Optimization of a Lower Bumper Support regarding Pedestrian Protection Requirements using ANSA and LS-Opt

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1 Introduction

A variety of pedestrian protection requirements must be considered during the vehicle development process, in order to improve the protection of vulnerable road users.

The lower bumper support, which is located at the vehicle front (s. Fig. 1), is designed to generate beneficial leg kinematics from early in the impact. In the EuroNCAP test protocol, the Flex-PLI leg impactor is used to assess the risk of injuries. This impactor has been developed for a more bio fidelity representation of a human leg than its predecessor, the TLR impactor (s. Fig.2). The leg injury values are obtained from the Flex-PLI by calculating knee ligament extensions and tibia bone bending moments (s. Fig. 3).

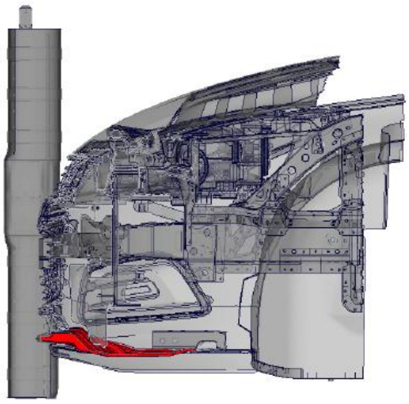


Fig.1: Lower Bumper Support

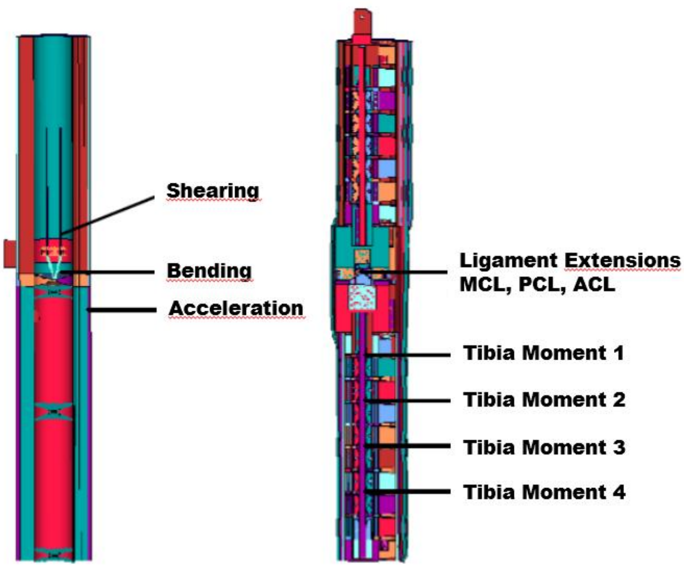


Fig.2: TLR Impactor (left) and FlexPLI Impactor (right)

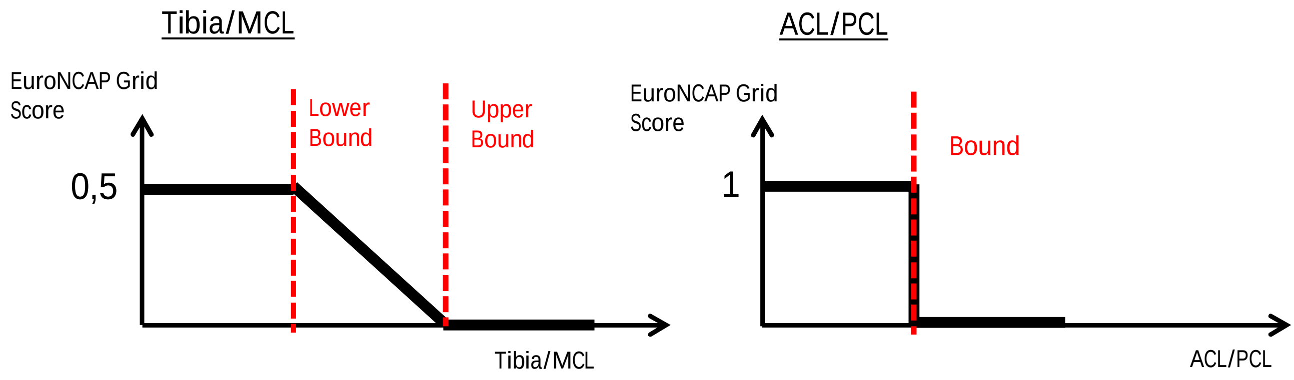


Fig.3: EuroNCAP Grid Score for FlexPLI injury parameters

For lower leg the EuroNCAP score per grid point is calculated from by the following formula:

EuroNCAP_Grid Score = min (Tibia_Points) + (min (ACL_Points; PCL_Points))*(MCL_Points) (1)

with $0 \leq$ EuroNCAP_Grid Score ≤ 1.

The total Euro NCAP rating for lower leg is scaled to a maximum of 6 points.

This presentation deals with the optimization of a glass fiber mat reinforced thermoplastic (GMT) lower bumper support geometry, using ANSA linked with LS-Opt, to meet the EuroNCAP requirements for pedestrian protection. To optimize the components geometry, a parameterized model of the component was built with ANSA-Morphing. LS-Opt was used to find design variables describing the lower bumper support geometry that enable an optimized EuroNCAP rating for Pedestrian Protection lower leg.

2 Parametrization of the Lower Bumper Support Model with ANSA

The design variables for the shape optimization were chosen as the width and depth of the lower bumper supports depressions. To modify them in an automated process by LS-Opt during the optimization procedure a parametrized model was built with ANSA using morphing boxes (s. Fig. 4 and Fig. 5) in which the morphing parameters are linked to the design variables.

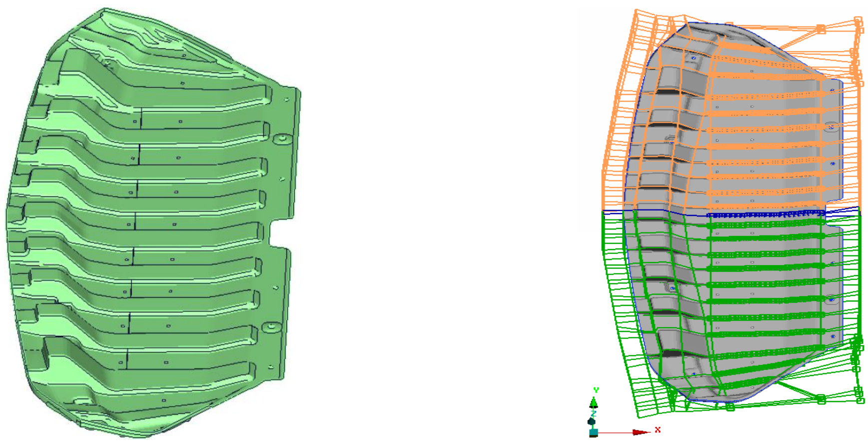


Fig.4: Lower Bumper Support with morphing Boxes

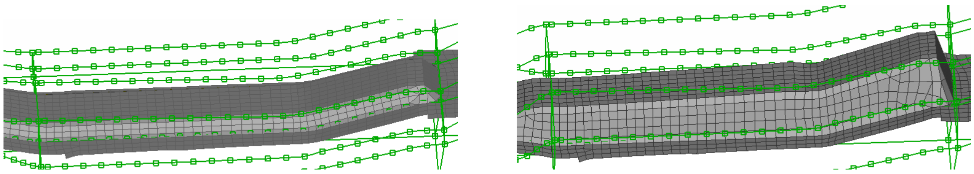


Fig.5: Morphing box for depression height

3 Analysis of Variances (ANOVA)

By means of an 'Analysis of Variances' (ANOVA) the importance of design variables for the target function can be assessed. Design functions that have a significant influence on the target function can be distinguished from rather insensitive design variables. Thus, an ANOVA can be used to reduce the number of design variables.
By evaluation of the cumulative distribution, insensitive design variables that can be neglected in the optimization can be identified easily (Fig. 6).

Fig.6: Cumulative Distribution of design Variables. Only 6 variables contribute significantly to the target function

4 Optimization of Lower Bumper Support Design

The lower bumper support geometry shall be designed to achieve the best possible EuroNCAP_Grid Score according to formula (1). This target has to be fulfilled for every leg position along the vehicle front.
Therefore, an optimization problem has been formulated that uses the maximization of EuroNCAP_Grid Score as target function. The Successive Response Surface Method (SRSM) has been used as optimization algorithm within LS-OPT. To reduce the computational effort, the optimization process has been performed for the most critical leg position. After an optimum for this position has been found, the performance at the other positions was checked. Thus, the optimization problem can be formulated as follows

Max(EuroNCAP_Grid Score) with $PCL \leq PCL^U$ and $ACL \leq ACL^U$

The restrictions for PCL and ACL are necessary to make sure that the MCL_rating contributes to the EuroNCAP Grid Score. Fig. 7 (left) shows the results for PCL for the different design variants analyzed within the optimization process. The green curves show design variants that fulfill all restrictions of the optimization problem while some restrictions are harmed by the design variants for the red curves.

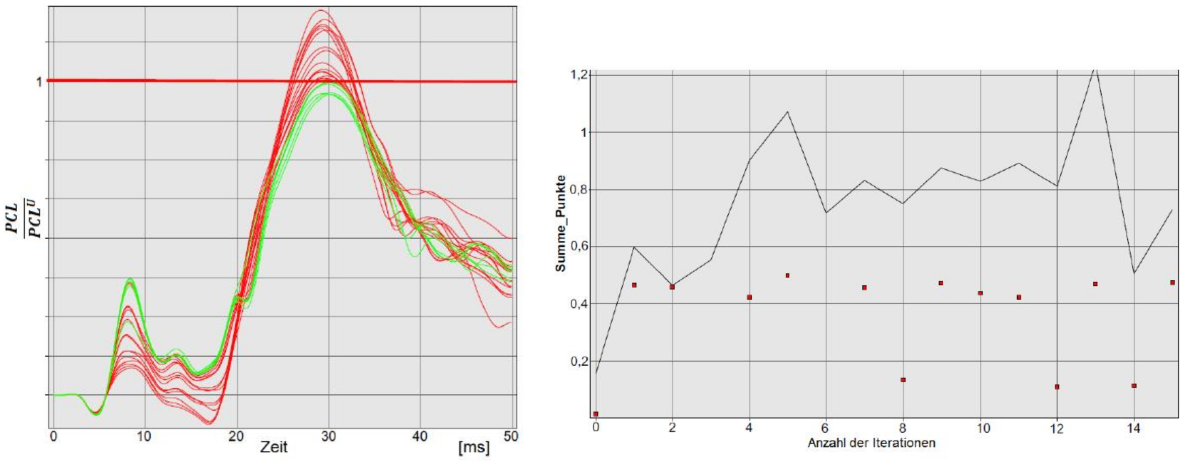


Fig.7: PCL values over time for optimization (left) and target function over number of iterations (right)

Although it is possible to fulfill the restrictions for PCL and ACL, the optimization problem has been formulated in an unfavorable manner because there is no convergence and the target function values are unsatisfactory (s. Fig.7 (right)). The reason for this behavior can be found in the plateau for tibia and MCL EuroNCAP Grid Score (s. Fig. 3) that enter the defined target function. This target function cannot be approximated well by a linear metamodel. In addition to that, not enough restrictions are active during the optimization procedure. To achieve convergence, the optimization problem needs to be reformulated. Fig. 8 illustrates the changes for evaluation of EuroNCAP Grid Score according to the calculated injury criteria for the target function. A linear approach has been used for tibia and MCL rating and the jump function triggered by ACL and PCL has been removed from the target function. Within the optimization process, ACL and PCL are only taken into account by the formulation of restrictions including a safety margin.

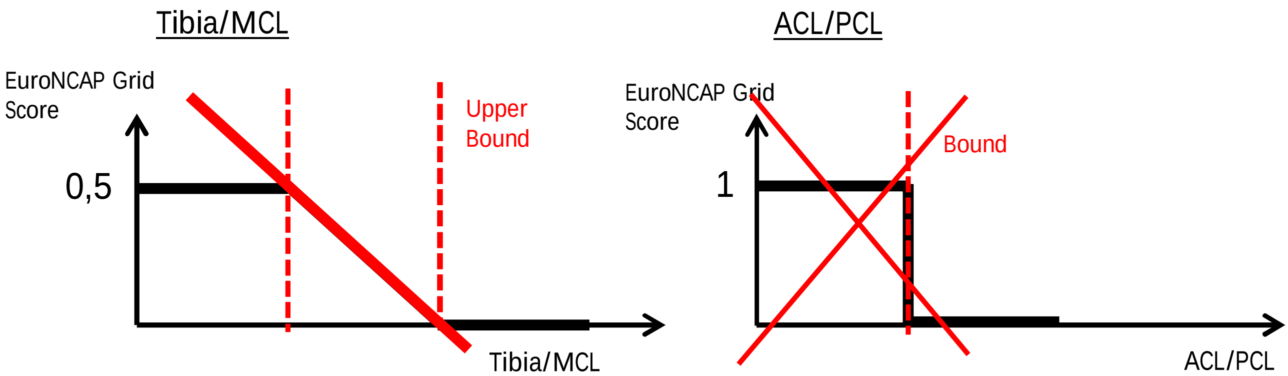


Fig.8: Modified target function

$$\text{EuroNCAP\_Grid Score}_{approx}=\min(\text{Tibia\_Points})_{linear} + \min(\text{MCL\_Points})_{linear} \quad (2)$$

The new target function can be written as :

$\text{Max(EuroNCAP\_Grid Score)}_{approx.}$ with $PCL \leq 0.99 \cdot PCL^U$ and $ACL \leq 0.99 \cdot ACL^U$

With this newly formulated optimization problem, a much better convergence behavior can be achieved and a component design which improves EuroNCAP Grid Score by 62% for the analyzed leg position has been found (Fig. 9).

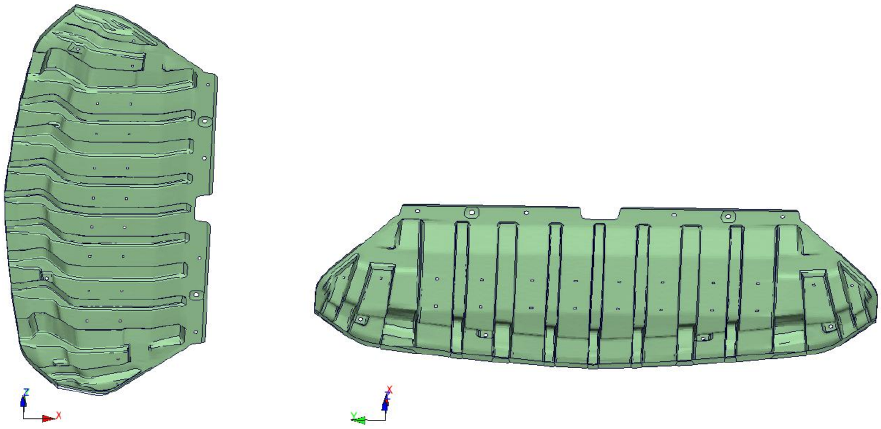


Fig.9: Optimized Lower Bumper Support

All other leg positions have been calculated with this improved component design. The results for the normalized FlexPLI injury criteria can be seen in Fig. 10. For outer leg positions the PCL exceeds its bound. This means that the EuroNCAP Grid Score for these leg positions will not include any points for knee ligament extension.

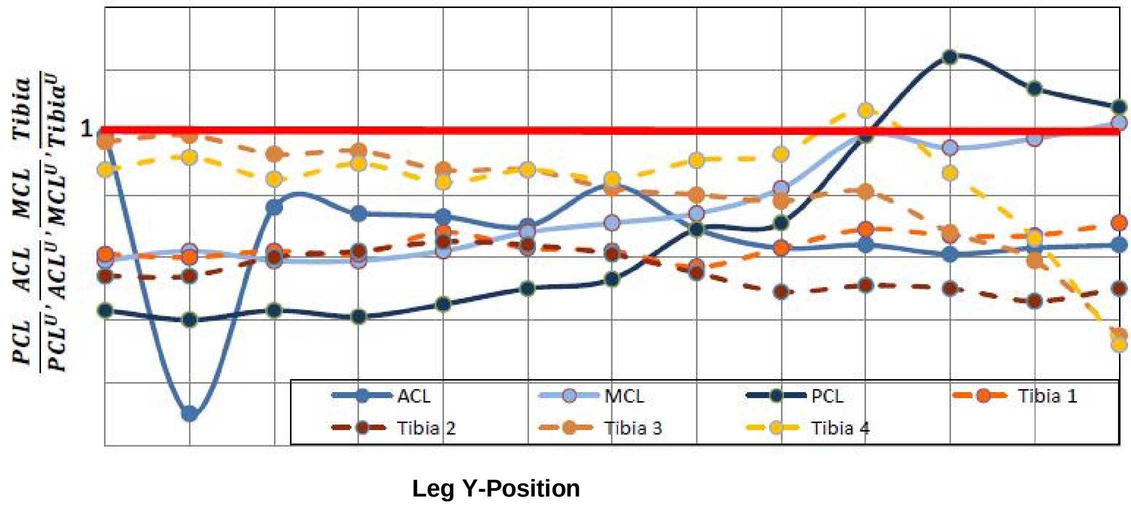


Fig.10: Normalized injury criteria over all position along the vehicle front

To improve PCL performance, an additional optimization has been performed, aiming to reduce PCL for outer leg positions (s. Fig. 11) while all other injury criteria stay below their ultimate values. From Fig. 12 it can be seen that for outer positions no combination of design variables has been found with PCL falling below the ultimate value.

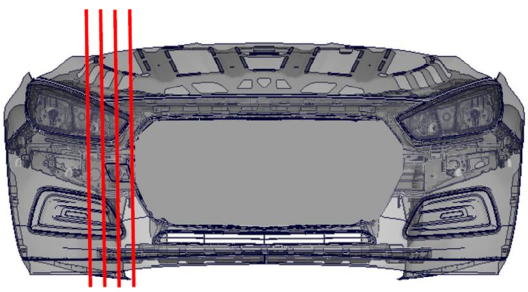
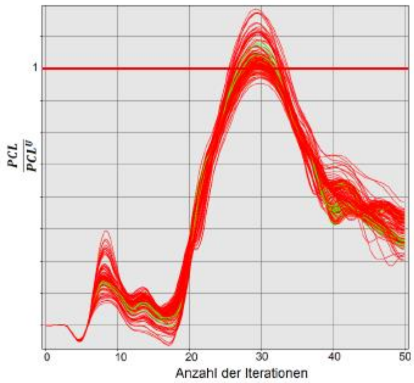
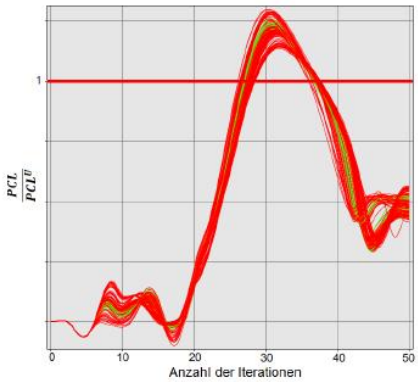


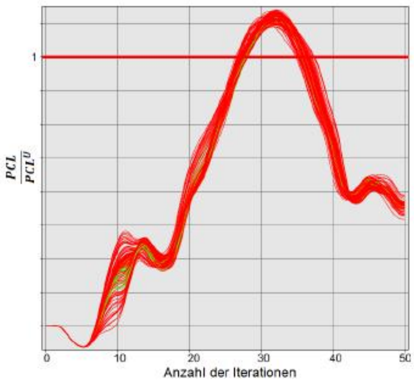
Fig.11: Outer Positions of the vehicle



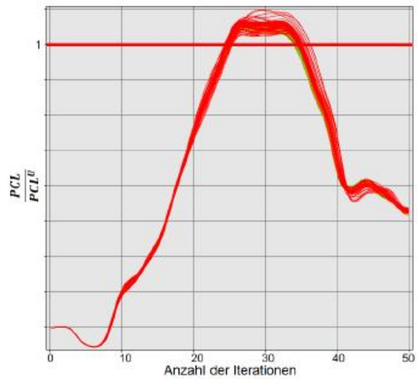
Pos. A



Pos. B



Pos. C



Pos. D

Fig.12: PCL at different leg positions

For these outer vehicle positions, PCL is not very sensitive against lower bumper support design, but more influenced by the shape of the vehicle outer front. This curved shape promotes a strong rotation of the leg during the impact that induces high PCL values and cannot be prevented by lower bumper support design.

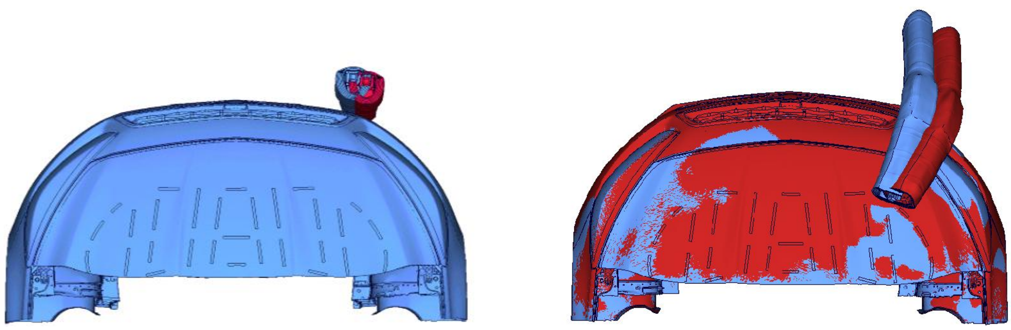


Fig.13: Leg rotation at outer positions

5 Summary

The optimization of a glass fiber mat reinforced thermoplastic (GMT) lower bumper support design has been performed using ANSA linked with LS-Opt, in order to meet the EuroNCAP requirements for pedestrian protection. The applicability of this optimization procedure in automotive practice has been demonstrated and discussed.

By using the EuroNCAP Grid Score directly as target function, the optimization problem did not converge and no improved component design was found. A significantly improved design could be found by modifying the target function using an appropriate approximation for the EuroNCAP Grid Score. Nevertheless, within the defined design space for outward leg positions no lower bumper support design variant could be found, that enables PCL to fall below its ultimate value. To fulfill the target for outer positions additional appropriate design variables have to be defined.