Introduction
Lightweight design in automotive development is not a new trend. Less weight means less material, lighter vehicles, and therefore less CO₂ emission. Thanks to smaller moving masses, cost efficiency is increased and the system’s driving characteristics are improved. Usually, new materials are major drivers of innovation in this area. In recent years, tons of steel could be saved in the automotive industry and were replaced by lighter aluminium components. But the search for lighter and better materials continues. Latest developments have allowed for the production and usage of composite materials in many automotive components (i.e., car interior lining). Until recently, those components were usually non-load bearing and non-safety-related parts. Today, an increasing number of detailed studies are performed to investigate the use of composite material also for load-bearing components. Due to the inherent characteristics of composite material, this requires a different development process. A recent study at Volkswagen Group Research aimed at defining a B-pillar of composite material and at the development of a robust and efficient design approach, to develop composite components optimized regarding performance and weight, at competitive manufacturing costs. The project was carried out with the support of Altair ProductDesign and with the use of the HyperWorks software.

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Composite Optimization at Volkswagen

The starting point of the study was an existing aluminium construction of the B-pillar, which was reinforced with additional steel and aluminium components. The Volkswagen and Altair ProductDesign engineers were looking for a lighter alternative to the component, made of composite material. Since it was important for the basic study to be able to compare the desired new construction with an existing known structure, the engineers choose the B-pillar of an existing Audi A8 (model D3). For the chosen model, the engineers had the necessary experience, the performance data and, in particular, the CAD data, which was intended to be the basis for the new composite version of the component. Based on this knowledge, the engineers then studied to see if they were able to develop and produce a composite version of the B-pillar that would be competitive with regards to performance, manufacturability, weight, and cost. The main objective of the project was to define a general process for a new, robust, and efficient design approach with the ability to develop all types of composite components and above all, test and validate them by means of simulation. The relevant load cases as occurring in the aluminium construction had to be used as specifications for the testing procedure. In the case of the B-pillar, these were a static roof crush, a seat belt anchorage test as well as an IIHS side impact.

The challenge in the definition of load bearing composite components is the combination of the non-linear characteristics of the application (large deformations, contacts, component failure) with a high number of design variables of the material (topology, number of layers, fiber orientation and so on). Preferably, a simulation and material model for such an approach should be strictly non linear. In combination with the high numbers of variables, however, this would result in very long calculation times and the commonly used development cycles for a modification of the component design would not be practicable. At this point, the engineers had several possibilities to reduce the complexity of the calculation.

If a large number of different design variables need to be considered, either a simplified model or a temporarily reduction of the linear material characteristics is possible. At a later development stage, with less design variables to be considered, a non linear model validation can be performed, offering a detailed and more quantitative prediction of the component characteristics.

The Development Strategy

Based on these considerations, Volkswagen Group Research decided to follow a two step optimization strategy and divided the general development approach in a concept and a fine tuning phase (see figure 1). During the concept phase, the engineers initially conducted a material independent analysis by means of a topology optimization, considering the material characteristics to be linear. The goal of this first phase was to gain knowledge about the basic structure of the component, the load paths and the fiber orientation of the different layers. Additionally, the results could also be used to gain suggestions for a possible rib positioning within the component. During this phase it was observed that the
component should be reinforced with ribs at its connection points as well as at the middle part of the component (see figure 2).

With this in mind, the actual process of composite material optimization was initiated and handled by means of a conceptual FEA model. Here, the optimization process of composite material in the automotive industry is similar to that of the aerospace industry, but the aerospace engineers do have the advantage that they can usually reduce their analysis to the linear area. The automotive engineers, however, also have to prove the non linear behavior of the component – at least towards the end of the development process. At this stage of the design process it is an advantage to limit the analysis to linear physics and be able to answer more general questions of the composite material definition.

**Optimization Process**

The optimization process of fiber composite material calls for a three step optimization. During a so called free size optimization, the engineers define where the single fiber layers of each orientation are needed, during a size optimization the engineers define the amount of layers needed, and during the last step the optimal stacking sequence of the ply is identified by means of a shuffle optimization.

In the first step, the free size optimization was conducted with OptiStruct, HyperWorks’ optimization tool. Here, the engineers analyzed which fiber layer was needed at which position within the component. Furthermore, it was possible to use the results of the free size optimization to define in which area of the component so called patches would be needed and if those resulting patches would have to be global (patches extending over the entire component) or local patches (to support smaller areas of the component).

Based on these results and under consideration of the production process, the engineers could now carry out a patch interpretation, delivering the specific patch distribution. Subsequently, the engineers performed a parameter optimization, again using OptiStruct. The goal was to define the necessary number of layers in each of its directions (see figure 4). In an additional step, the result of the patch distribution was then subject of a parameter optimization, in order to reduce the amount of patches needed. At this stage, the engineers were looking for a compromise between a very light but complex component and one that can be produced easily. The static stiffness of the component was supposed to be maintained as far as possible. This development phase resulted in a B-pillar made of fiber composite with a simple finish, showing a similar stiffness as the original B-pillar made of metal and a weight reduction of around 40%.

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feasibility study, this simplified structure setup was built as a prototype (see figure 6), due to cost and manufacturing reasons the engineers decided against including the rib structure.

The results of the analyzed quasi static component immersion test, as shown in the plots (see figure 7) give interesting insights into the material and component behavior. The different fiber composites could take in up to 25% more energy at 30% less mass than the metal component. However, these results also showed a higher deformation of up to 30%, which is not acceptable for the B-pillar of a car. As an effective countermeasure, the B-pillar would have to include some enforcing ribs which, however, would again significantly reduce the weight advantage of the composite construction.

**Project Summary**

In conclusion, the project goals were achieved only partially. It was not yet possible to produce a composite prototype of the B-pillar that would be able to meet the high test requirements while reaching the desired weight reduction. By adding the necessary reinforcement of the B-pillar, the weight advantages offered by glass fiber material would have been nullified and with regards to manufacturing, the engineers would also not have achieved any advantages with the new composite variant.

Nevertheless it was possible to build a component structure showing a similar force level as the series component structure, at a by 30% reduced mass. The foremost goal of the study, however, was to show that the chosen development process was expedient and practicable for load bearing structures made of fiber composites. The approach to split the entire process into a concept and a fine tuning phase, enabling the engineers to work at least partly with a better result quality and non linear parameters, helps to reduce the high number of possible parameters and to fine tune them for the special use case. In similar future projects, the use of non linear parameters in the fine tuning phase (not part of this study) will be mandatory as only those parameters will provide the engineers with absolute results (i.e. with crash tests) and therefore quantitative predictions. Furthermore, it will be necessary to precisely validate the simulation models to create a useful base especially for the desired variant studies.

The Volkswagen Group, especially the Audi light weight center in Neckarsulm, Germany is currently engaged with various research activities on fiber composites usage in car development. The approach as pursued and defined by Volkswagen Group Research could already be successfully used by the Audi engineers, following up on further projects to define laminate families and laminate structures. Future adjustments to the development process at the automotive OEM as well as to the HyperWorks software will lead to the possibility to take advantage of the immense potential of fiber composites for many additional vehicle components.

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