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Integration of aerodynamic simulation and design in conceptual automotive development

Mario Hirz, Martin Prenner, Severin Stadler
Graz University of Technology, Institute of Automotive Engineering
mario.hirz@tugraz.at

Abstract

Conceptual automotive development processes are characterized by a wide range of different working fields and influencing factors, which leads to the participation of diverse departments and disciplines. An optimized interaction of the involved parties based on efficient collaborative development processes, using computer aided tools, methods and strategies states an important factor for a successful development. The present publication focuses on the optimization of aerodynamic investigations in conceptual vehicle development. The main characteristics of aerodynamics are determined during initial development phases, because the early vehicle styling process defines the general shape of the car's outline. An early optimization of the vehicle main shape by use of computational simulation methods enables the effective consideration of aerodynamic requirements during the exterior styling development phase. This procedure enables a reduction of modification effort in subsequent engineering processes.

Keywords: computational fluid dynamics, computer-aided design, aerodynamic development, automotive concept phase.

Introduction

Automotive full-vehicle development processes start with the definition of product specifications, followed by the creation of initial vehicle exterior styling proposals under consideration of the general vehicle package configuration. In this early phase, highly flexible vehicle models can support the development and data handling of numerous variants and can enable an efficient optimization that takes into account legislative guidelines, styling and technical functionalities, and that helps to address the issues of drive-train configurations, energy storage systems, vehicle driving characteristics and much more. Integrated development strategies, including parametric associative geometry creation, interlinked with simulation and computation procedures, are applied to fulfil the requirements of the multidisciplinary working packages during these early development phases [1].

In this way, the initial stages in the creation of new cars are characterised by variant changes, alternating definitions and iterative actions, which are influenced by legislation, crash and safety standards, customer demands and of course the vehicle styling [2]. The main characteristics of aerodynamics are determined during primary development phases, because the early vehicle styling process defines the general shape of the car's outline. An important factor for a successful aerodynamic development states an optimized interaction between the styling process and technical engineering disciplines based on efficient computer-aided methods and strategies.

Today, vehicle styling is mainly created in computational styling software (CAS), which supplies subsequent engineering processes with geometrical information of different visible interior- and exterior surfaces of a car. This geometrical information is transferred from CAS into computer-aided design (CAD) software to be revised to fulfil the different technical requirements in view of surface quality, tolerances and data formats. Implemented in a vehicle product structure of a comprehensive CAD model, the styling surface data influence the boundary conditions of several engineering procedures. In case of the exterior surfaces of a new car model, the styling surfaces are considered in the vehicle packaging, the development of vehicle and pedestrian safety, in ergonomics investigations and of course in the aerodynamic optimization (Figure 1).

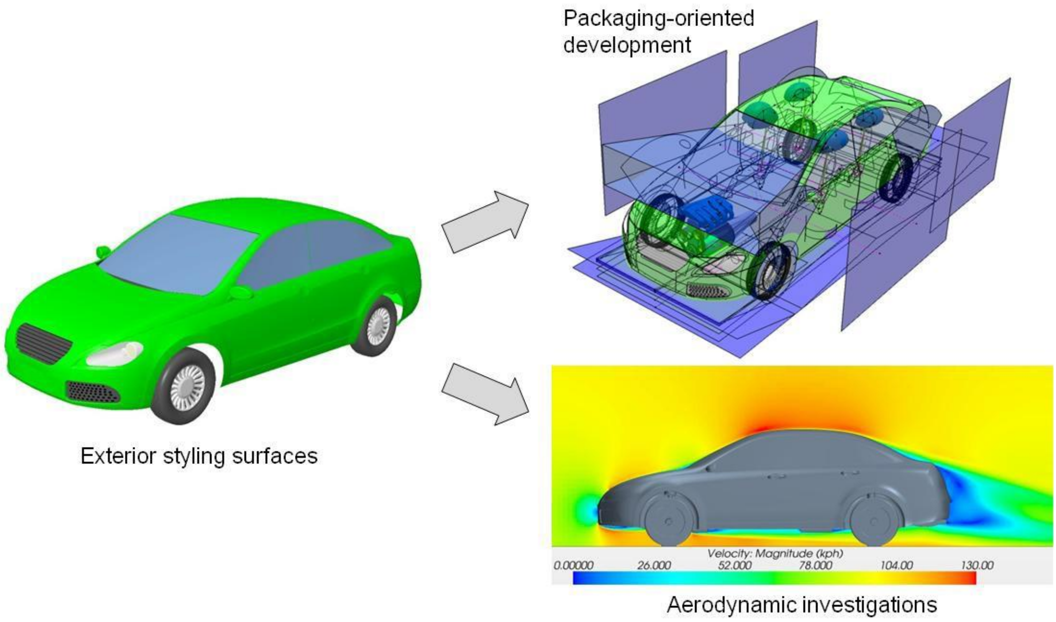

Figure 1: Exterior styling data as a basis for packaging-oriented development and aerodynamic investigations

Aerodynamic investigations in automotive development

The aerodynamic behaviour of vehicles directly influences the air resistance and thus the overall driving resistance. In case of automobiles, the drag is one of the important influencing factors of the fuel consumption [3]. In addition, the aerodynamic lift has an important influence on vehicle driving behaviour, especially at higher vehicle speed. These are the reasons, why the optimization of aerodynamic plays an important role in the development of new models. Besides several technology-based influencing factors, e.g. the type of vehicle, its size, the flow characteristics of the cooling system and others, the exterior styling plays a major role of aerodynamic investigations. In this way, the prediction of aerodynamic characteristics of different early styling proposals is carried out in parallel to the development of the vehicle outline. Due to the fact, that in these initial phases styling surfaces mainly exist as virtual models within CAS-software, the assessment and evaluation is performed based on computer-aided aerodynamic simulation processes.

In the early conceptual phase, the general shape of the car is developed and optimized; detailed modifications are performed in later steps. As an example, the angles of the front- and rear window, the shape of the engine hood, the car roof-contour and the rear end are defined by stylists and evaluated regarding their aerodynamic behaviour in more or less parallel simulation sequences. This simultaneous development requires a close co-operation of styling and simulation departments and in addition an efficient data management process.

Another challenge of this early development phase represents the uncompleted data status of the vehicle model. Due to the fact, that important components and modules of a new car model are developed in later steps, there is a big lack of information for a timely evaluation. With the target to bring the simulation close to early exterior styling development, the present approach provides a start-up model, which includes several simplified components for the creation of a conceptual vehicle model including all required components and modules for aerodynamic investigations.

Figure 2 shows an exemplary workflow of aerodynamic investigations in automotive development. The CFD-based evaluation and optimization starts very early in the concept phase, supporting the styling process of a new car model. Once having available scaled hardware models of the car (e.g. clay or foam models), the wind tunnel development starts and delivers both, measured values of aerodynamic behaviour for the support of simulation processes and the possibility of aerodynamic fine-tuning by application of detailed modifications directly at the hardware model. In later development phases, e.g. in the series development, the wind tunnel development becomes more and more important because of the availability of detailed hardware models including all mechanical components. The diagram shows, that the main potential for aerodynamic improvements can be achieved in the early phase during the definition of the general vehicle shape characteristics. Throughout later development phases, the car's main outline is determined; aerodynamically relevant modifications are performed by application of detailed modifications only. In the exemplary development process, 70% of the drag coefficient reduction (c_d) was achieved in the concept phase by optimization of the exterior surfaces. This fact points to the significance of CFD-based optimization in initial vehicle development.

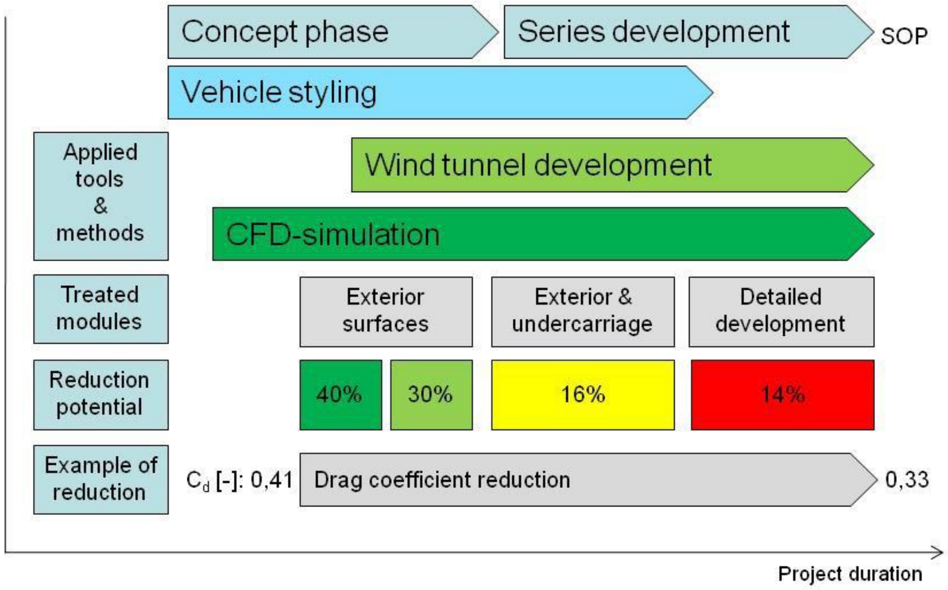

Figure 2: Exemplary workflow of aerodynamic investigations
in automotive development, according to [4]

Geometry model

The geometry model is developed within CAD-environment [6] and includes all geometrical information of the vehicle. In the course of conceptual design processes, the styling surfaces are delivered from CAS and integrated into the CAD model. Due to the fact, that the vehicle styling is accomplished under different boundary conditions and by use of different software packages, there often occur problems in the data transfer from CAS to CAD [5]. In any case, the delivered surface data have to be modified according the technology-based requirements of modern parametric-associative design. This includes the repairing of gaps, overlapping, discontinuous surfaces and other erroneous elements as well as the consideration of the higher demands on geometrical tolerances. In addition to the lack of surface quality, styling models do not include mechanical components or modules of undercarriage, wheels, suspension, brakes and others, which are basically required for an aerodynamic evaluation of a vehicle concept.

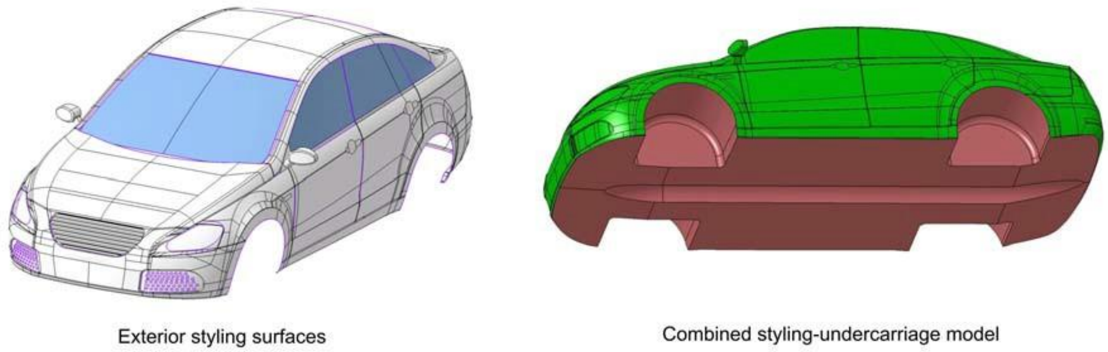

Figure 3: Example of exterior styling surfaces and a conceptual combined styling-undercarriage model

In the present approach, these missing technically detailed surfaces are added within the design process by use of a predefined catalogue of CAD models of specific modules and components. These models are combined in a CAD-based product structure and have a variable, parametric-associative structure which can be adapted to the corresponding exterior styling surface. Figure 3 shows an example of exterior styling surfaces and a conceptual combined styling-undercarriage model.

The parametric CAD model consists of a skeleton, which controls the main dimensions, an undercarriage module, suspension components including wheels, an engine compartment composed of dummy geometries of the corresponding components, several attaching parts and the geometry of the simulation environment. All modules are managed in a CAD-based assembly, whereby the geometrical dimensions are controlled by a generic parameter structure. Depending on the dimensions of the treated vehicle concept, the geometries are adjusted and positioned by defining the corresponding parameter values. In the following step, the components are joined with the imported and revised styling surfaces and form a vehicle geometry model, which fulfils the requirements of the subsequently performed CFD processes. Finally, the simulation area is defined in CAD too and the prepared geometry is transferred from the CAD environment into the pre-processor of the CFD software for further operations. Figure 4 shows a selection of components of the parametric CAD-model for early aerodynamic investigations.

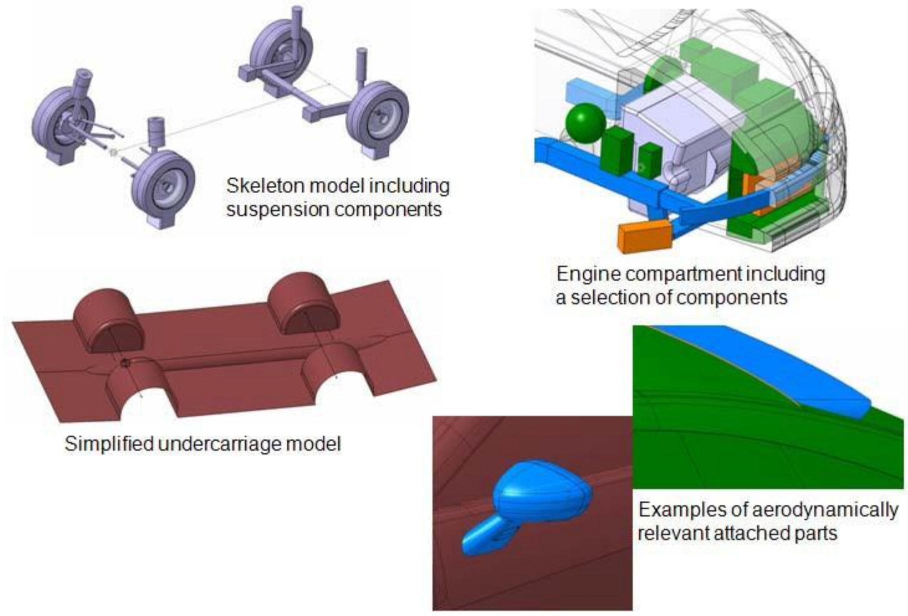

Figure 4: Components of the parametric CAD-model
for early aerodynamic investigations

CFD simulation

The aerodynamic simulation is performed in commercial CFD software [7], whereby the conventional simulation process has been optimized under consideration of the specific requirements of conceptual development. Figure 5 includes the sequences of the conventional and the optimized aerodynamic simulation process.

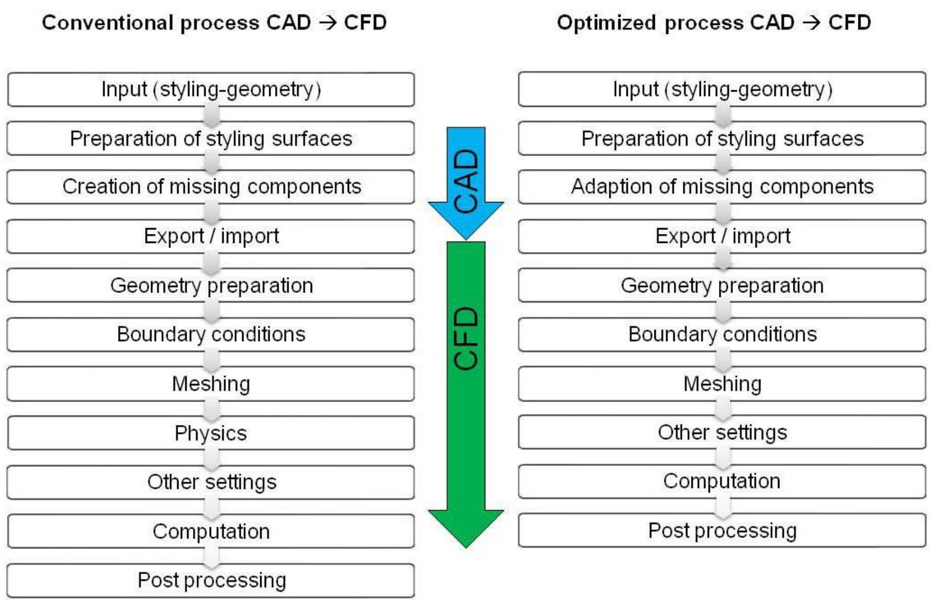

Figure 5: Sequences of a conventional and an optimized
aerodynamic simulation process [8]

The conventional process starts with the input of geometry followed by CAD-based surface modifications, including the preparation of styling surfaces and the implementation of missing components. The data transfer from the CAD environment into the CFD-software is carried out by use of neutral data formats. The pre-processing sequence includes a final preparation of geometry, the definition of boundary conditions, model meshing and the input of fluid mechanics related settings and adjustments. After having performed the computation procedure, the simulation results are worked out in the post-processing sequence. The conventional process has an iterative workflow and offers potential for improvements [9].

The optimized process includes several modifications. CAD-based start-up models contain variable template models of components for the early creation of comprehensive full vehicle models for aerodynamic simulations. A standardization of data import and export between CAD and CFD simplifies the geometry data exchange by use of predefined settings and adjustments. The CFD-simulation process itself is optimized by implementation of a start-up file including different information and predefined adjustments. In addition, the CFD workflow is partially automated by use of specific programmed routines (macros). The start-up file for CFD includes three different meshing regions (surrounding areas, radiators and fan) with 21 local mesh refinement areas.

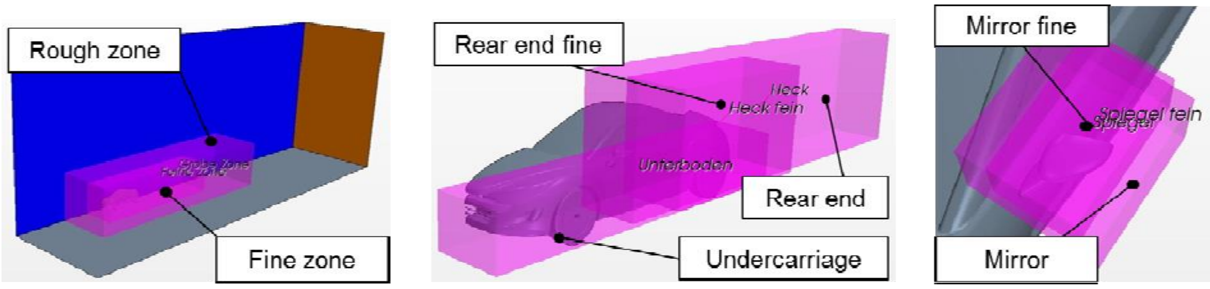

Figure 6: Examples of local mesh refinement areas of the start-up file for CFD [8]

These specified local areas cause a reduced total number of cells and so a reduced computing time but also enable accurate simulation results at the same time. The systems of coordinates in this file correspond with those of the CAD-geometry model. Physical boundary conditions and pre settings as well as reports and plots for the subsequent post-processing are integrated in this file. To reach the targets of automation and reduction of time consuming pre- and post-processing, a macro based workflow has been developed. It starts with the import of neutral geometry data, followed by the preparation of the simulation area, the radiators or the fan and finally supporting the post-processing. In this way, the manual data processing is reduced significantly.

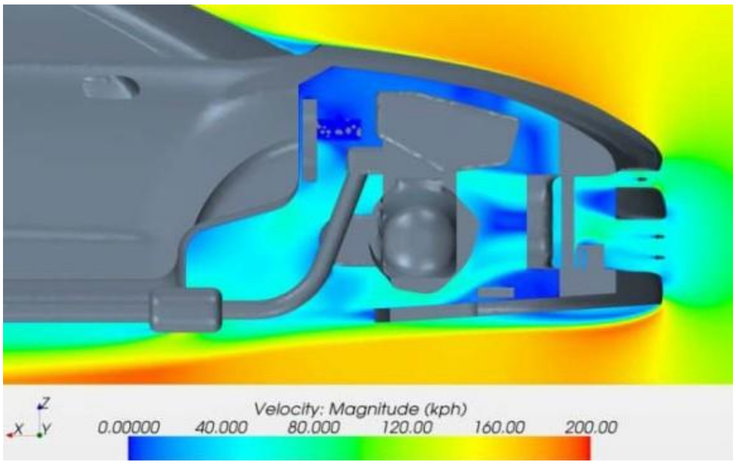

Figure 7: Engine compartment flow [8]

The post-processing section enables a visualization of flow- and pressure characteristics in different areas like the vehicle environment, the engine compartment or the cooling system. In addition, turbulences, flow velocities and pressure distributions can be illustrated. As a main result of the CFD simulation, specific values of drag- and lift coefficient are calculated, which serve as a basis for the assessment and evaluation of early vehicle exterior styling surfaces. As an example of post-processing results, Figure 7 includes a representation of flow characteristics through an engine compartment.

Conclusion

The present publication includes a study of aerodynamic simulation processes by application of computational fluid dynamics during conceptual development in the automotive industry. Based on this study, an optimized process has been developed, which covers the entire data flow, starting up with styling processes, the general vehicle layout and packaging studies within computational design software and considering several technical aspects, like crash- and pedestrian safety as well as legislation based boundary conditions. The generation of parametric start-up models and the programming of automated workflow-routines within the applied software packages form the basis for the creation of an optimized aerodynamic development process.

Combining the requirements of styling, design and simulation, the presented methods and strategies support an optimization of conceptual aerodynamic development by enhancement of data quality and reduction of computation effort at the same time. In this way, the publication includes major contributions for a further improvement of conceptual automotive development processes.

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