New Features in D-SPEX with Application

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Abstract:

This paper presents new features of the optimization post processing tool D-SPEX. The features are explained by means of various examples. The visualization of meta-models has been developed to a point where it can be a valuable tool for engineers. It aids to a new understanding of engineering problems and yields to novel solutions of existing problems.
By means of a material identification for strain rate dependent materials it shall be shown how the knowledge about relationships between parameters and responses can lead to exceptional solutions.
Furthermore various examples will be presented that shall try to give an impression of the way meta-models can help in understanding engineering problems.

Keywords:

Optimization, Visualization, Meta-Models, Response Surface Method, Design Exploration

1 Introduction to D-SPEX

D-SPEX is a Matlab based post processing tool that is specialized on the visualization of meta-model data provided by LS-OPT. It has been developed in cooperation with AUDI AG for the occupant safety department but is currently used in various disciplines by AUDI, DaimlerChrysler and other clients. Although D-SPEX is a Matlab based tool, Matlab is not needed in order to run D-SPEX. Installation packages are available for Windows and Linux.

D-SPEX is intended to provide features that are not currently implemented in the LS-OPT viewer. Therefore, it is a complement to the visualization capabilities of LS-OPT. Its primary focus is on visualization of meta-models although it also provides features to visualize stochastic results.

A screenshot of D-SPEX in action can be seen in Figure 1.

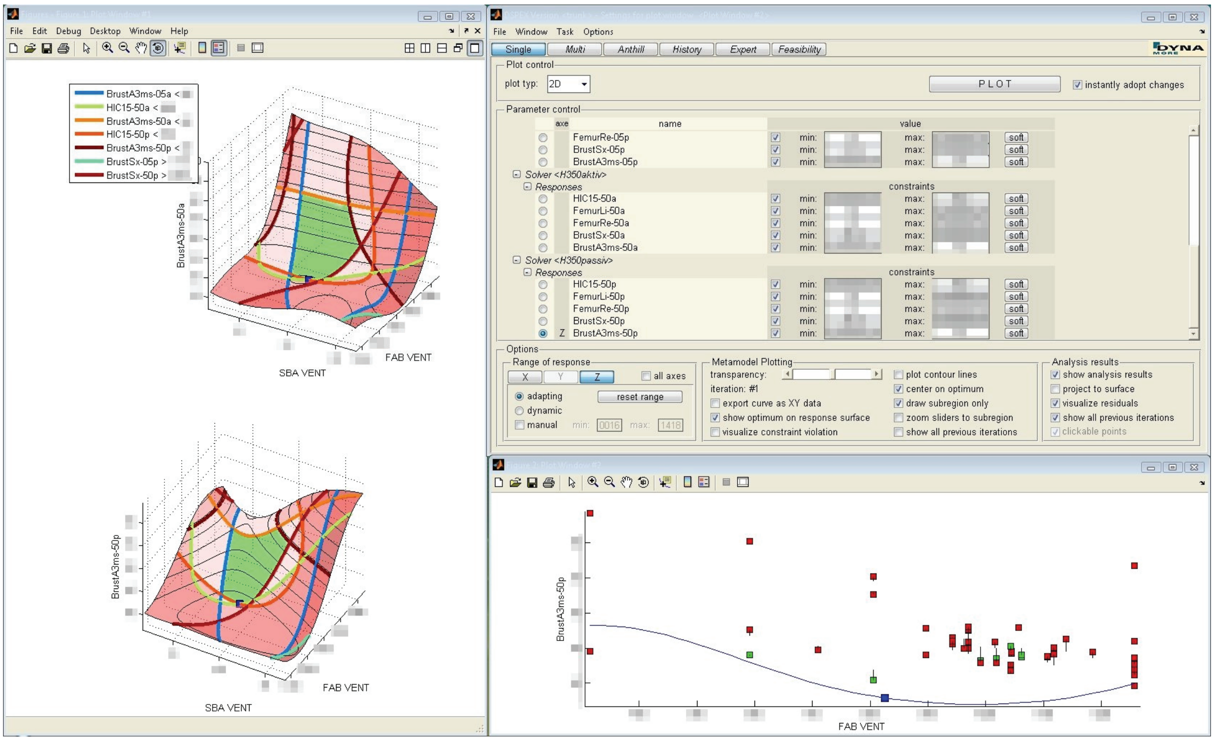

Figure 1: Screenshot of D-SPEX in action

1.1 Current Capabilities of D-SPEX

D-SPEX offers the possibility to plot meta-models for responses or composites in 2D or 3D (see Figure 1 and Figure 2). Additionally, analysis result points, residuals, that visualize the quality of the meta-model, or the optimal value determined on the response surface may be plotted.
Point information may be obtained by clicking on an analysis results point (see Figure 3). A window pops up, where the values for all variables and responses belonging to that point are displayed. Comparing results, e.g. from different load cases, is often easier if several plots may be displayed in one plot window. This feature is also provided by D-SPEX.

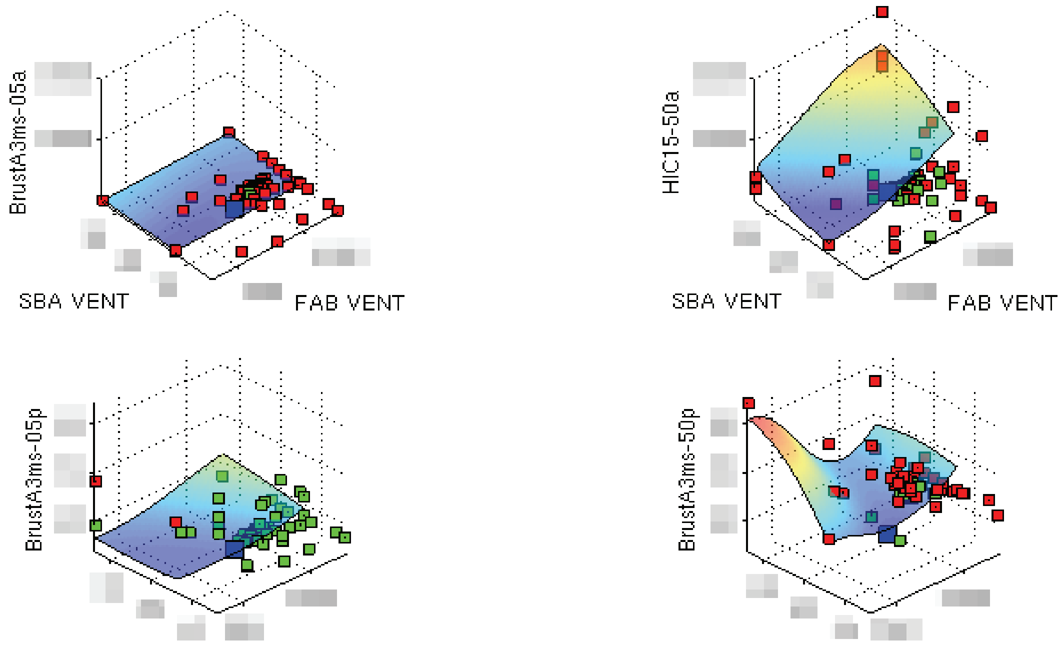

Figure 2: Meta-model with analysis results and optimum

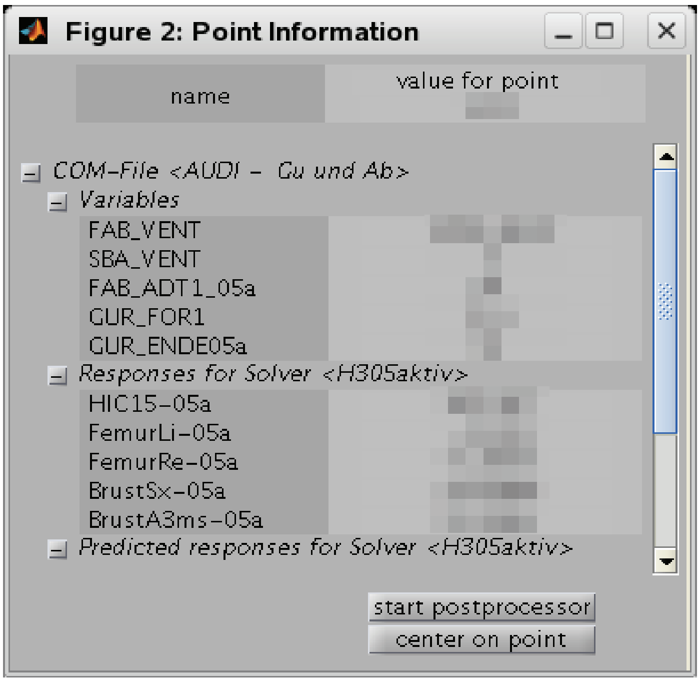

Figure 3: Point information window obtained by clicking on a point

Additionally, D-SPEX offers the possibility to plot history curves (see Figure 4). The trends of the curves for different runs may be compared, and relations of variables, responses or composites to the curves may be detected by using the colour of the curves to display the respective value of a variable, response or composite.

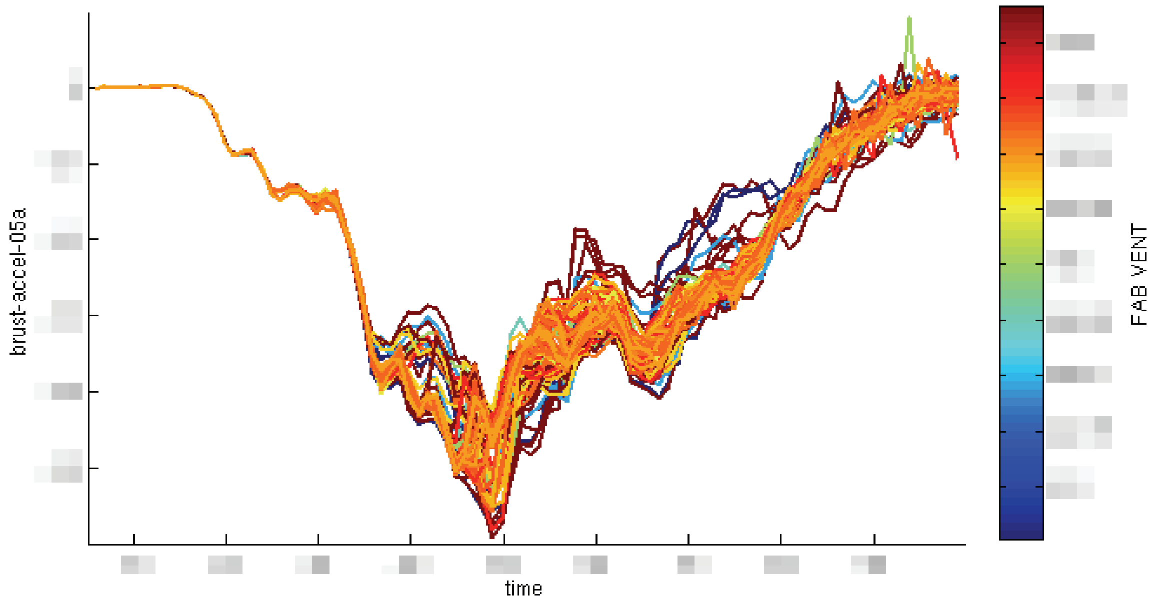

Figure 4: History curves of simulations obtained through optimization with colour display of the value of a variable

Furthermore D-SPEX offers the possibility to visualize stochastic results like the correlation matrix with correlation coefficients, histograms and anthill plots. The correlation coefficients show the linear relationship between variables and variables, variables and responses and responses and responses. The distribution of variables and responses are displayed in the histograms.
The correlation matrix may help to determine significant and insignificant variables. An example of a correlation matrix is displayed in Figure 5.

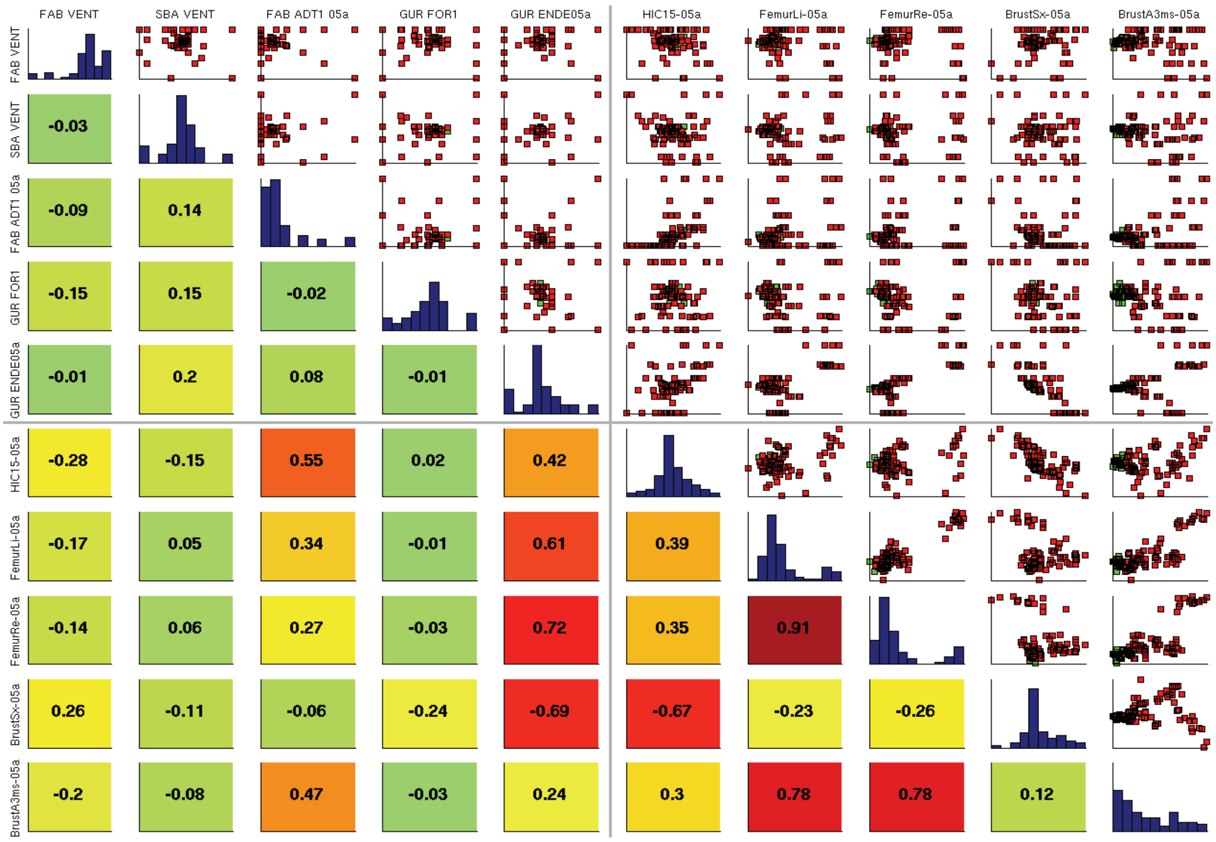

Figure 5: Correlation Matrix with correlation coefficients, histograms and anthill plots

For variable screening clearly arranged visualization of ANOVA is available by D-SPEX (see Figure 6). Like the correlation coefficients, ANOVA is a method to determine significant and insignificant variables. Usually ANOVA is applied on the basis of deterministic sampling such as D-Optimal designs based on Factorial DOEs.

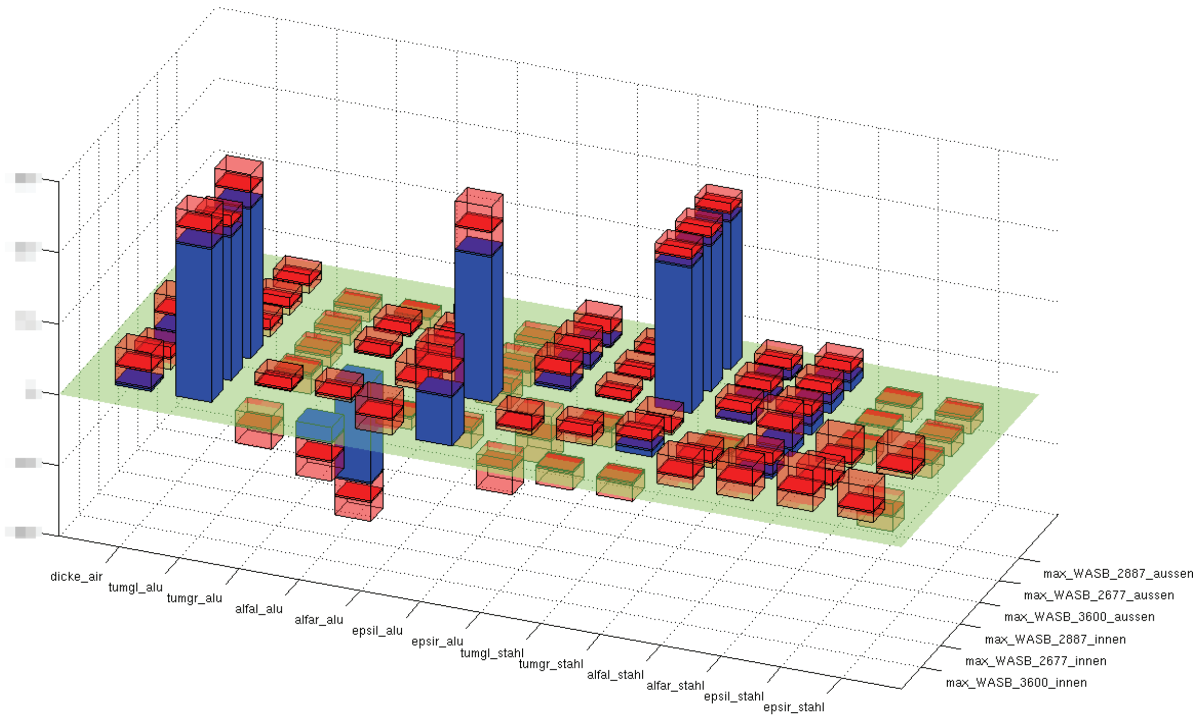

Figure 6: Analysis of Variance (ANOVA)

1.2 New Features – Version 0.2

From the use of D-SPEX, it turned out that new features were required to get a better understanding of the models. So there was the request to visualize constraints on the meta-model, what is especially helpful for multi disciplinary optimizations to understand the optimization results. Another request was to get an overview on feasible and infeasible parameter constellations, this led to the introduction of the *Feasibility* task.
Until now, meta-models were computed for responses and composites, but often history curves are considered that were only available for the computed parameter constellations (analysis points), so meta-models were extended to histories and it is now possible to compute "virtual histories".
Another improvement is the possibility to export 2D data curves from the meta-model, so a response curve subject to a variable may be exported as x-y data for any parameter constellation.

All the new features will be explained by means of application examples in the following sections.

2 Data Export: Evaluation of Constant Strain Rates

The Impetus pendulum developed by a.p.e. GmbH provides a straight forward and cost-efficient way for engineers to determine material properties of foams, see [2]. However to determine the material properties of strain rate dependent materials mostly indirect approaches have been used till now. In order to determine the strain rate dependency, parameterized materials have been used in conjunction with a simulation of the pendulum test and an optimization in LS-OPT in order to determine the parameters that lead to a material with equal or related properties.

Using D-SPEX together with the metamodels of LS-OPT we were able to provide a more direct approach to this problem. In our “prove of concept” we used the strain and the strain rate as parameters and the stress as response that depends upon these two parameters. In a test with the pendulum these three values can be determined at numerous points in time. This results in a number of points that in turn can be used to fit a response surface. In order to cover different areas of the response surface, tests with different masses and height of fall have been used on different samples.

The resulting response surface now represents a continuous relationship between strain, strain rate and stress. And although the strain rate changes during the experiment, which can be observed in Figure 7, the response surface is continuous and thus able to provide intersections at constant strain rates (see Figure 8). Therefore we are able to derive strain rate dependent material properties even from experiments that have not been carried out under constant strain rates.

One problem is that high strain rates cannot be achieved for small strains. In this case, estimated points have been introduced to fit the response surface. Another way to circumvent this difficulty is to use a double pendulum or smaller samples.

D-SPEX has been provided with the capability to export the curves of different constant strain rates in order to construct a nonlinear material model from these curves.

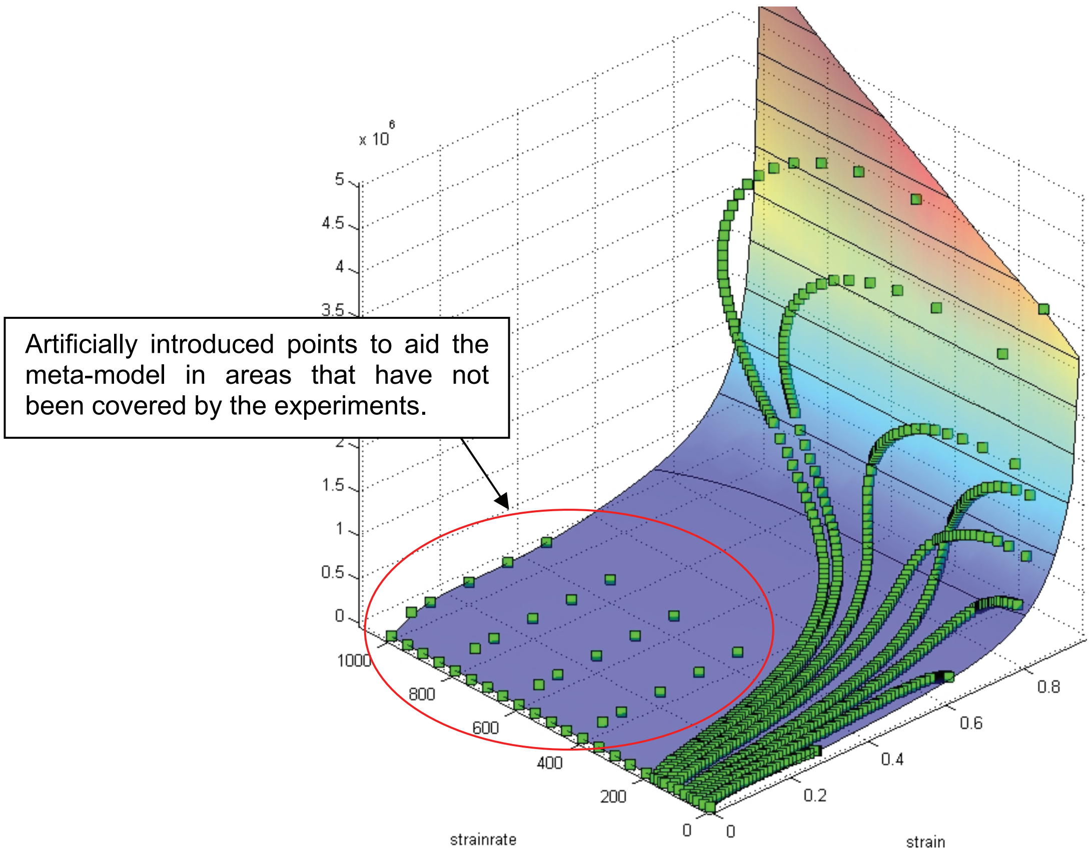

Figure 7: 3D meta-model of stress vs. strain and strain rate. The points to generate the meta-model are extracted from test data.

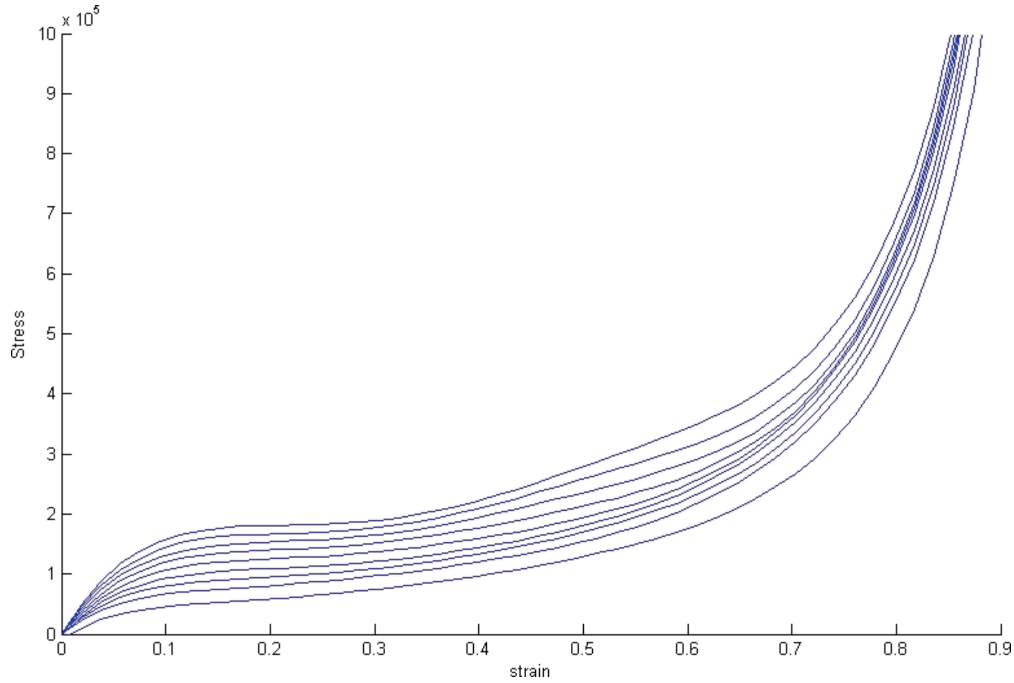

Figure 8: Stresses vs. strain curves at a constant strain rate. These curves are extracted from the metamodel and can be exported to ASCII files in order to generate a nonlinear table based material model.

3 Constraints: Optimization of an Adaptive Restraint System

D-SPEX now has the capability to visualize constraints directly upon the metamodels. This can significantly help to understand the optimization results especially for multi disciplinary optimizations.

As an example, the optimization of an adaptive restraint system is used (see [3]). Four different load cases are considered, belted and not belted using the “Hybrid III 5% Female” or the “Hybrid III 50% Male” dummy. Design variables are the upper force level, the trigger time of the seat belt system, the area of the vent holes and the trigger time of the airbag. The considered objective is the thorax acceleration, and additionally, constraints have been introduced to account for the head injury coefficients (HIC), the femur forces, the thorax intrusion and the thorax acceleration.

The colored lines in Figure 10 mark the boundary between the feasible and the infeasible region of a single constraint. The green region is the feasible area, where all constraints are fulfilled, in the red areas, constraints are violated. The darker the red is, the more constraints are violated. In addition to the constraints the optimum is plotted on the response surface. The plotted response represents the objective that is minimized, and the optimum is the smallest value within the feasible area.

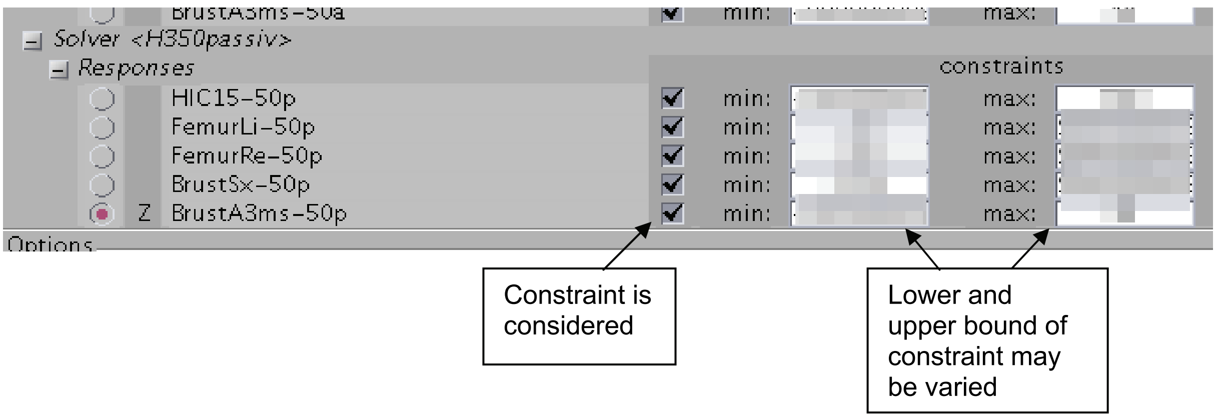

Figure 9: Controls for selecting responses as constraints and setting their lower and upper bounds

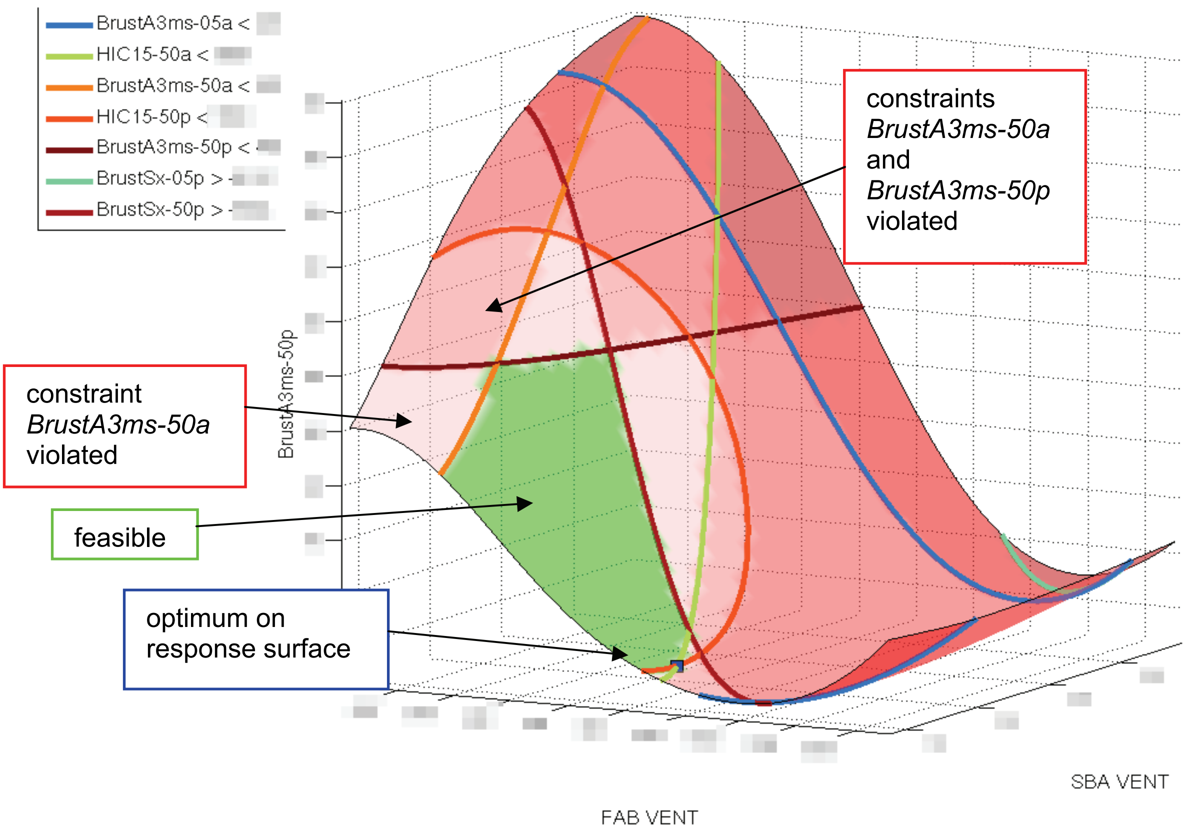

Figure 10: Constraints and optimum visualized on meta-model

Especially useful is the fact that the visualized constraints do not only consist of constraints of the load case the shown response belongs to, but of all load cases of this multi load case optimization.

Figure 9 shows the part of the D-SPEX window, where options for the constraints may be varied. There is a check box for each constraint which decides if the constraint is considered for visualization, and there are editable text fields for the lower and upper bound for each constraint. Thus constraints may be varied interactively after the optimization.

4 Feasibility: DOE Sensitivity Analysis with LS-OPT

D-SPEX has now a new task to determine the feasibility for any parameter combination in the design space. So the response values on the meta-model are calculated for a given parameter constellation and D-SPEX verifies if the parameter combination is feasible.

This feature is demonstrated using the example of a DOE (Design of Experiment) sensitivity analysis for simulating the radiation of a diesel particle filter (see Figure 11 and [4]). The design variables are several material parameters of the heat shield's materials, layer thicknesses of the heat shield, environment temperatures and temperature curve parameters of the heaters. As constraints, the temperatures at some elements of the heat shield were limited.

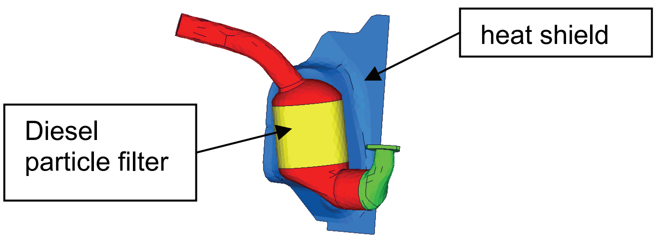

Figure 11: Diesel particle filter with heat shield

Figure 12 shows an infeasible parameter combination. The red and green bars under the variable sliders display the regions, where the variables may be moved to get a feasible (green) or infeasible (red) parameter constellation if all other variables are fixed.
The red and green response values are the values for the given parameter constellation on the response surface, so we observe which constraints are violated.

Comparing Figure 13 to Figure 12, the last variable is moved to the green region, so we get a feasible parameter constellation.

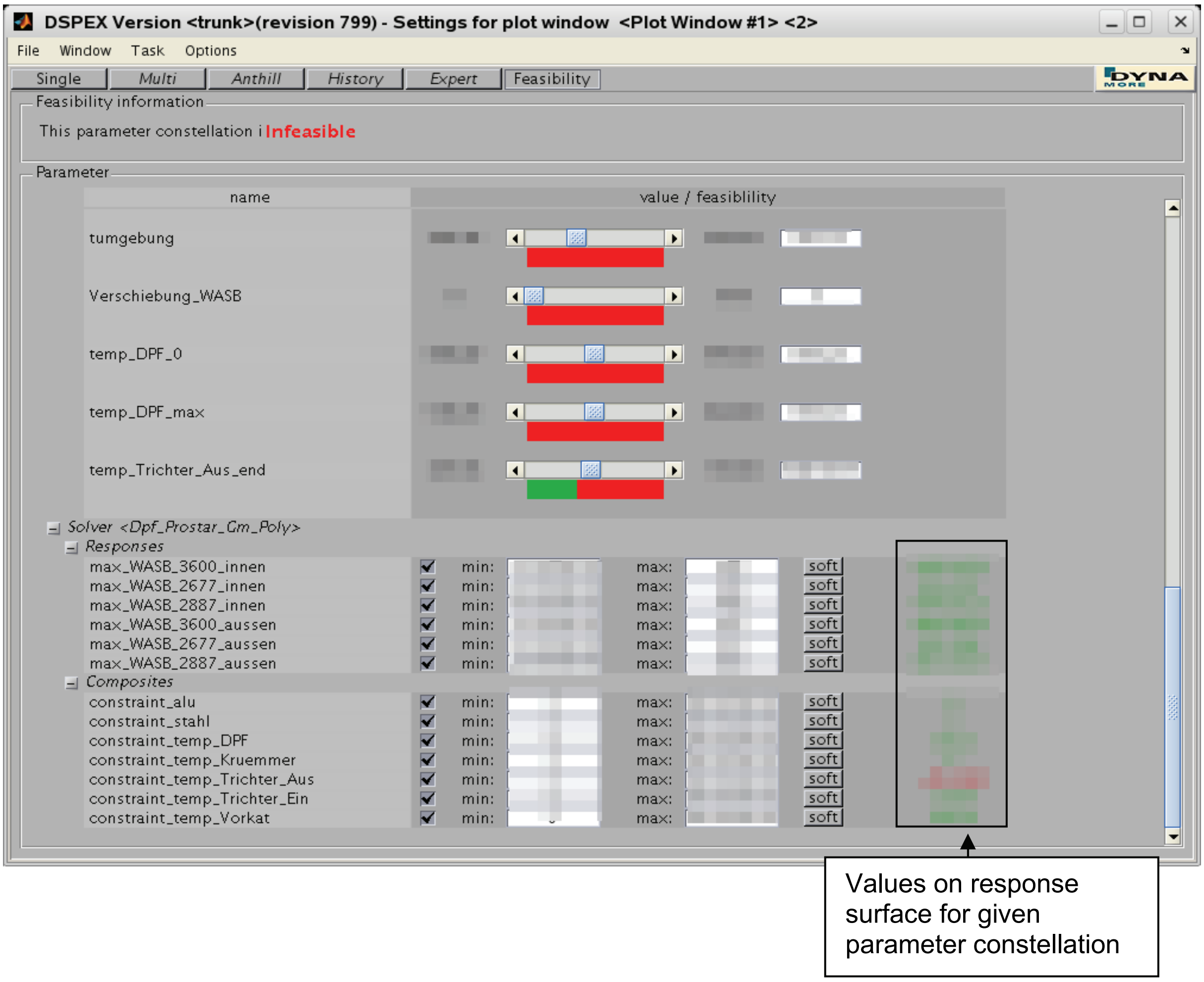

Figure 12: Feasibility task with an infeasible parameter combination

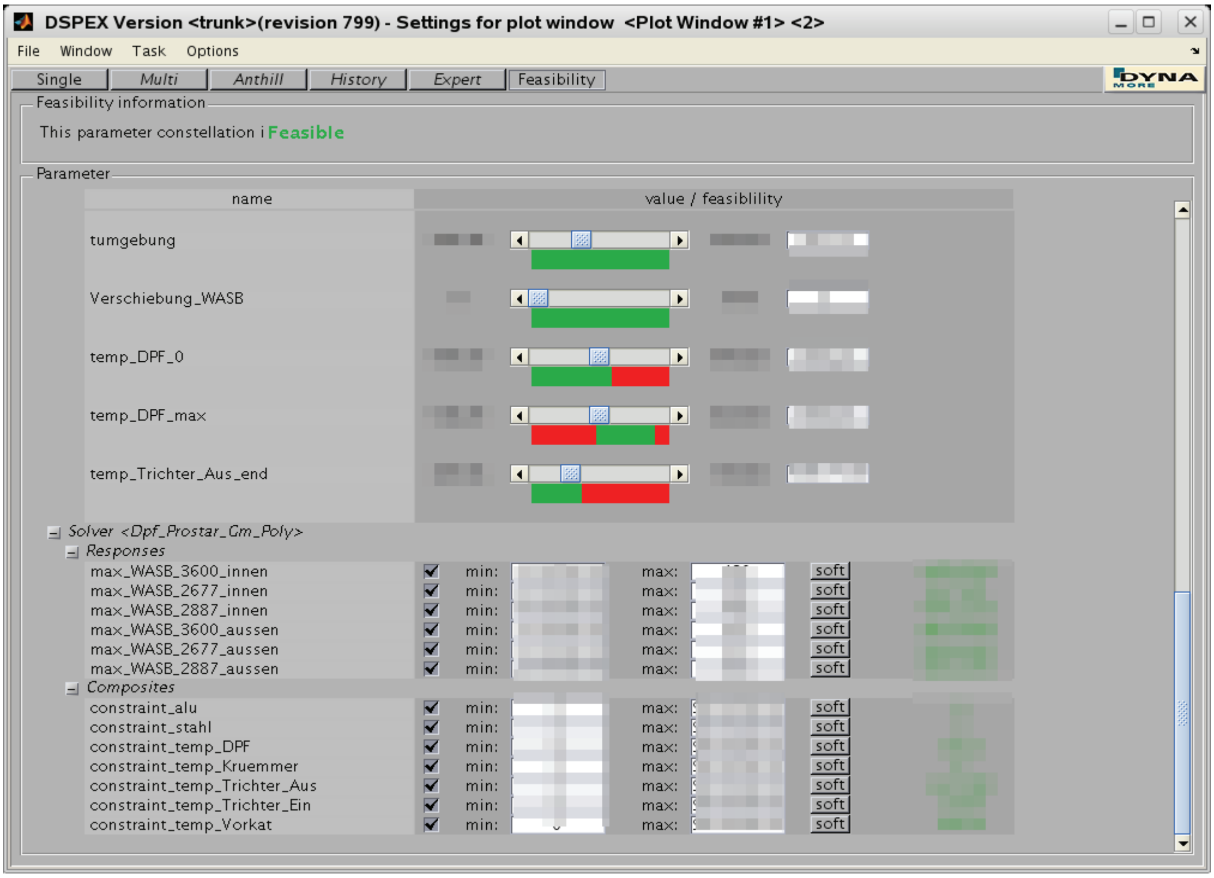

Figure 13: Feasibility task with a feasible parameter combination

5 Virtual Histories: Application of Shape Optimization with LS-OPT

In the past it was always difficult to evaluate history data of multiple runs. This evaluation was only possible for the mean, min or max history values and maybe some standard deviations of histories. A more specific evaluation would provide an understanding of the bandwidth of all histories, however it gives little or no answers to the question of what parameter has what kind of influence upon a history. Since histories are widely used in occupant safety in order to explain system behavior, it was absolutely necessary to find other means of visualization.

A first approach that had been used in D-SPEX was to plot all histories in a single plot and use a specific color for each history that is related to one of the parameters. This way it was possible to get a first impression, how the parameter influences the history. However just as with standard tradeoff plots, the interpretation of these plots was very difficult because of the multi-dimensionality. But even so it was one of the most appreciated features.

A new approach used in D-SPEX is to extend the meta-model concept to histories. It means that meta-models are created at a number of discrete points in time of the histories. So the individual meta-models can be used to assemble "virtual histories" that represent an estimate of a history for a specific parameter combination (see Figure 16). This now decouples the histories from the parameters which provides a couple of different means to explore the history data. The most obvious is that one is able to see interactively how changes of the design will affect the system behavior by using slider controls (see Figure 15). And similarly to the response surfaces the user is able to see the effects on multiple histories at a time.

Virtual histories furthermore provide the possibility to do sensitivity analyses upon history data. They allow the visualization of how a single parameter affects the system and in contrast to the simple coloring of existing histories it hides the effects of other parameters (see Figure 17).

To depict the virtual histories an example of a crash box optimization shall be used (see Figure 15). The crash box is illustrated in Figure 14. The virtual histories of the force can be seen in Figure 16. As an error indicator the standard deviation of the residuals has been used. This provides the means necessary to be able to estimate if the shown "virtual histories" are representative.

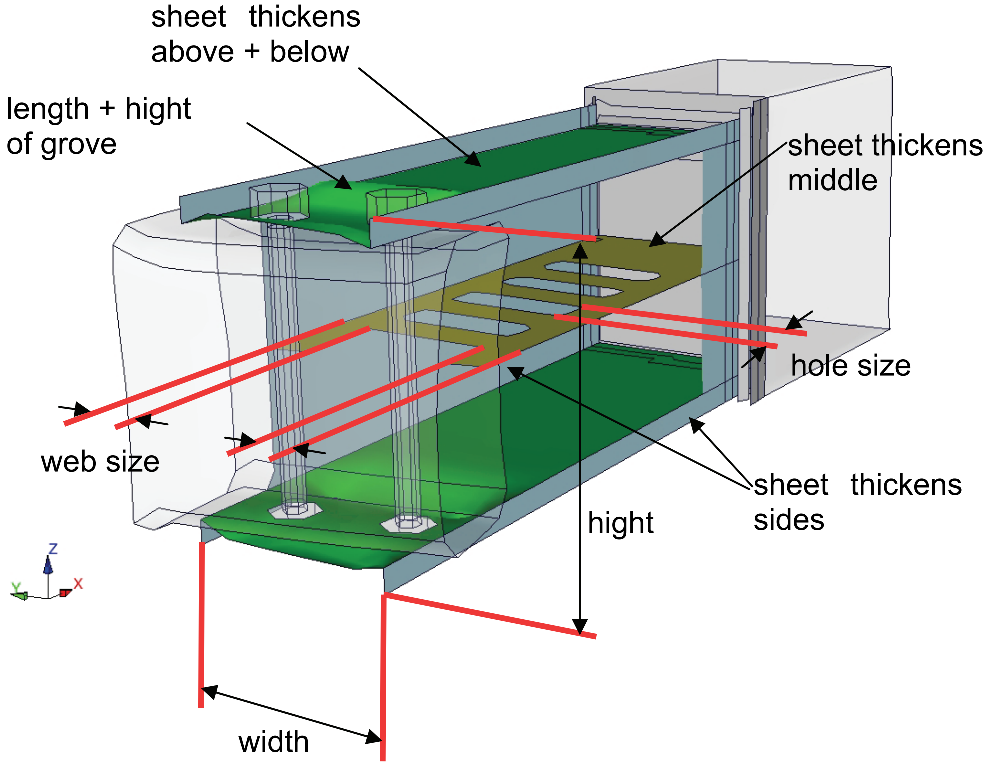

Figure 14: Crash box

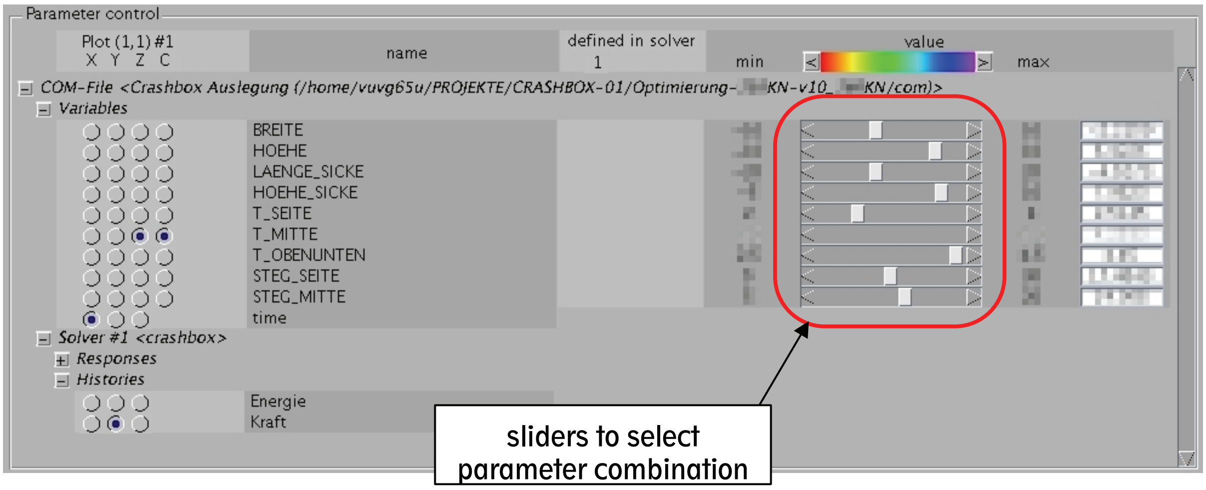

Figure 15: Controls for virtual histories

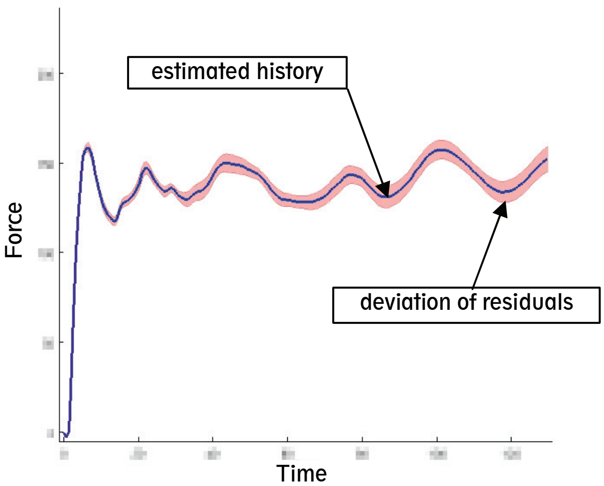

Figure 16: Virtual history and standard deviation of residuals as an error indicator

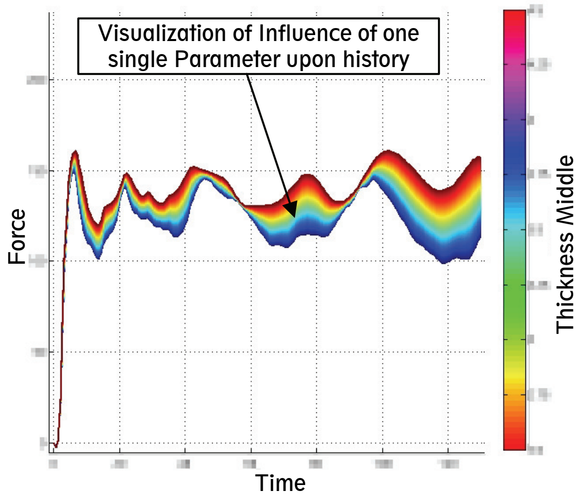

Figure 17: Variance of virtual history depending on one single parameter

6 Conclusions

D-SPEX provides in this new version a set of features that are unique for its kind of software. All these features have been developed because of the imminent needs of one or another project or discipline. Although D-SPEX has been started as a prototype and testing environment for features that are to be implemented into the LS-OPT viewer, it is now an outgrown product that is used in a production environment.

During project work, especially the visualization of constraints has been proven to be invaluable. Most times the engineer is not only interested in doing an optimization but also wants to understand why a optimum can be archived for certain parameter combinations. This knowledge might be crucial since the best achievable optimum is not always a good optimum. The knowledge about the system and its dependence upon its design parameters aids the engineer to make decisions. In many situations, the visualization of optimization constraints helps to explain why an optimum is found for a specific parameter combination. This is especially true for multi load case optimizations or multi disciplinary optimizations.

Another very unique feature is the visualization of “virtual histories”. This kind of treating the histories gives the engineer a whole new perspective; even so the “virtual histories” are only a rough estimate of the history that is to be expected. It gives the engineer a feeling of what the tendencies are.

D-SPEX is meant to be a tool that supports the engineer in the process of understanding their system behaviour.

7 References

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