Optimization Methodology in Structural Mechanics – Comparison of LS-OPT and Hyperstudy

Christoph Lind, Harald Schluder, Johannes Winklhofer
Kompetenzzentrum – Das virtuelle Fahrzeug Forschungsgesellschaft mbH

Abstract:

This paper introduces computerized optimization methods used in the commercially available optimization software LS-OPT (Version 2.2, Revision 199) and Hyperstudy (v7.0). The application of these methods is demonstrated with two examples. In the first example the goal is to reduce the mass of a longitudinal member while keeping or improving its properties in a frontal crash scenario. In the second example computerized optimization is used to adjust a simulation model to the corresponding experiment. The simulation models are calculated with the nonlinear finite-element-solver LS-DYNA.

In both examples LS-OPT and Hyperstudy are compared regarding calculation time and results obtained. The strategies of the different optimization methods are analysed. There is no recommendation for one or other optimization software. In both cases the advantages and disadvantages are mentioned.

Keywords:

LS-OPT, Hyperstudy, Successive Response Surface Method (SRSM), Sequential Response Surface Method

1 Introduction

Numerous design optimization software tools have been introduced during the last few years. These tools can be divided into 2 categories: topology optimization tools and parameter optimization tools. Topology optimization determines an optimal distribution of material with respect to given package space, loads and boundary conditions. Parameter optimization tools find optima for scalar values e.g. sizing values like diameter or sheet metal thickness. Changes of the shape of a mechanical structure can also be quantified with scalar values. Hence parameter optimization is suitable for sizing and shape optimization.

Examples given in this paper are solved with the commercially available parameter optimization tools LS-OPT and Hyperstudy. The numerical simulation models are calculated with the non-linear FE-Solver LS-DYNA. LS-OPT is a product of LSTC (Livermore Software Technology Company) and comes for free with LS-DYNA. Hyperstudy was developed by Altair and is a tool within the Hyperworks package. Both software tools offer the possibility to optimize non-linear simulation models of mechanical structures using mathematical methods based on Response Surface Methodology (RSM).

2 Response Surface Methodology

RSM is a statistical method for constructing smooth approximations of the objective function in the multi-dimensional parameter space. For illustration purposes, see Figure 1. So called experimental design points (variable sets) are selected within a pre-defined design space. For these points the defined model responses are calculated. In a subsequent step, polynomial functions are fitted to these experimental design points in order to substitute the original response. The fitting of the polynomial function is done by using regression analysis. Least squares approximations are commonly used for this purpose. In a last step an optimum point (minimum or maximum) is determined on the approximated response surface. Gradient methods are used for this purpose [1].

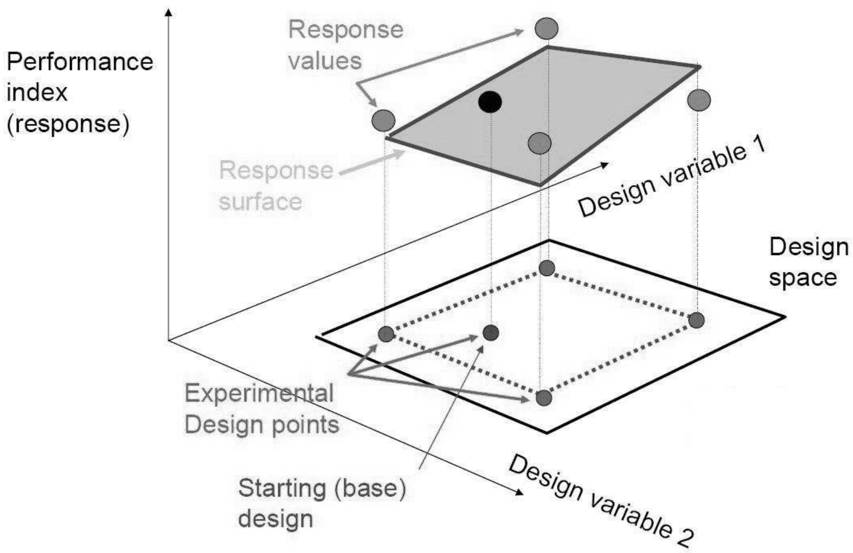


***Figure 1**: Principle of creating an approximation with Response Surface Methodology [2]*

2.1 Successive Response Surface Method

In LS-OPT a modification of RSM called Successive Response Surface Method (SRSM) is used to optimize designs. For the SRSM in a first iteration a sub region of the entire design space is defined as region of interest. The sub-region is approximated and the optimum is determined on the approximated response surface. For the next iteration a new region of interest is defined and the centre is located on the previous successive optimum. Progress is made by moving the centre of the region of interest as well as reducing its size (compare Figure 2). The iteration process is continued until the objective function or the design variables reach defined convergence criteria [3].

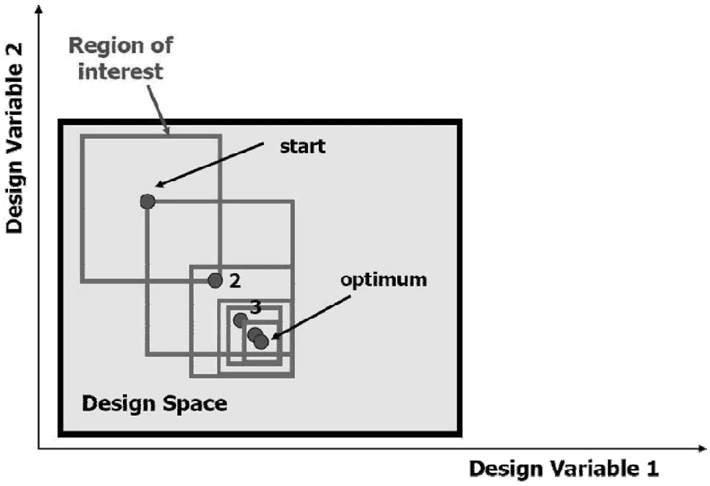


Figure 2: *Successive Approximation Scheme [2]*

2.2 Sequential Response Surface Method

The optimization method available in Hyperstudy is also based on RSM but is different to the method in LS-OPT. It is the so called Sequential Response Surface Method, see Figure 3. In this example f (x) represents a response of a numerical simulation model dependent on the design variable *x*. The task for this one-dimensional problem is to approximate and then maximise the unknown function *f (x)*. Based on the starting value of the design variable (1) and a small change of its value (2) a first linear response surface RS1 is created. A first approximate optimum is determined on the response surface (3a). The numerical simulation model is calculated with the variable determined for the approximate optimum (3b). In a second step a polynomial approximation of second grade RS2 is fit to the previously calculated responses. A second approximate optimum is determined on RS2 (4a) and the model is calculated for the determined value *x* (4b). Previously calculated responses are the basis for further approximation functions of second grade. Step 2 is repeated for every iteration until the design variable and optimum of the function *f (x)* reach defined convergence criteria. The method works equally for multidimensional optimization problems with 2 and more variables.

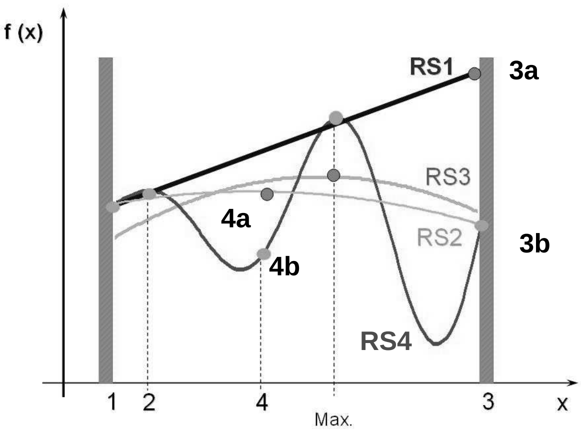


Figure 3: *Principle of determining an optimum with the Sequential Response Surface method [4]*

3 Optimization of a Longitudinal Member

One of two given examples in this paper is the optimization of an automotive longitudinal member made of Tailored Blanks, shown in Figure 4. Tailored blanks are made of sheet metals with varying thickness. The task is to minimize the longitudinal members mass taking the load case frontal-crash into account. The design variables for which the optimal values are determined are the thicknesses of the sheet metals t1, t2 and the position of the weld seam along the x-axis. Constraint function is the restricted longitudinal deformation of 100 mm. The performance of the different optimization methods available in LS-OPT and Hyperstudy is compared taking the reached results into account. The maximum number of calculations of the numerical simulation model is 65. The time for one calculation with the nonlinear FE-Solver LS-DYNA is the same for LS-OPT and Hyperstudy.

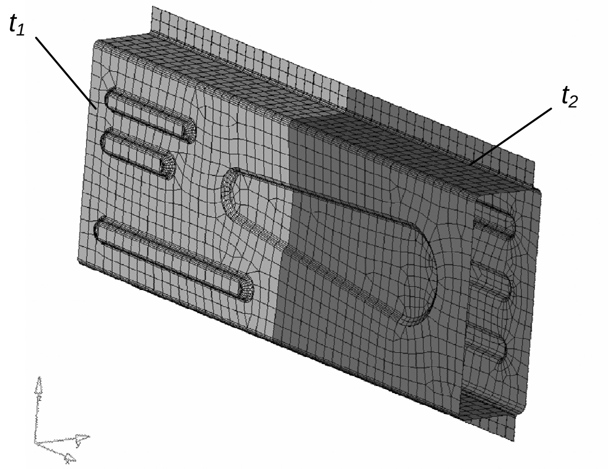


Figure 4: *Simulation model of a longitudinal member made of Tailored Blanks*

The discrete variables v1 and v2 can be modified independently within 1 and 9 and represent a defined position of the weld seam for the inner and the outer shell (compare Figure 5). The sheet metal thicknesses t1 and t2 are continuous variables between 1 and 4 mm. The goal is to find the optimum positions of the weld seams and the optimum thicknesses of the sheet metals t1 and t2 in terms of minimal mass and constrained longitudinal deformation. The defined optimization items are summarized in Table 1.

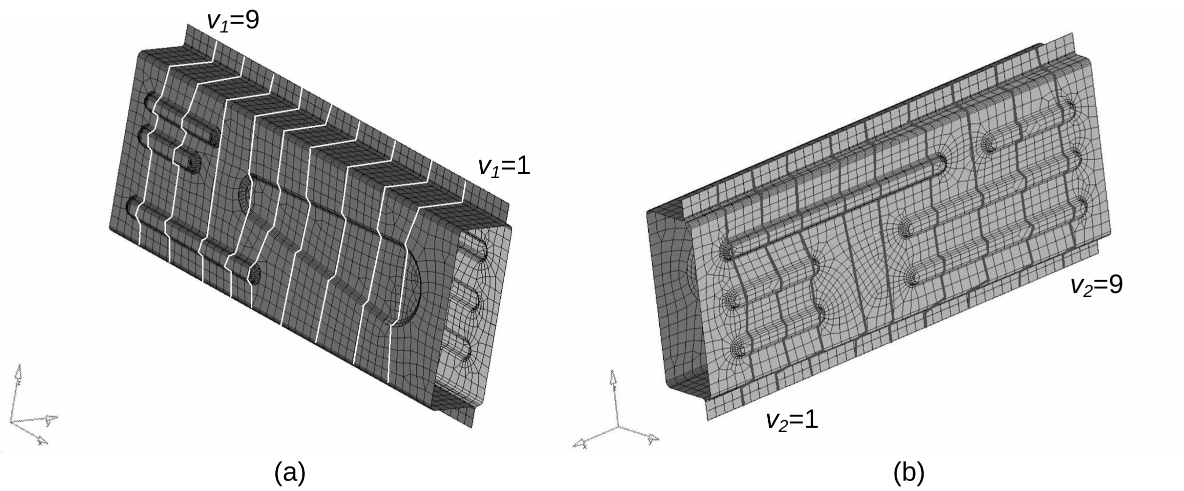


Figure 5: *Defined discrete positions for the weld seam; (a) v1 for the inner shell and (b) v2 for the outer shell*

Table 1: *Summarized optimization items*

		Initial Design	Boundaries/Constraint/Objective
Variables	t_1 [mm]	1,6	1÷4
	t_2 [mm]	1,6	1÷4
	v_1	5	1÷9
	v_2	5	1÷9
Constraint	Deformation [mm]	99	<100
Objective	Mass [kg]	3,41	Minimum

The results for the determined successive optima are shown in Figure 6. After 65 calculations of the simulation model or 9 iterations the final result of the optimization with LS-OPT is a longitudinal member with decreased mass that does not fulfil the constraint function. The actual optimum that fulfils the given requirements is an experimental design point determined in iteration 6 after 51 calculations. In this case clear converging behaviour could not be observed. LS-OPT demonstrated that the last calculated successive optimum was the best design. The actual optimum design was not directly obvious for the user. For the actual optimum, the determined sheet metal thickness of the rigid inner shell with the wide cross section was slightly decreased. The outer shell with the smaller cross section contributes less to the stiffness of the longitudinal member. For this reason the sheet metal thickness of the outer shell was partly decreased significantly (see Figure 7). The mass of the actual optimum design could be reduced, from 3,41 kg for the initial design down to 3,01 kg. This equals a mass decrease of 12 %.

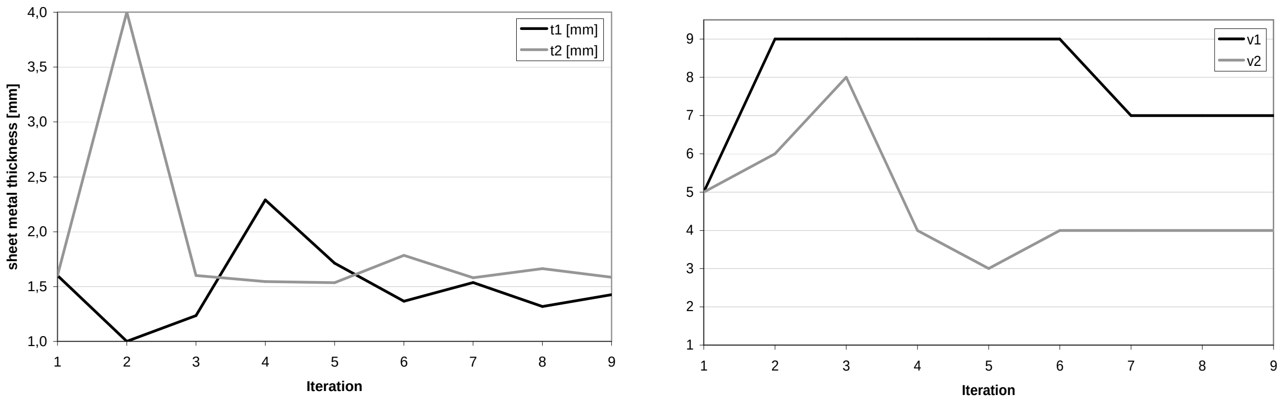
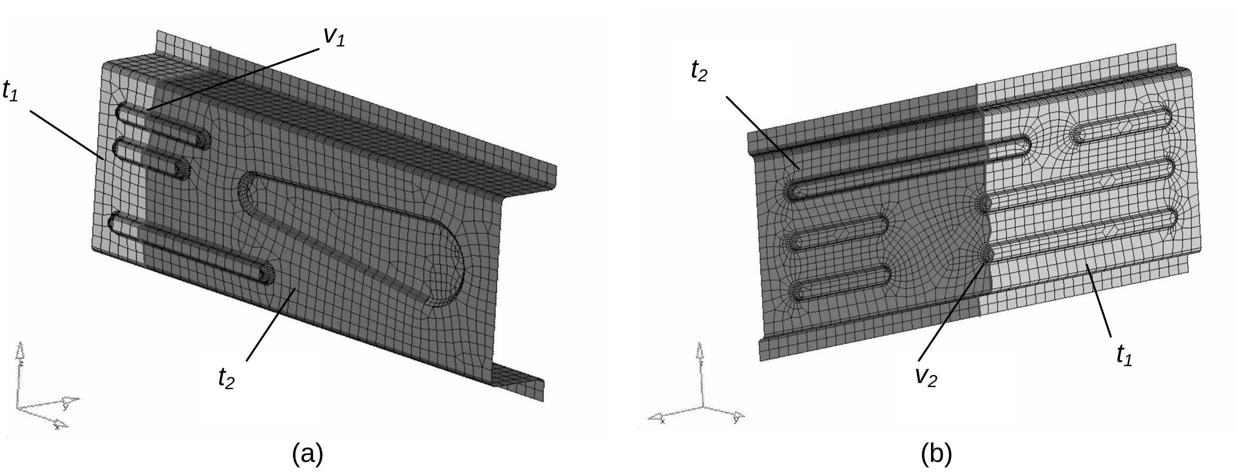


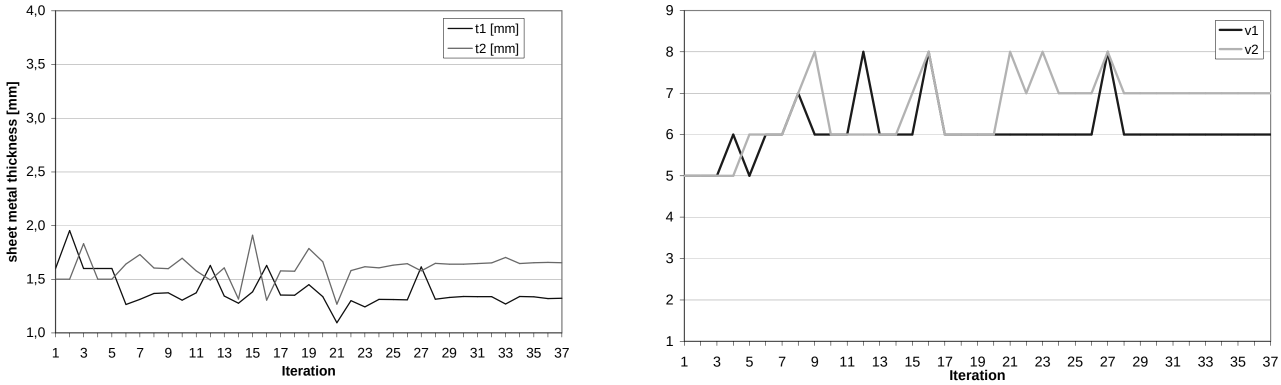
Figure 6: *Optimization with LS-OPT: Variables (a) t1, t2 and (b) v1, v2 for calculated successive optima*



(a) (b)

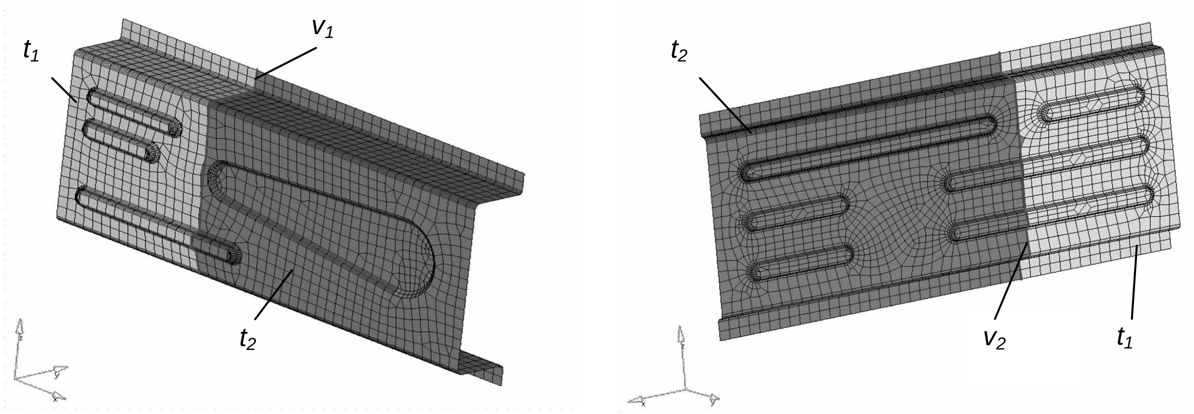
Figure 7: *Optimum design determined with LS-OPT (a) inner shell (b) outer shell with* t_1*=1,02 mm* t_2*=1,58 mm* v_1*=9* v_2*=4 Mass=3,01 kg*

The optimization with Hyperstudy stopped after 37 calculations of the simulation model when defined convergence criteria were fulfilled. The best design was determined after only 8 calculations. During the further 29 iterations no more improvement could be achieved. In this case the objective function did not converge to an optimum value. The optimization procedure was therefore not very efficient. The mass of best achieved design is 3,29 kg, which is, in comparison to LS-OPT (3,01 kg), a poor result. The optimization method Sequential Response Surface Method varied the variables v1 and v2 only within 6 and 8 and t1 and t2 only within 1 and 2 mm (compare Figure 8). Hence the design space was not covered sufficiently. This is the reason why Hyperstudy probably determined a local mass minimum.



(a) (b)

Figure 8: *Optimization with Hyperstudy: Variation of variables (a) t1, t2 and (b) v1, v2 within the design space over number of iterations*



(a) (b)

Figure 9: *Optimum Design determined with Hyperstudy (a) inner shell (b) outer shell with t_1=1,37 mm t_2=1,60 mm v_1=7 v_2=7 Mass=3,29 kg*

Figure 10 shows the constrained deformation dependent on the longitudinal members mass for all calculated designs. In comparison to Hyperstudy more calculations have been done, but LS-OPT determined a significantly better design. The mass reduction obtained with LS-OPT equals 12 %, whereas with Hyperstudy 4 %. The optimization Method in Hyperstudy namely Sequential Response Surface Method did not cover the whole design space and therefore probably determined a local optimum. LS-OPT did not show the best achieved result as optimum.

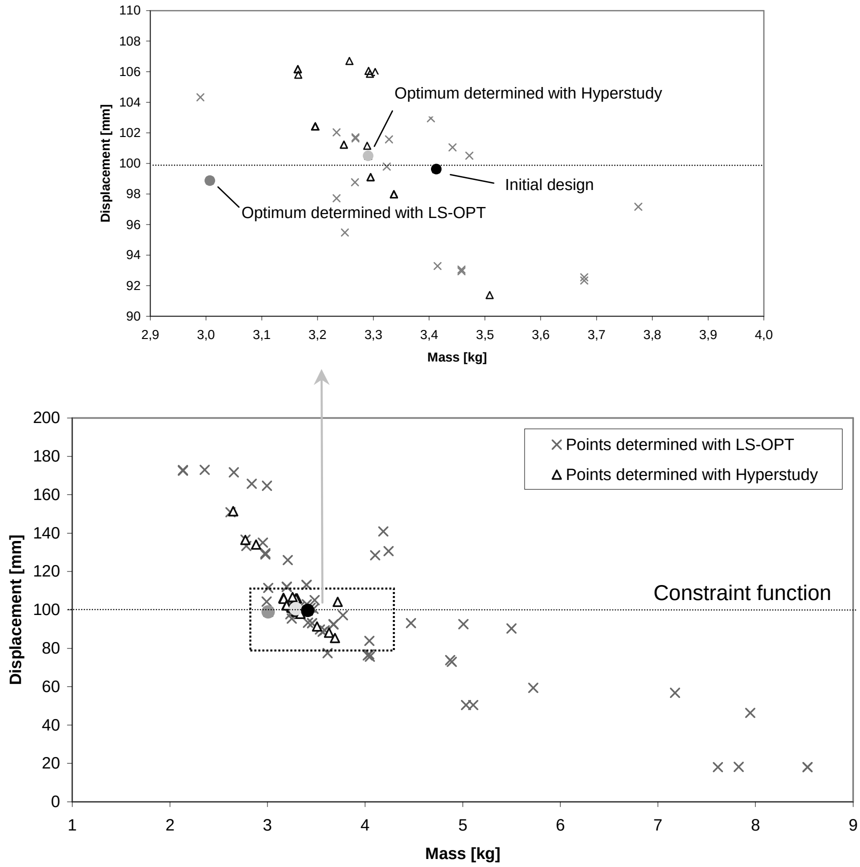


Figure 10: *Mass vs. displacment for all with LS-OPT and Hyperstudy calculated designs and determined optima*

4 Adjustment of a Numerical Simulation Model with Computerized Optimization Methods

Another useful application for computerized design optimization is to adjust a simulation model to the corresponding experiment. The experiment in this example is an automotive structure being deformed. Within this structure a plate is moved due to the deformation. This movement should be reproduced in a virtual experiment. The connection of the plate to the automotive structure is simulated using 4 sheet metal strips. The movement is simulated by a force pushing the plate in x-direction. The motion of the corners 1-4 is dependent on the width of the four sheet metal strips (see Figure 11).

The displacement of the corners of the plate measured in the experiment should be reproduced by the simulation model. The x-coordinates of the corners are determined at three points of time at 0.06, 0.08 and 0.1 seconds. The objective function is to minimize the sum of the displacement deviations between simulation and experiment at the defined points of time. The shape variables are the widths of the strips. The initial width of the strips is 16 mm. The widths can be varied between 15 and 20 mm. The initial sum of displacement deviations at all points of time is 40 mm. The task is to find the optimal width of each strip in order to minimize the displacement deviations between simulation and experiment.

In this example LS-OPT and Hyperstudy are linked with Hypermorph. Hypermorph is a tool available in Hypermesh that can be used for shape optimization purposes. One calculation of the numerical simulation model with LS-DYNA takes 90 minutes. The efficiency of LS-OPT and Hyperstudy is compared taking the results and the required number of calculations into account.

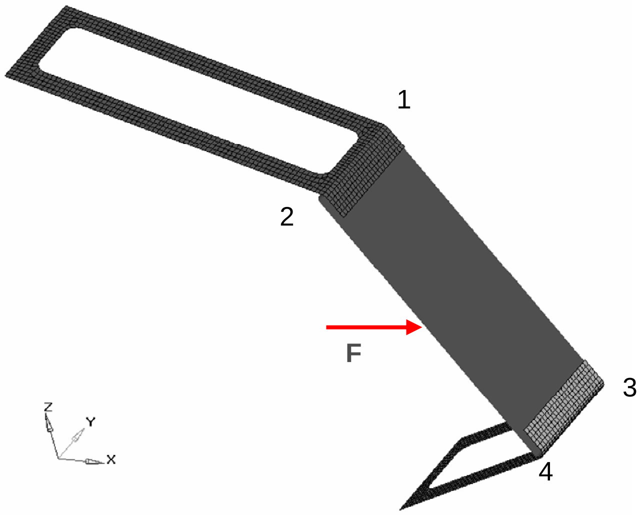


Figure 11: *Simulation Model of the plate. The Movement of the plate is caused by the force F and is dependent on the sheet metal widths of the strips 1 - 4*

LS-OPT calculated 80 experimental design points before convergence criteria were fulfilled. The actual optimum was determined after 70 calculations. The sum of the deviations could be decreased from 40 to 6.8 mm. Within 50 iterations, Hyperstudy determined a best design after 49 calculation of the simulation model. The minimum sum of displacement deviations is 6.34 mm. In this example Hyperstudy performed more efficiently. In comparison to LS-OPT, fewer calculations had to be made to reach a better optimum design. Figure 12 compares the initial design, the optimum design reached with LS-OPT after 70 calculations and the optimum design obtained with Hyperstudy after 49 calculations.

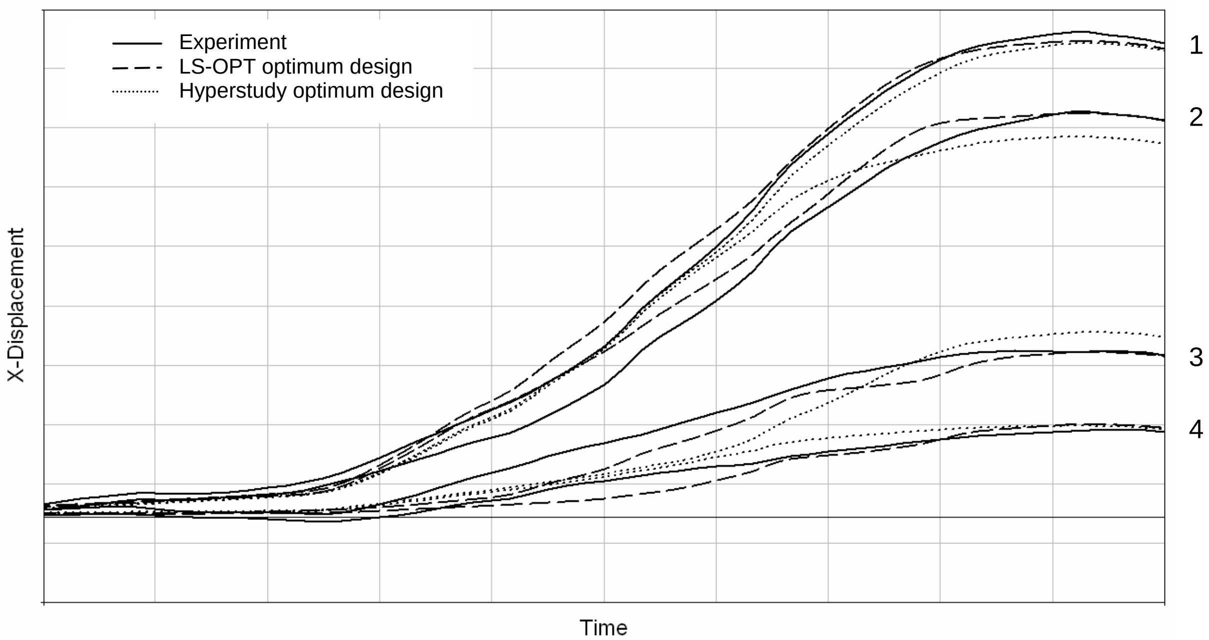


Figure 12: *Result of the optimization with LS-OPT and Hyperstudy: x-Displacement of the corners of the plate over simulation time*

5 Summary

This paper shows the application of computerized parameter optimization methods available in LS-OPT and Hyperstudy. LS-OPT and Hyperstudy proved to be very efficient for optimizing mechanical structures. In both examples, with both optimization software tools the designs could be improved significantly.

The mass of the longitudinal member could be decreased within one weekend of calculation time on a Siemens Fujitsu Celsius 610 work station. In comparison to Hyperstudy, LS-OPT covered the whole design space, calculated more different designs and for that reasons determined a significantly better design. When optimizing the given simulation model from example two, the results obtained with LS-OPT and Hyperstudy were quite similar. Hyperstudy made fewer calculations to reach a slightly better solution.

Experience with the given examples showed that LS-OPT calculates many experimental design points throughout the whole design space. Hyperstudy determines fewer designs within a smaller region. For that reason it is sometimes more likely that a local optimum is found. In comparison to LS-OPT, Hyperstudy can be more efficient although there is the risk that the best design is not found.

6 References

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