APPLICATION OF NON-PARAMETRIC SIZING OPTIMIZATION FOR CAR BODY PARTS USING SIMULIA TOSCA STRUCTURE AND ANSA

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ABSTRACT –
Weight reduction in the automotive industry is an essential measure to increase the vehicle efficiency and reduce material, manufacturing costs and emissions. The topology optimization has established itself as an innovative way for weight reduction, especially for casting parts, already in an early product development stage. In a similar manner, the sizing optimization facilitates efficient designing of sheet metal parts by variation of their thickness. The non-parametric sizing approach in SIMULIA Tosca Structure offers various possibilities for optimization of shell structures with respect to their weight, stiffness and dynamic behavior which makes it notably suitable for designing of car body parts. In the ANSA Task Manager, the Tosca sizing task is fully integrated with its complete pre- and post-processing capabilities which enables fast and reliable handling of optimization setup and results. This paper presents a sizing optimization procedure for car body components using the pre-processing performance of ANSA and Tosca, showing the possibility of weight reduction.

TECHNICAL PAPER -

1. INTRODUCTION

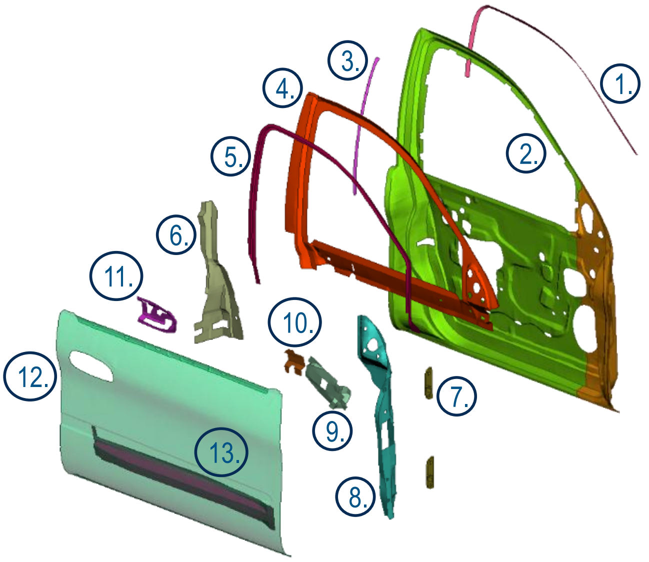
Lightweight engineering is one of the most prominent approaches to produce fuel efficient vehicles. An efficient method for designing lightweight vehicle bodies is the application of sizing optimization. This approach seeks to obtain optimum designs by optimal choice of sheet metal thickness without changing the general shape of the geometry. Thereby, material savings can be obtained by finding an optimum relation between weight, stiffness and dynamic behaviour (1). In contrast to topology optimization for example, it is generally common to apply sizing at a later stage of the product development, when the layout of the component (i.e. the topology) is more or less fixed, to obtain optimum shell thickness distribution and reduce further the weight of existing components where possible (2).
In this paper, the non-parametric sizing optimization workflow is described using a passenger car front door as example under consideration of stiffness and dynamic requirements. The workflow is based on the interaction of ANSA as pre- and post-processing tool and the optimization software SIMULIA Tosca Structure. The presented study shows different sizing approaches and illustrates benefits for the designing team to achieve material savings by optimum shell thickness distribution.

2. FE-MODEL AND SIMULATION OF A CAR DOOR

<u>Description of the model</u>

Generating FE-models of complex geometry and joining components is a fast and reliable process using the pre-processing capabilities of ANSA. Several automated tools like for example batch meshing and Data Manager provide integrated solutions.
The Batch Mesh tool performs automatic mesh generation on geometry or FE through customizable meshing sessions controlled by GUI or through script. The composition of the car door is shown in Figure 1. All shown components except the hinges represent sheet metal parts and are hence modelled as shell elements while the hinges consist of solid

structural elements. Here for example, special meshing scenarios are initially defined and saved ready to be applied on a possible newer version of some parts of the model. All spotwelds are modelled using solid property elements connected to the sheet parts using coupling constraints.



Component parts:
1. uper reinforcement
2. inside panel (tailor welded blanks)
3. window sill lip
4. window sill
5. window sill reinforcement
6. side reinforcement door lock
7. hinges
8. side reinforcement hinge
9. bracket window motor
10. door bracket
11. door handle
12. outside panel
13. side impact bar

Figure 1 – Overview of the sheet metal structure of the car door

<u>Load cases and boundary conditions</u>

Typical load cases for the stiffness analysis of a car door are door sag, overopening, frame and belt stiffnesses. For this study, the load application and the boundary conditions for these load cases are qualitatively chosen according to the procedure for door stiffness calculation described in (3).

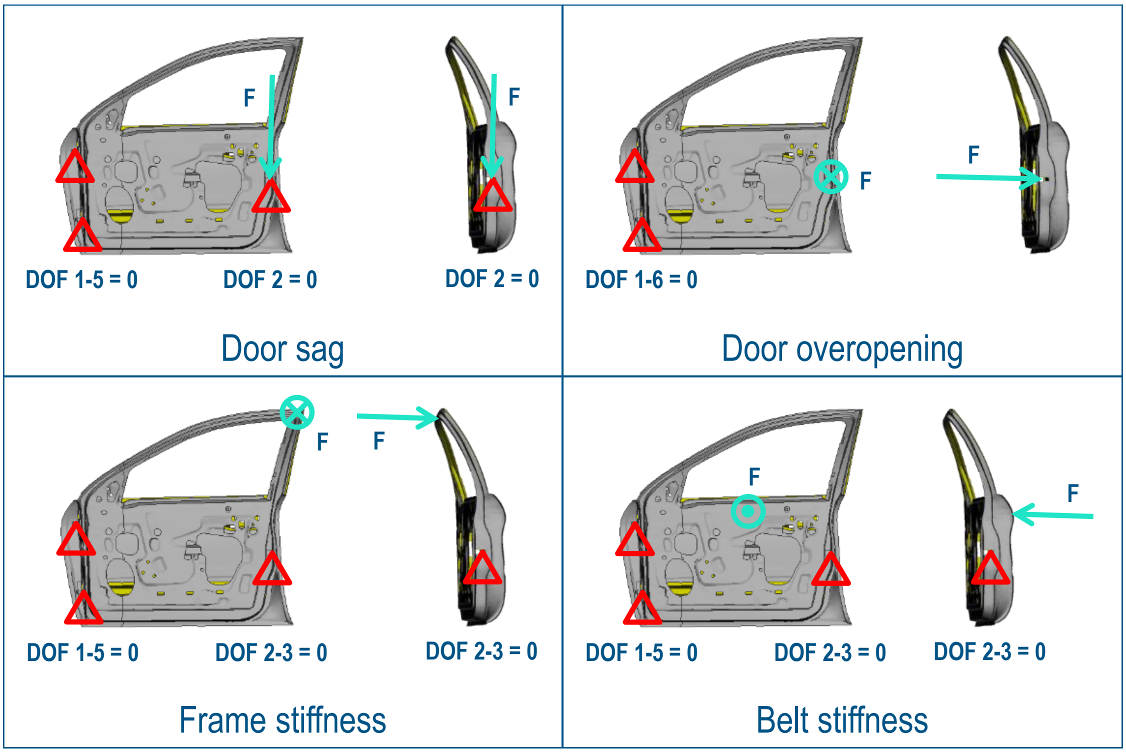


Figure 2 – Constraints and force application for the selected design load cases

In addition, to consider also the dynamic behaviour of the car door, the first three eigenmodes with their corresponding frequencies are calculated as well (Figure 3). For the eigenmode extraction, a complete DOF fixation on both the hinges and the door lock were assumed. ABAQUS was chosen as FE-solver for the complete car door simulation.

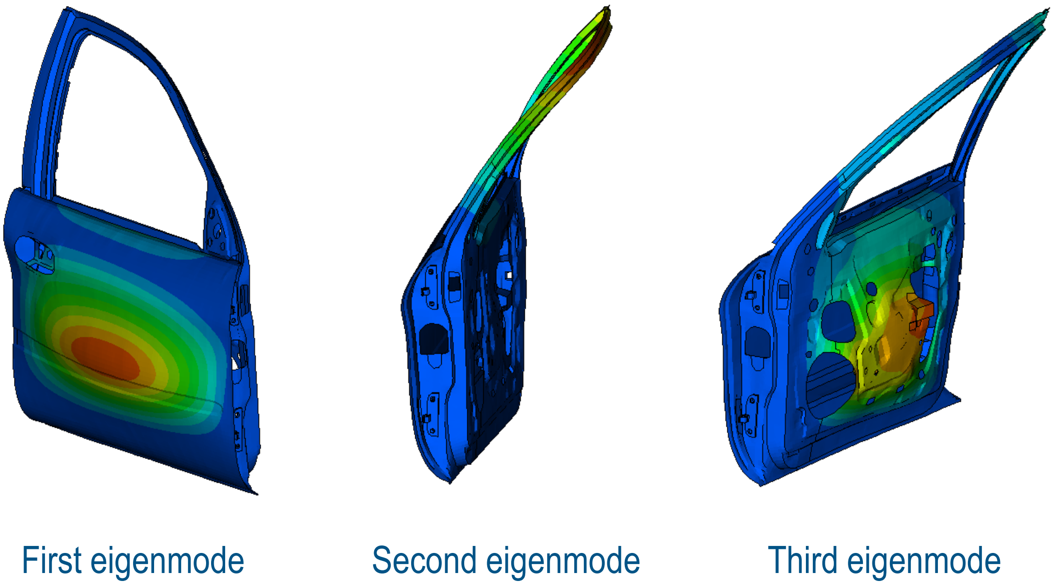


Figure 3 – Results of the eigenmodes calculation of the car door

3. OVERVIEW OF NON-PARAMETRIC SIZING

The main difference between non-parametric topology optimization and sizing in Tosca is in the type of the design variables. While in topology, the material properties of the design elements are modified to simulate hard structures with large contribution to the global stiffness, and soft or unnecessary structures, the thicknesses of the shell elements in the design space are modified in the sizing approach. The algorithm used for sizing in Tosca is a sensitivity based algorithm. Further, the non-parametric sizing approach in Tosca allows the handling of millions of design variables which is an advantage compared to the parametric approaches where the number of design variables is limited due to the different exploration algorithms.
To control the elemental thickness, lower and upper thickness bounds must be defined as boundary conditions for the sizing optimization (Figure 4). The thickness bounds can be defined in absolute values or relative to the initial elemental thickness.

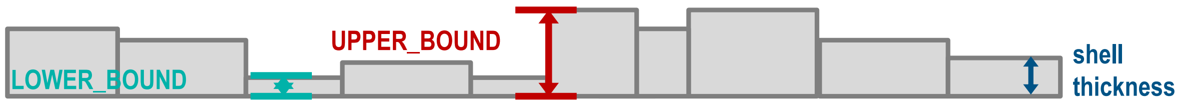


Figure 4 – Thickness bounds for sizing

There are two general approaches available for sizing in Tosca. The first one is the clustered approach, where a set of elements is clustered to one uniform shell thickness. Often, but not necessarily, the clustering is applied to the elements of each physical sheet metal component. In a second approach, a free sizing can be performed, where each shell element in the design space can obtain a separate thickness, thus allowing different thickness distribution inside a single component. Figure 5 describes both approaches schematically.

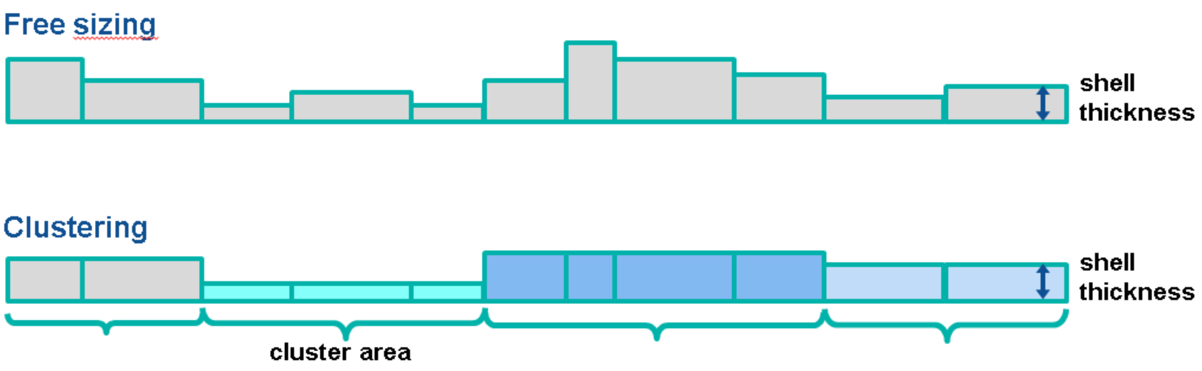


Figure 5 – Scheme of the free sizing and clustered groups approach

4. INTEGRATION OF THE TOSCA SIZING TASK IN ANSA

The new implementation of the Tosca sizing task in the ANSA task manager offers a very intuitive step-by-step definition of the optimization setup which simplifies the optimization pre-processing significantly. In ANSA, the Tosca sizing template can be used for completion of the whole setup, execution and post-processing of a sizing optimization with Tosca Structure. The setup of the optimization task is function based. The user has continuous interaction with the FE-model during pre- and post-processing of the optimization task. Further, a built-in consistency check assists the user while defining the optimization setup. The standard post-processing tools for the sizing optimization with Tosca are fully integrated in the ANSA task manager, allowing the user to inspect the changes in the thickness distribution and view the automatically generated convergence plots.

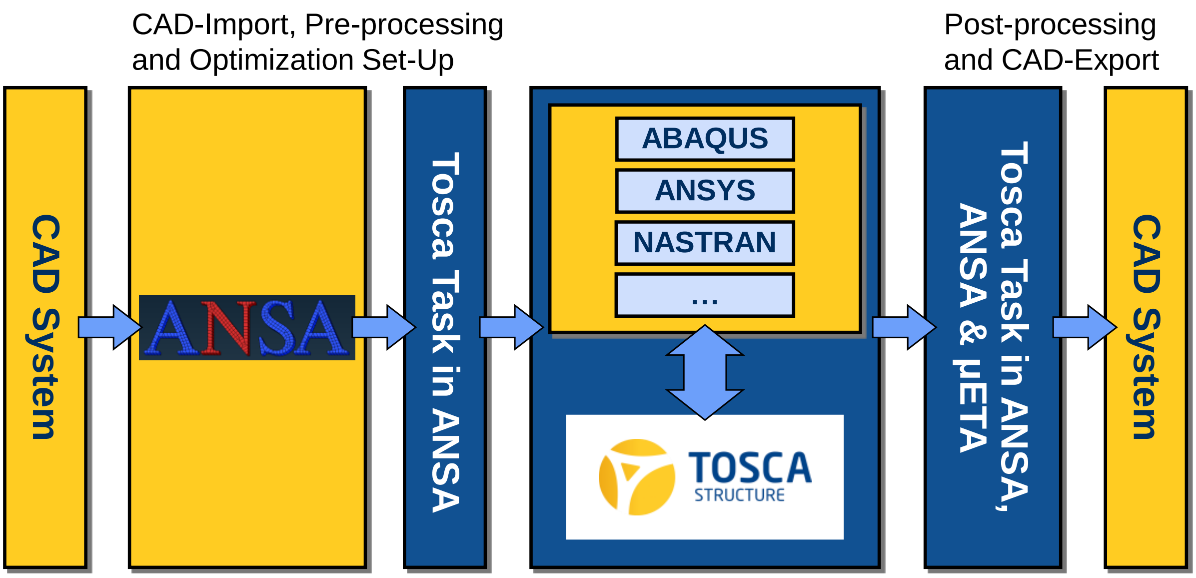


Figure 6 – Support of non-parametric optimization with the Tosca task in ANSA (4)

5. SIZING STUDY OF A CAR DOOR

In this study, both sizing approaches described in the previous chapter will be explored with focus on the potential of weight reduction. From among the possible entry points of application of sizing during the product development process, a situation is chosen for this case study, where a feasible design already exists. The goal is to deploy the non-parametric sizing technique to obtain the minimum weight design that satisfies all applied design restrictions.

Setup of the sizing task in ANSA

The objective of the sizing optimization is to reduce the weight of the car door. The stiffness in all four static load cases is represented by a maximum admissible nodal displacement, defined as constraints. The values of the first three eigenfrequencies are used directly as constraints. In total, 7 constraints are activated for the optimization run.
The design area for sizing is defined from 5 of the door structural components (Figure 7). All other components should remain unchanged by the optimization. The design components are:

- inside panel
- window sill
- side reinforcement hinge
- side reinforcement door lock
- window sill reinforcement

In the first run of the study, all components should maintain a uniform shell thickness. Hence a clustering restriction must be applied. In Tosca, the clustering restrictions are applied on a set of elements. In this case, separate Abaqus properties are also assigned to the element sets that need to be clustered. For that reason, no manual definition of the sets is required in ANSA, but these sets are defined automatically using the option “Create Sets From Props” upon importing the Abaqus FE-model in the task manager.

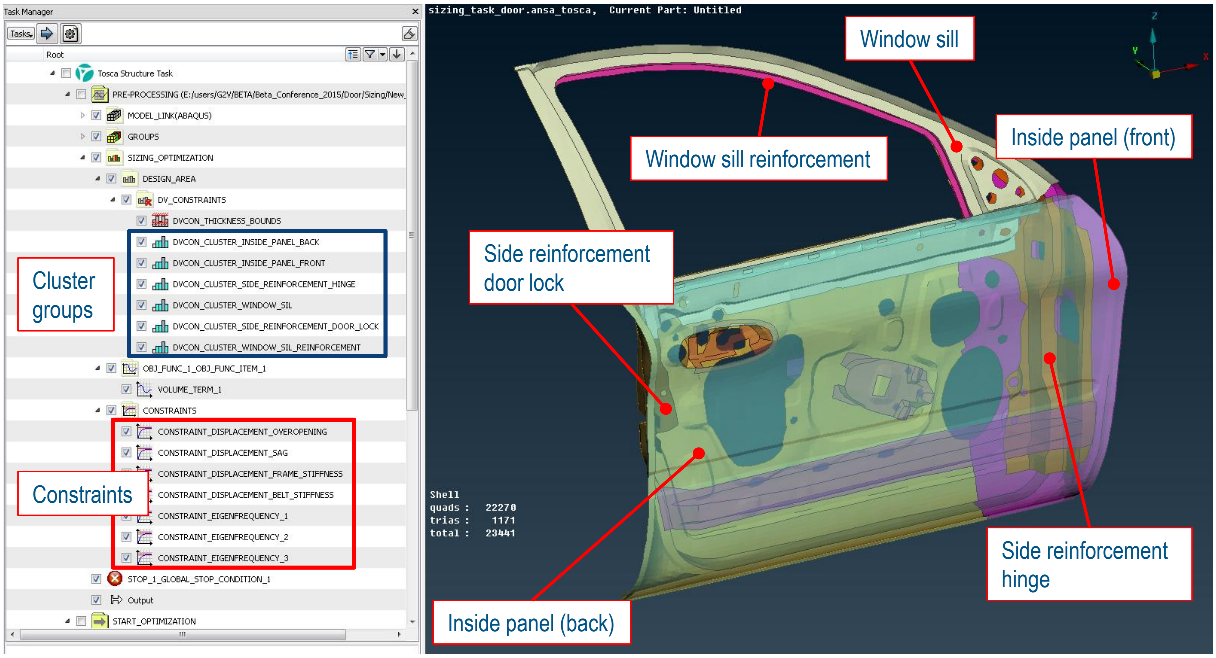


Figure 7 – Definition of the complete sizing task in ANSA

In this study, a restriction for the upper and the lower thickness bounds is specified so that the thickness of each element or clustered group can vary continuously between 0.5 and 2.5 mm.

Sizing optimization results

In only a few iterations, Tosca is able to determine the new optimal thicknesses of the design shell components to obtain a combination of minimum door weight while fulfilling all constraints. Figure 8 shows the initial and the optimum thickness distribution for the design components. There are no significant changes in the thickness of the design components because the initial design chosen for this study is already close to the optimum.

Nevertheless, the weight reduction after the optimization run is 5% of the total weight of the door.

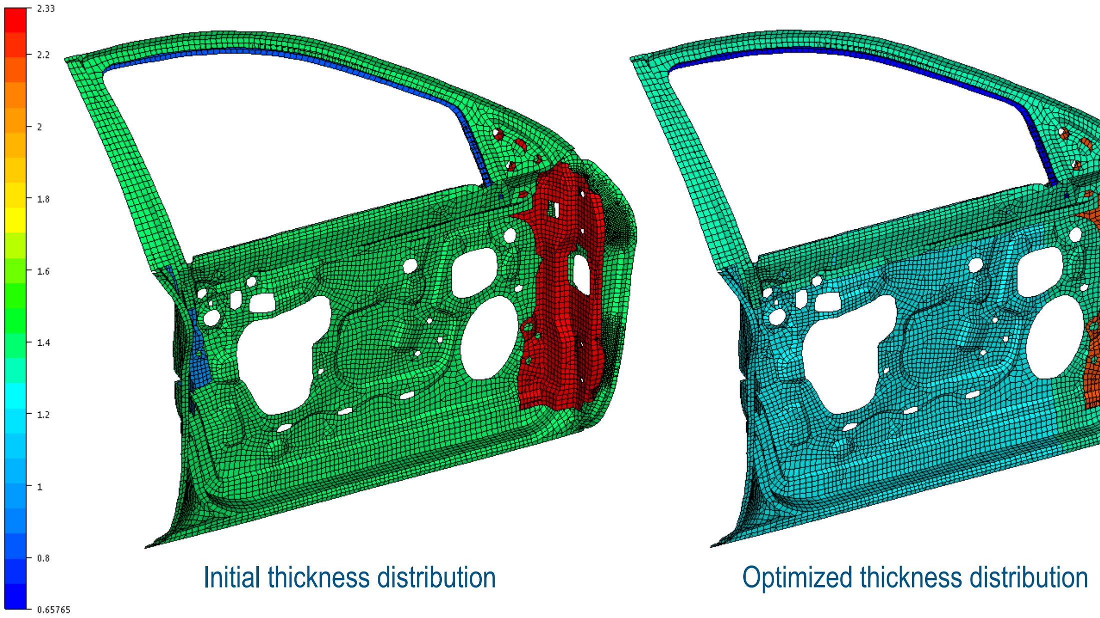


Figure 8 – Thickness change after the first sizing run with clustered components

For the second optimization run, the clustering of the design components is switched off, allowing each design element to obtain an individual thickness, resulting in a free thickness optimization with a total of more than 16000 design variables. In order to facilitate the interpretation of the free sizing results, an additional width filter is activated to enforce areas of certain width (in this study 60 mm) in obtaining similar thickness. The results of the free sizing run are shown in Figure 9. The design proposal calculated by the free sizing approach is 27% lighter than the initial design while fulfilling all the stiffness and eigenfrequency constraints (Figure 9 right).

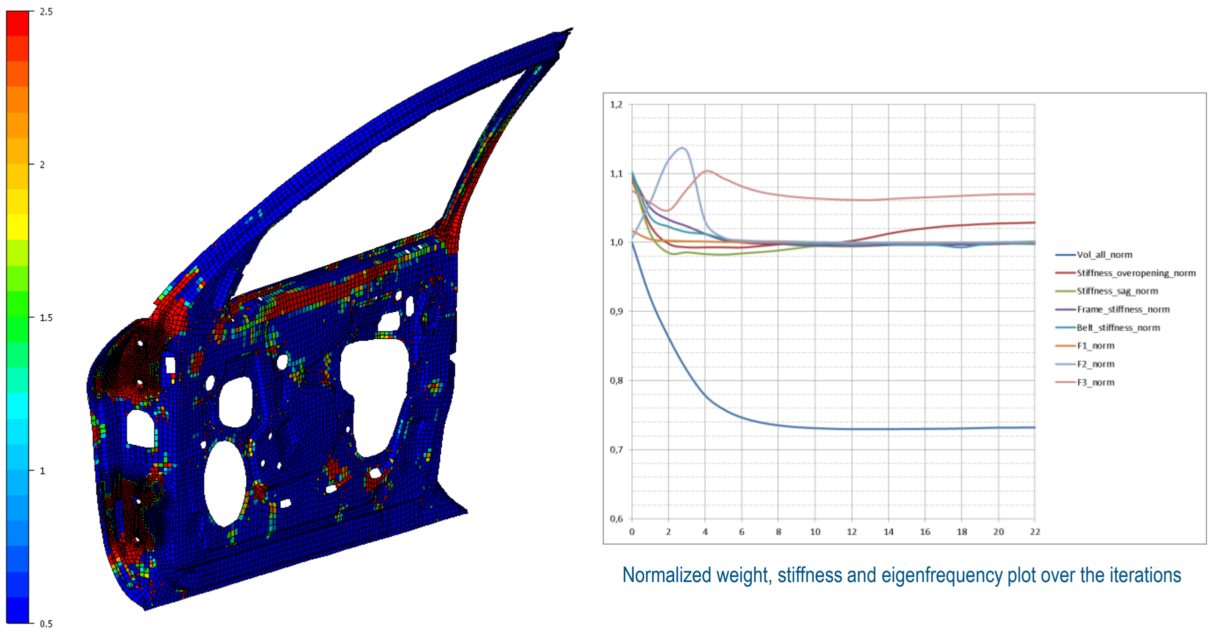


Figure 9 – Thickness distribution and convergence plots after the free sizing run

Results interpretation and possible next steps

As shown in Figure 9, the results of the free sizing resemble in a certain way those of a topology optimization. The converged thickness distribution (Figure 9 left) shows mostly areas having the maximum and the minimum allowed thickness. Generally, such free sizing results are difficult for direct implementation. However, they give a clear picture of stiffness relevant and less relevant areas. As the areas with high and low thickness can easily be distinguished, the results can give various hints and ideas to the car body designers, e.g. application of local reinforcement plates, use of tailor welded blanks, etc. As an example, based on the results of the car door free sizing, two components can be identified to explore and verify possible benefits from the free sizing results. A fast and easy way for such verification can be a new clustering of these components based on the thickness distribution from the free sizing run. Figure 10 (left) shows the free sizing thickness distribution in the inside panel and the window sill. On the right, an example of a new clustering suggestion is presented.

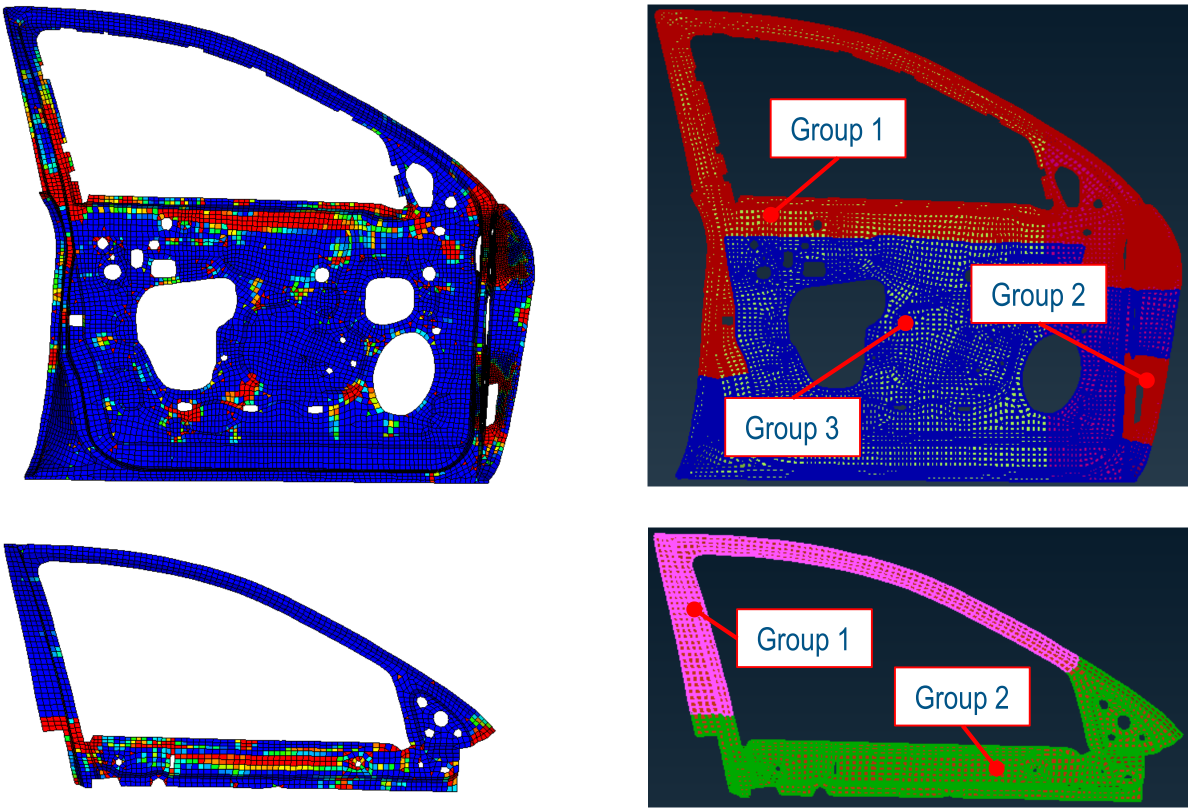
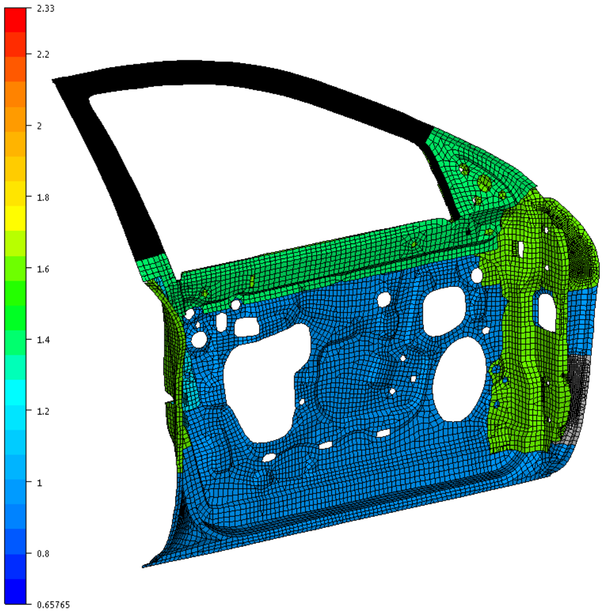
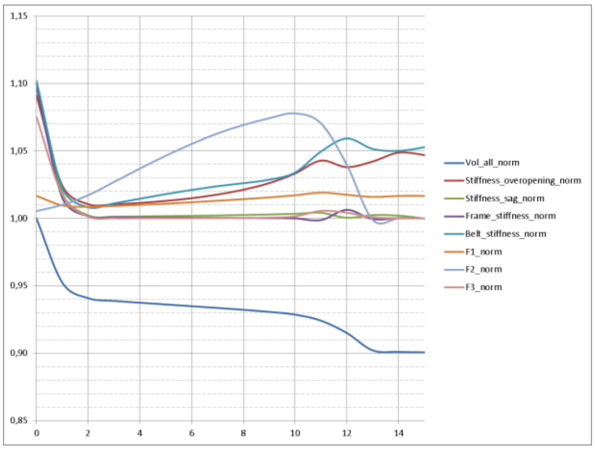


Figure 10 – Free sizing thickness distribution in the inside panel and the window sill and suggestions for new component clustering

The new cluster groups can be easily defined using the element selection tools in ANSA. After that, the first sizing run can be repeated with the new clustering of the two components while the cluster groups for the window sill reinforcement and both side reinforcements remain unchanged. The result of the second clustered sizing run is shown in Figure 11. Due to the different clustering, the thickness distribution differs from the one obtained after the first run (Figure 8). To enable a direct comparison of the thickness distribution between the first and the second run with clustered components, the legend and scale for the thickness used here is the same like in Figure 8. As a result of the new more flexible clustering, a total weight reduction of the car door by 10% is achieved compared to the initial design in this study which is twice as much as the weight reduction achieved through the first sizing run with clustered components.





Normalized weight, stiffness and eigenfrequency plot over the iterations

Figure 11 – Thickness distribution and convergence plots after the second sizing run with modified cluster groups

6. CONCLUSIONS

Non-parametric sizing optimization proves to be an efficient strategy to optimize the thickness of shell structures such as car body components. No necessity for parameterization of the individual shell thickness, and the possibility to efficiently handle millions of design variables, are some of the main benefits of the non-parametric sizing module of Tosca Structure, making the approach suitable for large scale components and full car body optimizations. In the presented study, a sizing optimization was performed to explore the potential for weight reduction of a car door while keeping a required stiffness and eigenfrequency level. Two different sizing strategies were explored. The free sizing approach where each element thickness is individual design variable shows a lot of potential for weight reduction and generates a good basis for identifying necessary reinforcements or areas of thickness increase. The proximate reuse of the free sizing design proposal by defining cluster groups of same shell thickness in a subsequent verification sizing run lead to 10% weight reduction compared to the start design in this study.
Alongside with the optimization software Tosca Structure, ANSA and MetaPost are very important part of the whole optimization process, starting with the FE-modelling of the car door and evaluation of the simulation results. Further, the fully integrated Tosca Structure sizing task in the ANSA task manager allows the user to easily create a complex setup for optimization including the easy, reliable and user-friendly definition of arbitrary cluster groups.

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