Application of the equivalent static load method for impact problems with GENESIS and LS-DYNA

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Automotive CAE Grand Challenge

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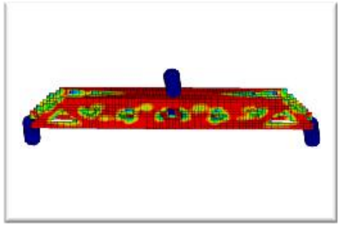
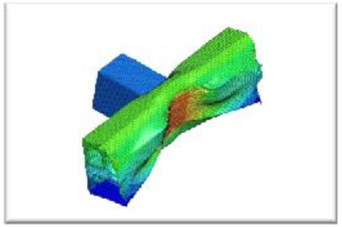
Outline



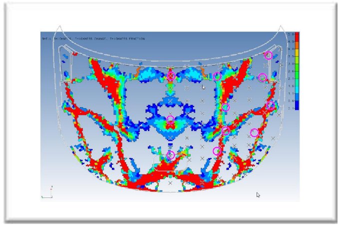
Introduction

Equivalent Static Load Method



Case Study 1

Extrusion Profile Optimization, Research Project Crash-Topo



Case Study 2

Optimization of an Engine Hood

Summary

Conclusions, Lessons Learned

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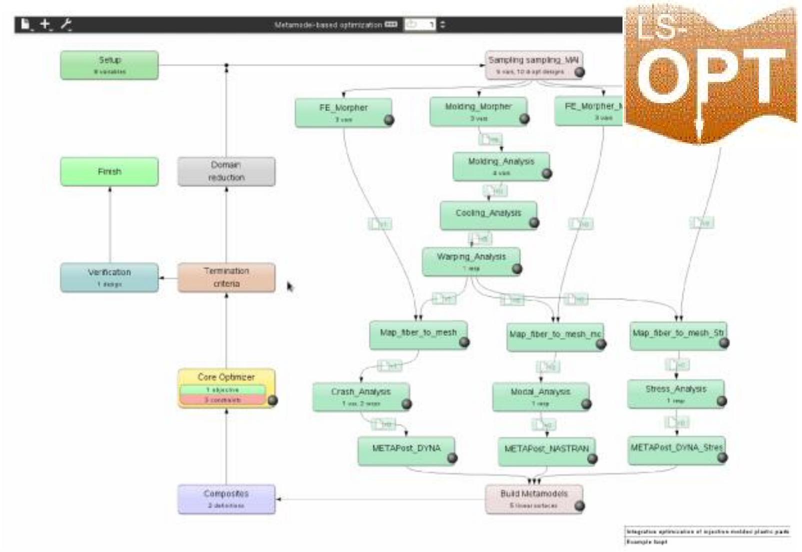
Introduction – Classification of Optimization

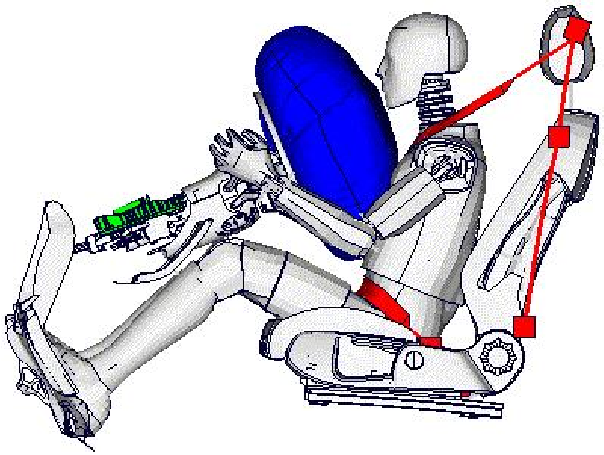
Nonlinear (Crash) Optimization

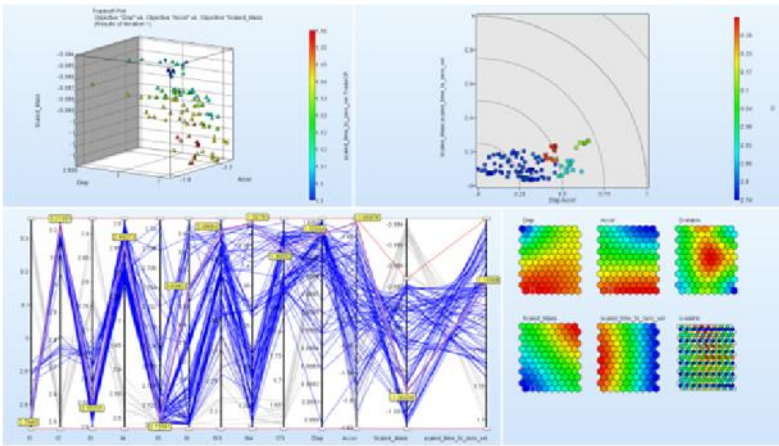
- Software Product: **LS-OPT**

Non-linear / Parametric

- Parameterization of input files
- Shape/Sizing Optimization
- Limited to moderate number of variables (~<50)
- Possible for general nonlinear applications: Crash, Fluid Dynamics, Nonlinear Static/Dynamic







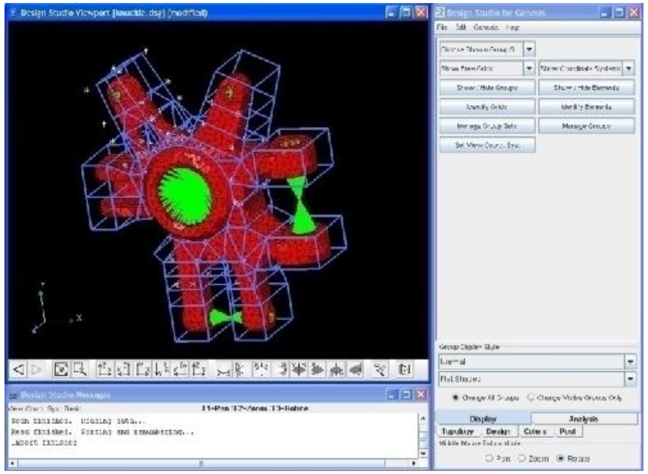
Introduction - Classification of Optimization

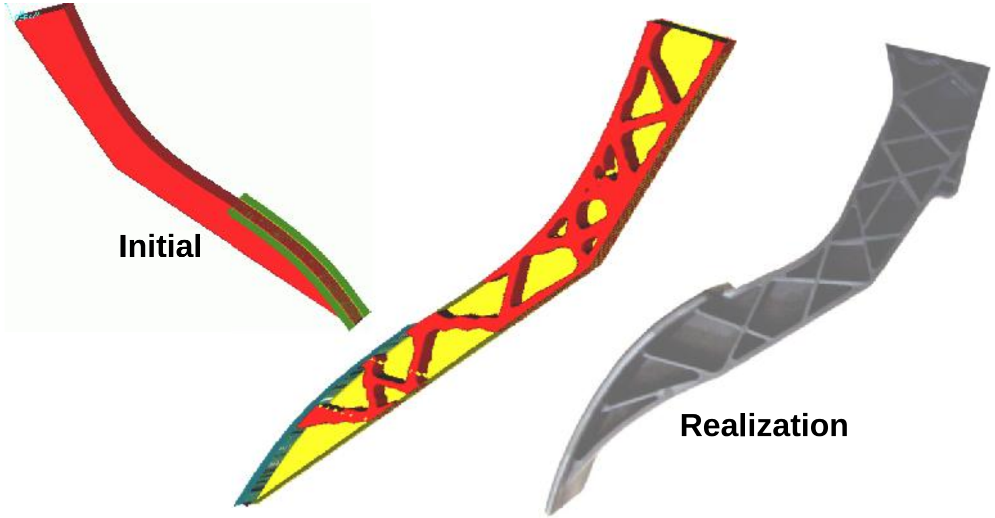
Linear Optimization

- Software Product: **GENESIS**

Non-Parametric

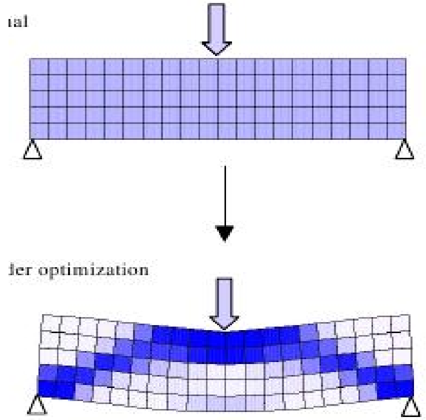
- Topology / Topometry Optimization
- Usually Linear FE-Problems
- Gradient based solvers – many design variables > 1000000
- CAE-Applications: Static Loads, Frequency Analysis, NVH,…





Introduction

- **Topology/Topometry Optimization for Crash?**
  - For topology optimization each element is a design variable - can be switched on/off → many variables
    - *Can not be solved with LS-OPT (too many variables)*
    - *Can not be solved for crash with gradient based topology solvers such as Genesis (strong non-linearities)*



- **Two considerable approaches**
  - Equivalent Static Loads Method – ESLM
  - Hybrid Cellular Automata (HCA)
    - Product: LS-TASC

Introduction ESL

Idea of the Equivalent Static Load Method

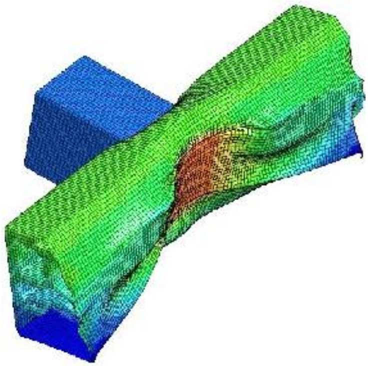
- Decomposition of the nonlinear, dynamic optimization problem in

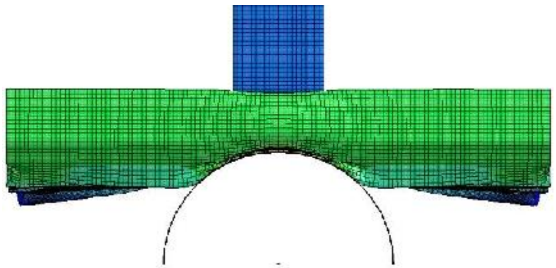
Nonlinear dynamic analysis → displacement field

Equivalent static loads for single time steps

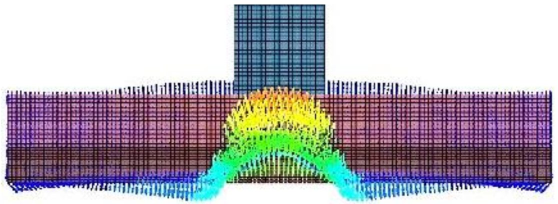
„multi load case topology optimization“ with equival. static loads

Displacement field:
$\boldsymbol{u}_t(\boldsymbol{x})$



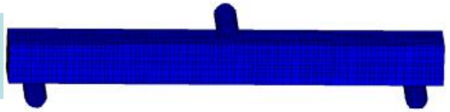


Equivalent static loads:
$\boldsymbol{F}_t(\boldsymbol{x}) = \boldsymbol{K}_{lin}\boldsymbol{u}_t(\boldsymbol{x})$



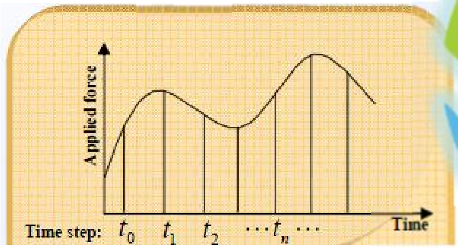
Introduction ESL

Baseline design



Structural analysis LS-DYNA (nonlinear, transient)

→ Deformation i[n]
t_i time steps



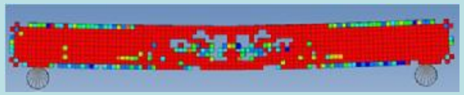
static loads
for time steps t_i
(time discretisation)

Topology/Material-update

optimal design?

linear „multi load case topology optimization“ with equivalent static loads (Genesis)

→ linear optimized topology

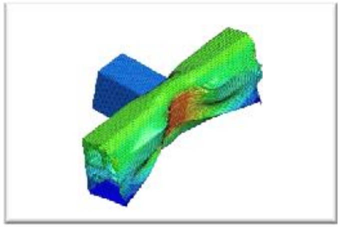


Optimal Design

Agenda

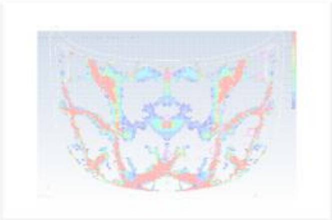
Introduction

Equivalent Static Load Method



Case Study 1

Extrusion Profile Optimization, Research Project Crash-Topo



Case Study 2

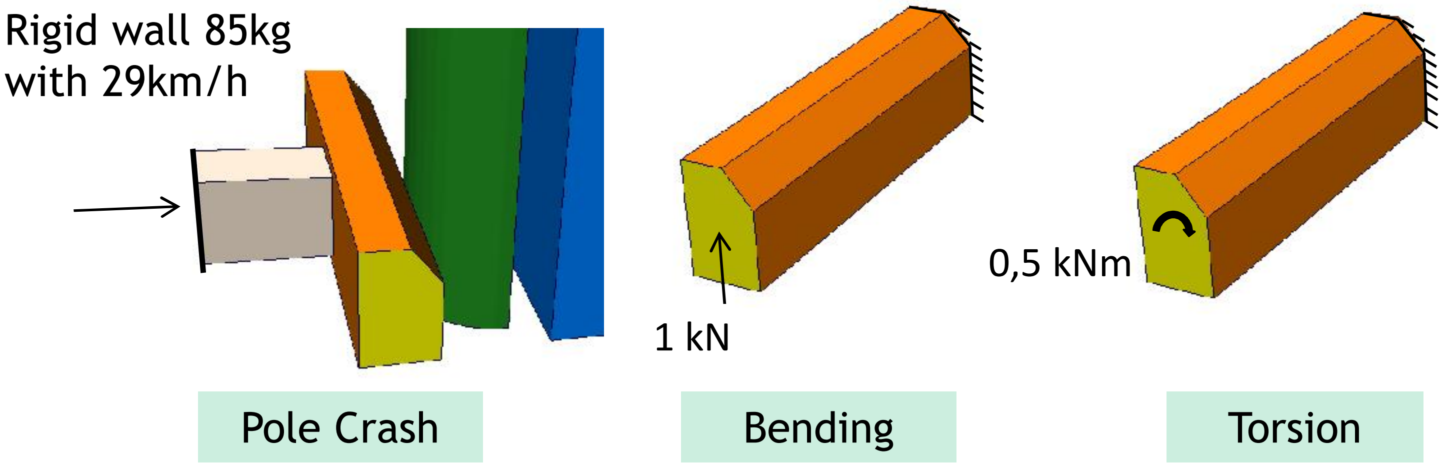
Optimization of an Engine Hood

Summary

Conclusions, lessons learned

Extrusion Profile Optimization

Load Cases



Targets

- LC Crash: Contact force < 40 kN, time history of contact force as uniform as possible, Intrusion < 70mm
- LC Bending: Displacement < 0.3867mm
- LC Torsion: Wrinkling < 3.554*10-3 rad
- Mass < 2.8kg
- 1.6 mm < fillet thickness < 3.5 mm

Extrusion Profile Optimization

- **Objectives**
  - LC Crash: maximize internal energy
  - LC Bending: minimize internal energy
  - LC Torsion: minimize internal energy
- **Constraints**
  - LC Crash: Intrusion<70mm
  - LC Bending: Displacement < 0.3867mm
  - LC Torsion: Wrinkling < 3.554*10-3 rad
- **Element discretization**
  - Hexaeder elements with 5mm edge length
  - Fully integrated elements

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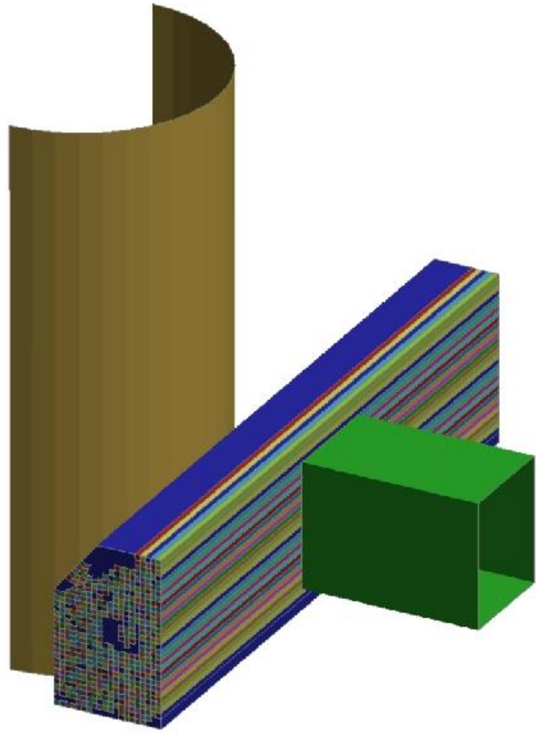

Extrusion Profile Optimization

- **Result example with ESL-Method**

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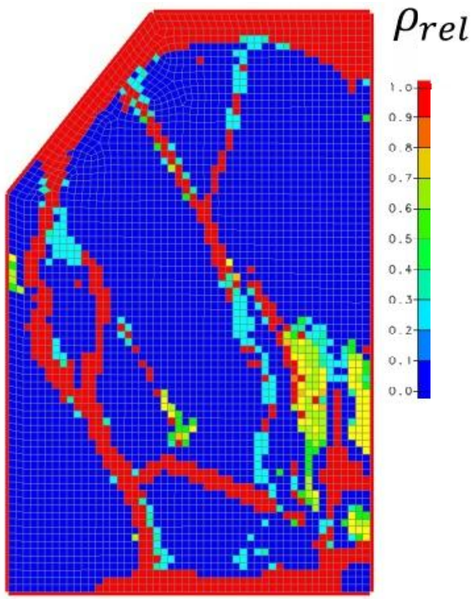
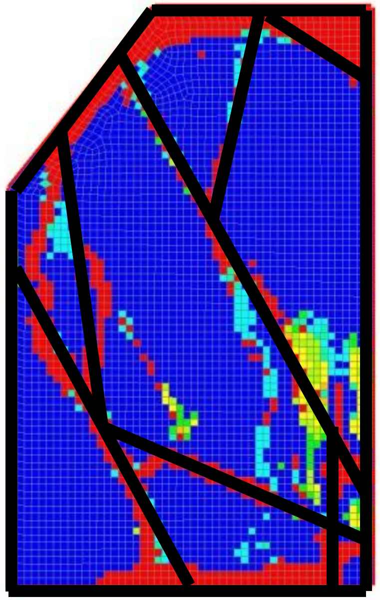
Optimized relative density distribution

Possible interpretation





Results might be transfered to SFE concept for subsequent shape optimization with GHT and LS-OPT - interface has been developed within research project

Extrusion Profile Optimization

Result example with ESL-Method

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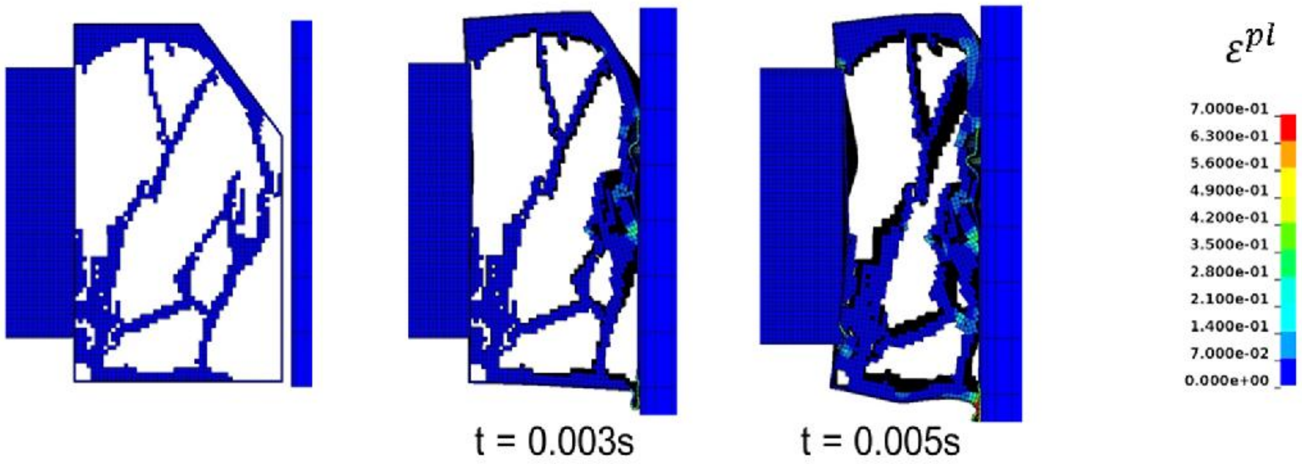
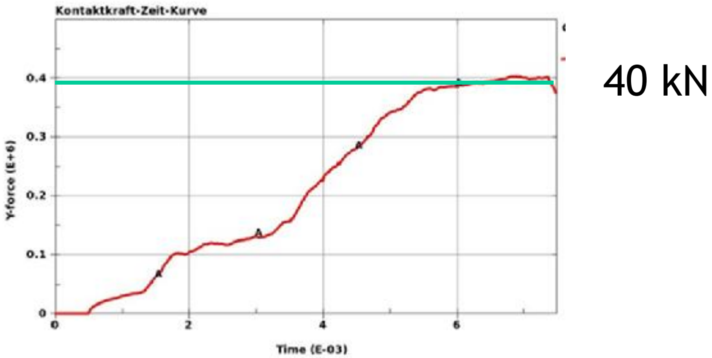
- Analysis results of optimized topology
  - Maximal Intrusion: 67,1 mm (constraint: d<70mm)



  - Maximum contact force: 40,4 kN



Summary

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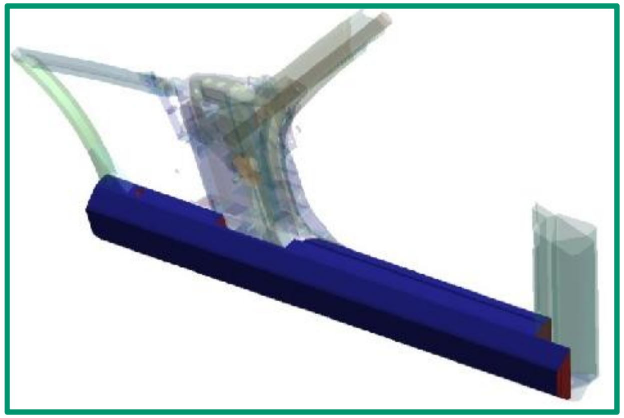
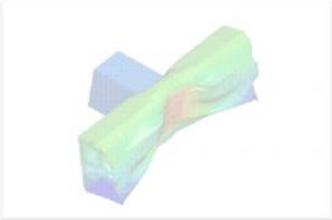
- Within the research project „Crash Topo“ topology optimization of extrusion profiles, mainly on the example of automotive rocker sills, was examined
- As one new approach for optimization the „Equivalent Static Load Method“ was applied
- An automated process with LS-DYNA and Genesis has been setup on an HPC environment
- Geometry of rocker sills can be very complex → no straight forward extrusion profiles
- Fine resolution (small element size) of solid elements within construction space is required, but lead to many elements (ex.: 1mm el.-length → ~10mio elements)
- Large buckling of fillets lead to limits of ESL method



Agenda

Introduction

Equivalent Static Load Method



Case Study 1

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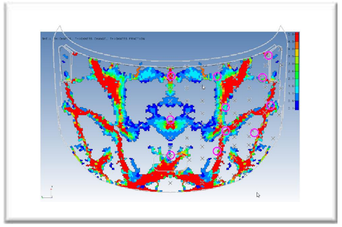


Case Study 2

Optimization of an Engine Hood

Summary

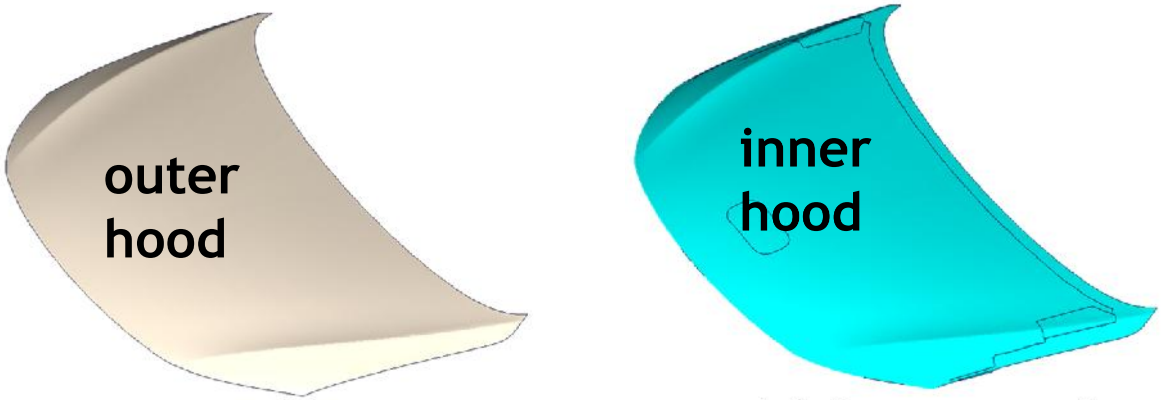
Conclusions, lessons learned

Project Task

- **Project Information**
  - Joint project between MAGNA STEYR Engineering AG & Co KG and DYNAmore GmbH
- **Motivation**
  - Development of a standardized method to design an inner hood panel
  - Method should be able to take into account different package and geometry conditions
  - Main load cases are head impact (pedestrian safety) and stiffness
- **Expected Results**
  - Design of inner hood panel with optimal HIC-value for head impact and stiffness values for static load cases

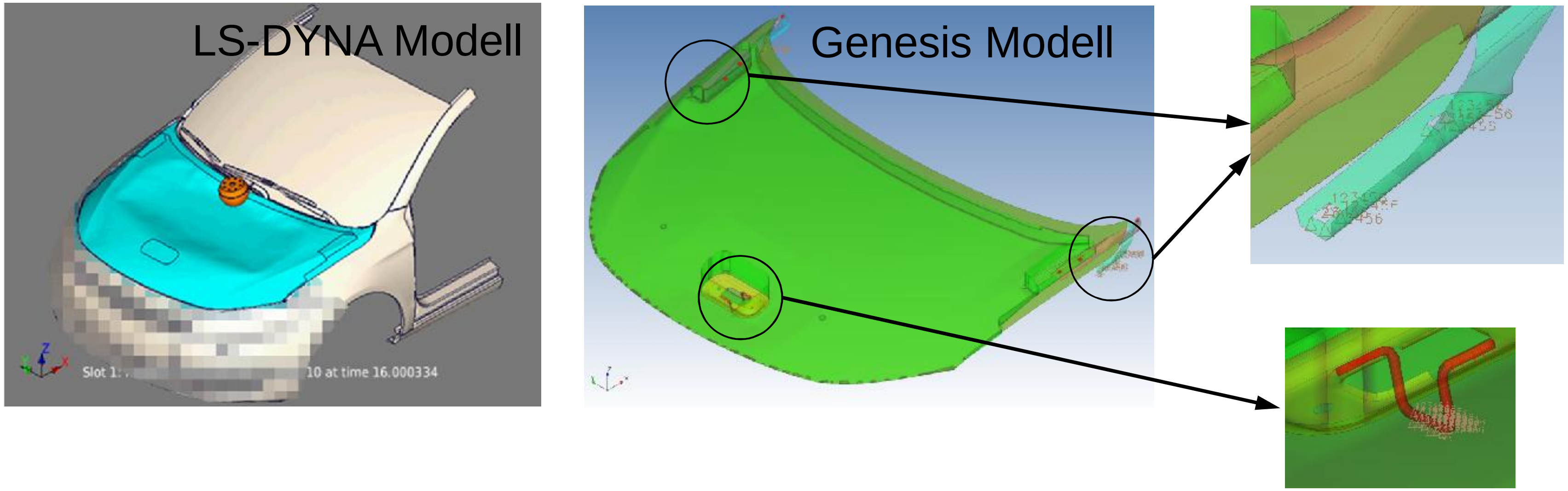
Optimization Model

- **Outer hood with constant shell thickness t=0,6mm and material H220**
- **Inner hood is a duplicate of the outer hood with same nodes and coincident elements but separate property with material DX 56D.**



- **Design variables for optimization are thicknesses of every single element (Topometry Optimization).**
  - Variation of thickness between 0,1mm and 5,0mm.
- **Reduction of number of variables**
  - Clustering of elements → 4 neighbouring elements have the same thickness during optimization.
  - Symmetry constraint in y-direction

- **LS-DYNA model for nonlinear impact simulation**
  - reduced car model with blocking package elements in the engine compartment
- **Genesis model for optimization with ESL method**
  - only hood with hinges and lock is considered
  - support with SPC's on the hinges and the lock
  - the preceding LS-DYNA simulation has been discretized with 9 equivalent static load cases (Δt=2 ms)



Load Cases

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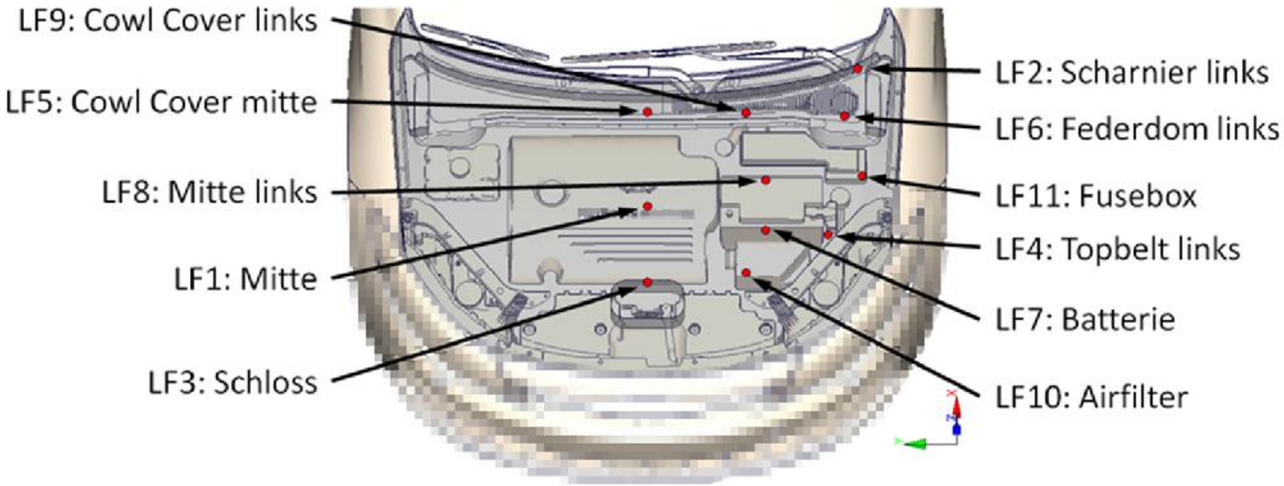
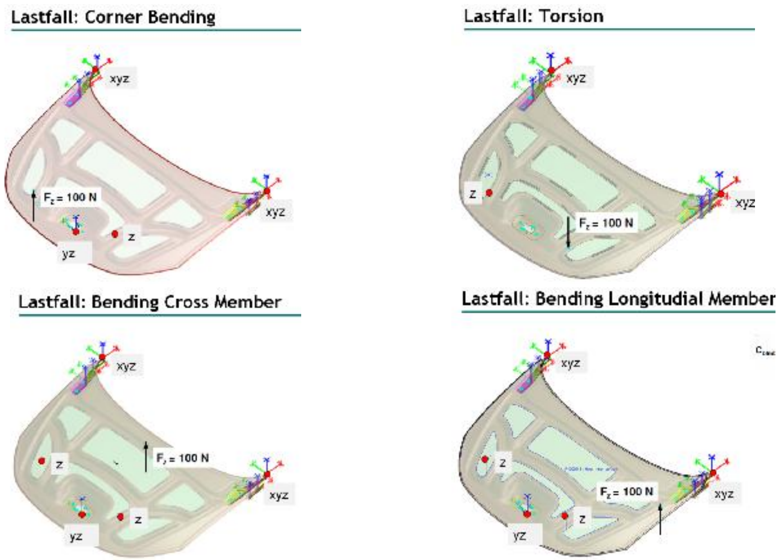
Head impact at 11 points



Static loads

- corner bending
- torsion
- bending cross member
- bending longitudinal member



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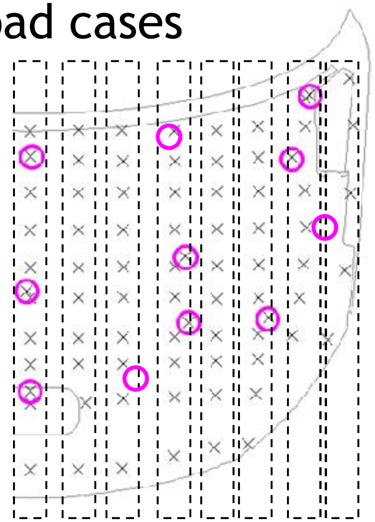
Objectives and Constraints

- **HIC-Value can not be used as an objective in linear inner topology optimization loop**
- **Opt. problem formulation for head impact instead**
  - Maximize deformation of the hood by avoiding contact with stiff (rigid) underlying structure
- **Objective**
  - Maximize strain energy for head impact load cases
- **Constraints**
  - Limits for displacement in z-direction for head impact load cases
    - About 80 points with maximum feasible deformation
    - Only for the ESL load cases with large deformation from 6ms on (7 per head impact point)
    - 11 (Head impact point) *7 (ESL) * 80 (Points with displacement limit) = 6160 (constraints)
  - Limits for displacement of the static load cases



Results

- **Evaluation of HIC values for each LS-DYNA simulation**
  - Starting design

Dyna-Rechnung	LF1_Mitte	LF2_Scharnier_li	LF3_Schloss	LF4_Topbelt	LF5_Cowl_Cover	LF6_Federdom	LF7_Batterie	LF8_Mitte_li	LF9_Cowl_li	LF10_Airfilter	LF11_Fusebox
0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

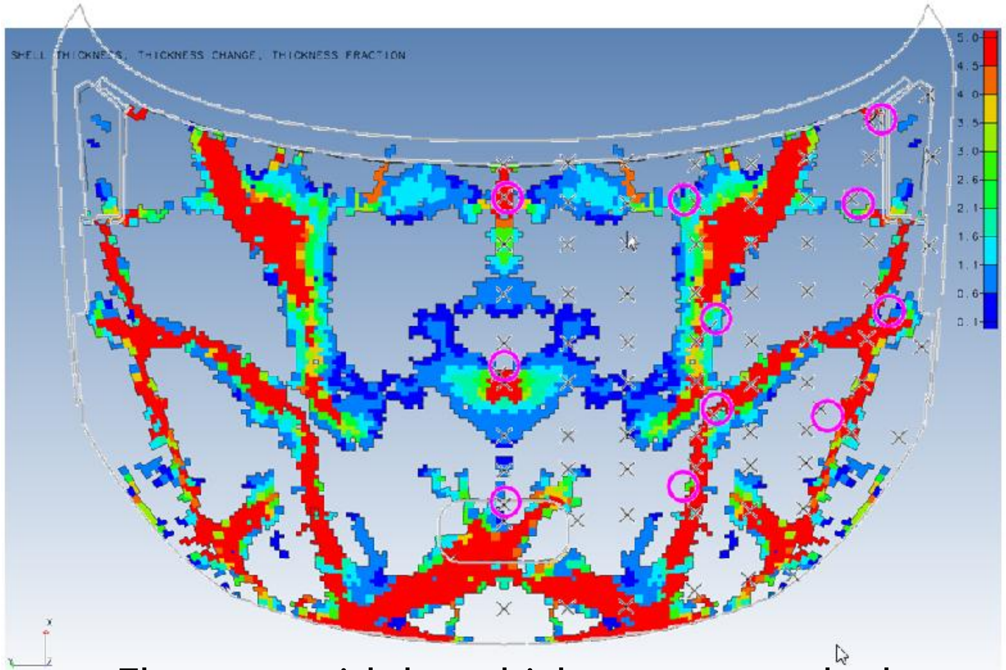
unter 900	900-1000	über 1000	Vmin > 0
4	2	3	2

  - Optimal design

Dyna-Rechnung	LF1_Mitte	LF2_Scharnier_li	LF3_Schloss	LF4_Topbelt	LF5_Cowl_Cover	LF6_Federdom	LF7_Batterie	LF8_Mitte_li	LF9_Cowl_li	LF10_Airfilter	LF11_Fusebox
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

unter 900	900-1000	über 1000	Vmin > 0
8	**0**	**3**	**0**

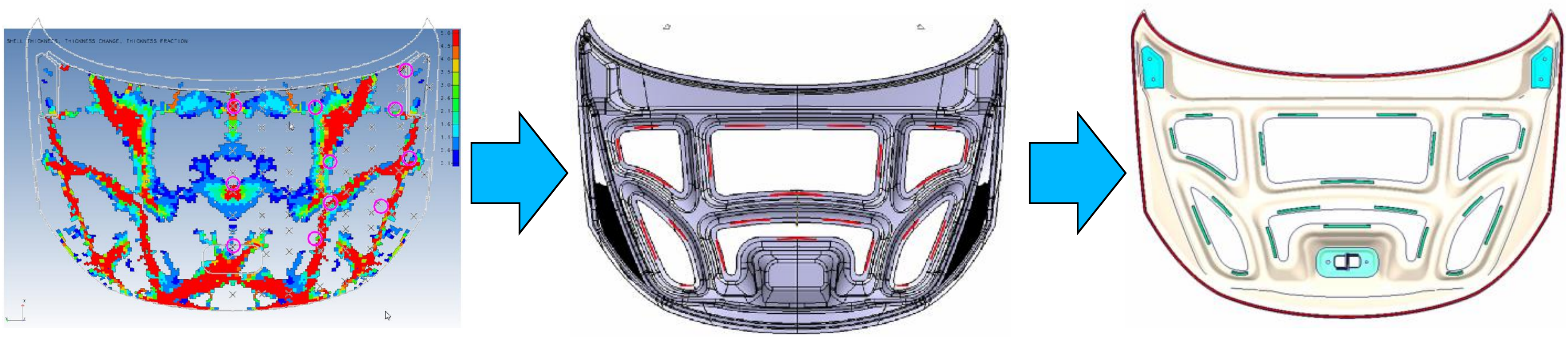
- **Element thickness distribution for the optimal solution**



Elements with low thickness are masked

Results

Interpretation of CAD-design of the inner hood



LS-DYNA simulation results of the final design

- Head impact, HIC values
  - On average, results of final CAD-design getting a little worse compared to final topometry optimization results
- Static loadcases
  - torsion → threshold value complied
  - corner bending → threshold value complied
  - bending cross member → threshold value slightly violated
  - bending longitudinal member → threshold value complied

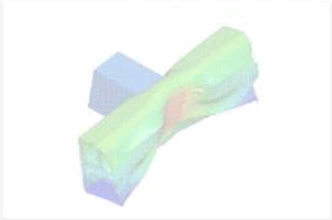
Summary, Next Steps

- Topometry optimization for the design of the supporting structure of an engine hood has been performed
- As a new approach for optimization the „Equivalent Static Load Method“ was applied
- An automated process with LS-DYNA for nonlinear pedestrian impact simulations and Genesis for linear topometry optimization was established
- The result is a preliminary CAD design of the supporting structure
- In a next step nonlinear parameter optimization with LS-OPT will be performed on the basis of the preliminary CAD design to refine functional requirements
- Parameters for the optimization with LS-OPT might be gauge thickness, properties of glue lines, geometric shapes based on morphing, etc.

Agenda

Introduction

Equivalent Static Load Method



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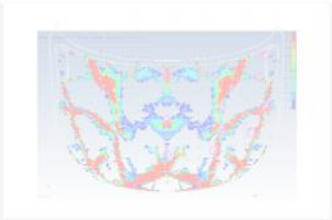

Case Study 2

Optimization of an Engine Hood

Summary

Conclusions, Lessons Learned

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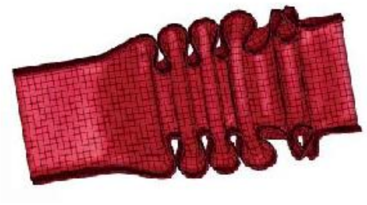
Conclusions

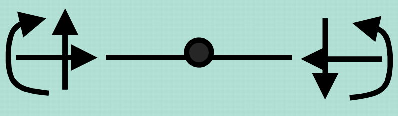
Limit of the ESL-Methodologie

- Local buckling/folding where plastic hinges occur leads to out of scale equivalent static loads

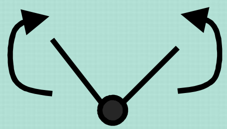


Nonlinear Model

(LS-DYNA)



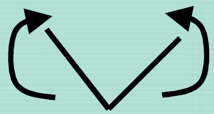
plastic hinge occur after exceeding yield stress



necessary force or moment respectively for large buckling deformation is relatively small

Linear Model

(Genesis equivalent static loads)



necessary force or moment respectively for same large buckling deformation

$\rightarrow \infty$

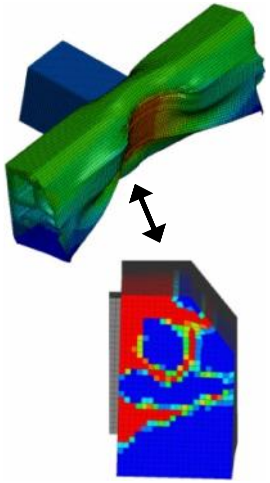
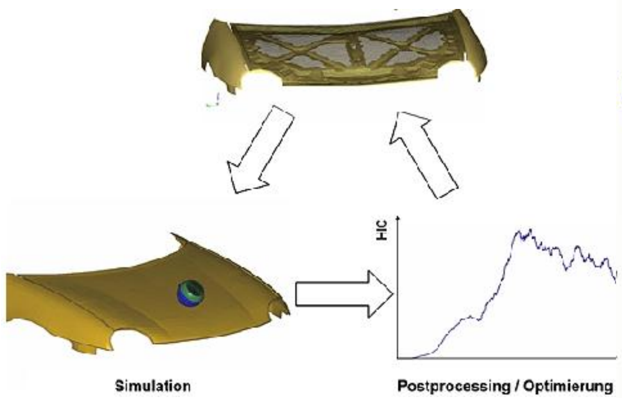
Conclusions

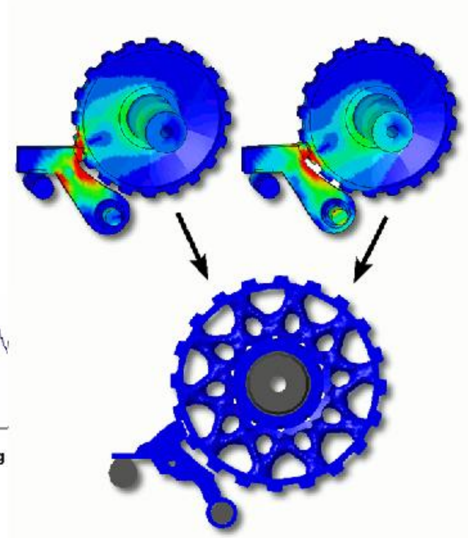
- **Formulation of Objectives**
  - Objectives are defined for linear optimization. This means, consideration of nonlinear responses are not directly possible
  - Examples: Minimization of HIC value for head impact is not possible as an objective
  - Alternative criteria have to be established
- **Formulation of Constraints**
  - Constraints are defined for linear optimization as well. Consideration of constraints based on nonlinear responses is not possible
  - Constraints are satisfied for the linear replacement problem. They might be violated for the real nonlinear problem
- **Automated Model Transition**
  - The nonlinear LS-DYNA model has to be translated to a linear Genesis model. Automation ot this process is a challenging task. Many Keywords and modelling features of LS-DYNA are supported, but not 100% yet.

Conclusions

ESL-Method is promising

- for nonlinear applications with rather moderate deformations or with more extensive buckling, for any contact problems, etc.
- Examples: Roof crash test, pedestrian safety load cases, pendulum impact, drop tests, gear wheels …



Advantages of ESL-Method

- Enables Topology/Topometry optimization for nonlinear problems
- Size/Shape (parametric) optimization with fewer nonlinear solver calls

Thanks for your attention!