Optimization of a Crash Management System considering Multiple Load Cases using ANSA and LS-OPT

Martin Feuerstein[1], Katharina Witowski[2], Heiner Müllerschön[2]

[1] Alcan Singen GmbH, Germany
[2] DYNAmore GmbH, Stuttgart, Germany

Summary:

This paper describes a multi objective optimization of a crash management system using LS-OPT. Shape optimization is done using ANSA' s Morphing Tool as pre-processor in LS-OPT. Several objectives from two different load cases are considered. The objectives are conflicting, so a usual multi objective optimization converting the problem into a single-objective optimization using a weighted sum strategy may not lead to the desired result. Hence multiple Pareto optimal solutions are calculated using a multi-objective genetic algorithm (NSGA-II). Response evaluations of the genetic algorithm are performed not directly, but by utilizing meta-models. These solutions are visualized using D-SPEX.

Keywords:

Multi objective optimization (MOO), LS-OPT, ANSA, morphing, D-SPEX, Pareto optimal solutions, shape optimization, meta-models, crash management system

1   Introduction

This paper describes the design of a bumper in a given constructed space. Two load cases are considered and the objectives are to remove the impact energy by plastic deformation of the bumper and to reduce the mass of the bumper. The given constraints are a maximal force level of the barrier contact force for the AZT crash repair test and that the bumper has an extruded section. The idea is to use the ANSA Morphing Tool to modify the geometry from a starting design, and to modify some sheet thicknesses using LS-OPT.

2   Problem Description

2.1   Load Cases

There are two load cases considered, the AZT crash repair test and the RCAR test.

2.1.1 AZT Crash Repair Test

The AZT barrier has a mass of 1000kg, it impacts the vehicle with a velocity of 16km/h and an impact angle of 10°, see Fig. 1.
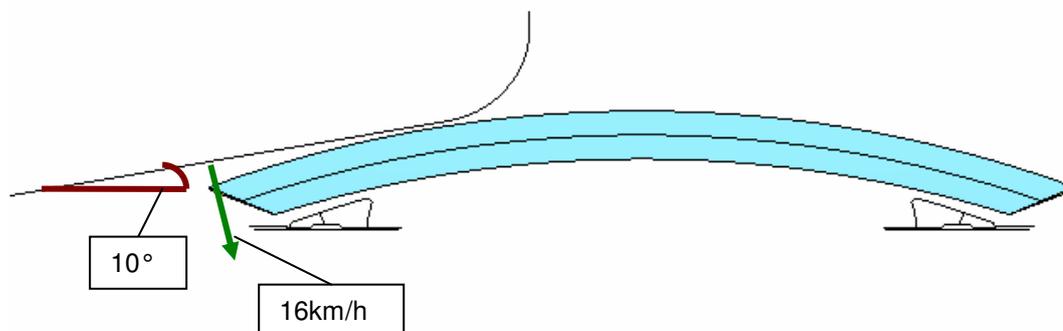
Fig. 1: AZT Crash Repair Test

2.1.2 RCAR Test

For the RCAR test, the vehicle impacts the barrier with a velocity of 10km/h, see Fig. 2.
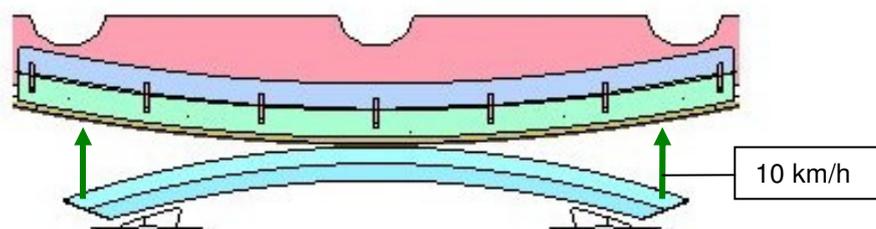
Fig. 2: RCAR Test

2.2   Optimization Problem

2.2.1 Shape Optimization using ANSA's Morphing Tool

As starting geometry, a shape with constant cross section in the given constructed space is selected to obtain a bumper with extruded section. This geometry is modified during the optimization using ANSA's Morphing Tool. Four morphing parameters are defined to modify the shape of the bumper, see Fig. 3. The morphing boxes and parameters are defined such that the constant cross section of

the bumper is preserved. As an additional geometrical restriction is given that the back part of the bumper keeps its height. Some resulting shapes are presented in Fig. 4. For the definition of the morphing boxes and the optimization task in ANSA, we refer to [2], [7].

Morphing parameters
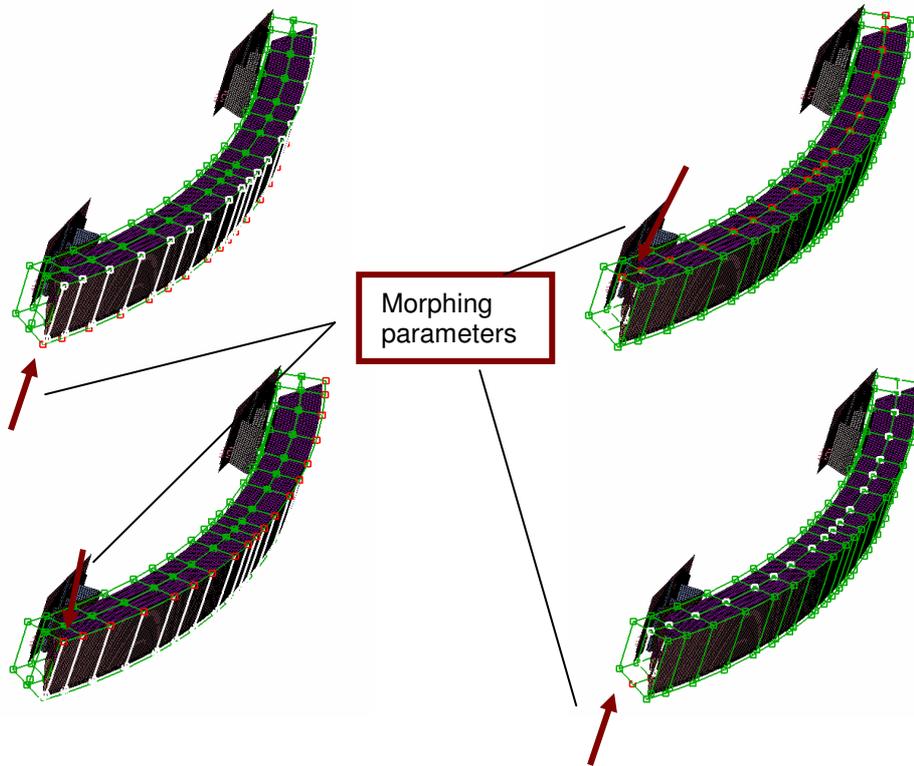
Fig. 3: Four Morphing Parameters as design variables for shape optimization
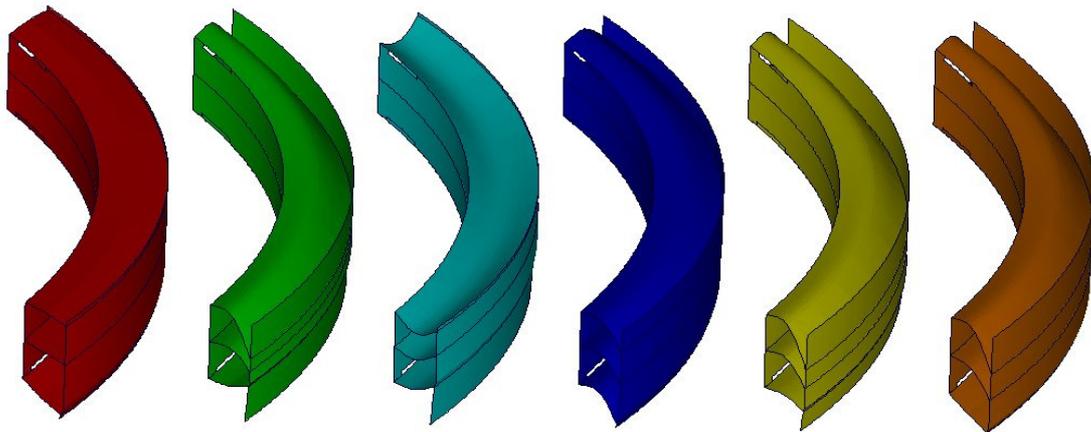
Fig. 4: Shape results of ANSA morphing

2.2.2 Design Variables

The bumper is distributed into five parts, see Fig. 5. In addition to the morphing parameters, the sheet thicknesses of these five parts are defined as design variables. Hence we get nine design variables in total.
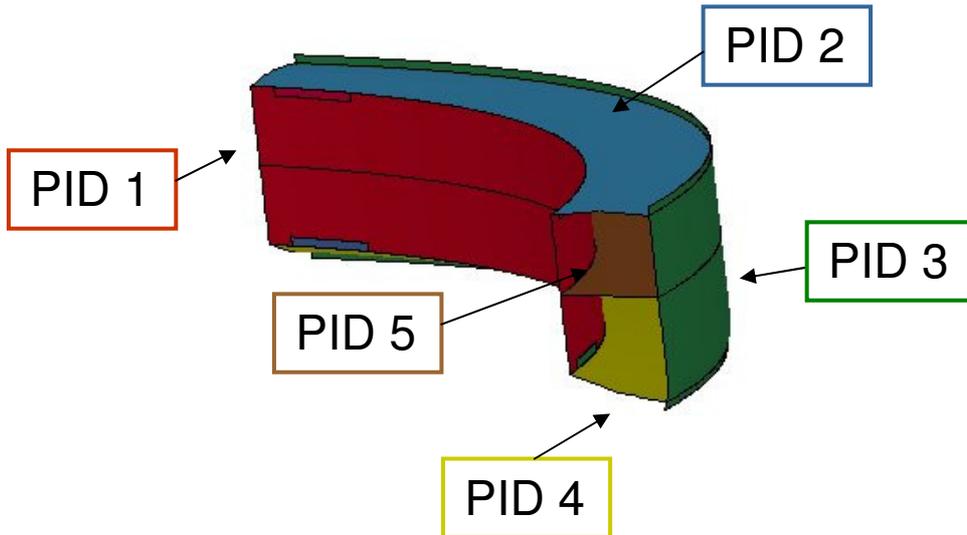
Fig. 5: Parts with variable sheet thickness

2.2.3 Objectives

To optimize the energy absorption by plastic deformation of the bumper for the AZT crash repair test, the contact force between the barrier and the vehicle should be as near as possible to the maximal force level. Hence the sum of squares error between the calculated force curve and a target curve with a constant value of 120kN, which is the given maximal force level, is considered, see Fig. 6. Not the whole curve is considered, but the end time is the time, when the force value is zero again. LS-OPT provides a function to find the time at a specific value of the function ('Lookup'), [1].
The objective considered for the optimization is defined as

$$\text{MSE\_Force} \quad = \quad \sqrt{\sum_{i=0}^{3}\left(\text{x\_Force}(t_i) - 120\right)^2} \ . \tag{1}$$
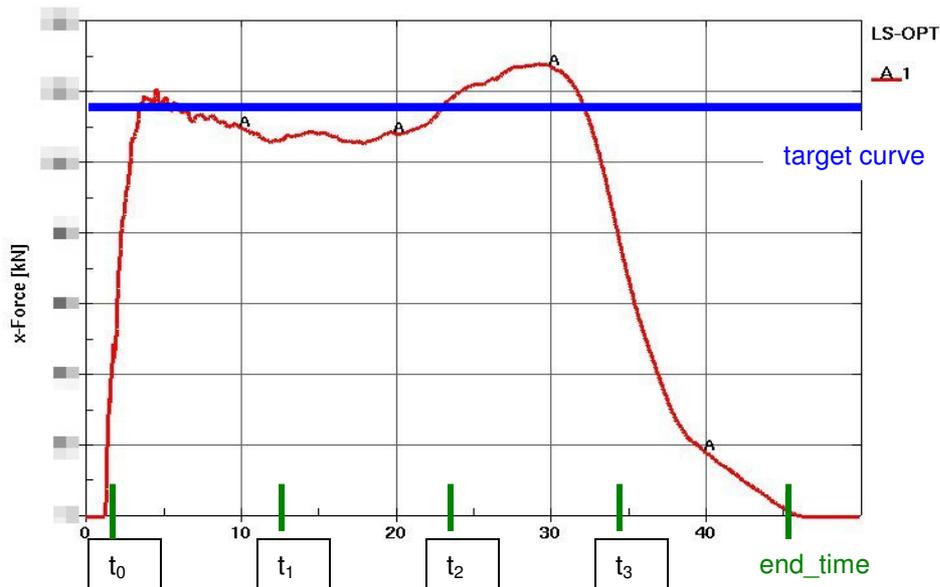
Fig. 6: Adaptation of force curve over time

For the load case RCAR, the maximal intrusion of the bumper is important. The intrusion is defined as the difference of the displacement of the center of mass of the vehicle and a node at the inner edge of the bumper, see Fig. 7.

center of mass
of vehicle

20992098

node at inner
edge of bumper
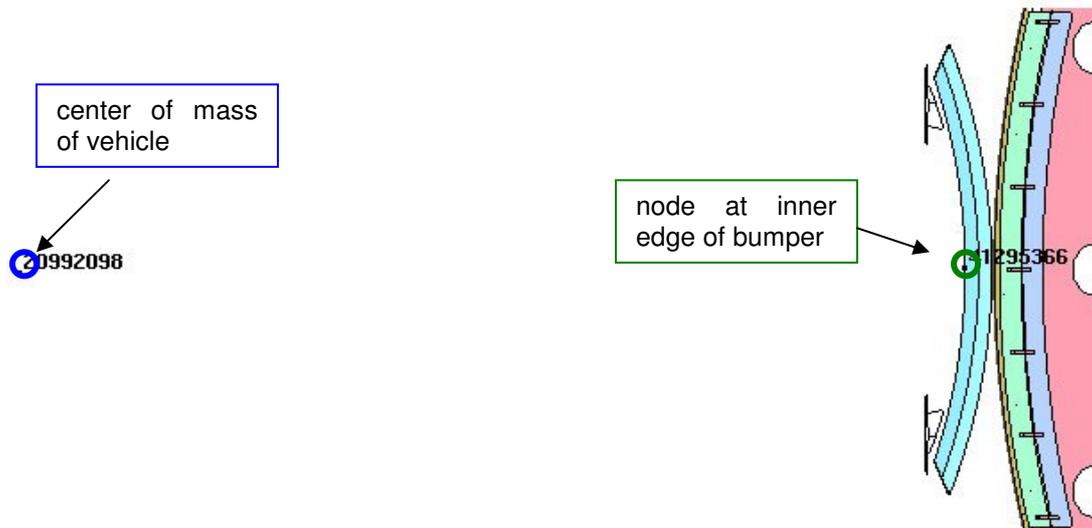
1295366

Fig. 7: Objective Max_Intrusion, difference of displacement of node 20992098 and node 1295366

The last objective considered is to minimize the total mass of the bumper.

For an optimization that leads to one single result, a weighted sum of all objectives is optimized. If the objectives are conflicting, the result strongly depends on the selected weights. LS-OPT offers in addition the possibility to compute multiple Pareto optimal solutions on a selected meta model, [1], [4].

3   Optimization Results

Fig. 8 displays the results of the optimization of a weighted sum of the three objectives. The weights are selected so, that the objective values are normalized with respect to the starting design results. Thus all objectives are treated equally. The optimized force curve and the intrusion improved compared to the starting design, but the mass of the optimal run is too high. That is a typical effect with conflicting objectives. Hence we look at the set of Pareto optimal solutions calculated on the meta-model to select a solution that suits better to the application.
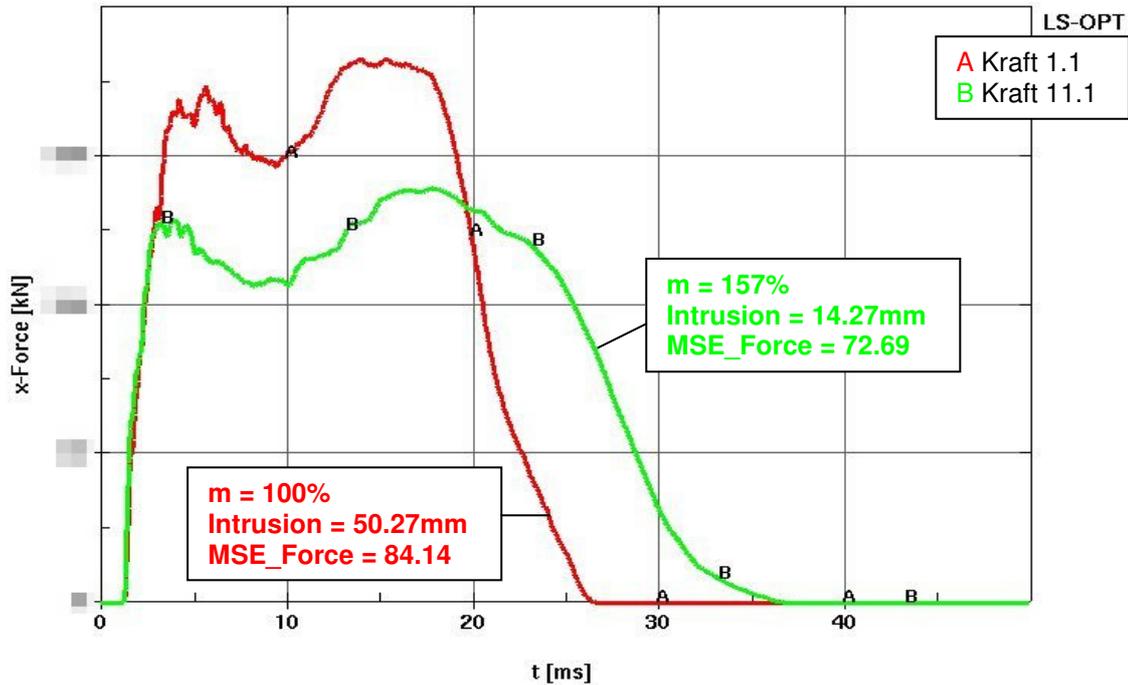
Fig. 8: Comparison force curve starting design – force curve optimized design

3.1 Pareto Optimal Solutions

If the user adopts the successive response surface methodology, LS-OPT offers the possibility to compute a set of Pareto optimal solutions at the same time. The meta-models are used to evaluate designs to determine the Pareto optimal solutions. Using the meta-models reduces the computational cost of identifying the Pareto optimal set, but the accuracy of the resulting solution depends on the quality of the meta-models. In our case, we used radial basis function networks to approximate the surfaces.

In order to aid the engineer in understanding different trade-offs, the optimization post processing tool D-SPEX provides some features to visualize the Pareto optimal solutions.

3.1.1 Visualization of Pareto Optimal Solutions using 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. 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, [6]. D-SPEX offers advanced features to visualize Pareto optimal solutions.

If the optimization problem has more than three objectives, all dimensions may not be visualized at once. Hence, 2D or 3D section planes have to be selected for visualization. The objectives that are not visualized are set to fixed values. The Pareto optimal solutions data set provided by LS-OPT may not have continuity among objectives. If only the points that lay exactly on the section plane are selected, only a few or no points will be available for plotting. Therefore, a set of points within a small distance ε to the selected section is plotted. The bandwidth ε may be selected by the user as a percentage of the design space, Fig. 9. To provide an impression of the proximity of the selected points to the section plane, the points are color-coded from black to white depending on the distance to the plane. The closer the point is to the plane, the darker the color is.

As a further dimension, a variable, response or composite may be selected to color the points. To visualize the relation between objectives and variables, responses or composites, it is also possible to plot objectives against variables, responses or composites in any combination, [5].
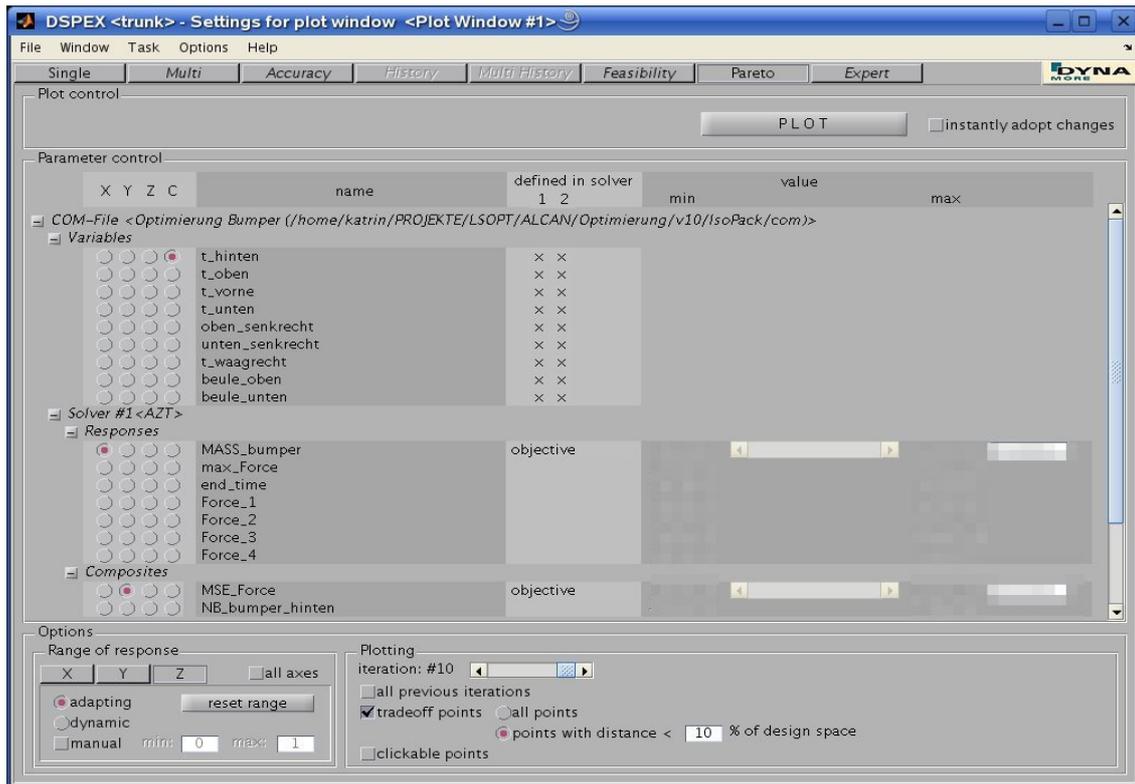
Fig. 9: D-SPEX graphical user interface: Selection of objectives, responses, variables to be plotted, and bandwidth of plotted points

3.1.2 Pareto optimal solutions of the crash management system
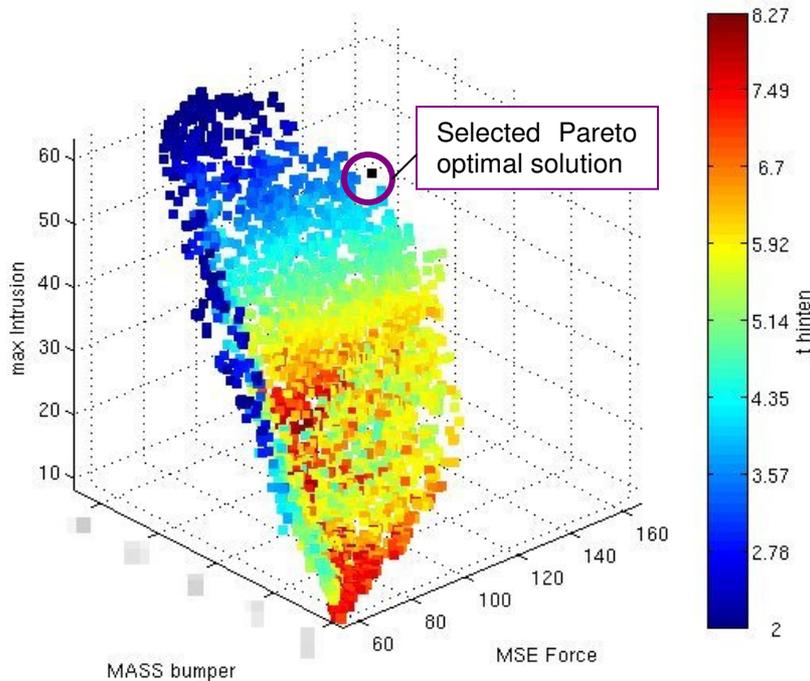
Fig. 10: Pareto optimal solutions calculated on the meta-model

Fig. 10 displays the three dimensional Pareto optimal solutions for the three objectives *MSE_Force* (load case AZT), *max_Intrusion* (load case RCAR), and the total mass of the bumper *MASS_bumper*. In addition, the points are colored according to the design variable sheet thickness of PID 1 *t_hinten*.

From these solutions, the user may select the compromise that suits best to the application. With this tradeoff plot, the engineer can decide how to compromise between the three objectives and he can select his favorite design.

To get the parameter combination that leads to a selected solution, the points are clickable. A window opens up containing all variable and response values belonging to the selected solution, Fig. 11. The selected point is marked in black, Fig. 10.

Fig. 12 shows a 2D section of the Pareto optimal solutions. The objective *Intrusion_max* is set to a fixed value, and a band with a bandwidth of 10% of the design space around the fixed value is displayed.
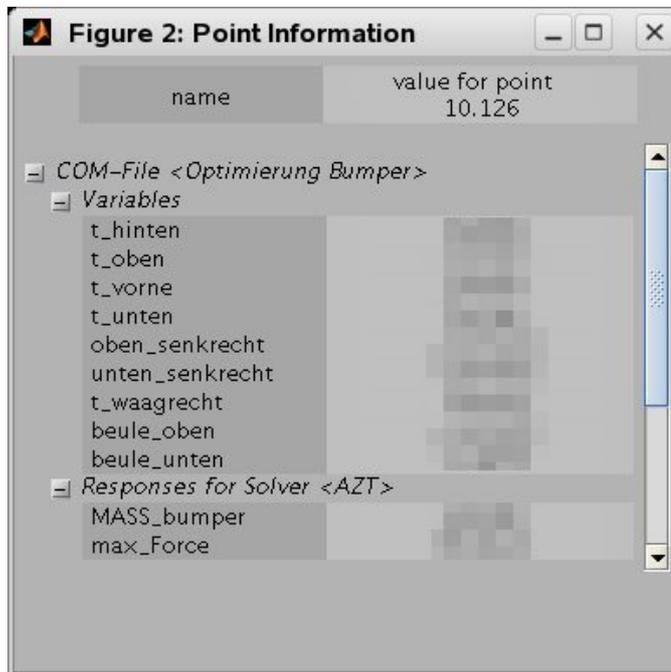
Fig. 11: Variable and response values of the selected Pareto optimal solution
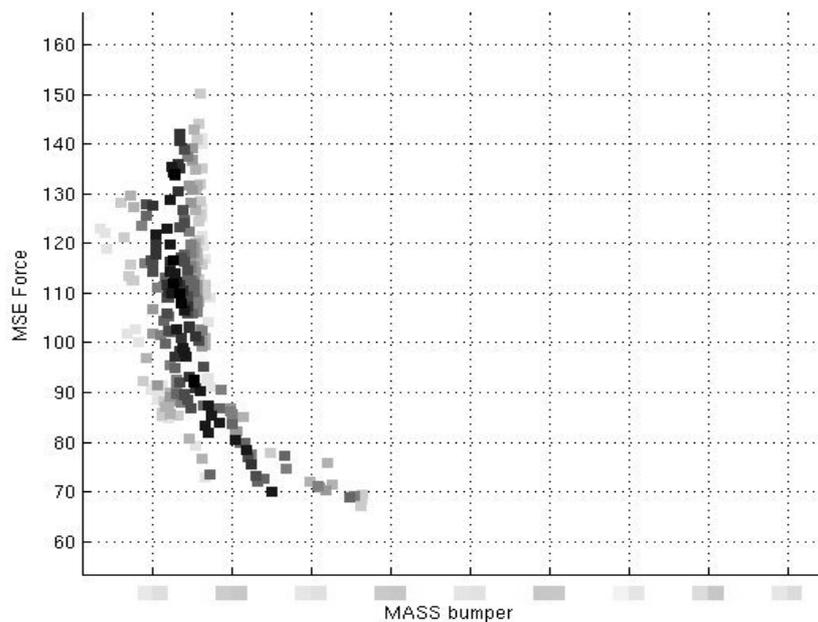
Fig. 12: 2D section of Pareto optimal solutions, max_Intrusion = 50mm, 10% bandwidth of design space displayed

4   Summary

This paper describes a multi objective optimization of a crash management system using LS-OPT. Two different load cases and three objectives are considered. To realize shape variations, ANSA' s Morphing Tool is used, that provides easy coupling with LS-OPT. In addition, sheet thicknesses of five parts of the bumper are considered as design variables. In total, 9 design variables are introduced. For the multi objective optimization, the conversion to a single-objective optimization is not sufficient hence the calculation of Pareto optimal solutions is necessary. These solutions are calculated meta-model based to keep the computational costs (number of solver calls) within an acceptable range.

The Pareto optimal solutions were evaluated with the visualization tool D-SPEX that provides special features to visualize multi objective problems.

5   Literature

[1]   Stander, N., Roux, W., Eggleston, T., Craig, K., LS-OPT User's Manual, Version 3.3, Livermore Software Technology Corporation, Livermore, 2008
[2]   ANSA version 12.1.3 User's Guide, BETA CAE Systems S.A., 2007
[3]   Introduction to D-SPEX, Version 0.3, DYNAmore GmbH, Stuttgart, 2008
[4]   Goel, T., Stander, N., Multi-Objective Optimization Using LS-OPT, 2007
[5]   Witowski, K., Thiele, M., Goel, T., Visualization of Pareto Optimal Fronts for Multiple Objectives with D-SPEX, 2008
[6]   Witowski, K., Thiele, M., Seer G., Mühlhuber, W., van den Hove, M., New Features in D-SPEX with Application, 2007
[7]   Korbetis, G., Shape optimization with ANSA and LS-OPT using a new flexible interface, 2007