Topometry and Shape Optimization of a Hood

Yong Ha Han[1], Katharina Witowski[2], Nikolay Lazarov[2], Krassen Anakiev[2]

[1]Hyundai Motor Group
[2]DYNAmore GmbH

1 Introduction

To comply with the regulations of pedestrian safety, particularly the head impact requirements, the geometry of the hood panel is significant.

The objective of this research was to develop a standardized automated method to design a hood which meets the pedestrian headform impact safety regulations and additionally the stiffness and fatigue requirements.

The developed method was performed in two steps.

As a first step, a topometry optimization of the inner hood panel using Genesis from Vanderplaats R&D and the Equivalent Static Loads Method (ESL) has been executed. The dynamic simulations were performed with LS-DYNA® as the coupling module ESLDYNA of Genesis was used. From the result a preliminary CAD design of the inner hood panel was generated.

This design is just one possibility to interpret the result of the topometry optimization. Furthermore, since the ESL method is an interaction of nonlinear dynamic simulations and linear static optimization, nonlinear dynamic quantities such as HIC values cannot be considered directly in the linear static topometry optimization. Hence a second step was necessary to refine the functional requirements.

A parametric multi-disciplinary shape optimization with LS-OPT® was carried out using the preliminary CAD geometry as a baseline design. The parameters of the optimization with LS-OPT were gauge thicknesses and geometric changes of the inner panel structure. To apply the geometric parameters the ANSA Morphing Tool from BETA CAE Systems S.A. was used.

The method was performed for two different models, a steel and an aluminum hood. As a result, a new design of the hoods with significant improvement of the performance and reduced mass was proposed.

2 Topometry optimization with Genesis/ESL

In order to gather a rough idea of the shape of an improved inner panel structure a topometry optimization was executed using the coupling module ESLDYNA of Genesis [1] and the Equivalent Static Loads Method (ESL), [2] and [3]. For some other similar projects using the ELS method and LS-DYNA please refer to [4], [5] and [6].

The general idea of a topometry optimization is to vary the thicknesses of particular elements or element clusters in order to get stiffer or softer fractions of structures.

2.1 Problem description

In the first optimization step 15 head impact and two stiffness load cases – bending and torsion - were taken into account, in overall 17 load cases. The objective was to get better HIC values for the head impact load cases compared to the original structure and to limit the displacements of the loading points considering the stiffness load cases. The pedestrian safety impact points were chosen area-wide regarding the hood symmetry in order to cover the most critical positions concerning the HIC values, Fig. 1 - left. The load application points for the stiffness load cases are located on both front corners of the hood, Fig.1 – top right and bottom right.

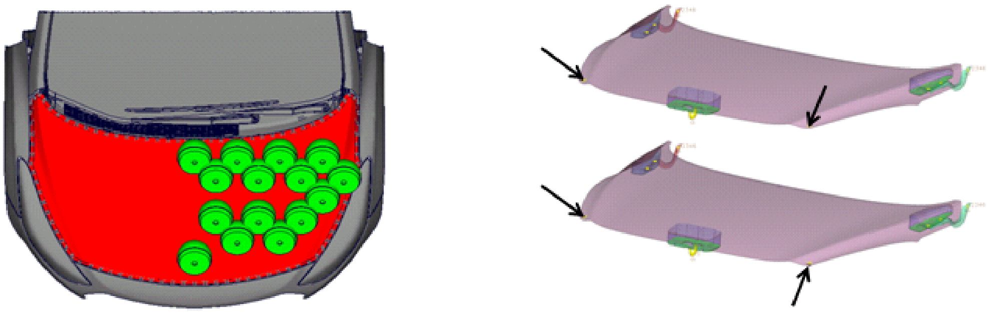

Fig.1: Loadcases for the topometry optimization: position of the 15 head impact points (left), load case "bending" (top right) and load case "torsion" (bottom right).

2.2 ESL Optimization with Genesis and LS-DYNA

The ESL method represents the linking between dynamic nonlinear simulations using LS-DYNA and a static linear optimization executed with Genesis. At the beginning a LS-DYNA simulation is needed in order to get the displacements at certain user-defined discrete time points. After gathering the displacement fields, equivalent loads are calculated and applied on a similar linear static model, so that the same deformation as for the dynamic model is achieved. A multidisciplinary optimization based on the linear static model is performed, Fig. 2 - inner loop. Regularly a new LS-DYNA update run is submitted, Fig. 2 - outer loop, before the inner loop is repeated once again, so that better agreement between linear static model optimization and nonlinear dynamic simulation takes place. The procedure iterates until the convergence criteria are met.

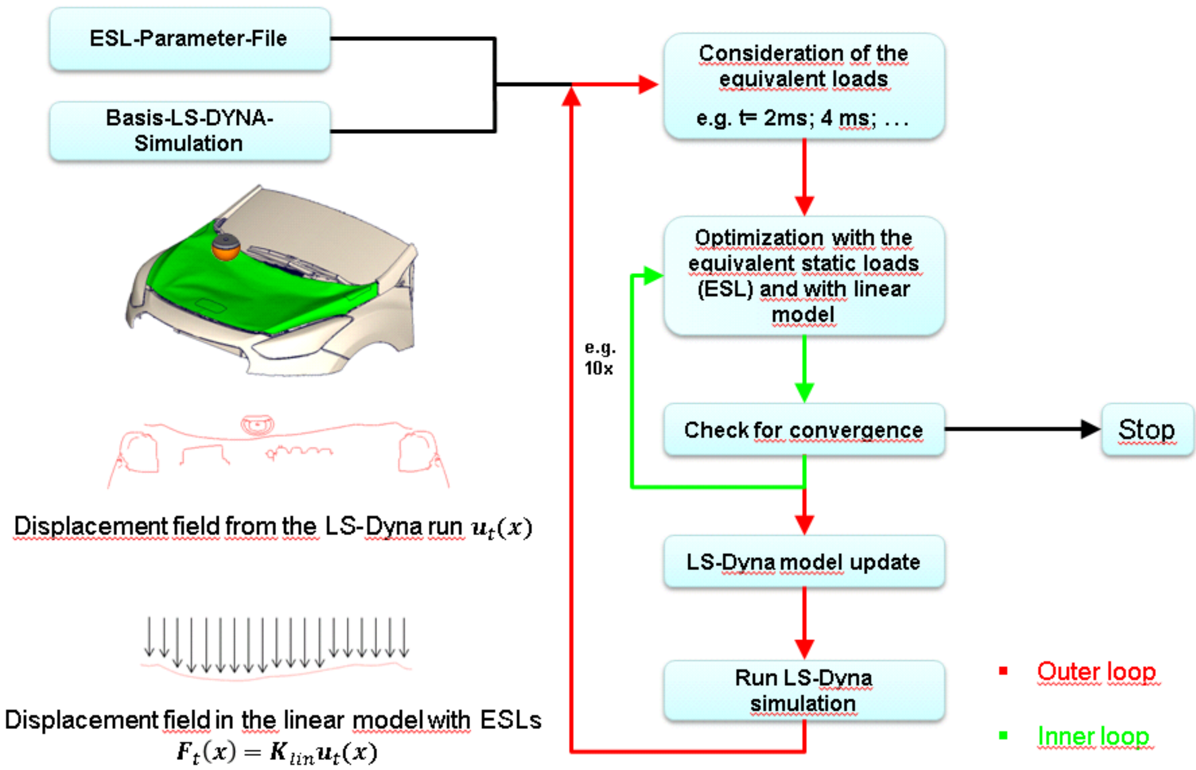

Fig.2: ESL Optimization loop using LS-DYNA and Genesis.

2.3 LS-DYNA model setup

The full pedestrian safety FE model was reduced in order to run the simulation in shorter time. The results for HIC of the reduced model were compared with these of the full model to ensure that they are similar. Furthermore some parts that didn't show deformation during the head impact were switched to rigid, as shown in Fig. 3.

Fig.3: LS-DYNA FE model reduction: full model (left), reduced model (center), deformable parts of the reduced model (right, green transparent).

Another modeling characteristic is that the hood is built up with two layers of coincident elements, but with different part ids, so that both can get different thickness, Fig. 4. That is the already existing inner hood was replaced with the element surface. The thickness of the first layer (outer hood) remains constant for all elements while the other one (inner hood) varies element-wise during the optimization.

Fig.4: LS-DYNA FE model specialty: outer hood considered with constant thickness (left) and Inner hood with element-wise variable thickness (right) modelled as coincident surfaces.

2.4 Genesis linear static model setup

In order to save some simulation time and for the cause, that the most deformations take place on both hoods – inner and outer, it is reasonable to further reduce the LS-DYNA model concentrating mainly on those structure parts to create the static linear model for the topometry optimization with Genesis, Fig. 5.

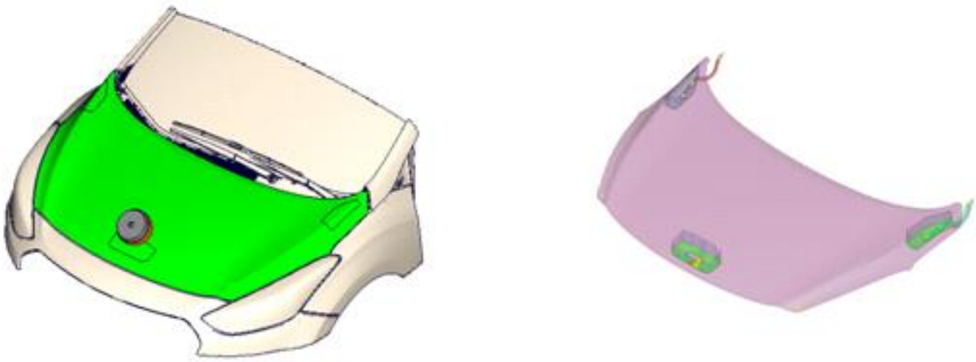

Fig.5: Genesis model: LS-DYNA model (left) and Genesis model – inner and outer hood with hinges and lock (right).

2.5 Genesis optimization setup

The thickness of each cluster of 4 neighbor elements from the inner hood panel is considered as a design variable for the topometry optimization. Thus it should be possible to gain a proper design of the inner hood structure. Two objectives were used – maximizing the strain energy for all head impact load cases and minimizing the strain energy for the stiffness load cases. In the first case a softer structure is aimed and in the second a stiffer one. The background of targeting at a softer structure for the ESL load cases is as follows. The HIC value can´t be directly considered as an objective function or as a constraint for the optimization, which is performed via linear static equivalent model (gradient based) and it´s only possible to define entities as objectives or constraints that can be directly evaluated from the linear model. That is not the case for the accelerations, which are the main member of the HIC value. An alternative was found by combining the already mentioned aiming at yielding structure and setting displacement constraints all over the designed region in order to avoid contact between hood and engine as shown in Fig. 6. In addition further constraints were defined in order to restrict the stiffness load cases. Furthermore a symmetry plane was used considering the design region in order to save some optimization time.

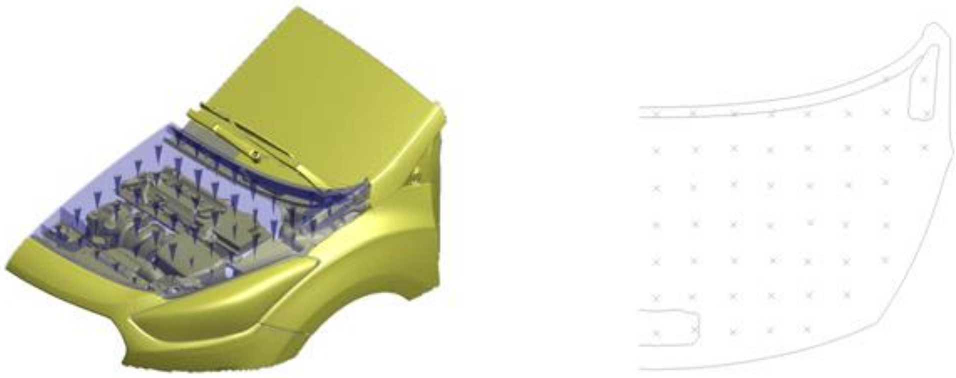

Fig.6: Constraint definition for the ESL load cases: point raster of approximately 100mm x 100mm on the hood with allowable z-displacement.

2.6 Results

2.6.1 Steel hood

For obtaining convergence 22 iterations (outer loops) were needed. The absolute value of the multi objective function curve increases round iteration 10, what points at “softening” the structure, and decreases at the end because Genesis tries to satisfy the constraints as well, see Fig.7 left. The red points on the constraint violation curve mean that there is at least one constraint that is not satisfied and the green ones that all constraint limits are met, see Fig. 7 right. At iteration 22 there are only feasible solutions what means, that there is good agreement between the nonlinear dynamic model and the linear static one with which the topometry optimization is performed.

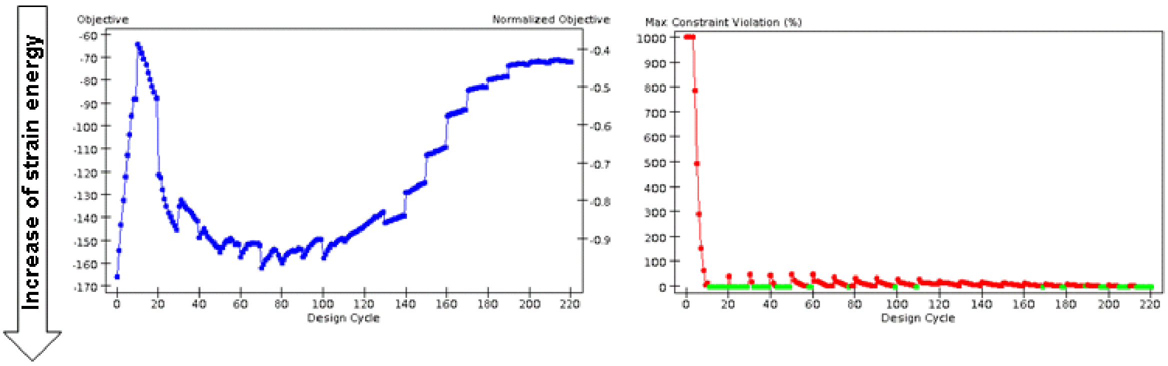

Fig.7: Optimization results of the steel hood: objective progress (left) and constraint violation progress (right).

Evaluating the thickness distribution of the optimum iteration one can recognize some “stiffness paths” which can be interpreted from a CAD designer in order to create an applicable structure, Fig. 8.

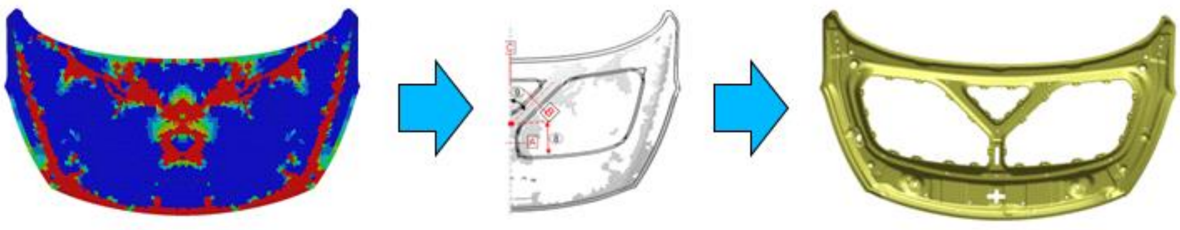

Fig.8: Steel inner hood design: thickness distribution of the optimum iteration (left) showing in red all elements thicker than 5mm, CAD Interpretation design (center) and new surface mesh (right) as a start structure for the subsequent shape optimization.

The CAD interpretation design was meshed and all load cases including the closing load case were simulated with LS-DYNA in order to test the newly created structure and compare the results to the initial inner hood design. In overall there were 4 HIC values improved and the thresholds for both stiffness load cases and the closing load case were complied.

2.6.2 Aluminum hood

The results of the optimization of the aluminum hood were evaluated in the same way as the steel hood results. The optimization progress results are shown in Fig. 9 and the final geometry is displayed in Fig. 10. For achieving convergence 15 outer loop iterations were needed. In comparison with the steel hood, the aluminum one shows better objective function values and indicates at the end an even decreasing behavior despite the need of limiting the constraints.

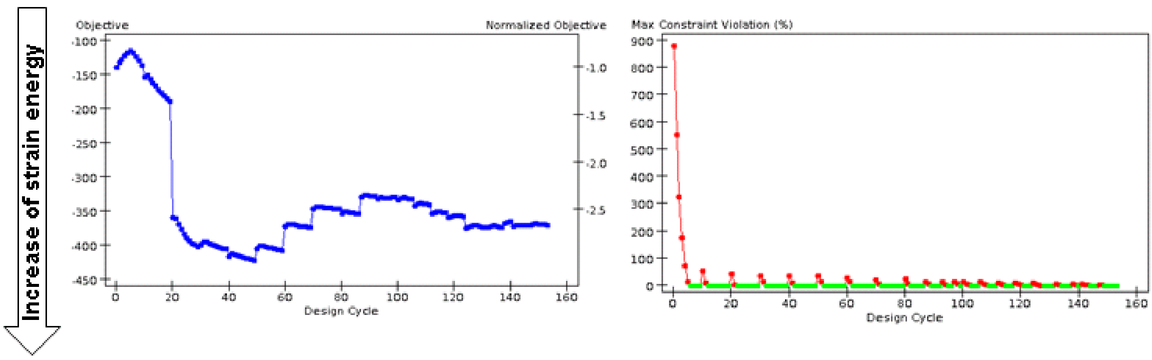

Fig.9: Optimization results of the aluminum hood: objective progress (left) and constraint violation progress (right).

Like the steel hood results, the thickness distribution results were interpreted in order to create a feasible design of the inner hood panel, which on his part was used as initial geometry structure launching the subsequent shape optimization.

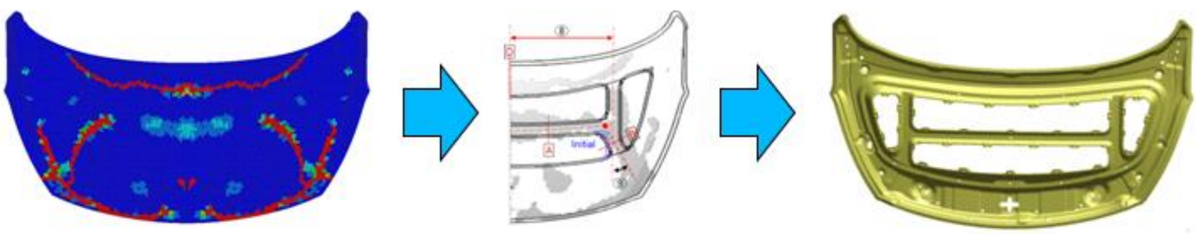

Fig.10: Aluminum inner hood design: thickness distribution of the optimum iteration (left) showing in red all elements thicker than 5mm, CAD Interpretation design (center) and new surface mesh (right) as a start structure for the adjacent shape optimization.

The results of the newly created structure were compared to the initial inner hood design as well. In overall there were 7 HIC values improved and the thresholds for both stiffness load cases and the closing load case were complied.

3 Shape optimization with LS-OPT

In a second step, a shape optimization with ANSA [7] and LS-OPT [8] using the interpreted result of the topometry optimization as baseline design was performed to refine the results. The ANSA Morphing Tool was coupled as a preprocessor in LS-OPT to modify the shape of the model. The Finite Element simulations were performed with LS-DYNA.

3.1 Problem description

The same 15 head impact load cases were considered in this optimization, as well as the stiffness analysis regarding torsion and bending, Fig. 1, and additionally a hood closing analysis, Fig. 12, 18 load cases in total. The objective was to minimize the mass of the structure, subject to constraints on displacements for the torsion and bending load cases, on the stress for the hood closing analysis, and on the HIC values for the head impact load cases, Fig. 11. The parameters, 8 geometry variables and the thicknesses of inner and outer hood panel, are displayed in Fig. 13.

	≡	HIC < 650	≡	1.00 point
	≡	650 ≤ HIC < 1000	≡	0.75 points
	≡	1000 ≤ HIC < 1350	≡	0.50 points
	≡	1350 ≤ HIC < 1700	≡	0.25 points
	≡	1700 ≤ HIC	≡	0.00 points

Fig.11: Pedestrian impact assessment criteria and limit values, [9].

Fig.12: Load case hood closing analysis: finite element model (left), extra part definition at the inner panel in order to evaluate the stress due to hood closing (right).

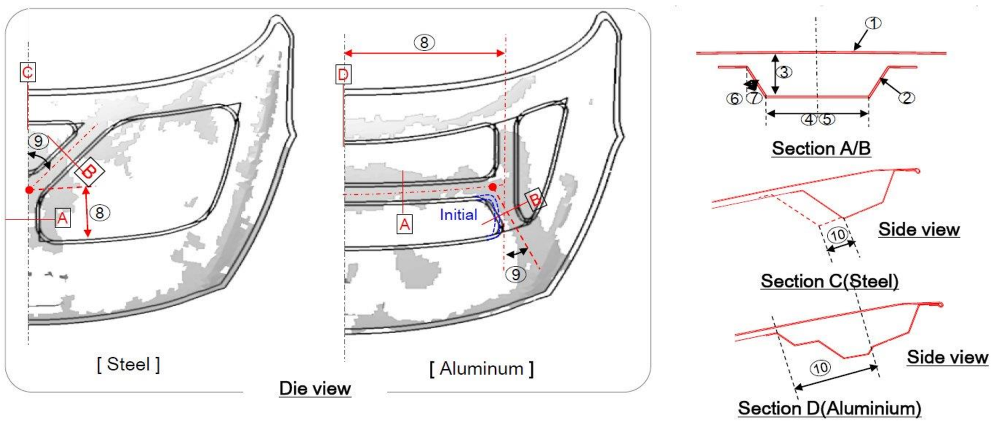

Fig.13: Geometry variables (beam depth, width and angle, position of crossing point and angle, rear frame width). Additional parameters are the thicknesses of inner and outer hood panel.

3.2 Setup in ANSA

Morphing can be applied in order to change the geometry of a finite element model. For this reason it was very useful for specifying the shape optimization parameters. In this research the ANSA Morphing Tool was used. In ANSA, morphing boxes and morphing parameters need to be defined, as well as the optimization task as an interface to LS-OPT. A selection of geometries that were generated for both steel and aluminum hood are displayed in Fig. 14.

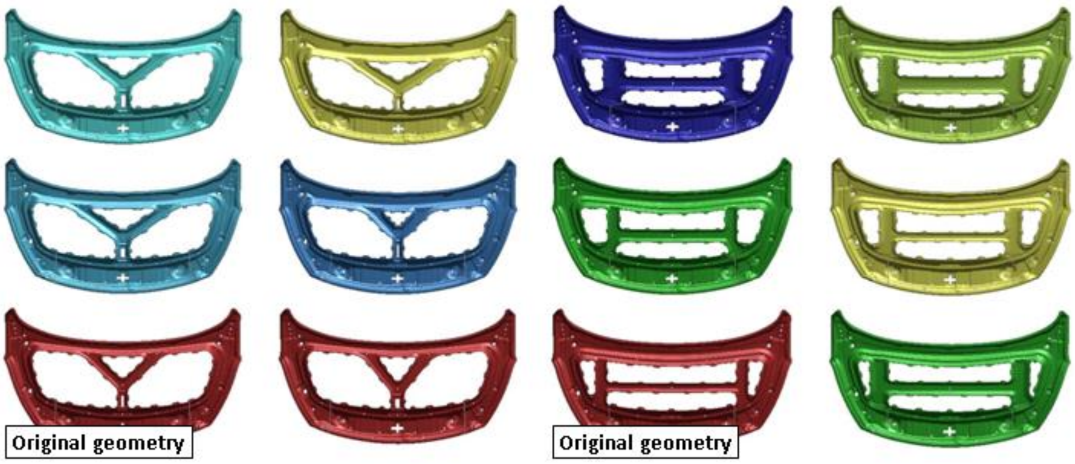

Fig.14: Selection of geometries obtained from ANSA Morphing: steel (left) and aluminum (right).

3.3 Setup in LS-OPT

In LS-OPT, a stage that interfaces with ANSA as a preprocessor has to be defined, and a stage for each LS-DYNA load case. The result of the ANSA stage is an LS-DYNA input file containing the respective inner hood panel. This file is used as an include file for all LS-DYNA stages.
The optimization was performed using a sequential response surface method (SRSM) with linear metamodels. 17 LS-DYNA simulations were performed per iteration per load case.
The main LS-OPT GUI window visualizing the optimization process is displayed in Fig. 15.

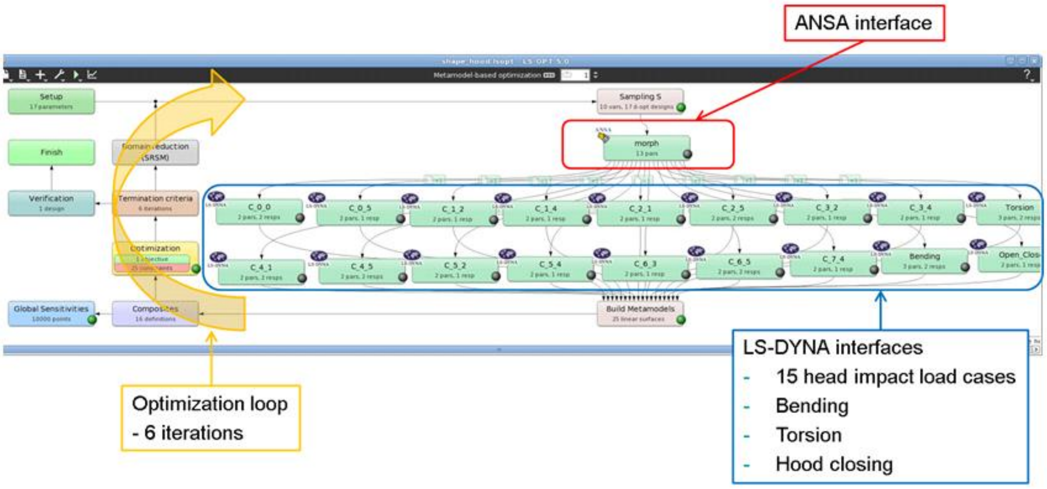

Fig.15: Main LS-OPT GUI window.

3.4 Results

3.4.1 Steel hood

To evaluate the results, the Optimization History plot is useful. It displays the optimal value of a selected entity over the iterations.
The mass was improved, Fig. 16 – top left. It turned out that the stiffness analysis load cases and the hood closing analysis are not critical at all – the constraints are always satisfied. The HIC values of four head impact load cases are always within the best interval. The HIC values of five load cases are always within the same range, Fig. 17 - left. The evaluation of all simulation points for those load cases shows that there are no simulations available with better HIC values. The Parallel Coordinate plot is useful here, Fig. 17 - right. Hence it's probably not possible to improve those values. But for six load cases, the HIC values could be improved, Fig. 16 – right and Fig. 19. For one of those load cases, the computed final optimal value is not feasible for metamodel accuracy reasons, but since the result of the 5th iteration has a feasible computed value, and also the other HIC values are already improved, this value was used as final optimum. The final geometry is displayed in Fig. 18.

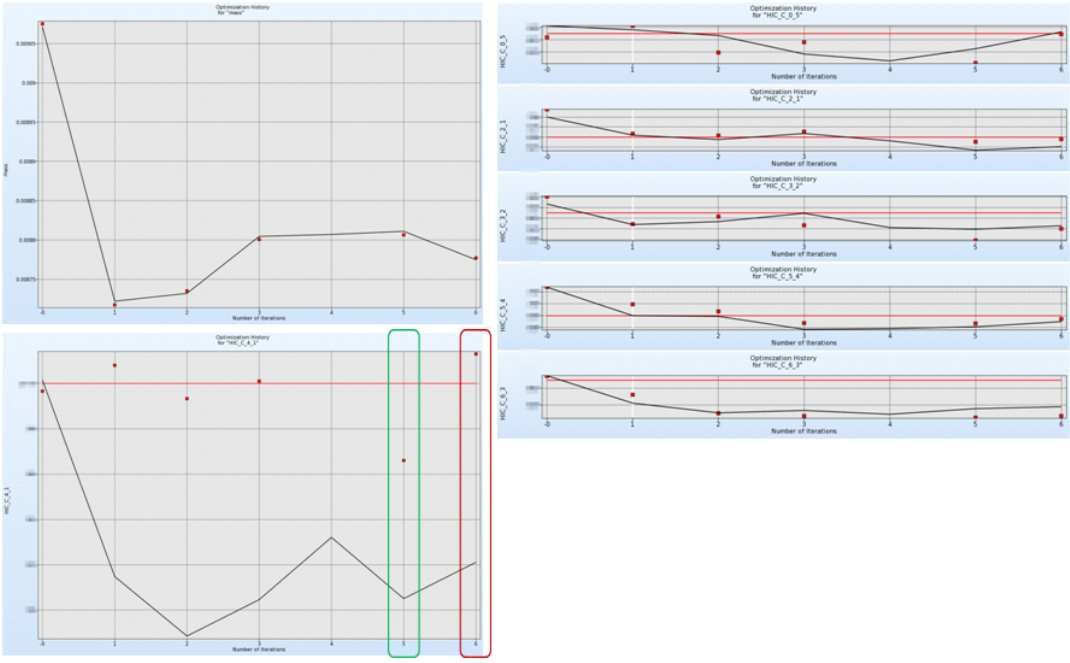

Fig.16: Optimization history of mass (top left), HIC value with infeasible computed optimum (bottom left) and HIC values that could be improved (right).

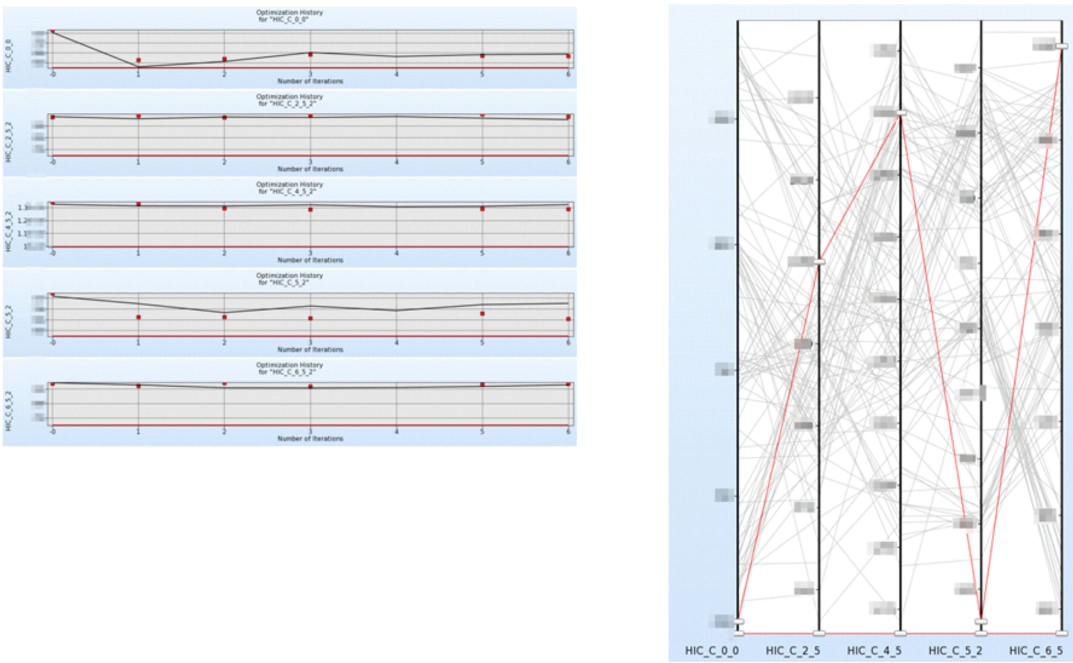

Fig.17: Optimization History of HIC values that could not be improved (left) and Parallel Coordinate Plot of the HIC values that could not be improved for all simulations (right).

Fig.18: Initial design (left), design after topometry optimization (center) and design after shape optimization (right) of the inner steel panel.

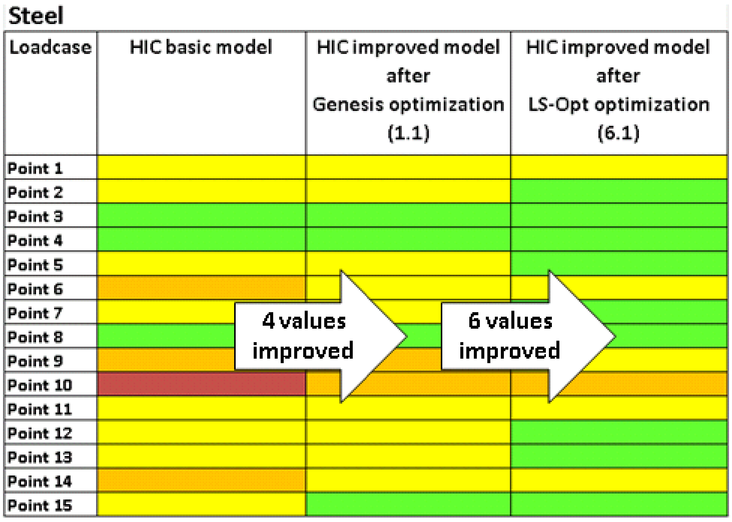

Fig.19: Comparison of HIC values of basic model, model after topometry optimization and final optimum for the steel hood.

As an additional result, there are 5 other points with HIC values within the same ranges as the optimal value. If the optimal geometry is not appropriate, e.g. for manufacturing reasons, any of those points could be used as well.

3.4.2 Aluminum hood

The results of the optimization of the aluminum hood were evaluated in the same way as the steel hood results. The final geometry is displayed in Fig. 20. The mass and six HIC values could be improved, Fig. 21. 21 more points could also be used as final design, since the HIC values are in the same range as the optimum.

Fig.20: Initial design (left), design after topometry optimization (center) and design after shape optimization (right) of the inner aluminum panel.

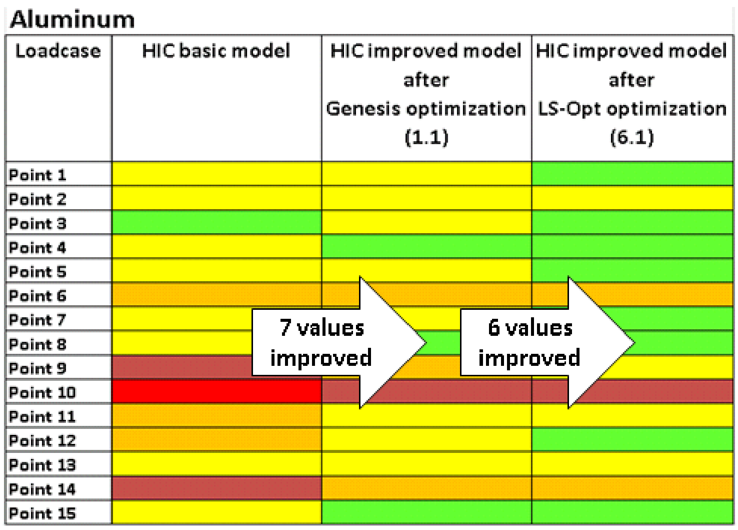

Fig.21: Comparison of HIC values of basic model, model after topometry optimization and final optimum for the aluminium hood.

4 Summary

The optimization of the hood has been performed in two steps.
In the first step, a topometry optimization with Genesis/ESL for the design of the supporting structure of an engine hood has been performed. The result was a preliminary CAD design of the inner hood. Since the objectives and constraints have to be defined for the linear optimization in the ESL method, alternative criteria need to be established for nonlinear responses like HIC values. Another challenging task is the translation of the nonlinear LS-DYNA model to a linear Genesis model. The interpretation of the result of the topometry optimization was a design with improved HIC values for four load cases for the steel hood, and for seven load cases for the aluminum hood, respectively.
In the second step, a shape optimization has been performed with LS-OPT, ANSA and LS-DYNA to refine the functional requirements of the model. The mass as well as six HIC values could be further improved. The constraints defined for torsion, bending and the hood closing analysis were not critical.
In total, 10 HIC values could be improved for the steel hood, and 13 HIC values for the aluminum hood, respectively.

5 Literature

[1] "GENESIS Version 14.0 Design Manual", Vanderplaats Research & Development, Inc., 2014
[2] Prof. Park,G-J: "Equivalent Static Loads Method for Non Linear Static Response Structural Optimization", LS-DYNA Forum, Bamberg, 2010
[3] Shin MK, Park KJ, Park GJ: "Optimization of structures with nonlinear behavior using equivalent load", Comp. Meth. Appl. Math.,196, p.1154-1167, 2007
[4] Dr. Engleder, S., Dr. Kassegger, H: "Eine effiziente CAE-Prognose im Fußgängerschutz durch den Einsatz von Optimierungstools", LS-DYNA Forum, Filderstadt, 2013
[5] Witowski, K, Müllerschön, H, Erhart, A, Schumacher, P, Anakiev, K: "Topology and Topometry Optimization of Crash Applications with the Equivalent Static Load Method", 13th International LS-DYNA Users Conference, Detroit, 2014
[6] Witowski K., Erhart A., Schumacher P., Müllerschön H.: "Topology Optimization for Crash", 12th international LS-DYNA User Conference, Detroit, 2012
[7] "ANSA version 15.1.x User's Guide", BETA CAE Systems S.A., 2014
[8] Stander, N, Roux WJ, Basudhar, A, Eggleston, T, Goel, T, Craig, K: "LS-OPT® User's Manual", Version 5.1, Livermore Software Technology Corporation, 2014
[9] "Euro NCAP Assessment Protocol – Pedestrian Protection", European New Car Assessment Programme, 2014