Efficient Robust Shape Optimization for Crashworthiness

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Abstract

Recent studies for crashworthiness have been realized using more and more complex geometries and detailed finite element modelling. Such model complexity with the required high non-linearity (material, geometry and contact) leads to high numerical effort, which is in particular challenging for optimization studies for industrial-sized problems with their high number of design variables, constraints and objectives, e.g. Duddeck (2008). Standard approaches have therefore only a restricted ability to explore sufficiently well the design space, which becomes even more crucial in cases where the robustness of the derived optima has to be assured (robustness in the means of insensitivity of the design with respect to inevitable fluctuations in design and noise variables). Nevertheless robustness analysis should be included into the optimization loop because optimization normally drives the design to the limits. The objective of the study at-hand is therefore to investigate methods to reduce a) computational effort for single simulations and b) the number of design evaluations required for robust design optimization.

To fulfil this it is explored how physical surrogate models (sub-structure and equivalent linear FE models) can be used to replace nonlinear full vehicle models. The sub-structuring approach is beneficial in situations where only a small part of a large complex structure has to be optimised, e.g. Averill (2004). Careful treatment and update of the interface condition is required. The second approach uses the Equivalent Static Load Method (ESLM) proposed by Park (2010). Here a nonlinear deformation field is multiplied by a linear stiffness matrix to generate equivalent loads which are then used in the optimization based only on linear FE simulations. In an iterative process, the robust optimization can be realized where most of the computations are based on linear simulations with reduced numerical effort.

A true robust design optimization (RDO) embeds the robustness analysis into the optimization loop instead of assessing the robustness of the design only at the end of the optimization. Hence a double-loop approach is necessary, the external loop for optimization and the internal loop for robustness. To avoid excessive numerical costs for this, a modified double loop RDO approach has been implemented for the first time, in which the robustness analysis is based on ESLM computations in cases where the design points are of low criticality (outside a defined Target Interval TI). In cases where designs are closer to the boundaries of the feasible design space the more correct nonlinear model is used. All three approaches contribute remarkably to simulation time reduction and enable therefore the usage of RDO in industrial context, which is shown in validation examples considering uncertainties in shape and impact conditions.

References

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