DOE SENSITIVITY ANALYSIS WITH LS-OPT AND VISUAL EXPLORATION OF DESIGN SPACE USING D-SPEX

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ABSTRACT

This paper describes the approach of a DOE (Design of Experiments) sensitivity analysis using LS-OPT in conjunction with AURA for simulating the radiation of a diesel particle filter. The process flow from preprocessing to the visual evaluation of the results using the D-SPEX (Design SPace EXplorer) software is presented.

 For the purpose of this sensitivity analysis the geometrical arrangement as well as polynomial curves from the AURA input had to be parameterized. Further more various discrete and coupled scalar parameters where used in this investigation.

INTRODUCTION

Sensitivity analyses determine the influence of input parameters on output values, in order to detect significant and insignificant parameters of a model. This paper describes the approach of a sensitivity analysis using LS-OPT [2]. In order to evaluate and interpret high-order nonlinear optimization results it is necessary to find ways of visualizing the computed results. Metamodels and their visualization as a continuous description of the underlying physical problem can significantly aid the process of understanding the relations between parameters and their influences on the results. For the purpose of visualizing and exploring metamodels the software D-SPEX has been developed in cooperation with AUDI AG and is a key part of the sensitivity analysis presented in this paper.

PROBLEM DESCRIPTION

The given model is a diesel particle filter with a heat shield, see Figure 1. A water tank is situated near the filter and a heat shield is inserted to insulate the tank from the heat produced by the filter. The sensitivity analysis determines the influence of assigned parameters, e.g. materials or thicknesses of layers of the heat shield, on certain responses from the simulation of the particle filter and the heat shield.
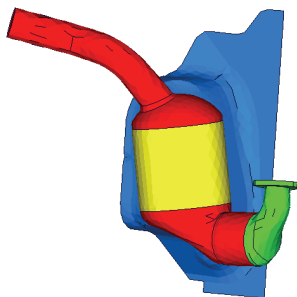

Figure 1: Diesel particle filter with heat shield

APPROACH

A total of 100 parameter combinations are created by LS-OPT applying a D-optimal point selection to a space filling sampling. The radiation simulations are done with AURA [1]. The geometric parameters of the heat shield are defined using the preprocessor ANSA [3]. The response values were evaluated and visualized using LS-OPT and D-SPEX, respectively.AURA

AURA is a collection of programs for the computation of radiation that considers one-dimensional heat conduction. AURA enables the output of response values, e.g. the temperature on certain elements. For a radiation simulation, AURA requires a surface grid, material values such as reflection, variables representing emission and heat conductivity, boundary conditions such as the physical configuration of the geometry components and initial temperatures, and additional control parameters. A schematic example of an AURA model is displayed in Figure 2.
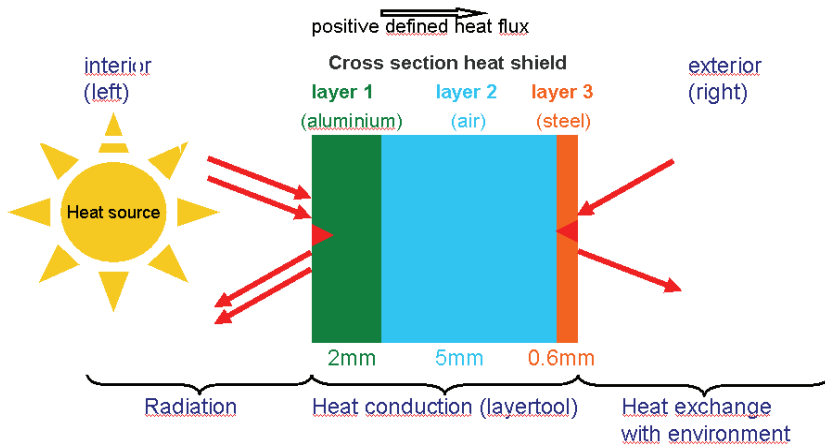

Figure 2: Example of an AURA model configuration

DOE SENSITIVITY ANALYSIS

VARIABLES DEFINED IN LSOPT

The variables defined for the sensitivity analysis are environment temperatures, emission and heat transmission coefficients, thicknesses and materials of the layers as well as the distance of the heat shield to the diesel particle filter and the polynomials defining the temperature of the heat source over the time. They are visualized in Figure 3.
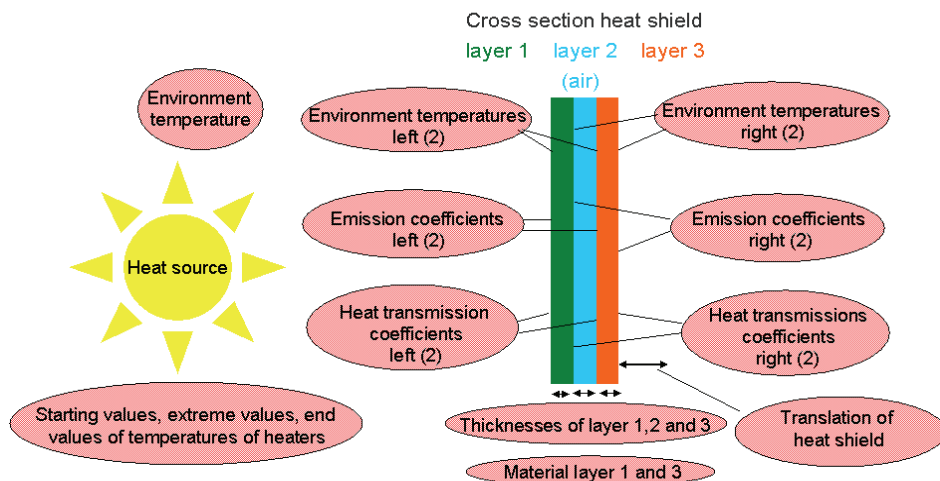
Figure 3: Variables defined in LS-OPT

COUPLED VARIABLES

In order to parameterize the material properties of a layer (Figure 3.), it is necessary to modify three interdependent parameters: heat conductivity, density, and heat capacity. All material parameters are discrete but depend on one another. In addition, the thickness of Layer 1 is a discrete value that depends on the material. For Layer 3, the thickness is a continuous variable, but the minimal and maximal values depend on the material. The values of the parameters of Layer 3 are displayed in Table 1.

Table 1: Four example materials for Layer 3

Material	Thickness [m]	Heat conductivity [W/mK]	Density [kg/m³]	Heat capacity [J/kgK]
Aluminium	0.0005 – 0.005	273	2700	909
Steel	0.0005 – 0.005	40	7800	450
Synthetic material	0.001 – 0.005	0.3	1300	1800
Insulation	0.005 – 0.015	0.05	200	2000

To implement such interdependent variables in LS-OPT, one of the values is defined as a discrete variable in LS-OPT, the other parameters are, according to the interdependence of the variables, replaced in the AURA input file using a Perl [4] program.

ANSA AS A PREPROCESSOR IN LS-OPT

If geometric variables are considered, a preprocessor may be defined in LS-OPT. In this case, ANSA is used to vary the distance of the heat shield to the diesel particle filter. The required coupling to ANSA is defined in several scripts that call ANSA in a batch mode. During the batch-session ANSA scripts are loaded and executed to perform the necessary modifications such as translation, morphing operations. These ANSA scripts on the other hand are accessing ASCII files which are parameterized for LS-OPT. This way a single parameter in LS-OPT can be mapped to an arbitrary complex geometric operation in the preprocessor.

VARIATION OF TEMPERATURE CURVES

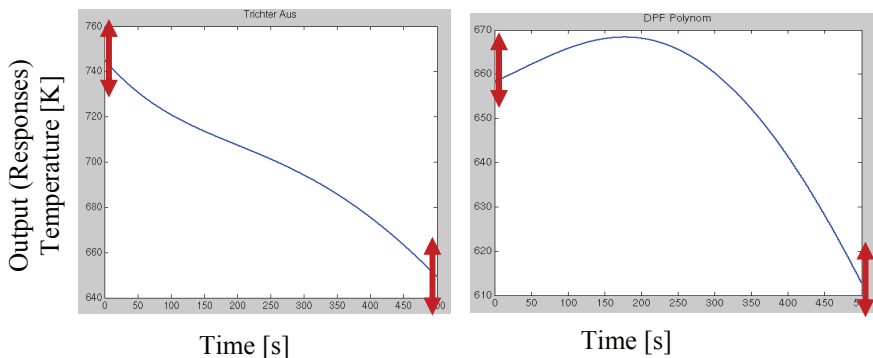In AURA, temperature curves can be defined as polynomials or xy-tables.

Figure 4: Temperature curves of the diesel particle filter (left) and hopper (right)

To modify these curves, the starting values, maximal values, and end values of the curves are needed as parameters in LS-OPT. An external script acting as another preprocessor calculates a spline according to these supporting points which is than incorporated to the AURA input.

RESPONSES

Figure 5 shows the elements, S2677, S2887, and S3600, where the temperature of the heat shield is evaluated. During the simulation, time and temperature values for these elements are written to files. The notable values can be extracted from the files and LS-OPT can read them as history variables.
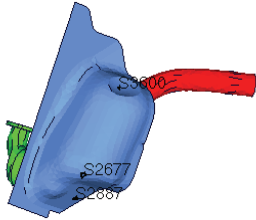

Figure 5: Elements (S2677, S2887, S3600) where the temperature is evaluated

PROCESS FLOW

The entire process flow from the variable definition to the visualization of the results with D-SPEX is displayed in Figure 6.
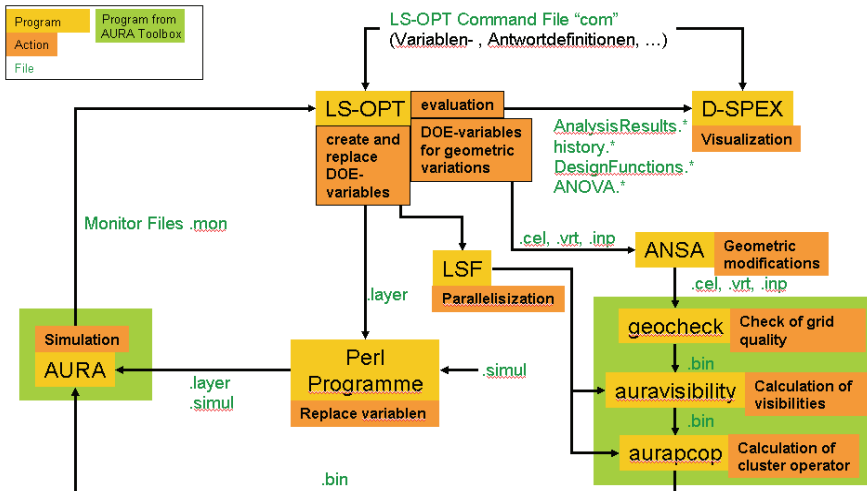

Figure 6: Process flow of the sensitivity analysis

LS-OPT creates the parameter combinations. ANSA is used for geometric modifications. If the geometry is modified during the sensitivity analysis, the programs geocheck, auravisibility and aurapcop from the AURA toolbox have to be executed to prepare the radiation simulation. Auravisibility and aurapcop might be parallelized, so if multiple processors are available, a queuing system, here LSF, has to be provided. Some Perl programs are used to replace interdependent variables and variables in a second file. Then AURA calculates the radiation simulations, LS-OPT evaluates the results and they are visualized using D-SPEX.

VISUALIZATION OF THE RESULTS WITH D-SPEX

The figures in this section were created using the MATLAB based software D-SPEX. It is a software tool used to explore the design space and to evaluate relationships between variables and responses. Currently, D-SPEX is a stand-alone product developed from DYNAmore GmbH in cooperation with Audi AG. Features that are successfully tested in D-SPEX will be implemented into LS-OPT in cooperation with LSTC. D-SPEX allows the visualization of 2-dimensional curve plots and 3-dimensional curve or surface plots from metamodels. For an n-dimensional problem, where n is the number of design variables and n is greater than the number of axis's representing variables, all those variables that are not considered in the plot can be set to fixed values using scroll bars. Thus the displayed curve or surface is merely an intersection through the n-dimensional surface. Furthermore a visual representation of the analysis results can be added. The analysis results will be visualized as simple points. In addition it is possible to visualize the residual of each simulation point with respect to the metamodel by representing it through a line connecting the computed result with the predicted result. The capabilities of D-SPEX also include the visualization of histories from the simulations, for example the evolution of the temperature through time. A special feature is the ability to construct and visualize virtual histories. Virtual histories are created by fitting a response surface to each value in time of a history. This way it is possible to look at a probable history for a specific parameter combination that has not been calculated in one of the simulations. Other features of D-SPEX include statistical evaluations such as mean values, standard deviations, correlation matrix and ANOVA (Analysis of variance) results.

The D-SPEX control panel and an example of a 3D plot with analysis results which displays the temperature of element 3600 (Figure 5) over the environment temperature of Layer 1 and the thickness of Layer 2 (Figure 3) , is exemplarily depicted in Figure 7.
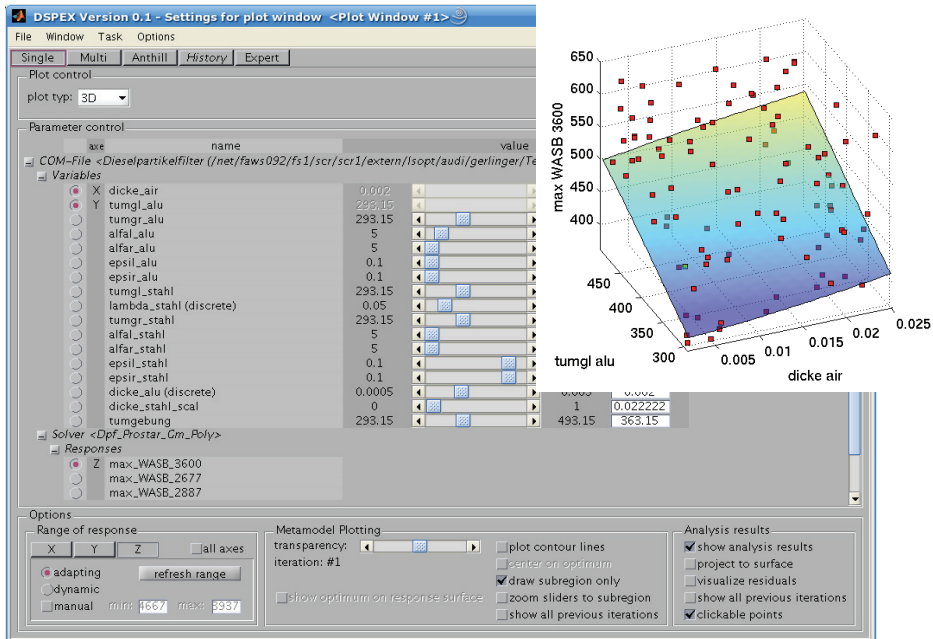
Figure 7: Control panel of D-SPEX and 3D plot of meta model and simulation points
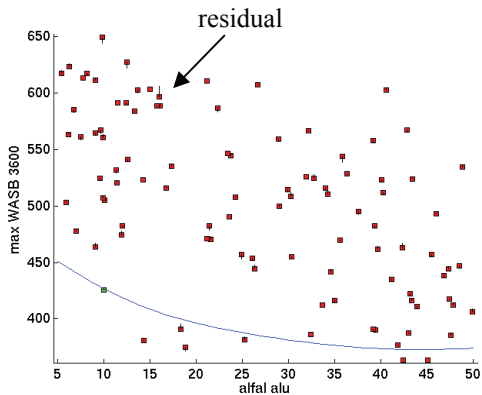

Figure 8: 2D plot of response surface and simulation points with residuals, temperature of element 3600 over heat transmission coefficient of Layer 1.

Figure 8 shows a 2D plot of a response surface with simulation points. The simulation points are projected onto the section plane of the response surface so the distance from

each of the points to the curve is not a measure of the quality of the response surface. The residuals represented by the vertical line, connecting the computed results with the predicted results, are a more adequate measure of the quality of the response surface.
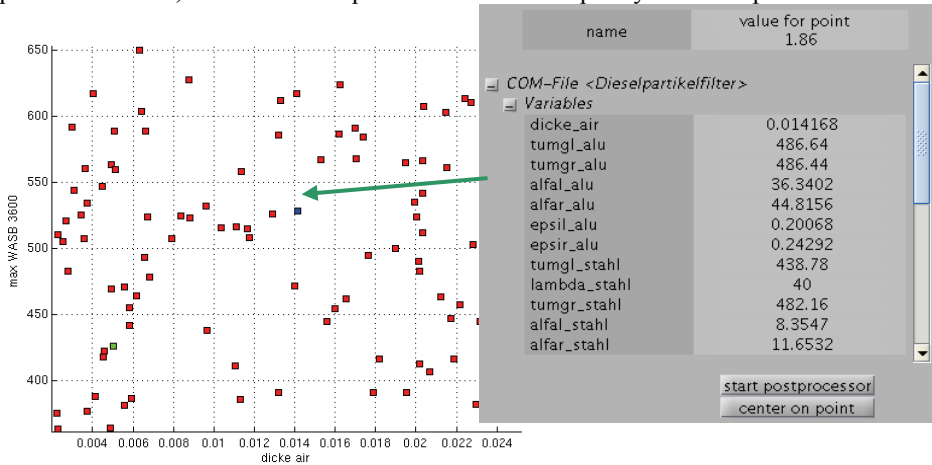

Figure 9: Anthill plot and point information window

D-SPEX offers the possibility to obtain information of points by simply clicking on them. By clicking on a point, a window opens up with all variable and response values concerning this point and the ability to start arbitrary postprocessors (Figure 9).
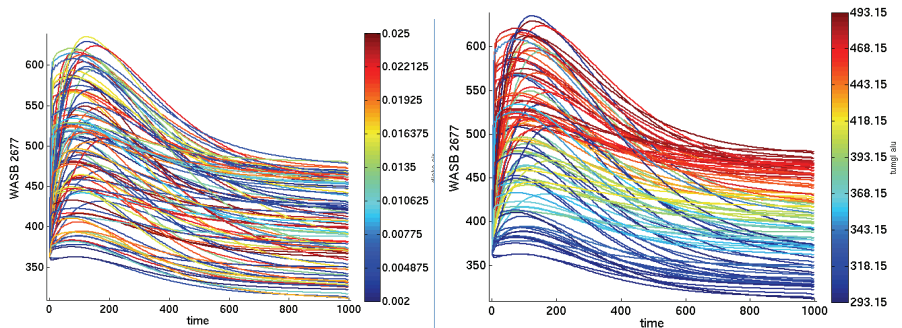

Figure 10: Temperature against time, color
variable dicke_air (left) and tumgl_alu (right)

Figure 10 shows histories of the temperature evolution over time. By selecting a variable or response which is represented through the color of the history one has the ability to determine the significance of that variable or response to the shown history.

On the right side the variable chosen for the coloring has a clear significance for the history where on the left side the significance is not determinable.
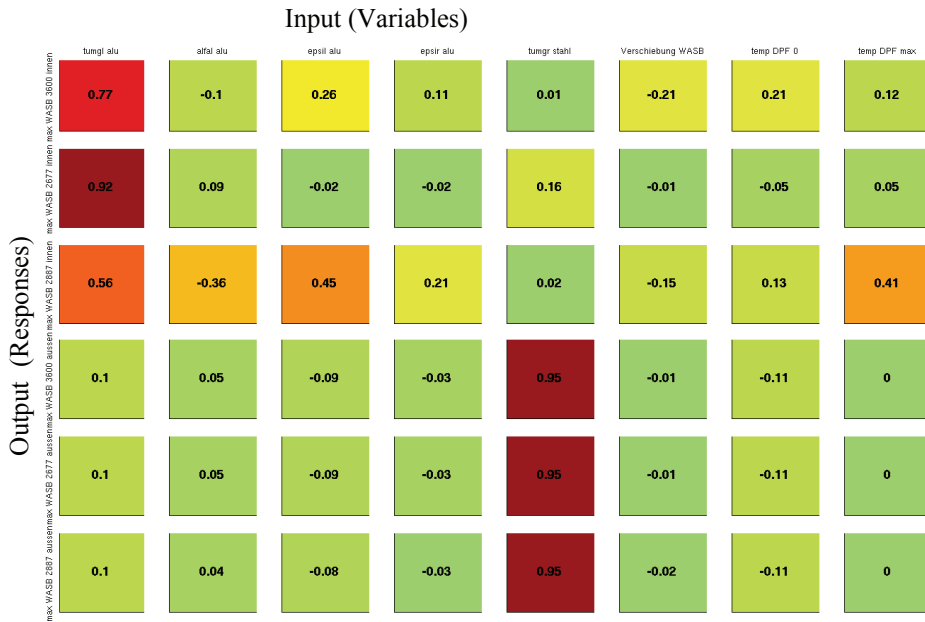

Figure 11: Correlation matrix for selected variables

Figure 11 presents a correlation matrix of selected variables and responses. The numbers displayed in the colored fields are the linear correlation coefficients. If the absolute value of the linear correlation coefficient is close to one, there is a high linear dependency of the response on the variable, if it is close to zero, the variable is insignificant.

Another method of observing the significance of variables is to consider ANOVA plots as shown in Figure 12. The lengths of the bars represent the regression coefficient from a linear regression. The red parts of the bars visualize the 90% confidence interval of that regression coefficient. Meaning that with a probability of 90% the regression coefficient can be expected within the range represented by the red part of the bar. If there is no blue part in a bar the variable may be considered insignificant with respect to the response. However, the confidence interval is greatly influenced by the number and influence of variables involved in the investigation and the number of simulations conducted. It may occur that a variable seems insignificant in one context but when

disabling some of the more eminent parameters or increasing the number of simulations the significance of a variable becomes evident.
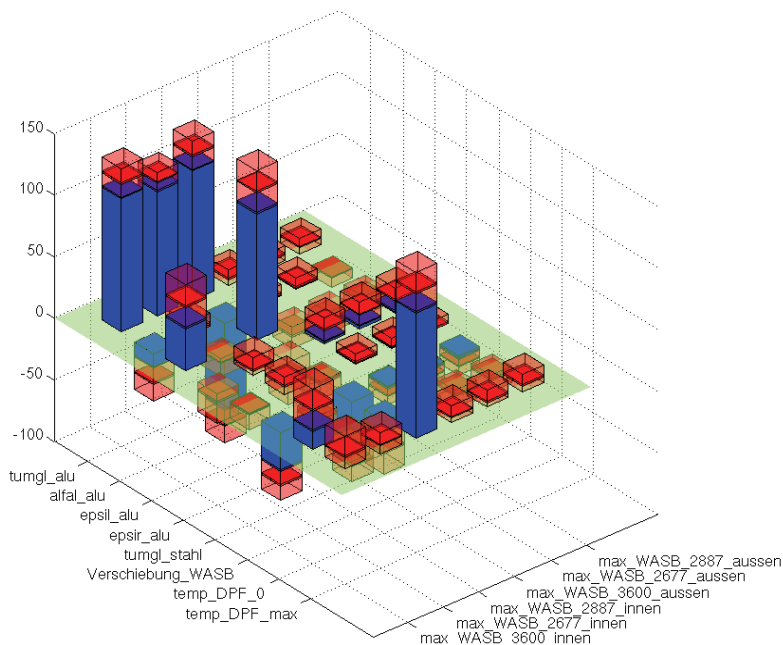

Figure 12: ANOVA for selected variables

SUMMARY

The paper described a DOE sensitivity analysis using LS-OPT. The difficulty of the interpretation of the results of the presented sensitivity analysis is caused by the high dimensionality of the problem. The visualization software D-SPEX offers possibilities to plot results extracted from LS-OPT, for example simulation points, metamodels and statistical values. D-SPEX proved to be successful detecting sensitivities of responses and variables and determine significant and insignificant parameters.

REFERENCES

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