CAE Simulations for Passive Safety focused on the Porsche Cayenne - the Transition to New Technologies

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ABSTRACT

Simulation technologies are methods which have been traditionally applied in automotive engineering for a long time. Over the decades, enormous progress has been achieved in both, the simulation methods and the CAE-programs used. Thanks to the high efficiency levels of the current computer generation and the use of economically priced commercially available hardware such methods are being applied on a wide-spread basis today. Visionary concepts of the past are turning into reality.

When considering the process of automotive engineering and the futuristic potential inherent in those methods, it becomes obvious that virtual automotive development still is in its infancy. This applies to the whole range of options from the coupled parallel/sequential simulation of manufacturing processes to the cross-functional simulation, including efficient management systems designed to handle the entire CAE process [1]. At the same time, the CAE model transfer between the various expert departments on the one hand and between the OEMs and the system suppliers on the other has to be optimized while developing suitable documentation- and Data-Mining systems [2]. What must also be mentioned is the need for continuous updating of the traditional methods in terms of numerical data and technical content. Currently, in the early phases of automotive engineering, the development activities are mostly handled in a sequential manner [3,4]. That is where the newly conceived CAD/CAE methods come in quite handy: They allow component geometries to be prepared on the basis of topologies and parameters and subsequent modifications to be implemented quite rapidly [5]. For the synergy effects of these innovative design tools to be made full use of it is necessary, however, to combine the parametric concept geometry model with mathematical optimization methods. This approach allows the inherent design potential to be fully opened up and thus the defined targets to be reached in the most optimum way [6]. Even though such numerical design strategies have already been used in certain areas, their wide-spread and consistent introduction into conceptual design is yet to come. It is with these innovative CAD/CAE strategies that the present paper is dealing.

INTRODUCTION

The virtual development of the Cayenne [7] was faced with two central tasks: to ensure the geometric compatibility of the vehicle components and guarantee the safe functioning of the complete vehicle and its individual components. The geometric layout of the components is confirmed virtually by means of digital geometrical prototypes - generally called “Digital Mock-Ups“ (DMU) - and complemented by reference hardware set-ups. To confirm the functional reliability, digital function prototypes are used which are referred to as simulation models.

Geometric confirmation of components

The Digital Mock-Ups and reference hardware were realized early on in the concept phase. The aim was to enhance the efficiency of development by providing the responsible teams and expert departments with early documentation and coordination of the respective space requirements.

Confirmation of functions

Unlike the geometric confirmation of components, the functional confirmation necessitates simulation models of individual components, sub-systems and the complete car. Depending on the type of functional confirmation required, different simulation models are generated which allow problems from various areas (e.g. structural mechanics, rigid-body mechanics and fluid mechanics) to be settled using both discrete models (spring-mass models) and continuous modes (beams/shell/volume models).

The development of the Cayenne's structure has been decisively marked by crashworthiness aspects. The Cayenne is in compliance with both current and future worldwide legislation and customer requirements. In addition, the car fulfils a range of supplementary in-house demands. The constantly increasing number of crashworthiness criteria is shown in **Figure 1**.

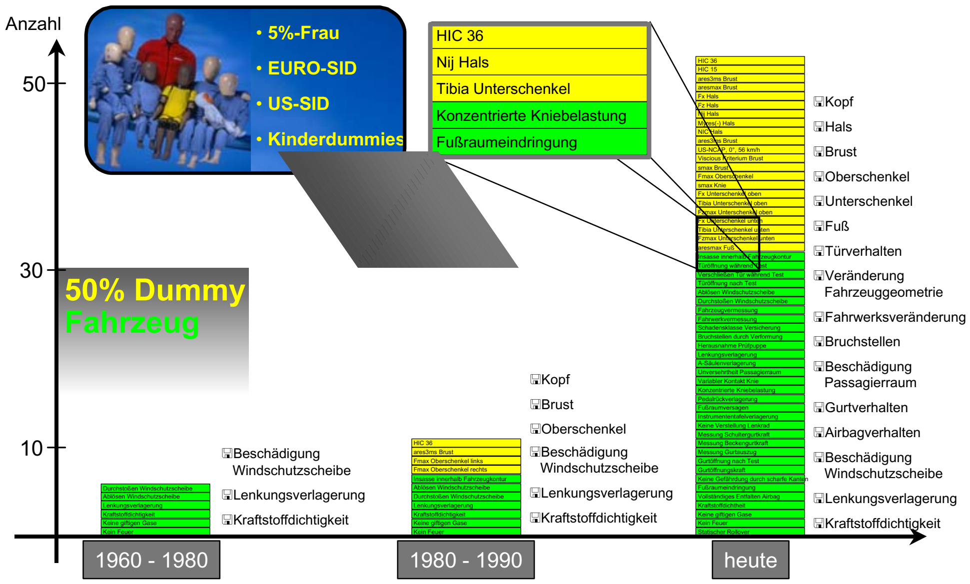

Figure 1 Worldwide crashworthiness criteria [8]

Application of simulation methods for the confirmation of functions

Aims of CAE application

The work of the development engineers was particularly supported by the early and intensive use of CAE methods with special focus on the forecasting quality. This helped to avoid expensive and time-consuming development loops and also allowed the number of high-cost test carriers to be substantially reduced: some few only were needed for the verification, fine tuning and quality assurance of the components and subsystems. It is thanks to this approach, that it was possible to meet the ambitious development deadlines of the Cayenne project. Yet, the application of CAE was not an end in itself but always seen in competition with the classical test-oriented development methods with the aim being to guarantee the best possible efficiency in terms of cost, time and quality.

The development strategy called for work-sharing with component and system suppliers which also resulted in new challenges for the Simulation and Calculation department regarding CAD/CAE process control. To be able to correctly assess the overall system with the help of CAE it was necessary to obtain a sufficiently precise description of the supplied components and systems and to harmonize the time schedule and content of the CAE models with each of the suppliers.

Integration into the development process
In view of the progressive increase of modification costs versus development time it is essential for concept-relevant problems to be solved in the earliest phase of a development. **Figure 2** illustrates an example of CAE application in vehicle development.

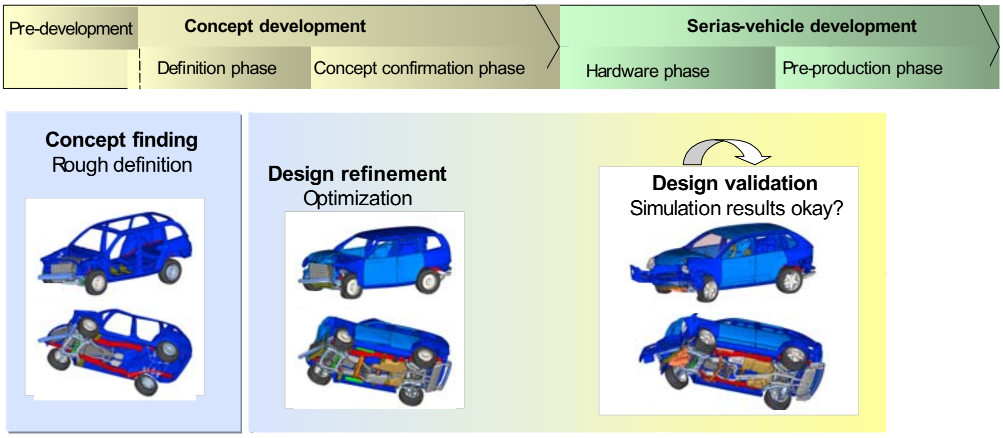

Figure 2 Complete-vehicle CAE models used in various development phases

- **Concept development**

In the early phases of the product creation process, the focus is on virtual prototyping. At this stage, tests are primarily made via computers. On the basis of collective loads component configurations were simulated as well the interaction of all the parts of which a vehicle is made. The concept development phase ends with preliminary component tests, e.g. a hydro pulser endurance run of the load-bearing components, and in first hardware tests carried out to assess the endurance strength and safety of the vehicle.

- Definition phase

In the definition phase, the concept variants were checked for their fulfilment of the crashworthiness and stiffness requirements with minimized weight. The drivetrain was defined in a way so as to obtain an optimum compromise between the Porsche-typical on-road handling characteristics and optimum response on off-road tracks and ice- or snow-covered road surfaces.

- Concept confirmation phase

In the concept confirmation phase, the chosen overall concept was checked for its compliance with the crashworthiness criteria and demands on driving stability. At the same time, the strength-relevant collective loads were determined and the preliminary dimensions of all components were stipulated.

- **Series-vehicle development**

In series-vehicle development, the component and system functions were defined, optimized and confirmed well before procurement started thus making it possible to perform tests with largely functionally optimized solutions which came as close as possible to the final production variant.

- Hardware phase

The next step in series-vehicle development were the hardware phase in which the Testing department was supported, for example, by specific test specifications prepared and executed with the aim of minimizing the overall test expenditure. Based on the results of these tests, potential of optimization were identified. Improvements were also performed for quality assurance. The computer models were validated with the help of those test results.

- Preparation of series production

The series-production-preparation phase mainly served to evaluated production-related optimizations and to provide the evidence required for type approval.

Simulation models from various CAE domains

Unlike the geometrical confirmation of components, the confirmation of a component's functional reliability requires models from various CAE domains, such as, e.g., structural mechanics, rigid-body mechanics and flow mechanics, **Figure 3**. As the Cayenne development progressed, the complexity of the models continued to increase while the quality of the respective data was constantly improved. The validity of the CAE models was permanently monitored through corresponding component- and complete-vehicle tests.

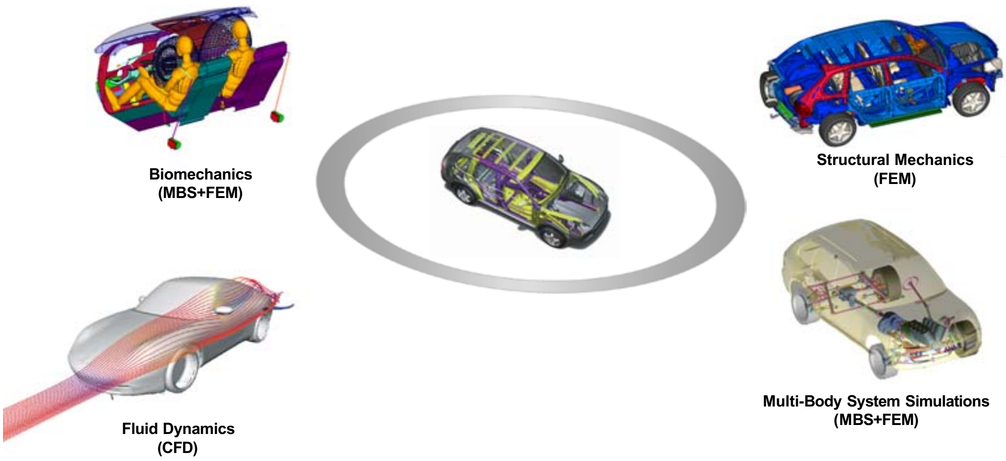

Figure 3 Digital models for different CAE domains

- Multi-Body System models (MBS)

Unlike FE models, the so-called multi-body models do not require any geometrical descriptions yet and therefore could be generated early on in the definition phase. They were used to evaluate the driving dynamics and NVH properties and also served to determine the load data needed for operational-strength layout.

- Finite-Element models (FEM)

FE models were used to design the vehicle structure in terms of stiffness, strength, NVH properties and crashworthiness. This CAE domain relies on one common CAE model.

- Fluid-Dynamics models (CFD)

To safely realize the ambitious goals set for the Cayenne, calculations were performed parallel to the wind-tunnel tests with the aim being to determine the respective cooling-capacity requirements. The calculated results were used to optimize the radiator through-flow in the wind tunnel. In addition, CFD simulation was employed to assess the efficiency of the brake cooling system.

Virtual prototyping in CAE body applications

One of the most important tasks within the scope of complete-vehicle CAE is the generation of virtual prototypes for assistance during all development phases. Like the real prototypes, their virtual counterparts are used as cross-functional tools to answer questions and solve problems from all the expert departments involved in vehicle development, **Figure 4**.

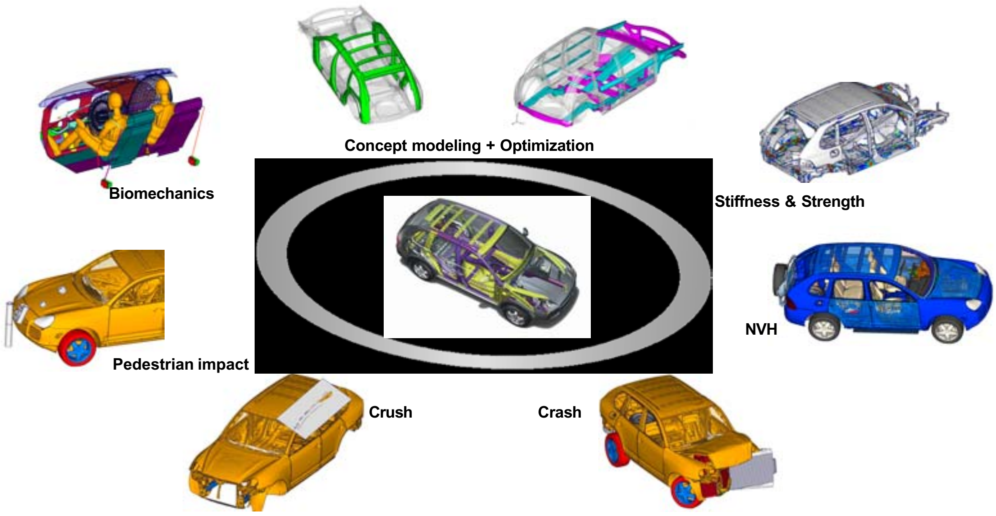

Figure 4 Digital models for various CAE body applications

FE crash models

The FE crash model, **Figure 5**, which provided the basis for the projection and optimization of all safety-relevant systems was the first CAE model to be generated. It served to evaluate components and systems such as belt and seat anchorage devices, seat systems as well as doors and roof systems and was also used to assess the complete vehicle and its various equipment options. Further, simulations were carried out which also included vehicle occupants and served to optimize the vehicle interior in terms of head impact and restraint system efficiency. Thanks to the modular structure of the model with virtual node-independent part connections [10], the loadcase, equipment or optimization variants could be submitted most quickly. In addition, a corresponding master model was generated which was continuously updated throughout the entire development process.

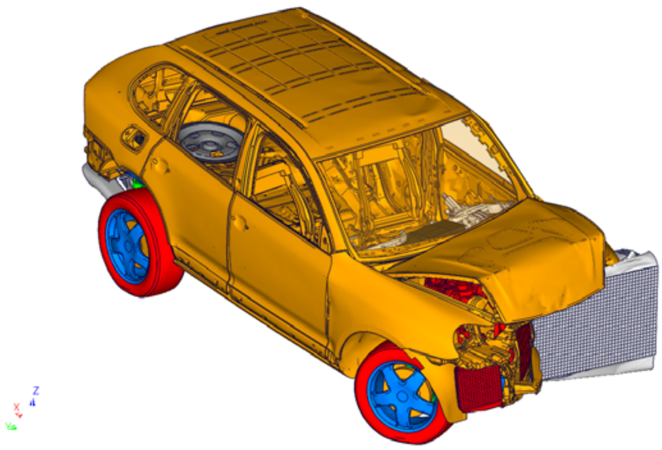

Figure 5 Cayenne FE crash model in the series-vehicle development phase

The time required for the generation of an FE crash model is shown in **Figure 6**. About 60% of this time are needed for the creation of the body model. Until a few years ago, most of this 60% share was used up for the generation of the body in white (BIW), doors, lid/hood and roof. Since the simulation procedure was extended to also include the greenhouse (e.g. NVH and FMH) the equipment elements had to be represented in a most detailed and complete manner. Usually, elements with edge lengths of 2 to 5 mm are used. The equipment account for about 30% of the entire body modeling expenditure.

FE rigidity models

FE rigidity models were used to check whether the operation-related deformations of the body, engine, transmission, and chassis remain within the function-relevant statical and dynamical aims. The specified torsional rigidity of the body was reached through consistent optimization.

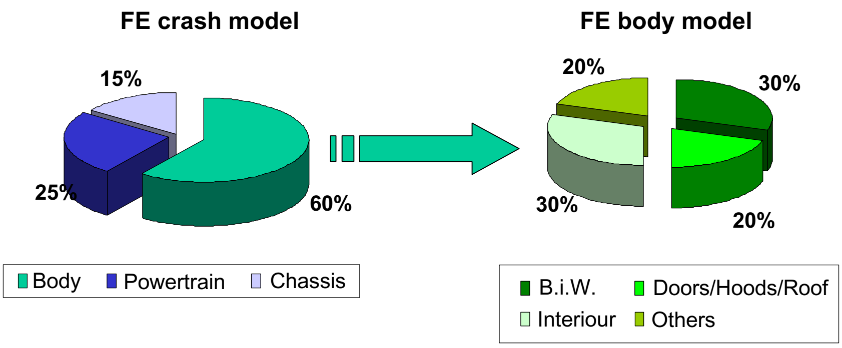

Figure 6 FE crash model generation expenditure

FE strength models

The FE strength models served to assess the response of the vehicle structure under normal operating loads. They differ from the rigidity models because of their considerably more detailed description: depending on the development status, geometrical details in the range of several millimeters are represented. In the strength calculations, structural properties - such as, e.g., the contact forces at interfaces - are taken into account which usually can be neglected in stiffness calculation. Special attention was focused on the force-transmission interfaces between the chassis and body.

Innovative design tools

The early phases of a vehicle development project are of particularly great significance since, at that level, demands and modifications do not entail any consequential costs yet because the vehicle concept still is at a virtual stage. Anyhow, even though information about the vehicle properties and the manufacturing process are incomplete, it must be possible to make conclusive and reliable decisions on alternative vehicle concepts in that early concept phase already.

That is where the afore-mentioned innovative CAE concept tools are brought into the play to efficiently support the decision-making departments in the concept phase of an automotive development. During the early project phase, the concept-finding process must be backed up by analytical layout formulae - or, in other words, Computer-Algebra-Simulations (CALS) - and future-oriented design grammars, **Figure 7**. Knowledge-based tools and Data-Mining techniques must be applied in order to fully benefit from the simulation results – an approach which helps to detect and minimize risks at the earliest possible development stage. Further, these tools allow design concepts to be assessed and preselected at the interface between Advanced and Concept Engineering.

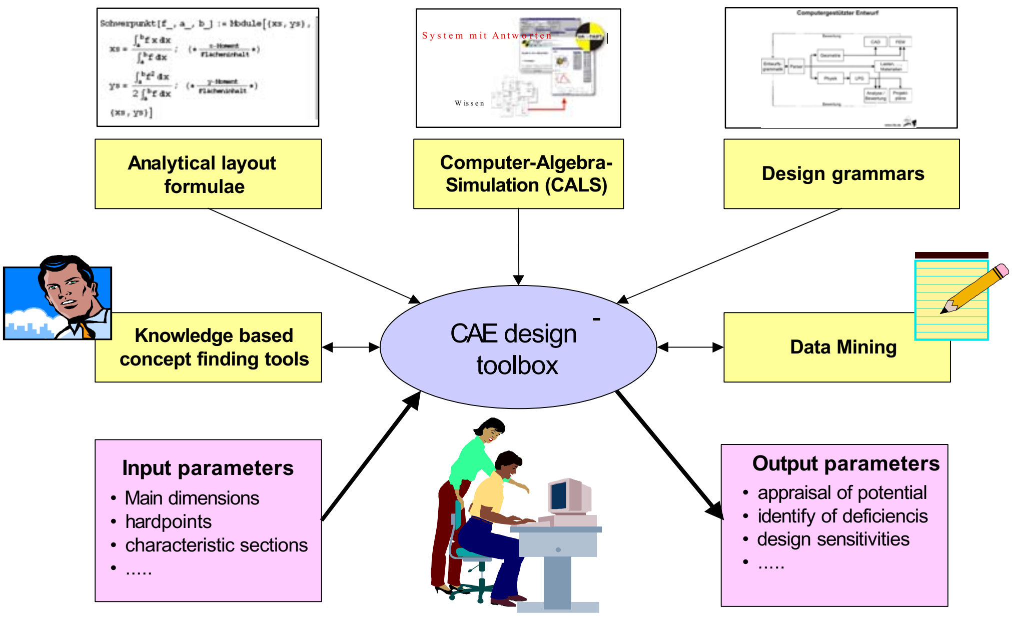

Figure 7 Toolbox for CAE-support in the early development phases

CAE simulations have proved their worth in terms of both, the confirmation of operational reliability and as helpful decision-making tools. Frequently, however, the number of design parameters is so great that even experienced design engineers might find it difficult to make right choices for an optimum design solution. Fortunately, today, they can rely on what is called parameter optimization – a method which allows design parameters to be selected in such a way that a design is realized which represents an optimum solution in terms of quality.

The optimization strategies employed can be roughly divided into deterministic and probabilistic methods. While the classical deterministic simulations ignore the uncertainty aspect, probabilistic simulations make allowance for the fact that real systems are always fraught with a certain degree of uncertainty (scatter). Probabilistic simulations are the only way of determining the consequences of such uncertainties for the efficiency (robustness) of a system in the early stages of a development and thus allow suitable corrective measures to be taken ("Uncertainty Management"). A suitable approach to solve the afore-mentioned problems are stochastic simulations using the Monte Carlo method. Today already, the design variables are optimized on the basis of a parametric SFE CONCEPT body model (variation of geometries) [5]. In the future, this approach will be complemented by a second method using a body model described by design grammars (variation of topology) [9], **Figure 8**.

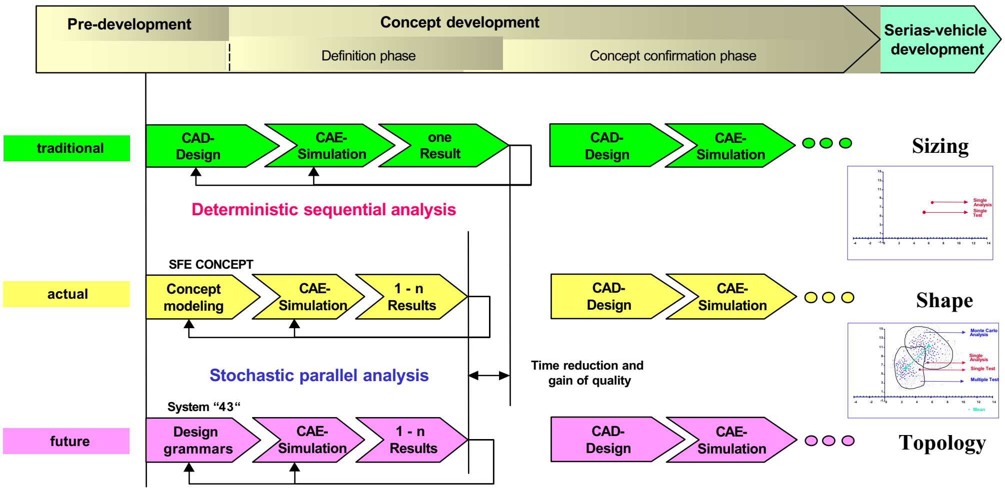

Figure 8 Change of paradigms through the introduction of new CAE design tools

Summary and Conclusions

Today's CAE applications are based on traditional development sequences: A concept is first realized by means of CAD and then checked for its functional reliability by means of CAE. When using this approach, however, the CAE results can be made available with a considerable time lag only so that quite frequently, important concept decisions must be taken without prior confirmation by CAE. To guarantee efficient CAE support also in the early phases of a vehicle development, appropriate tools and methods must be provided which are specifically conceived for the design process and which enable the CAE engineer to rapidly identify the influencing parameters, work out recommendations and thus actively participate in the concept development process.

The functionality of the concept geometry is confirmed by performing FEM simulations on the basis of a topology-based parametric vehicle-concept model. These simulations help to rapidly evaluate and compare different concept variants under consideration. The geometric design variables of the concept model are varied by way of stochastic optimization in order to identify relevant design parameters and confirm the functional reliability at an early project stage. The resulting optimized concept geometry is then imported into the conventional CAD systems allowing the actual production-body development to be started.

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