# LS-Dyna study of the innovative concepts of engine bonnets to improve the passive safety of head impact

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**Abstract:**

Pedestrian protection is one development issue where up-frontloading is essential. Bringing in new innovative ideas, based on analytical approaches and parameter studies, which would allow checking the efficiency of the concept even before the CAD work starts, leads to a good head start. LS-Dyna can be used as one tool to carry out such fundamental examinations.
This presentation starts by providing an update on pedestrian protection, giving a brief overview of head impact legislation and the head injury criterion. Afterwards, a simplified analytical approach is used to give an idea of a minimum HIC value depending on the bonnet shape and clearance below the bonnet. Then a first parameter study aims to find the main factors for the head impact related values, examining first a simple steel plate and then a flat sandwich panel. The study then continues to evaluate an innovative sandwich concept for engine bonnets. Several materials and various designs of sandwich bonnets are reviewed, constituting the issue of the next step of the parameter study. Comparison of such results to a standard steel concept shows the advantage of having a smooth distribution of the values throughout the bonnet surface, a slight improvement in HIC and an important reduction in weight.

**Keywords:**

Pedestrian Protection, Head Impact, HIC Value, Engine Bonnet, Bonnet Concepts
Analytical Study, Parameter Study, Up-Front-Loading
Innovative Bonnet Concepts, Foam Concept, Sandwich Structure, Hybrid Structure

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# LS-Dyna study of the innovative concepts of engine bonnets to improve the passive safety of head impact

LS-Dyna Studie innovativer Konzepte von Motorhauben zur Verbesserung des passiven Fußgängerschutzes beim Kopfaufprall

S. Edelmann / C. Gross / H. Chladek
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## Overview

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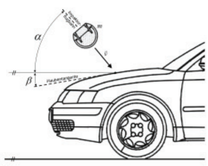
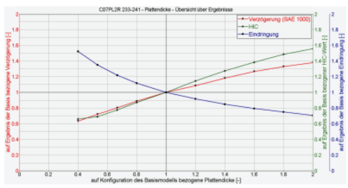
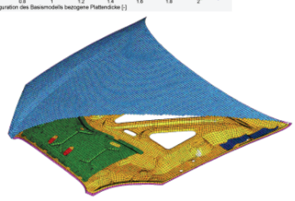
- Introduction
  - Up-front loading
  - Head impact
- Analytical Study
  - Minimum HIC Value
- Parameter Study
  - Simple Flat Plate Example
- Bonnet Concepts
  - Innovative Sandwich Bonnet Design
  - Sandwich Concept Matrix
- Summary



$$HIC = \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2,5} (t_2 - t_1)$$





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# Introduction

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- Up-front loading
  - Today, CAE simulation is widely integrated into the development process of the new vehicles
  - This integration can be improved by using CAE techniques right from the beginning of any new development
  - Moreover, today's CAE tools allow detailed studies of innovative concepts even before the CAD work starts
  - This presentation will cover the following issues
    - Brief update on the pedestrian protection
    - Parameter study for the evaluation of the main factors
    - CAE study of the innovative concepts for the engine bonnets
    - Successful use of the LS-Dyna for such concept studies

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# Introduction

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- Head Impact - State of regulation (Europe)
  - European Phase 1 regulation applies since 2005
  - European Phase 2 is under discussion
    - GTR proposal may lead to modified future Phase 2 regulations

| Phase 1 | | current Phase 2 | | GTR proposal / future Phase 2 | |
|---|---|---|---|---|---|
| **ISO Child** | **EECV Adult** | **EEVC Child** | **EECV Adult** | **ISO Child** | **ISO Adult** |
| m = 3.5 kg<br>v = 35 km/h<br>α = 50° | m = 4.8 kg<br>v = 35 km/h<br>α = 35° | m = 2.5 kg<br>v = 40 km/h<br>α = 50° | m = 4.8 kg<br>v = 40 km/h<br>α = 65° | m = 3.5 kg<br>v = 35 km/h<br>α = 50° | m = 4.5 kg<br>v = 35 km/h<br>α = 65° |
| **Limit** | **Limit** | **Limit** | **Limit** | **Limit** | **Limit** |
| 2/3 HIC ≤ 1000<br>1/3 HIC ≤ 2000 | HIC ≤ 1000 | HIC ≤ 1000 | HIC ≤ 1000 | 1/2 HIC ≤ 1000<br>1/2 HIC ≤ 1700 | 2/3 HIC ≤ 1000<br>1/3 HIC ≤ 1700 |

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# Introduction

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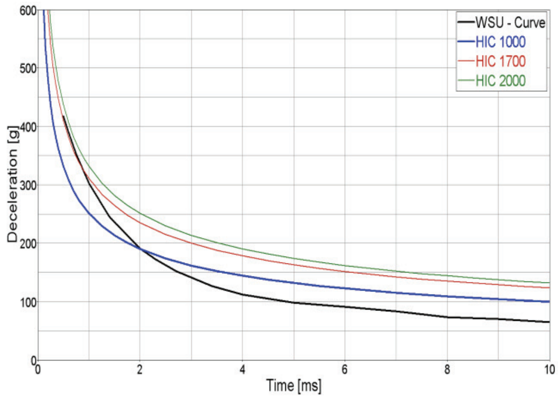
- Head Impact - Head Injury Criterion
  - Wayne State University:
    Severity of brain injuries depends on the height of the impact pulse and its duration (WSU Tolerance Curve)
  - Head Injury Criterion

$$HIC = \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2,5} (t_2 - t_1)$$




  - WSU Tolerance Curve can be approximated for HIC = 1000

$$t\, a^{2.5} - 1000 = 0$$

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# Analytical Study

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- Overview
  - Aim: to obtain a minimum theoretical HIC Value
  - Simplified analytical approach
    - Aim: Determination of minimum HIC value for a chosen intrusion
    - Given initial conditions taken over from ISO Child head load case
    - Analysis of the ideal elastic load case
    - Analysis of the ideal plastic load case
  - Variation of parameters
    - Bonnet angle $\beta$ to the horizontal
    - Aims:
      - Determination of HIC for a constant intrusion $s$
      - Determination of intrusion $s$ of constant HIC
      - 3D-plot of HIC against intrusion $s$ and bonnet angle $\beta$

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# Analytical Study

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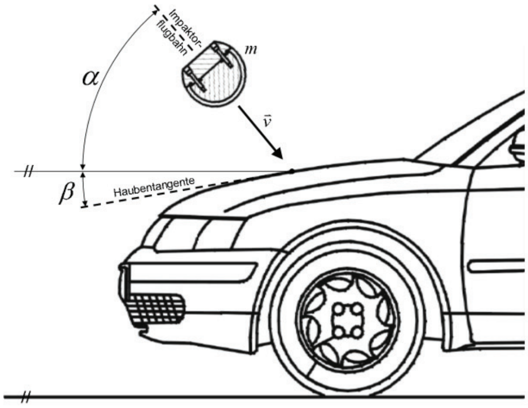
- Introduction - simplified analytical approach
  - Given initial conditions
    - α = 50°
    - m = 3,5 kg
    - v = 9,72 m/s
      - Consideration of the vertical component only
        => $v_z$ = 7,45 m/s
  - Chosen initial conditions
    - β = 0°
      => $v_z$ = 7,45 m/s
    - Maximum intrusion:
      $s_{max}$ = 50 mm

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# Analytical Study

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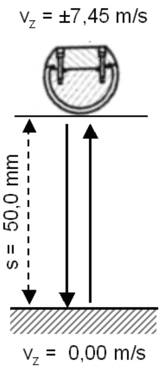
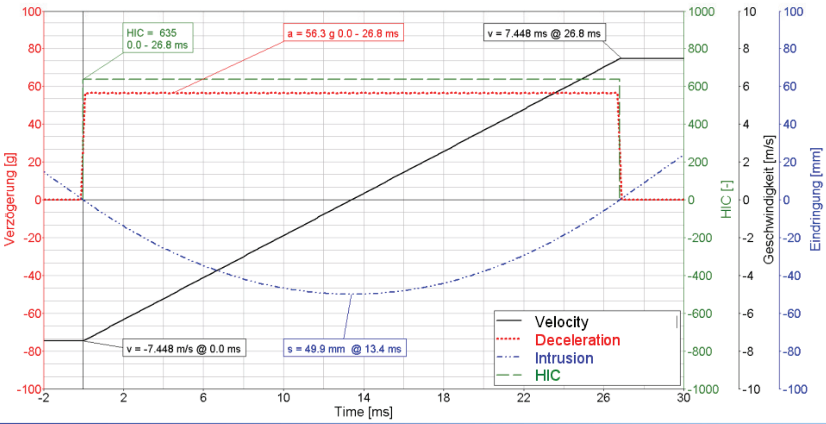
- Ideal elastic load case
  - For an ideal elastic case the velocity is reduced to 0, then increases to the reversed start value

    => $v_{START}$ = - 7,45 m/s, $v_{INTERM}$ = 0 m/s, $v_{END}$ = +7,45 m/s

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# Analytical Study

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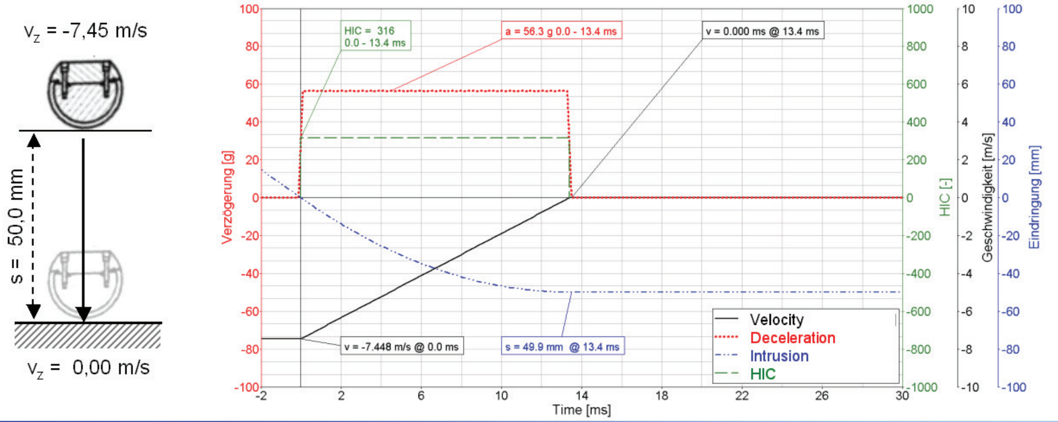
- Ideal plastic load case
  - For an ideal plastic case the velocity is reduced to 0

    => $v_{START}$ = - 7,45 m/s, $v_{END}$ = 0 m/s
    - Further study based on the ideal plastic model (lowest HIC)

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# Analytical Study

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- Ideal plastic load case – analytical formulas
  - Head Injury Criterion: $HIC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2,5}(t_2 - t_1)$
  - For a constant deceleration: $\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right] \rightarrow \bar{a}_{\Delta t} \Rightarrow HIC = (\bar{a}_{\Delta t})^{2.5}\Delta t$
  - Velocity normal to bonnet: $v_\perp = v_{ges} \cdot \sin(\alpha + \beta)$
  - Uniformly accelerated motion: $a = \frac{\Delta v}{\Delta t} \longrightarrow t = \frac{2s}{v} \quad a = \frac{v^2}{2s}$

$$\Rightarrow \quad HIC = \frac{(v_{ges} \cdot \sin(\alpha + \beta))^4}{2^{2.5} \cdot g^{2.5} \cdot s^{1.5}}$$

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# Analytical Study

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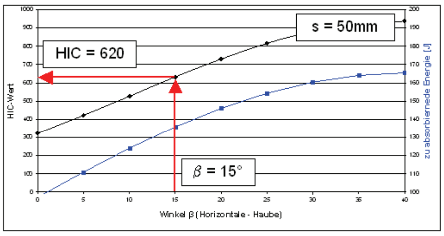
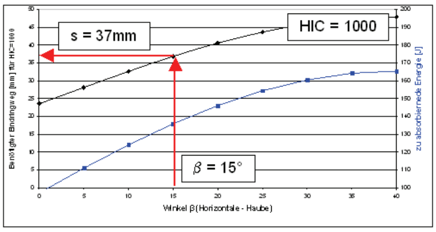
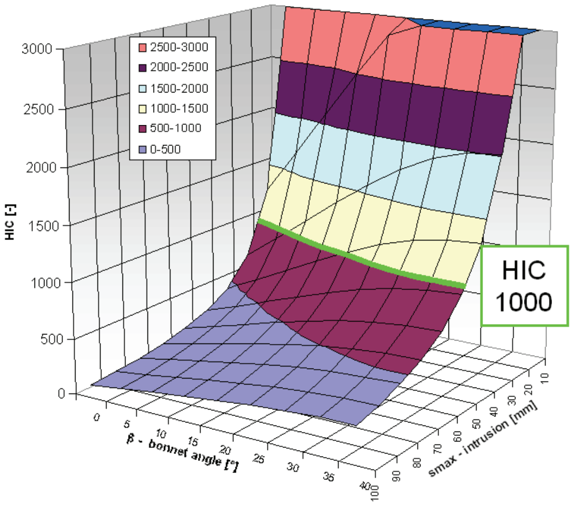
- Ideal plastic load case – HIC Value diagrams
  - HIC with intrusion *s* = 50 mm




  - Intrusion *s* with HIC = 1000




HIC on $\beta$ and *s*






# Parameter Study

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- Overview
  - Strategy
    - Head impact on a CAE model of a simple flat plate
  - Parameters of the steel plate
    - Usual design parameters for the standard steel bonnet design
      - e.g. thickness, yield stress, etc
  - Parameters of the sandwich concept
    - Introducing the sandwich concept
    - LS-Dyna application of the sandwich structure
    - Parameters of the sandwich structure
      - e.g. density and thickness of the foam layer
  - Conclusion

# Parameter Study

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- Strategy
  - Effects in head impact on an engine bonnet are determined by various design parameters
  - These parameters depend on the desired design and various technical issues e.g. the stiffness of bonnet
  - Parameter study
    - Aim: Evaluation of the influence of the main parameters
    - Model: simple flat plate
      - focus on the parameters
      - minimize structural effects
    - 1st step: Parameters of the steel plate
    - 2nd step: Parameters of the sandwich concept

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# Parameter Study

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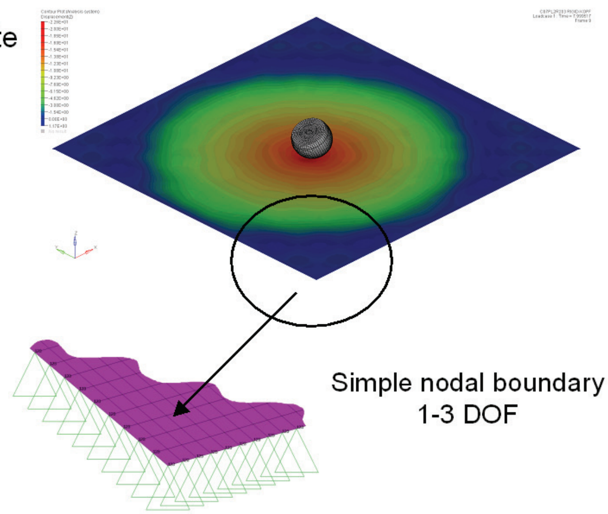
- 1st step: Parameters of the steel plate
  - CAE Model
    - 1500 x 1500 mm steel plate
    - t = 1.5 mm (≙2 sheets of ~0.75 mm)
  - Parameters
    - Boundary conditions
    - Young's Modulus
    - Density
    - Thickness
    - Yield Stress
    - ....

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# Parameter Study

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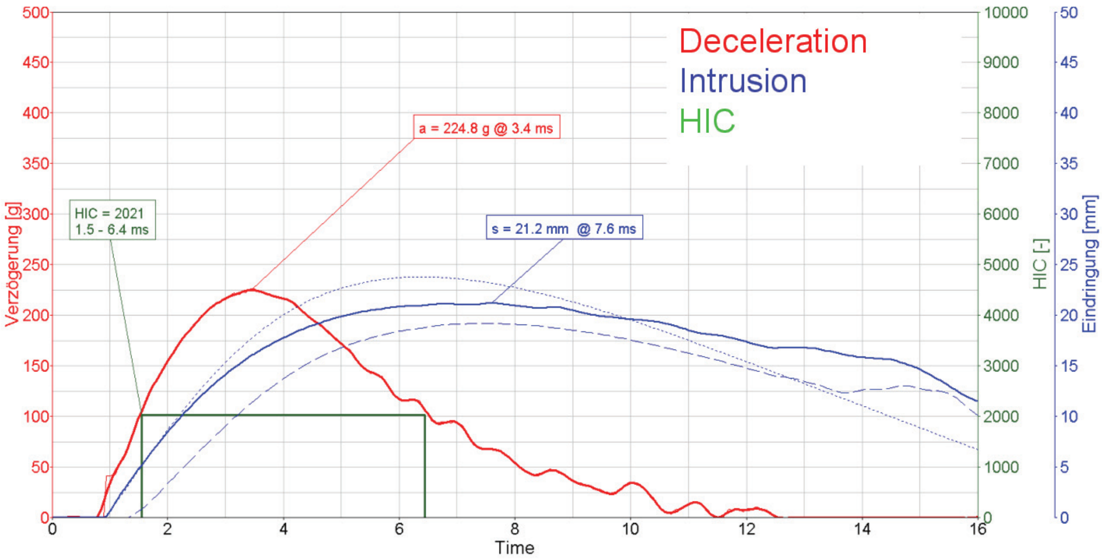
- Basis: steel plate, t =1.5 mm, Yield = 180 N/mm²

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# Parameter Study

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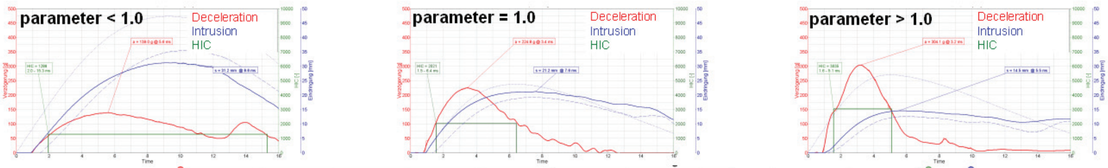
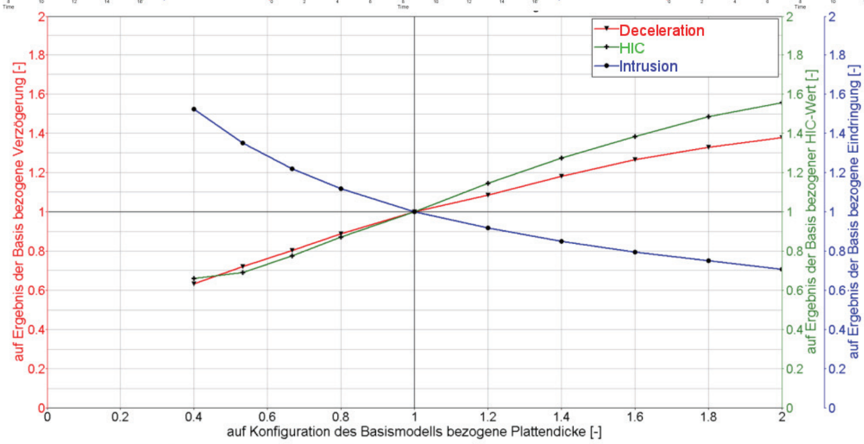
- Variation of the thickness

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# Parameter Study

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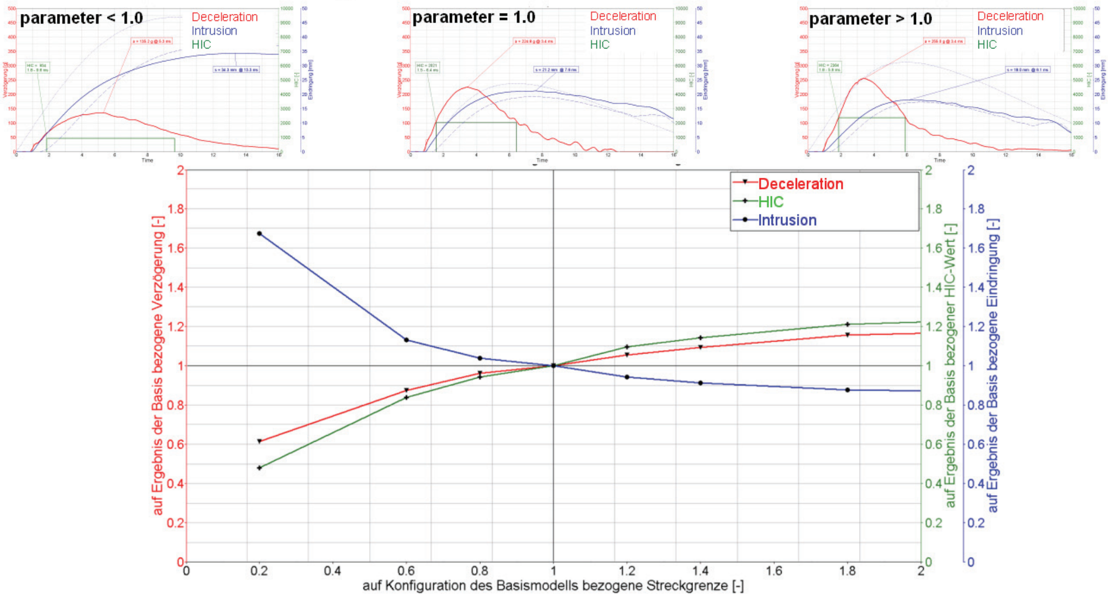
- Variation of the yield stress

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# Parameter Study

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- 2nd step: Parameters of the sandwich concept
  - Extension of the parameter study from the analysis of a simple steel plate to a sandwich hybrid structure
  - Introducing the sandwich concept
    - The sandwich structure consists of a combination of a foam layer between 2 sheets of steel or other material
  - LS-Dyna application of the sandwich structure
    - Sandwich structure is build-up on a 2D / 3D / 2D mesh with the combination of sheet / foam / sheet
    - Use of standard material data for the individual layers
  - Aim: Investigation of various parameters in order to obtain a basis to switch to the innovative engine bonnet concept

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# Parameter Study

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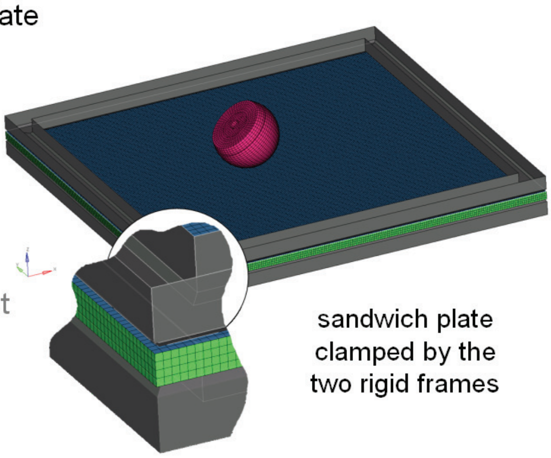
- 2nd step: Parameters of the sandwich concept
  - CAE Model
    - 1000 x 1000 mm sandwich plate
    - 0.7 mm top sheet
    - 20 mm foam layer (EPP)
    - 0.8 mm bottom sheet
  - Parameters
    - Thickness of the top sheet
    - Thickness of the bottom sheet
    - Density of the foam layer
    - Thickness of the foam layer
    - ….

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# Parameter Study

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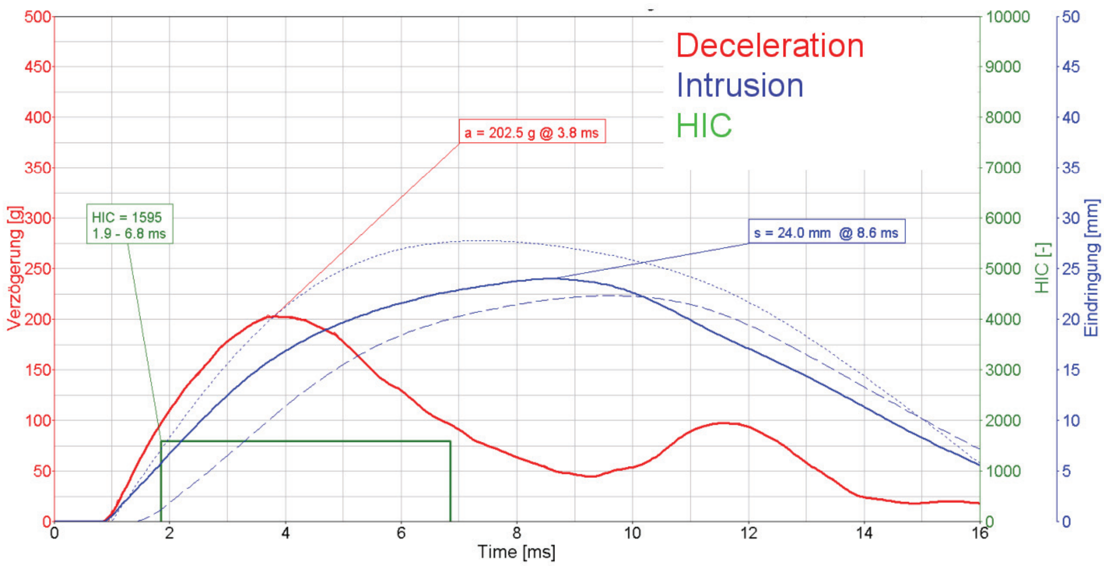
- Basis: sandwich concept, foam density = 60 g/l

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# Parameter Study

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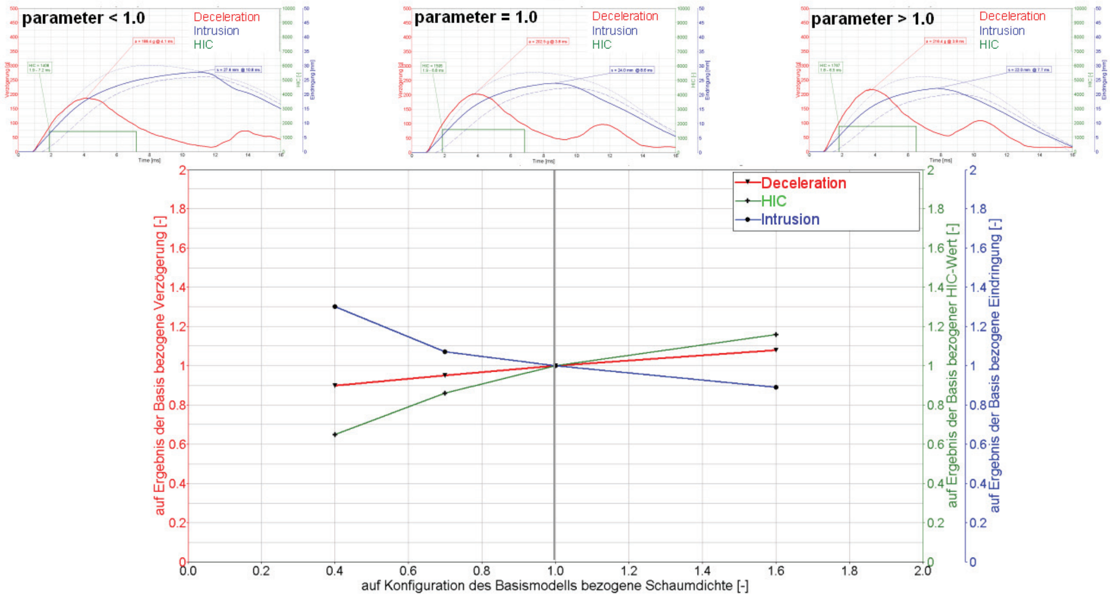
- Variation of the foam density

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# Parameter Study

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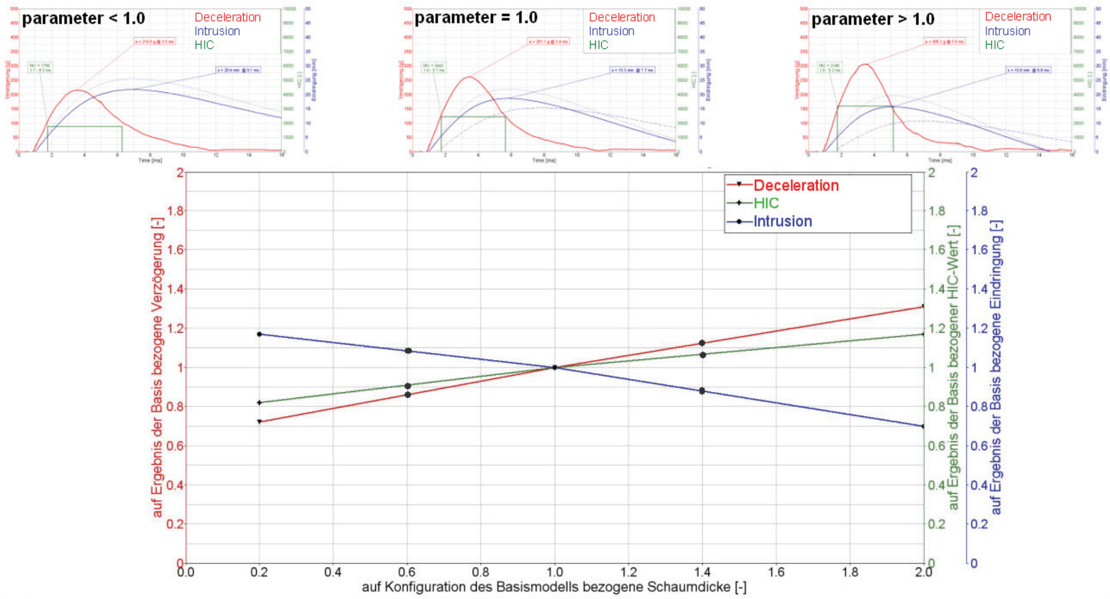
- Variation of the foam thickness

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# Parameter Study



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- Conclusion
  - Steel plate
    - No main factor of the individual parameters could be determined
    - Most parameters show the same tendencies
      - e.g. change in thickness -> change in mass and stiffness => change in deceleration and HIC, reversed change in intrusion
    - A reasonable tuning can be done changing thickness and yield stress
    - Some of the parameters are superposed by general effects
  - Sandwich concept
    - Type and quality of the foam are the main factors for tuning
    - Thickness and density of the foam are also important parameters
    - Nonetheless, the influence of these factors is minor when using typical dimensions and materials for the sandwich layers



# Bonnet Concepts



Oct. 12, 2007

- Overview
  - Standard steel bonnets
    - Local effects due to the lower frame
    - Local effects due to the engine package
  - Innovative bonnet concept
    - Sandwich design
    - Thick / thin layer design
  - Bonnet Matrix
    - Different material designs
  - Conclusion

# Bonnet Concepts

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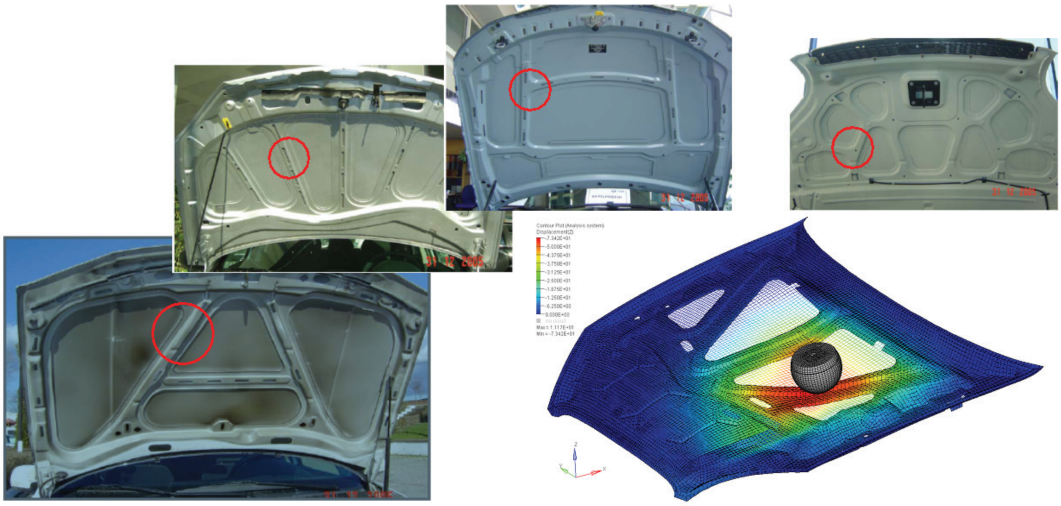
- Standard steel bonnets
  - Results for the head impacts show a wide range in various impact locations due to the local structural effects of the lower frame



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# Bonnet Concepts

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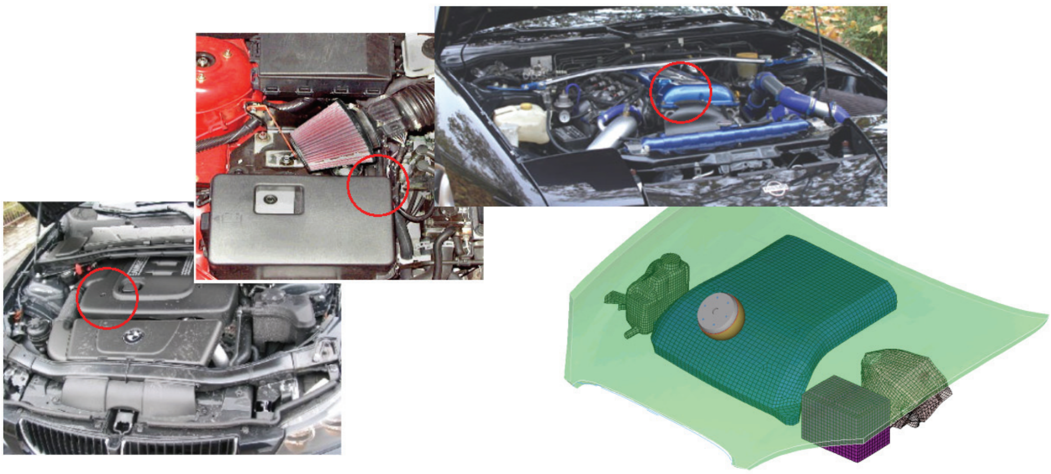
- Standard steel bonnets
  - Results for head impacts show a wide range in various impact locations due to the local blocking effects of the engine package



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# Bonnet Concepts

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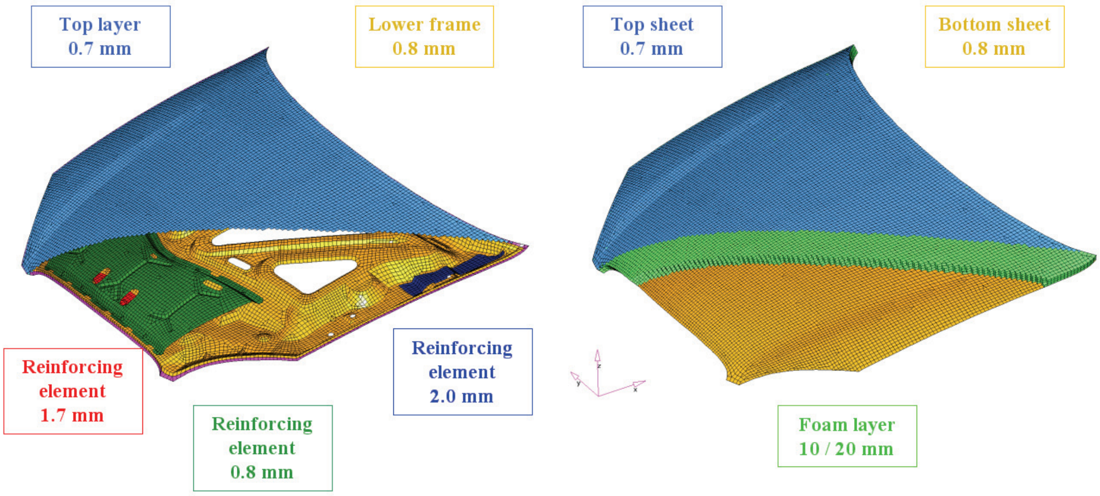
- Innovative bonnet concept
  - Standard steel bonnet versus sandwich design







# Bonnet Concepts

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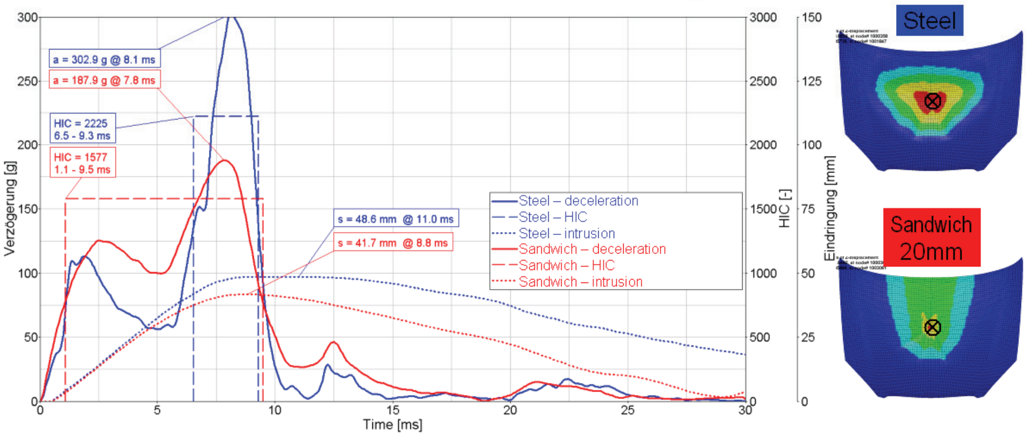
- Innovative bonnet concept
  - Standard steel bonnet versus sandwich design


- 1st peak: sandwich concept leads to a smoother deceleration
- 2nd peak: blocking effect is lower in sandwich concept



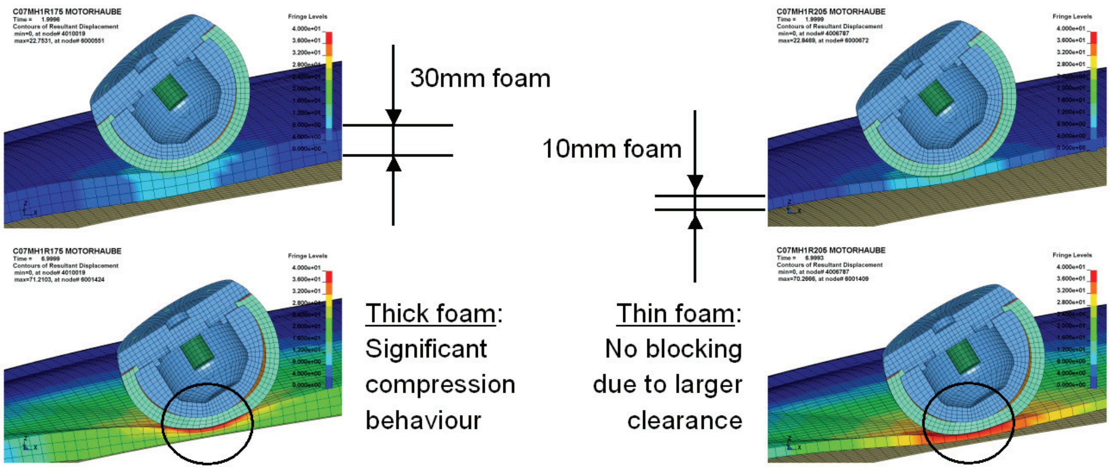
 

# Bonnet Concepts



Oct. 12, 2007

- Innovative bonnet concept
  - Thick versus thin sandwich design (30 vs. 10 mm)
  - Thin foam has 3 times higher density than the thick foam






# Bonnet Concepts

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- Innovative bonnet concept
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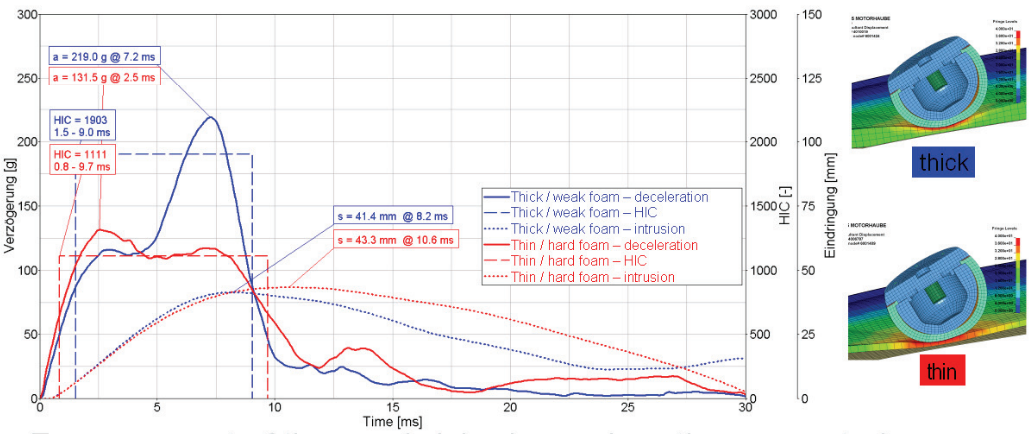


  - Foam, as part of the sandwich, damps less than expected

# Bonnet Matrix

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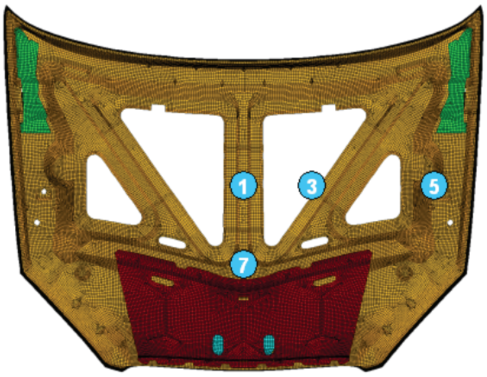
- Overview
  - Aim: Analysis of the potential of various sandwich concepts
  - Basis: Comparison of the various sandwich concepts to the standard steel bonnet
  - Stiffness tuning for a more realistic comparison
  - Examination of 4 impact points
  - Matrix of 4 different sandwich concepts (various materials, thickness)

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# Bonnet Matrix

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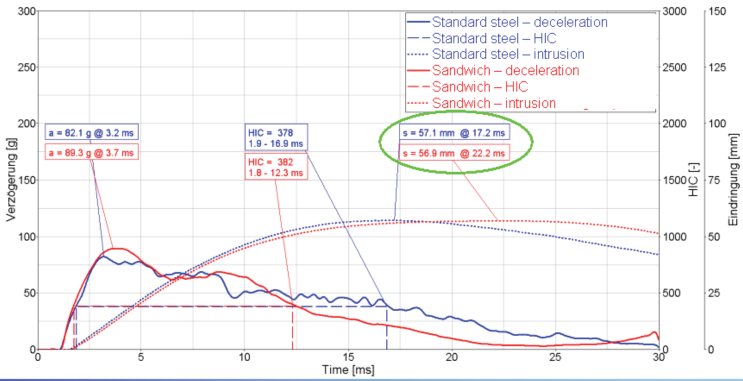
- Stiffness tuning
  - Aim: realistic and “fair” comparison of steel and sandwich bonnets
  - Basis: stiffness of standard steel bonnet at impact point 3
  - Similar stiffness was achieved by a similar maximum intrusion of a sandwich bonnet without package
  - Stiffness tuning was done by modifying the thickness of the top and bottom layer within realistic ranges

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# Bonnet Matrix

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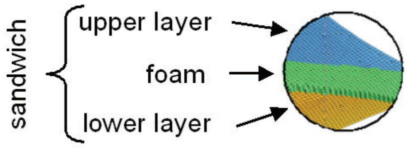
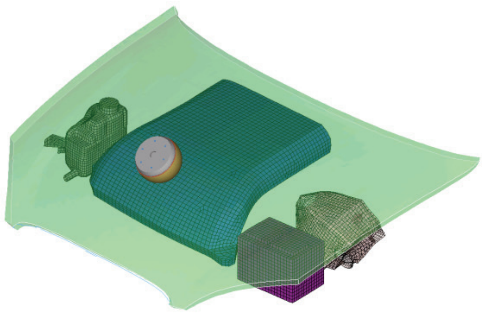
- Matrix of various sandwich concepts
  - Basis: comparison to the standard steel bonnet
  - Various sandwich designs
    - A: plastic / foam / plastic
    - B: steel / foam / steel
    - C: aluminium / foam / aluminium
    - D: steel / foam / plastic
  - Examination using a model with motor package
    - Realistic conditions
    - Examination of the various impact situations



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# Bonnet Matrix

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- 1st matrix
  - Results standardized based on impact point 3 on steel bonnet

| | | Steel | A | B | C | D |
|---|---|---|---|---|---|---|
| P01 | HIC | 1.3 | 2.3 | 1.3 | 1.2 | 1.0 |
| | s(max) | 1.0 | 0.8 | 1.0 | 1.0 | 1.0 |
| | a(max) | 1.1 | 1.3 | 1.1 | 1.1 | 0.9 |
| P03 | HIC | 1.0 | 2.1 | 1.0 | 1.2 | 1.0 |
| | s(max) | 1.0 | 0.8 | 0.9 | 0.9 | 0.9 |
| | a(max) | 1.0 | 1.2 | 0.7 | 0.9 | 0.7 |
| P05 | HIC | 1.8 | 1.5 | 1.1 | 1.3 | 1.5 |
| | s(max) | 0.9 | 1.1 | 1.1 | 1.1 | 1.1 |
| | a(max) | 1.2 | 1.1 | 1.0 | 1.0 | 1.3 |
| P07 | HIC | 0.8 | 1.5 | 0.9 | 1.2 | 0.8 |
| | s(max) | 1.0 | 1.1 | 1.1 | 0.9 | 1.1 |
| | a(max) | 0.8 | 0.7 | 0.6 | 0.9 | 0.5 |
| | Mass | 1.0 | 0.3 | 0.6 | 0.4 | 0.6 |

Basis
≤ 105%
> 105%

Example for the smoother distribution when using a sandwich bonnet

Steel bonnet:
results vary from 80% to 180%

Sandwich bonnet:
results vary from 90% to 130%

  - Using a sandwich design leads to a smoother distribution
  - Mass can be reduced immensely

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# Bonnet Matrix

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- 2nd matrix
  - Results standardized based on all impact points on steel bonnet

| | | Steel | A | B | C | D |
|---|---|---|---|---|---|---|
| P01 | HIC | 1.0 | 1.7 | 1.0 | 0.9 | 0.8 |
| | s(max) | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 |
| | a(max) | 1.0 | 1.2 | 1.0 | 1.0 | 0.8 |
| P03 | HIC | 1.0 | 2.1 | 1.0 | 1.2 | 1.0 |
| | s(max) | 1.0 | 0.8 | 0.9 | 0.9 | 0.9 |
| | a(max) | 1.0 | 1.2 | 0.7 | 0.9 | 0.7 |
| P05 | HIC | 1.0 | 0.8 | 0.6 | 0.7 | 0.8 |
| | s(max) | 1.0 | 1.2 | 1.3 | 1.3 | 1.3 |
| | a(max) | 1.0 | 0.9 | 0.8 | 0.8 | 1.1 |
| P07 | HIC | 1.0 | 2.0 | 1.1 | 1.6 | 1.0 |
| | s(max) | 1.0 | 1.0 | 1.1 | 0.9 | 1.1 |
| | a(max) | 1.0 | 0.9 | 0.7 | 1.2 | 0.7 |
| | Mass | 1.0 | 0.3 | 0.6 | 0.4 | 0.6 |

Example for better HIC results when using a sandwich bonnet

- Basis
- ≤ 105%
- > 105%

Steel bonnet: standardized to 100% for all 4 impact points

Sandwich bonnet: results vary from 60% to 110% for concept B and vary from 80% to 100% for concept D

  - Using a sandwich design leads to equal and better results
  - Mass can be reduced immensely

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# Summary

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- Innovative bonnet concept
  - Compared to a standard steel bonnet, an innovative sandwich concept for an engine bonnet offers some improvements concerning head impact
  - Results for the head impact are distributed more evenly on the bonnet surface
  - The effect of using a foam as a damping element and thus improving the HIC values was lower than expected
  - Nonetheless, a slight improvement in HIC values can be achieved when using a tuned sandwich design
  - Using a sandwich concept, the weight of the bonnet can be reduced about 20% to 40 % while maintaining the same general stiffness of the bonnet

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# Summary

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- LS-Dyna study
  - Based on simple CAE models with standard material data, an innovative concept can be analysed and evaluated without any CAD work or hardware tests
  - So CAE simulation can be established not only in the up-front loading and development phase, but also presents a very efficient tool for new studies and innovative ideas
- Forecast for the sandwich concept
  - This study presented various general effects which may enhance the development of a new bonnet, thus reduce time and cost
  - In the next step, a more detailed analysis of this concept should be carried out, working together with CAD and the design department while merging other technical requirements

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