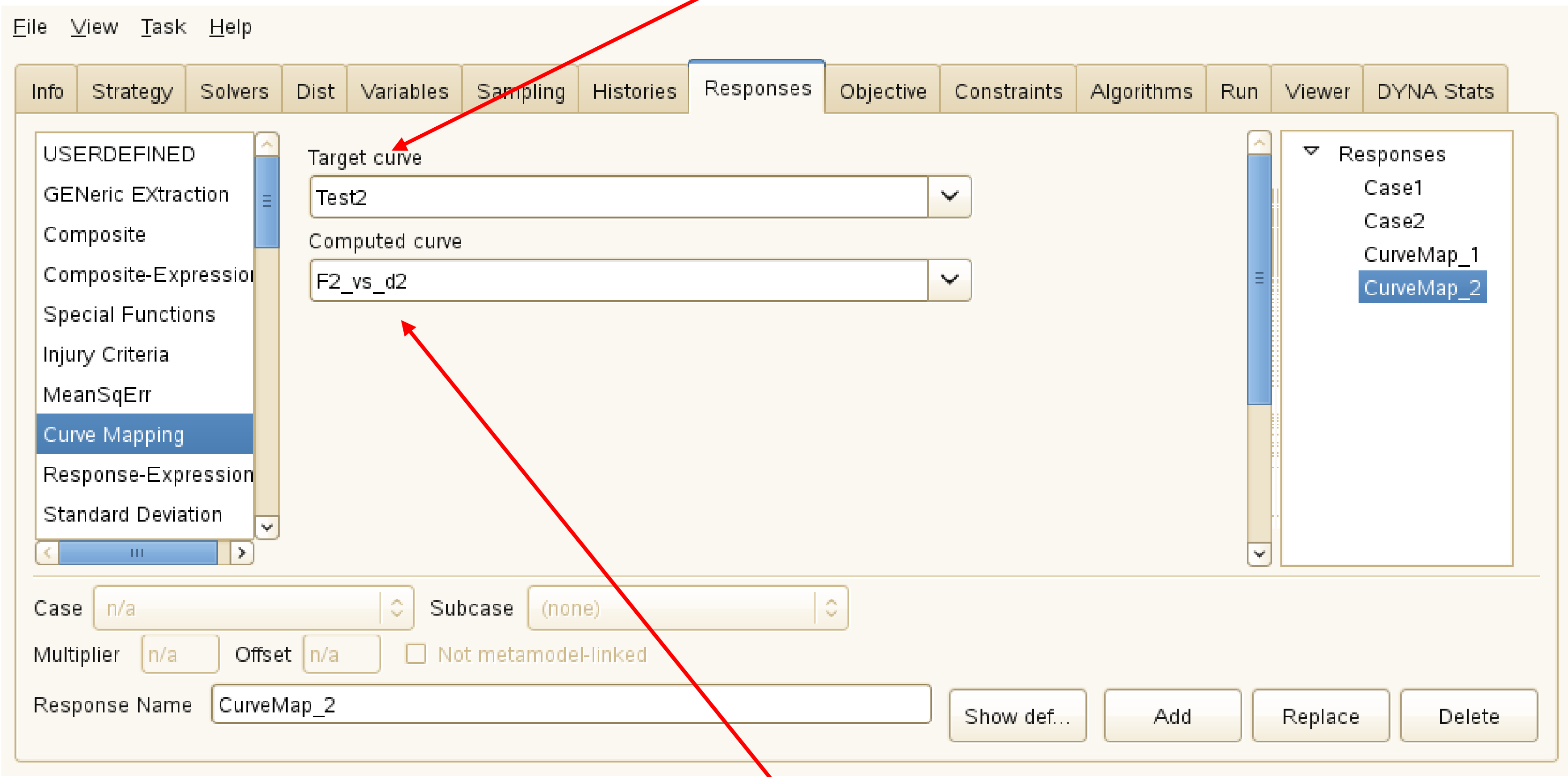


Optimization

- Metamodel-based, sequential
- Metamodel constructed at each time step to produce a virtual history at an arbitrary design point (similar to ordinate-based metric)
- Optimization convergence is ensured through sequential improvement (classical Sequential Response Surface Method)
- Avoids any additional nonlinearities due to the curve matching metric

LS-OPT 4.2 Interface for Curve Mapping

Imported experimental curve in 2-column format



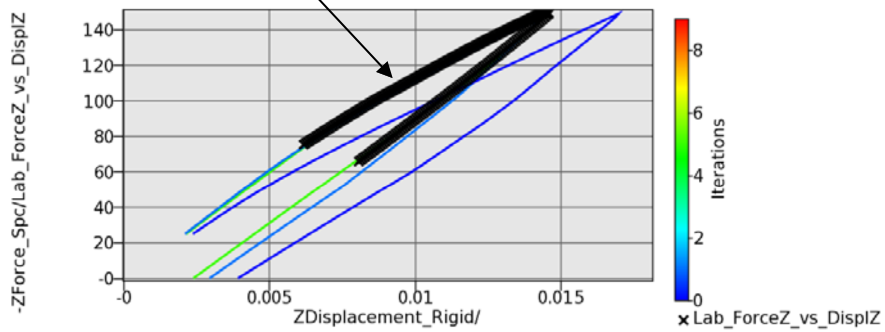
Computed history/crossplot

Problem data

- 4 parameters
- Loading & unloading in one curve
- Partial experimental curve

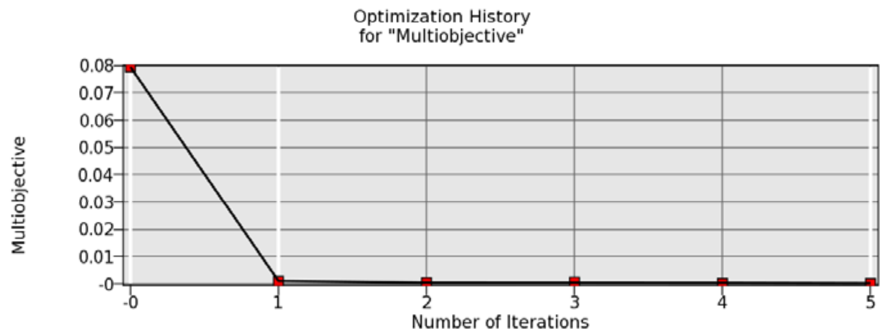
Curve Match vs. Iteration number

Experimental curve



Results

- Converges in 2 iterations (17 simulations)



Courtesy TRW

Optimization history of Discrepancy

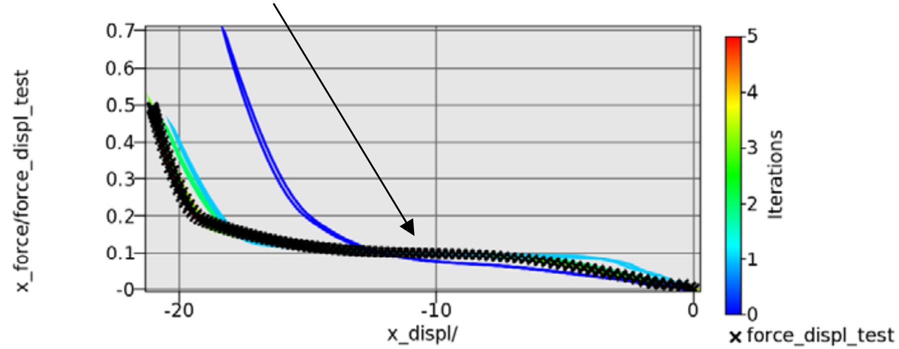
Partial Curve Mapping: Hysteresis examples

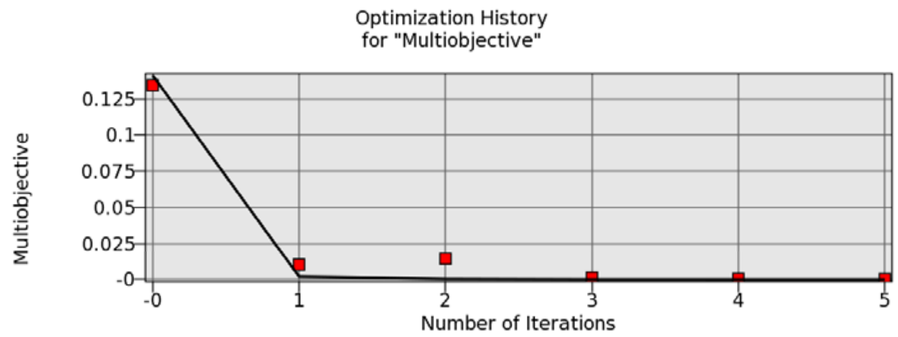
Problem data

- 5 parameters
- Loading & Unloading in one curve

Curve Match vs. Iteration number

Experimental curve





Results

- Converges in 3 iterations (31 simulations)

Optimization history of Discrepancy

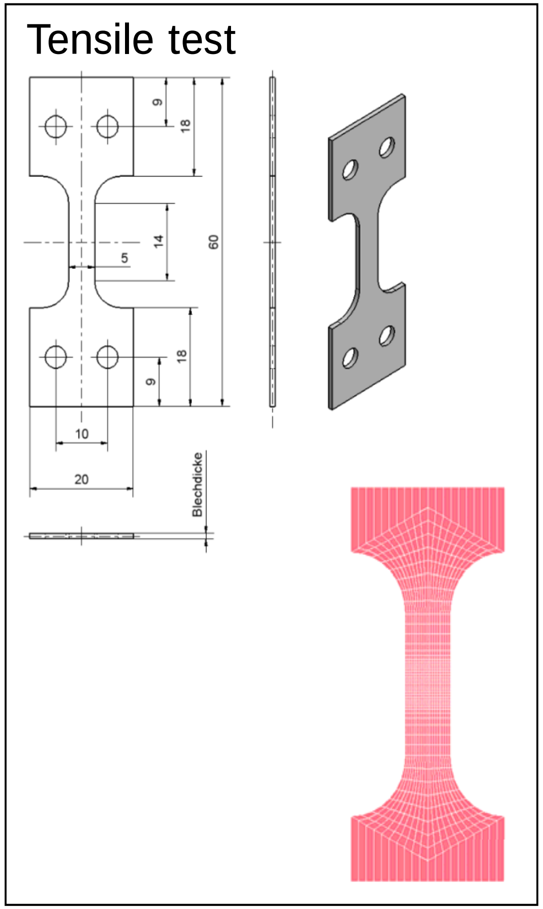
Example: GISSMO Material Model (LS-DYNA)

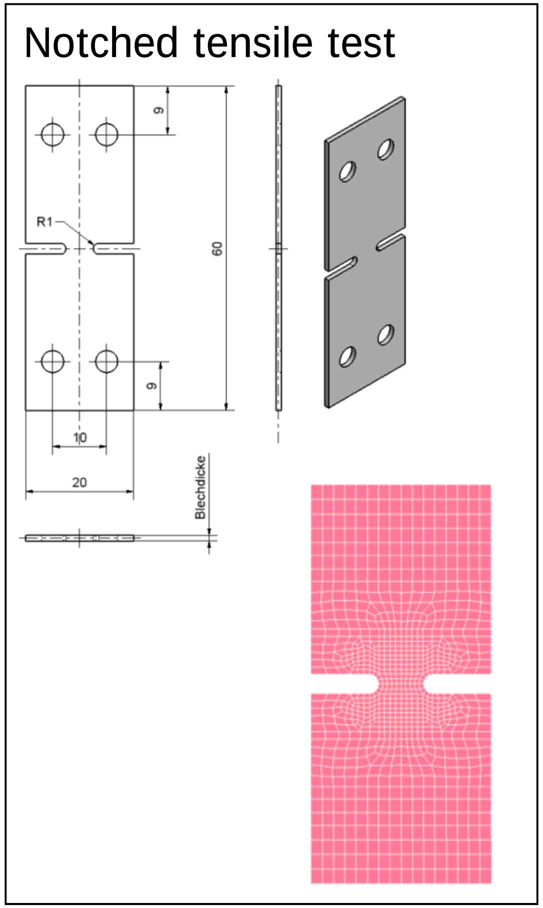
- GISSMO (Neukamm, Feucht, Haufe)* is a material model available in LS-DYNA
- Damage model for use in both stamping and crash simulations
- Experiments used to calibrate GISSMO are often characterized by a steep failure curve. Springback could be present
- Example has 3 test cases and 7 unknown parameters. Typically tensile and shear tests

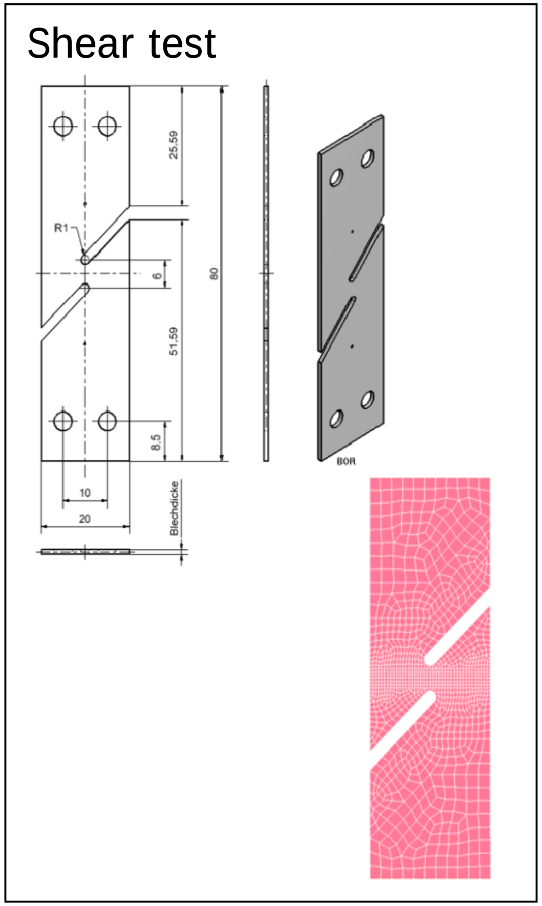
*Neukamm, F., Feucht, M., Haufe, A. Consistent damage modeling in the Process Chain of Forming to Crashworthiness Simulations. *Proceedings of the 7th LS-DYNA Anwenderforum, Bamberg, 2008.*

Example: GISSMO Material Model (LS-DYNA)

- Experimental test program for calibration

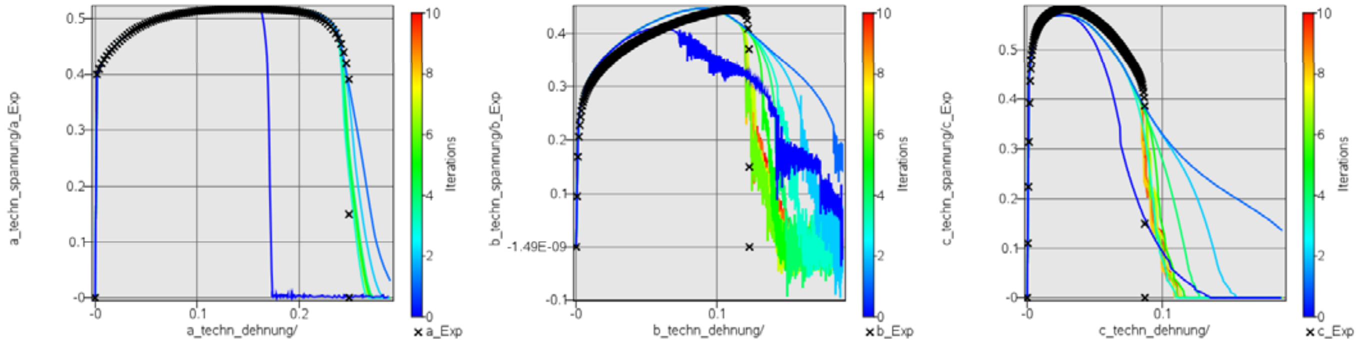




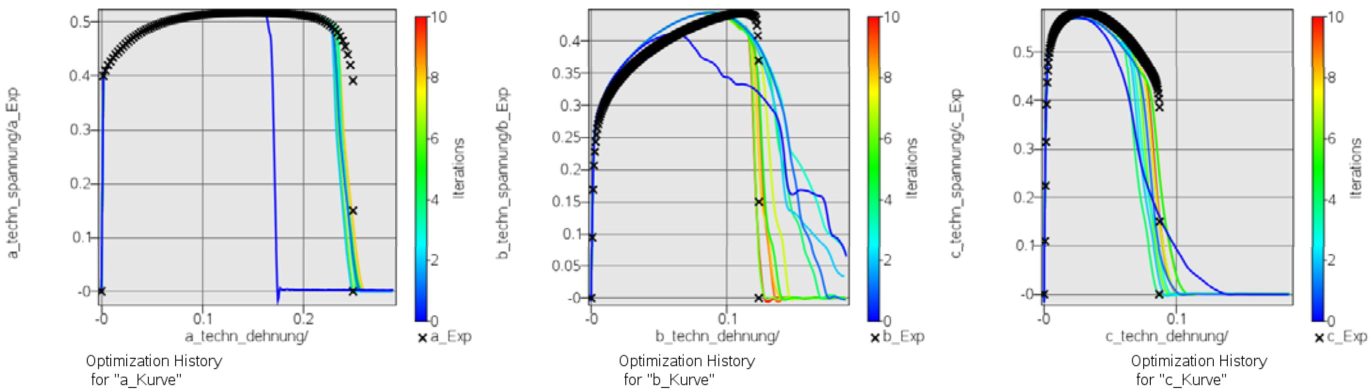


Example : GISSMO Material Model (LS-DYNA)

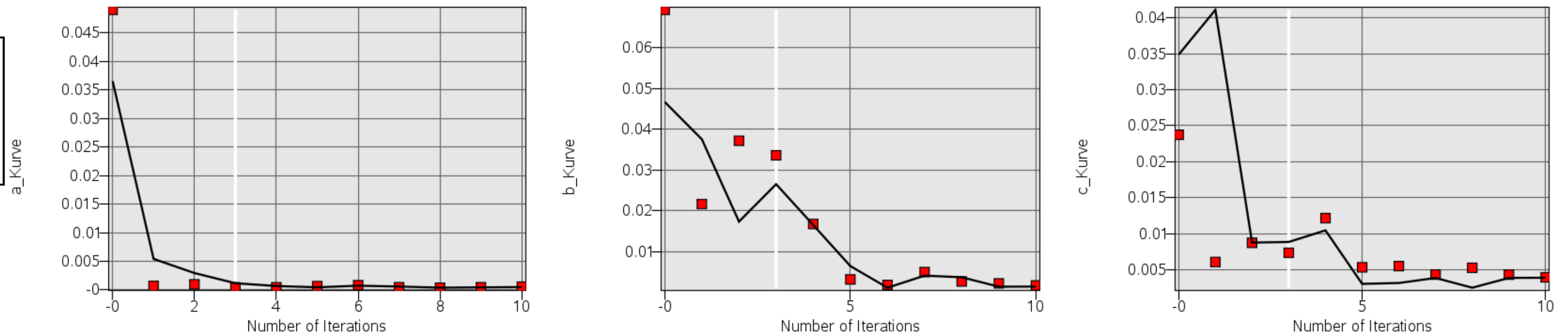
MeanSqErr



CurveMap



Mismatch History



Conclusions

- Partial Curve Mapping allows the identification of hysteretic curves
- Short/long test curves of computed curves can be handled
- Both the ordinate and the abscissa are incorporated
- Curve normalization ensures that the result is independent of the chosen measurement units
- LS-OPT input specification is very simple

Curve mapping is available in *LS-OPT Version 4.2*