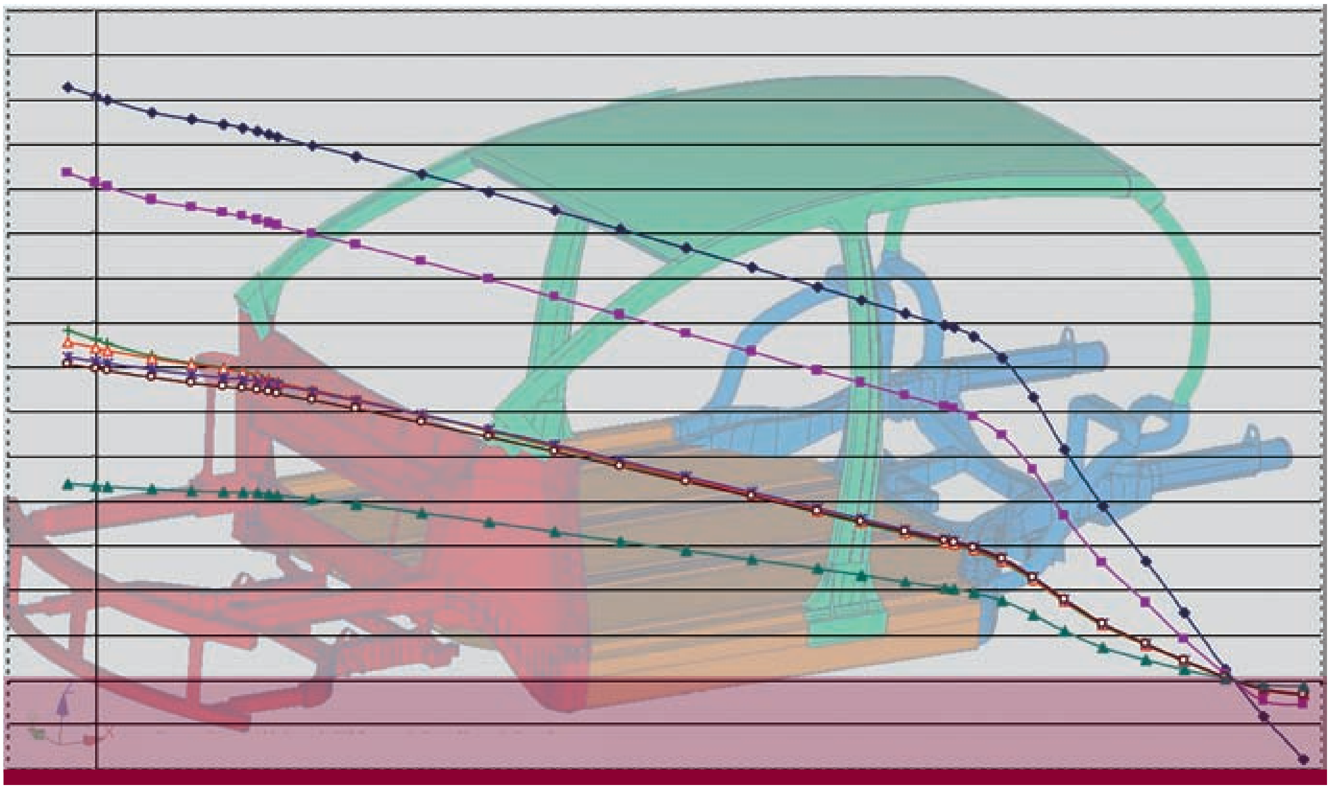

Highly-integrative Lightweight Car Body Concept

The car body concept “Functional high integration“, developed within the scope of the joint project of the Volkswagen AG Group Research and the Technical University of Braunschweig, describes a cost-effective integrative lightweight car body. In this paper the approach for laying the new car body structure concerning its stiffness will be explained, along with presenting the component and function integration on the basis of the floor pan components.

1 Introduction

In the automobile industry increasing demands on the vehicle as a whole concerning safety, comfort, driving performance and environment-friendliness lead more and more to goal conflicts which cannot be solved with conventional car body concepts in an economical way. In addition to that, the customer seeks individuality and diversification which leads to an increasing line of models and car bodies. Along with a stagnant number of models sold this also results in a decreasing number of sold car bodies per model. The investment per model, for pressing tools for instance, remains on the same level independently from the number of lots. This results in a demand for new car body concepts for small and medium-sized series with comparatively low investment and production costs in order to also economically cover versions with lower lots as well. This calls for ways of construction and material concepts which are at least self-financing in spite of higher material costs and a lower number of sold lots by reducing expenses of facilities and resources.

Based on this the project "Fascination car body construction" was initiated by the company research of the Volkswagen AG in cooperation with the TU Braunschweig. Within the scope of this project, two new car body concepts for passenger cars were developed. The idea for the following concept of "Functional high integration" was to develop a cost-effective integrative lightweight car body.

Figure 1 shows first ideas for function integration.

The goals compared with a standard car body are:

- Reducing weight of floor modules with function and component integration by approx. 15 %
- Reducing the number of components needed for the floor module by at least 40 % (number of parts < 50)
- Reducing costs for the floor module in spite of switching from steel to aluminium (savings done through a simplified manufacturing method of the supporting structure)
- Getting the same mechanical characteristics (stiffness, crash performance) as a comparable standard car has made with a steel shell construction by cleverly arranging the components and a support orientated design

Especially extruded aluminium profiles, compared with deep-drawing components, feature relatively low tool costs being one or two scales below the costs of pressing tools.

Apart from the reduced investments the number of manufacture and mounting operations are to be cut down through a consequent function integration (and the component reduction connected with it) which also results in saving costs. Especially when constructing car bodies the chosen concept can significantly cut down the number of geometry and welding points.

Figure 2 shows the breakdown of the car body concept into the segments of

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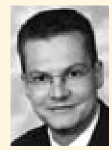

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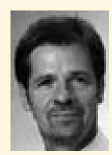

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2 Introducing the Concept of "Functional High Integration"

The concept of "Functional high integration" describes a car body construction mainly based on extruded aluminium sheaths and large brass components featuring component and functional integration in the area of supporting structural components.

Compared with conventional ways of construction, this structure consists of a heavily reduced number of components. In combination with an optimised force transmission along with a manufacturing method chosen accordingly, this approach results in a weight reduction as well.

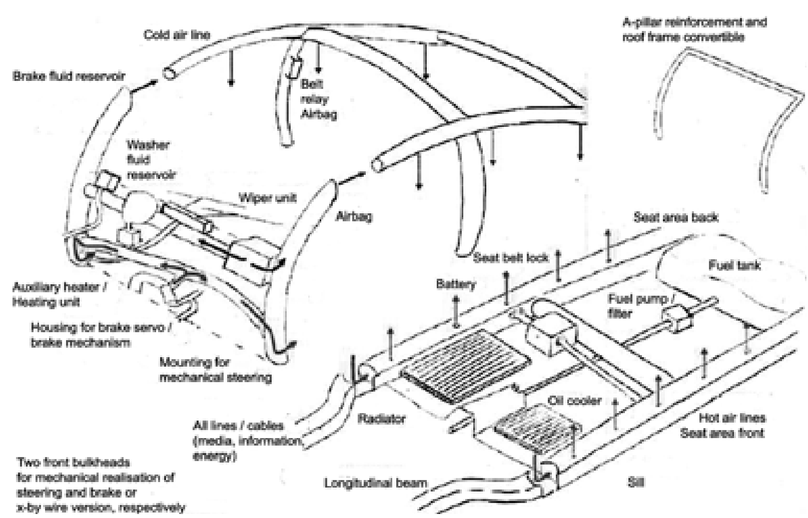
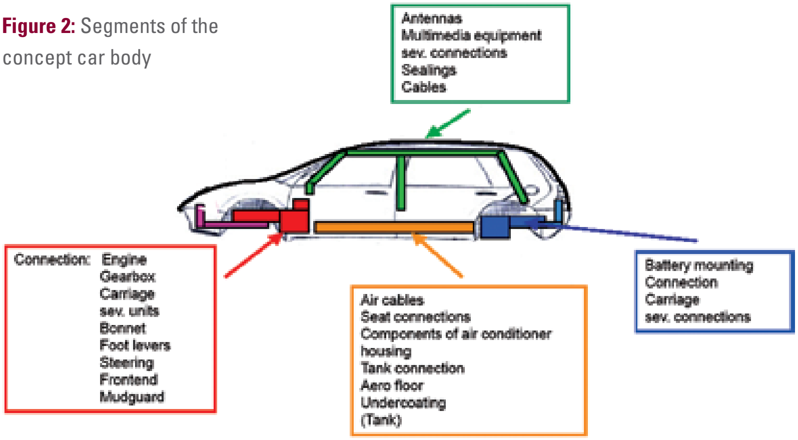


Figure 1: First ideas for function integration

Figure 2: Segments of the concept car body



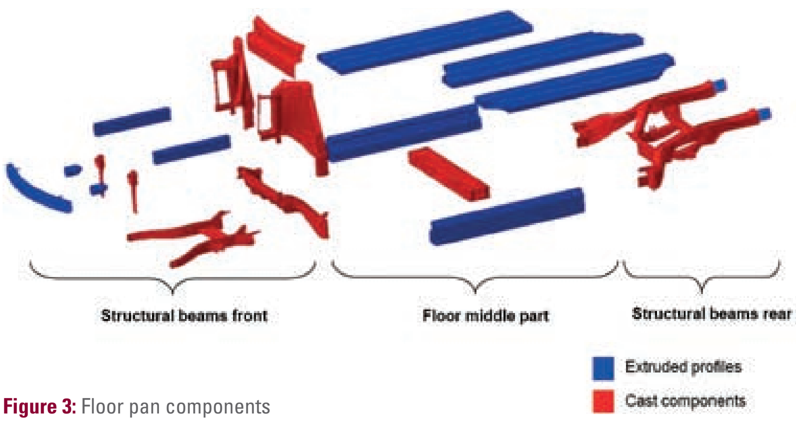


Figure 3: Floor pan components

car top, structure beams front, floor middle part and structure beam back along with approaches for possible integrative solutions.

The next passage shows the conceptual approaches with the floor pan components as an example.

3 Conceptional Approach of Constructing the Floor Pan Components

The floor pan component, comprising of both structure beam areas and the floor middle part, mainly consists of extruded aluminium sheaths and aluminium pressure casting components. Figure 3 shows the conceptual draft of the floor pan component consisting of about 25 single parts. The front and rear structure beams have a significant integration potential through combining several components. In order to put this potential into practice manufacturing methods should be deployed which allow for a high amount of design freedom. Especially aluminium pressure casting is very suitable for manufacturing complex geometries even with thin walls as well as producing components with large geometric dimensions and a high amount of stiffness.

Analysing the integration potential of the floor middle part, Figure 4, has shown that integrating different material cables and cable guides in the structure appears to be very promising. The middle part of the floor is used for integrating functions not belonging to the car body itself such as air, water, fuels and other operating supply items to save secondary weight.

Material cables need closed, dense cross-sections. With the usual steel shell construction these can be produced by assembling one or several components. An interesting alternative are extruded aluminium profiles. Through omitting many sealing components and / or cutting down the number of assembly operations through component reduction, extruded aluminium profiles offer a high integration potential. Extruded aluminium profiles can easily be manufactured as a multi-cell profile with great freedom in designing the cross-section geometry characterised by a good specific stiffness. Thus, they allow for using near-net-shape semi-finished parts.

While putting the floor concept into practice the benefits of the shell construction (complex geometries, lightweight potential concerning stiffness) should be combined with the benefits of frame mode construction (e.g. cost-effective semi-finished parts, complex cross-sections of closed profiles), but without their downsides. Using nearly flat, almost "shell-like" multi-cell profiles have shown to be the best solution. The middle part of

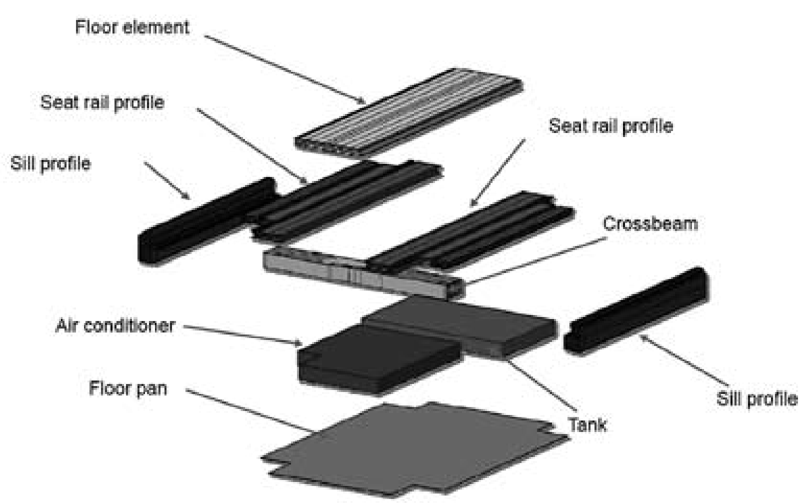


Figure 4: Middle part of floor

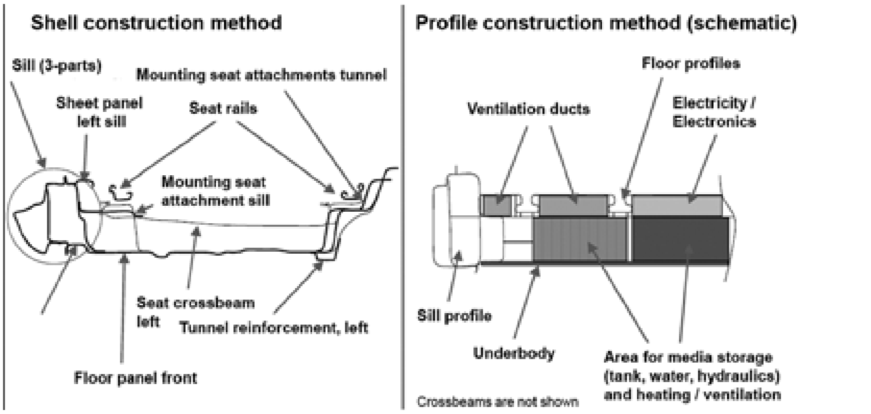


Figure 5: Comparison of construction methods on the basis of the floor middle part

the floor consists of two box shaped profiles, three shell-like extruded profiles and one hybrid beam. This crossbeam, consisting of a cast part with plastic inlays and extruded profiles, allows, apart from integrating material cables, for optimising today's demands on side crashes. While deploying extruded sheath profiles (~ 400 mm width and 50 mm height) the limits of the technical practicability were reached. The problem of amplified tolerance fields through a tolerance compensating join patch design has been taken into consideration just as welding the five profiles in one single processing step.

Figure 5 shows the design of the middle part of the floor in a cross-section and compares the chosen way of construction with the already known shell construction. In this schematic presentation one can see the potential of reducing the number of components used compared with the conventional design.

4 Design of the Car Body Structure

When designing the car body different guidelines concerning stiffness, crash efficiency and lightweight must be followed. That's why the mechanical characteristics are determined by the first car body drafts, are getting compared with the technical requirements and the construction is thus modified. One key criterion when designing car bodies is their stiffness. Due to its relatively easy determinability it is a first design criterion for a new car body structure and a necessary pre-condition for a good crash efficiency. The stiffness has a significant influence on driving performance, driving safety, comfort, acoustics and the accuracy of fit of doors and flaps.

In order to evaluate the technical quality of the described car body concept, the statical and dynamic stiffnesses of a first constructive draft of the developed car body structure, **Figure 6**, have been determined through FEM calculations. In this case, the stiffnesses of the car body concept were too low compared with a similar standard car built in a steel-shell manner. The statical torsional stiffness, for instance, reached only 34 % of the stiffness of a standard car at about half the weight. Thus, investigating on the potential for increasing the stiffness was a crucial point in designing new concept. The goal was to find basic measures to get the stiffness of a comparable standard car.

The basis for this investigation was the concept car body's torsion line. The latter is determined by mounting a static torsional moment on the body-in-white firmly attached at the back in the area of the front axle. The torsion angle located graphically across the car's centre line is the torsional line, **Figure 7**. The torsion angle at the front axle's level indicates the torsional stiffness in Nm/°. The goal was, apart from reducing the torsional angle, to get a distribution of stiffness in the car body as even as possible, indicated by the largely constant increase of the torsional line.

In the first step, the areas of the car body were identified which have a dominant impact on the torsional stiffness. Then these areas were investigated regarding structural measures for increasing the statistical torsional stiffness. These investigations were mainly limited to basic measures, such as implementing panels indicating hints for changes in the construction.

4.1 Identifying the Dominant Areas Regarding Torsional Stiffness

Within the scope of this investigation there were no methods available for determining the dominant areas concer-

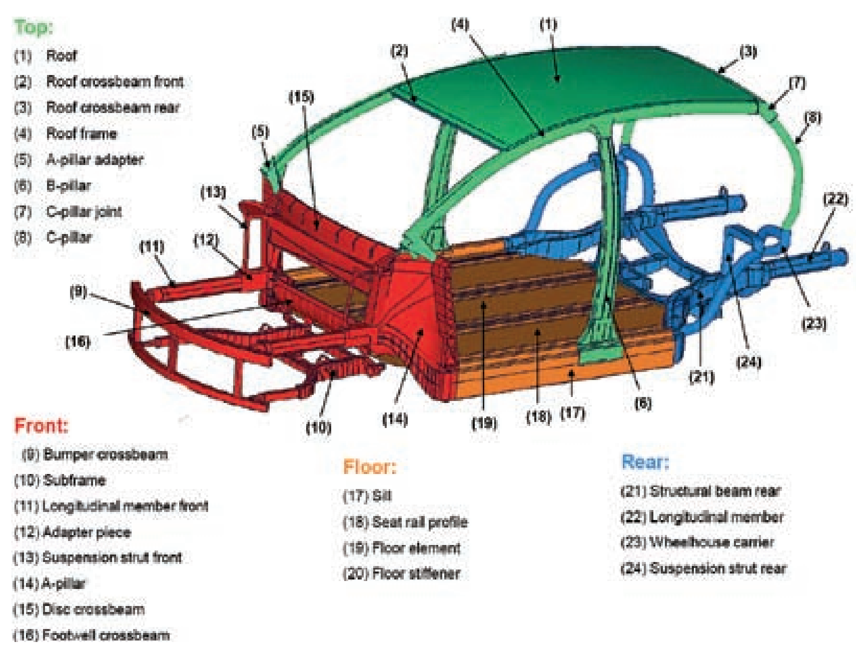


Figure 6: Car body concept "Functional high integration" – first construction draft

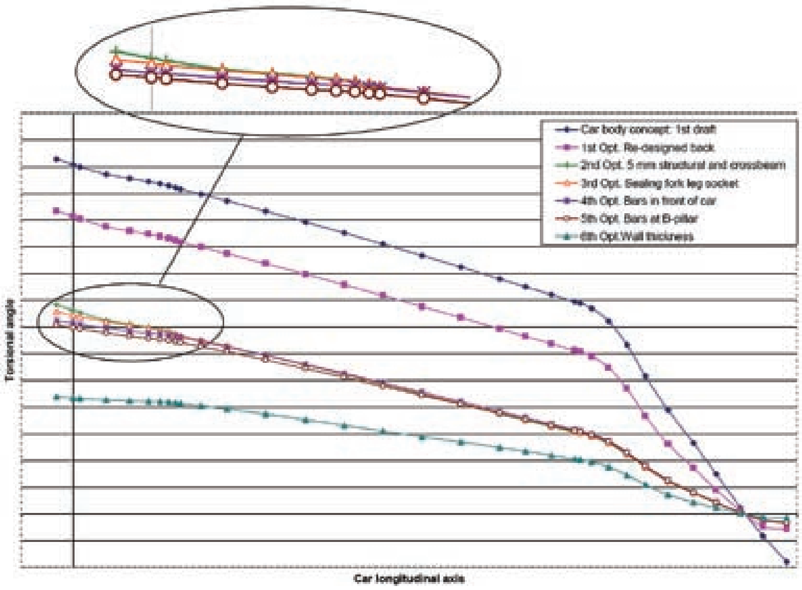


Figure 7: Torsional lines of the single optimisation steps of the concept car body

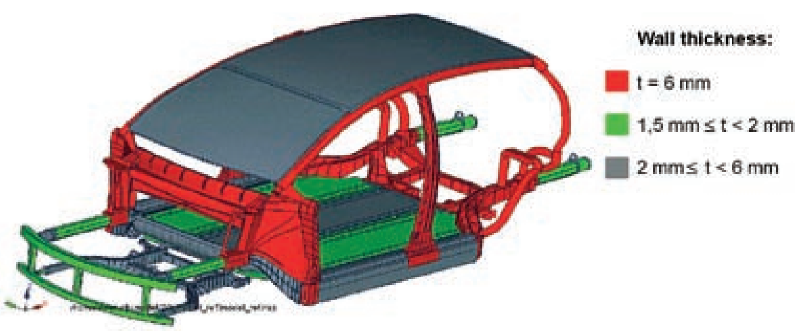


Figure 8: Result of the first wall thickness optimisation – red: dominant areas regarding torsional stiffness

ning the torsional stiffness. That's why we used a calculational wall thickness optimisation by means of FEM, with which we were able to indirectly draw conclusions as to the sensitive areas.

The goal function of this (only indirectly utilised) wall thickness optimisation is to minimise the car body weight. An auxiliary condition is to achieve the torsional stiffness of a comparable standard car built with the steel-shell method.

The design variables of the wall thickness optimisation are the wall thickness of the single components. The upper and lower limit for the wall thickness result from the calculation programme's elemental definition or the extruded profile process's technical limits, respectively. The initial thickness of all components is 2 mm and will be varied between 1.5 and 6 mm during optimisation calculation.

A strong increase of the wall's thickness in the computer simulated optimisation points to a dominant impact on the component regarding the torsional stiffness.

In **Figure 8** the components which need to have a wall thickness of 6 mm according to the optimisation to achieve the specified torsional stiffness, are marked red. The components with a wall thickness of less than 2 mm are marked green.

As described above, we assumed that the components having experienced an increased wall thickness during optimisation, will have a dominant impact on the torsional stiffness. It has become clear that the floor along with the front structural beam cannot contribute to an increase of stiffness really. Compared to that, the back's structural beams, designed as a cast element, and the area around the back wheelhouse carrier as well as the C-pillar have a large optimising potential. A-pillar, also designed as a large cast element, front suspension strut mounting, disk crossbeams, roof frame and B-pillar all have a significant impact on the torsional stiffness. Thus an important step towards identifying the dominant areas has been completed.

4.2 Basic Measures for Increasing the Static Torsional Stiffness

In case achieving the required torsional stiffness was limited only to optimising the wall thickness, the concept model would have a car body weight within the range of the steel-shell construction of the reference car. This is far too heavy for an aluminium construction.

So the goal was to achieve the specified torsional stiffness along with a significantly reduced car body weight through specific structural changes in the aforementioned areas of the concept car body. **Figure 9** shows an overview of the optimisation steps which have been carried out regarding the most important key values along with the degree of optimisation compared with the standard model concerning torsional stiffness. Furthermore, the respective lightweight construction quality (as low as possible), a measure for the quality of transferring the weight into stiffness, and the respective car body weight are given.

As the first measure the back has been totally restructured. A C-pillar and a D-pillar replaced the C-pillar, the wheelhouse carrier was shaped even further and the two D-pillars were connected with each other with a crossbeam. This crossbeam is additionally connected with the two back longitudinal beams. The torsional stiffness is noticeably increased with the wall thickness still being unchanged (Figure 7, reduction of the torsional angle), but it still misses the stiffness aimed at, the stiffness of a standard car.

Another computer simulated wall thickness optimisation showed that the back part still had a heavy impact on the torsional stiffness. That's why a sensibility analysis was carried out as the next step to determine which component in the back could make the highest contribution to increase the stiffness. A sensitivity analysis determines the impact of a single parameter on the goal value by changing only one parameter at a time

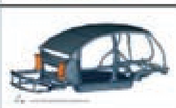
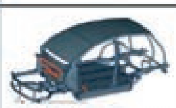
		Torsional stiffness	Lightweight quality	Car body weight
Concept model 1st constructional draft		34 %	140 %	48 %
1st Optimisation re-designed back		40 %	132 %	53 %
2nd Optimisation Wall th. = 5 mm front structural and crossbeams		58 %	101 %	59 %
3rd Optimisation Sealing openings of suspension strut		60 %	99 %	59 %
4th Optimisation Bars in car front		62 %	98 %	61 %
5thOptimisation Bars at B-pillar		64 %	96 %	62 %
Final optimisation Wall thickness optimisation		103 %	65 %	67 %
Comparable standard car		100 %	100 %	100 %

Figure 9: Overview of the single optimisation steps and their key values

while the rest remains constant. Here, the wall thickness of only component (structural beam, wheelhouse carrier, C-pillar, D-pillar, crossbeam) was increased from 2 mm to 4 mm and up to 6 mm, while the resulting torsional lines were being watched. The outcome was that the highest stiffness increase, while increasing the car body weight only slightly, was achieved by thickening the walls of the structural and crossbeam to 5 mm. This measure resulted in an increase of the torsional stiffness to 58% of the compared stiffness and, at the same time, had a positive influence on the torsional line's curve. The stiffness transmission from the passenger cell to the rear of the car was much more even.

In the area of the front of the car the torsional line still had a too large gradient. Sealing the holes in the front suspension strut mounting gave an improvement of 2 %, while the car body weight only increased very slightly. Furthermore, the impact of different bars in the front part was investigated upon with another sensitivity analysis. The result was that the torsional stiffness was significantly increased by a dome strut connecting the two suspension strut mountings with the disk crossbeam, diagonal bars in the area of the front wall and a bar in the area of the A-pillar base. These bars are only to be understood as hints towards areas still to be optimised. The diagonal bars, for instance, have a similar effect to that of a panel which could be produced with a thin piece of metal sheet. The bar at the A-pillar base gives a hint in the direction of rounding off the part between the A-pillar base and the sill. Looking at the torsional line one can see that the gradient in the front part area could be significantly lowered through these measures.

Another positive impact was achieved by rounding off the upper B-pillar joint, also indicated through bars. The torsional angle curve (torsional line) could be lowered further by applying this method.

In the end, by optimising the wall thickness the torsional stiffness of that of a comparable standard car built with the steel-shell method was achieved, while at the same time the weight was cut down to 67 % of the standard car body.

The last step was to determine the bending line, the diagonal measure change and the dynamic stiffness values which are also within the allowed range.

5 Summary

This article introduces the car body concept "Functional high integration" developed within the scope of the joint project "Fascination car body construction" of the Volkswagen AG Group Research and the Technical University of Braunschweig. It is about an aluminium car body construction method featuring component and function integration, based on extruded profiles and large cast components in the area of supporting structural elements. The structure consists of a heavily reduced number of components compared with conventional construction methods. Through this and the component design suitable for production, tool and investment costs were able to be cut down significantly. Existing profile cavities are, among other things, used for air, water or fuel. In combination with an optimised power transmission and a component design suitable for the bearing the load and a manufacturing method chosen accordingly, a weight reduction was achieved as another benefit of this approach.

Furthermore, apart from displaying the component and function integration on the basis of the floor pan component, the approach for designing the new car body structure regarding stiffness was described. Based on the first conceptional draft, hints on constructional measures for increasing stiffness were given through static calculations. We were able to show that the stiffness of a comparable standard car built with the conventional steel-shell method could be achieved along with a cut-down in weight by applying the suggested measures.

The next step will be to take a closer look at the productibility and the costs of the single components and to evaluate the described car body concept anew. ■