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Integration of Digital Mock-Up and Multibody Simulation in the Product-Development Process

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Abstract

Global competition in the automotive industry results in increased efforts to shorten development cycles while increasing the level of quality, maintaining costs in line with market requirements and accommodating a growing variety of new models. An essential step towards meeting this challenge is the integration of computer-aided (CA) technologies and methods in the product-development process.

Digital mock-up (DMU) and multibody simulation, the focus of this paper, have a strategic role at Audi, particularly in the suspension development. An overview of DMU technology will show the fields of application at Audi such as vehicle packaging, fitting simulation and clearance studies.

For the simulation of moving parts and assemblies in the vehicle during driving conditions, a complete DMU representation also requires including the movement information in addition to the static geometry information. An interface between the DMU system and the multibody simulation environment of ADAMS and ADAMS/Car provides a way of transferring the movement of parts calculated in the simulation into the DMU environment. The displacement information can be used for animations and for generating movement envelopes for clearance analyses.

Examples of a suspension assembly and an engine envelope will demonstrate the process of generating movement envelopes in the DMU system. The movement information for the suspension assembly is obtained from an elastokinematic suspension analysis in ADAMS/Car and for the engine envelope, movement results are provided by simulations with an ADAMS/Car vehicle model.

Introduction

The focus in the automotive industry on global competition and market requirements leads to shorter development cycles and a broad product palette while emphasizing quality, costs and time to market.

During the last ten years, the number of different models at Audi has grown continuously from three vehicle models series to more than twelve models and variants including niche products such as the TT roadster. Simultaneously, the development cycles have been reduced from about five to six years to the current three to four years.

Due to the limitations of traditional methods, the required increase in efficiency in the development can only be achieved through new techniques and processes. Examples are the use of synergy effects through cooperation and the integration of suppliers in the development and manufacturing process.

Another essential step is the integration of computer-aided (CA) methods in the product-development process. In this set of methods, digital mock-up (DMU) technology and multibody simulation play a strategic role at Audi.

CA-Methods in the Product-Development Process

The typical product-development process at Audi (shown in figure 1) is divided into two major phases:

1. Concept-development phase
2. Production-vehicle engineering phase

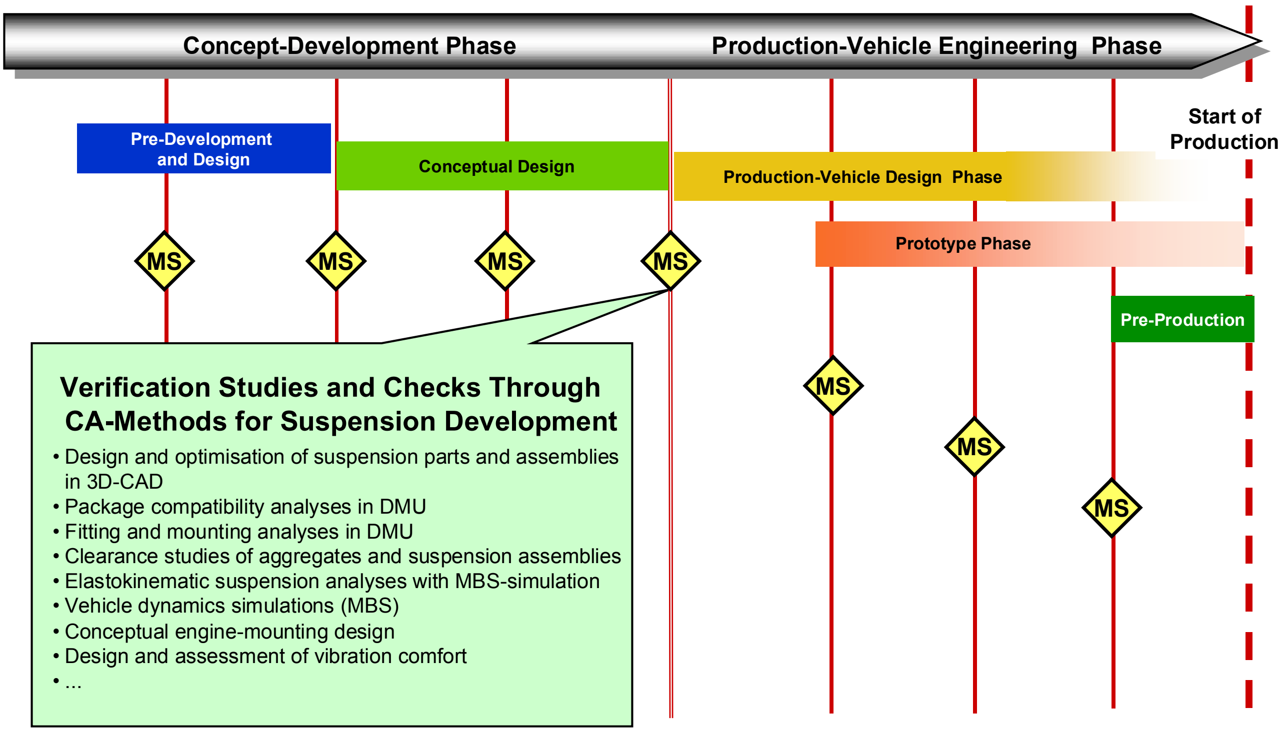

Figure 1: Product-Development Process

Each development phase consists of sections with milestones (MS) at which important decisions have to be taken based on the progress at the current state of development. In order to keep the development cycles short, reliable milestone decisions need to be made at a very early time in the development phase. This is called 'front loading' and means an increased investment of capacity at the beginning of a development.

Due to the fact that this takes place so early in the development phase, prototype hardware is only partially available, so that the necessary decisions have to be made on a software basis. At each milestone, virtual checks including certain investigations and analyses have to be performed using CA-techniques, thus contributing to increase the quality and reliability of decisions. Considering the process in the suspension development at Audi, the following virtual securing checks for verification have to be done during the concept development phase as a prerequisite at the milestone starting the production-vehicle-engineering phase:

- Design and optimisation of suspension parts and assemblies in 3D-CAD
- Package compatibility analyses in DMU
- Fitting and mounting analyses in DMU
- Clearance studies of aggregates and suspension assemblies in DMU
- Elastokinematic suspension analyses using multibody simulation
- Vehicle dynamics simulations
- Conceptual engine-mounting design considering engine movements during driving conditions
- Weight approximation
- Stiffness, strength and structural dynamics using finite-element analyses
- Topology optimization of suspension parts
- Fatigue analyses for safety relevant parts
- Design and assessment of vibration comfort
- Ride quality investigations
- Ergonomic restrictions and requirements

As the list of checks shows, DMU and multibody simulation techniques have a central and even increasing importance to ensure the milestones in the product-development process at Audi.

Digital Mock-Up

The term 'mock-up' describes a physical prototype or a model with which the completeness and the feasibility of building the product can be assessed and guaranteed; it is also used to guarantee the functionality and the fulfilling of the required properties of the product. Digital mock-up describes a computer-based description of a product that is used throughout the entire development process as a basis for making decisions about the development of the product. This definition is very broad, and its technical realisation represents a very significant challenge. In fact, simulation systems are known to have their limits, for example when dealing with aspects of vehicle comfort, flexible parts such as hoses or cables, or surface properties of different materials.

Currently, DMU is concentrated in three areas:

1. The description of the structure of a product
2. The visualisation of a product in a 3D-geometry system
3. Performing simulations on the basis of geometric information.

In order to handle a complete product - such as a vehicle with all its relevant parts - in a DMU system, the geometric data are transformed from their CAD representation into triangulated surfaces. In doing so, the quantity of data is reduced to about 10-20% of the original amount allowing large numbers of parts to be visualised.

In addition to visualisation, the DMU system determines how space is occupied. To do this, the 3D virtual space is divided into cubes of constant edge length, known as „Voxels“. Using the 3D geometric data, it is determined whether these cubes are occupied by a part or not, and this information is then stored in a so-called spacemap. Using these data, analyses of the geometry can be carried out very quickly, for example determining whether a cube is simultaneously occupied by two parts, thereby causing a collision. Currently, DMU systems mainly provide the following functions:

1. Checking parts for collisions
2. Checking that parts are maintained at a required minimum clearance from oneanother
3. Determining which other parts are in the geometric neighbourhood of a part

In this way, DMU offers the possibility of determining the geometric correctness and the feasibility of construction of a vehicle based on virtual techniques. This yields important information for making the milestone decisions in the product-development process before hardware prototypes are even available. Necessary changes to parts can thus be made early, avoiding costly changes to machine tools. As such, DMU represents a significant component in the product-development process and allows the goals related to quality, costs and time-frames to be reached.

With the development of the new Audi A2, the complete integration of DMU into the product-development process at Audi was started.

In order to ensure that the DMU analysis provides sufficiently high-quality results, it is necessary that the movement of vehicle parts be accounted for. One possibility is to interactively examine the part motion directly within the DMU system, simulating predefined part positions through transformations and rotations. Simple rigid-body motion can be simulated in this way, for example the glove-compartment flap, the ash tray, gear shifter and various mounting and unmounting procedures.

A sufficiently exact description of the complex motion of suspension and aggregate parts is only possible with multibody simulation or on basis of experimental results.

In the field of multibody simulation, Audi uses the simulation software ADAMS and ADAMS/Car as a strategic tool in the product-development process. Extensive functionality for suspension analysis and design has been integrated in a customised version of ADAMS/Car adapted to Audi-specific requirements and design methods. The Audi-specific functionality and specialized postprocessing is implemented in a system called 'KINELA' which is embedded in ADAMS/Car. In this way, it is also possible, for example, to generate special output data files in ADAMS that can be read by the CAD system Pro/ENGINEER (atp file) and 'Virtual Workshop' (atv file).

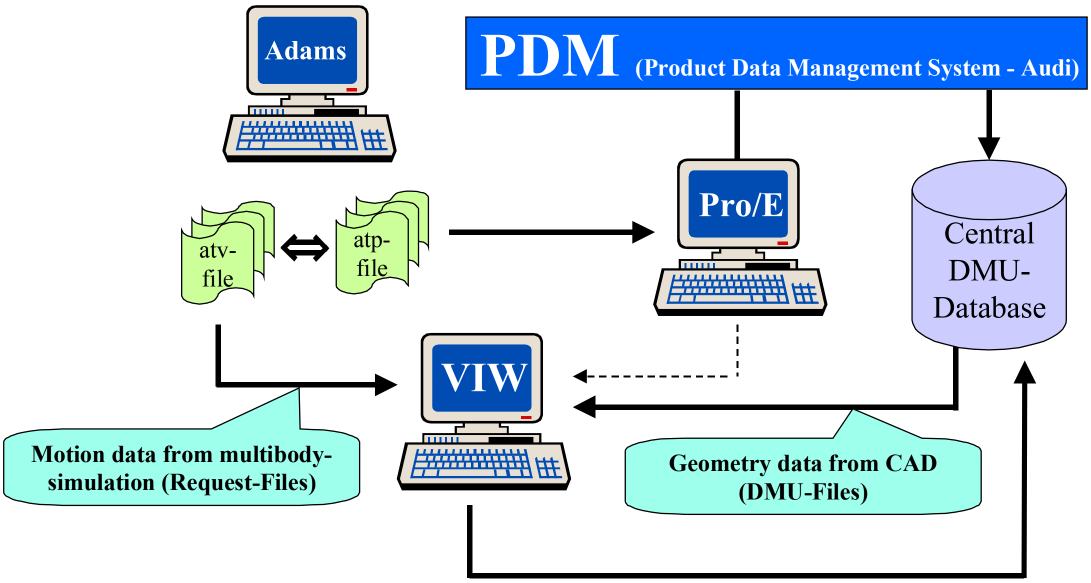

Figure 2: Dataflow for generating envelopes in the case of suspension systems

The current version 3.7 of 'Virtual Workshop' has an interface for reading in ADAMS request files. Using this interface, the motion data obtained from the ADAMS simulation can be read into the DMU system and can be coupled with the corresponding geometry data to simulate arbitrary kinematic positions of parts (see figure 2). It should be noted that in order to select the relevant positions for the DMU investigation, specific knowledge of the kinematics of parts on the part of the user is required. Moreover, the very large amounts of data are difficult to handle. This was the reason for using envelopes in order to represent the movement of parts in the DMU.

In the case of engine movements, currently the movement information is largely obtained from driving tests. At Audi, a non-contact incremental measuring system has been developed to determine engine movements during driving. In general, a set of different driving maneuvers such as snap start, driving on a bumby road and jolting, worthwile in assessing engine movement, are performed under different conditions. The measured displacement vectors of the aggregate can be transferred to the DMU system via a file interface to serve as movement representation. For certain driving maneuvers engine movements are also obtained from simulations with vehicle models in ADAMS/Car.

Methods for Generating Envelopes in the DMU System

In order to further reduce the amount of geometry data, 'Virtual Workshop' offers a means of generating geometric envelope surfaces of static and dynamic parts and assemblies. These envelope surfaces have no interior structure and therefore account for a smaller data quantity which can be handled more easily. Using this envelope technique, the entire motion envelope can be simulated for all relevant part positions while keeping to a very high degree the accuracy of the ADAMS simulation. This allows efficient DMU analyses of parts that execute complex motions.

'Virtual Workshop' offers several different enveloping mechanisms. The functions 'VOX-Surface' and 'VOX-Pack' were found to be the most successful at Audi. 'VOX-Surface' is based on the principle of the surface copy in which from at least six orthogonal spatial directions, only the surfaces lying in the foreground are copied to the envelope. In this way, interior surfaces in the envelope are eliminated. Experience has shown that envelopes generated with 'VOX-Surface' often have gaps and holes in them, although these are not significant for the DMU analyses. On the other hand this method guarantees a high degree of accuracy because the original surfaces are copied to the envelope.

In the 'VOX-Pack' mechanism, the virtual space is divided into cubes of arbitrary edge length. The external cubes are determined based on the geometry data. Within each cube, the contour of the 3D geometry is used if this geometry is convex. For concave surfaces a plain surface segment is generated to connect to the surfaces of the neighbour cubes, see figure 3. With this method, the surface contour is coarsened, analogous to a wrapping an object in cellophane. Hollow bodies with small openings can easily be simplified using this method. Another advantage of this method is that it always generates a single closed surface. Through this method the envelope surface differs from the original contour relating to the edge length of the cubes.

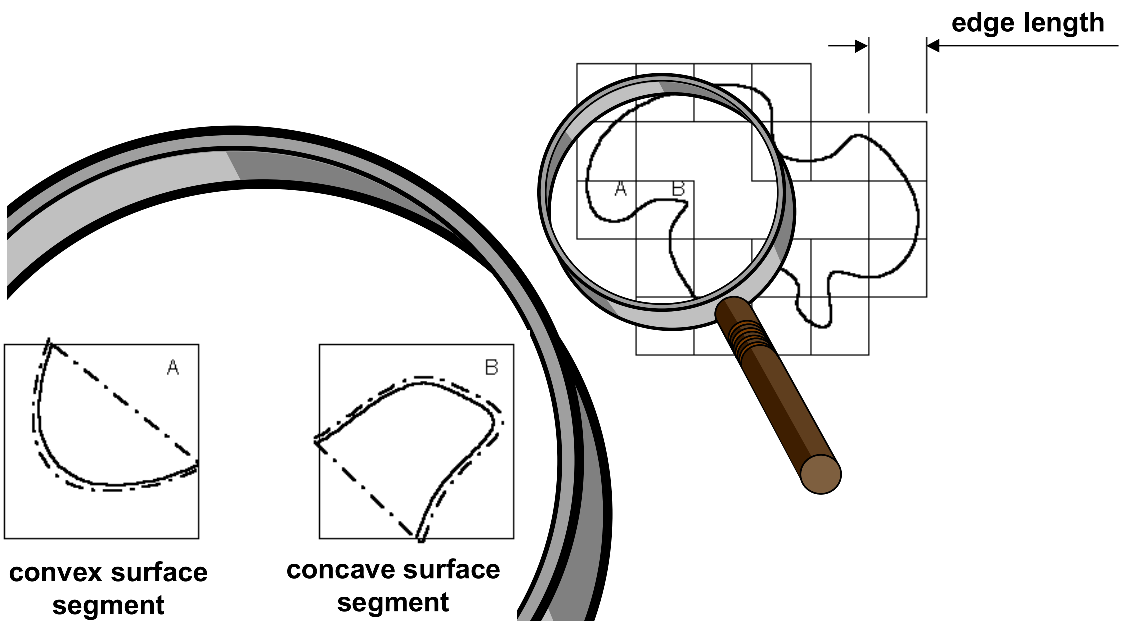

Figure 3: Mechanism of ‘VOX-Pack’

In order to generate the motion envelopes of suspension assemblies, the CAD data in Pro/ENGINEER are structured in such a way that groups of parts can be defined in correspondence with their motion information. This structure is saved within the Pro/ENGINEER assemblies, which is then archived in the Audi PDM system. In the PDM system, the parts packages can be identified and placed into a centralized DMU database. Specific requests for the translational and rotational displacements (Euler angles) of moving parts originating from ADAMS that match the geometric data of the axle are generated and can be read into Pro/ENGINEER as well as 'Virtual Workshop'. Within 'Virtual Workshop' the geometry data are coupled with the corresponding motion information and for each parts group a motion envelope is generated. These motion envelopes are then placed in the central DMU database again. Thus, both static as well as dynamic geometry data of the axle are available to the DMU system. It is also possible to generate a total envelope over all single envelopes.

DMU Representation of a Suspension Assembly

In the DMU representation of the suspension assemblies the consideration of movements is of essential importance for vehicle package-analyses. Figure 4 and 5 show the static VOXEL-models and dynamic envelopes of the front axle of the Audi A6. The envelope was generated using the VOX-Pack method with cubes of 5 mm edge length. Creating a total envelope out of 11 single envelopes including data minimization took 51 hours of computing time.

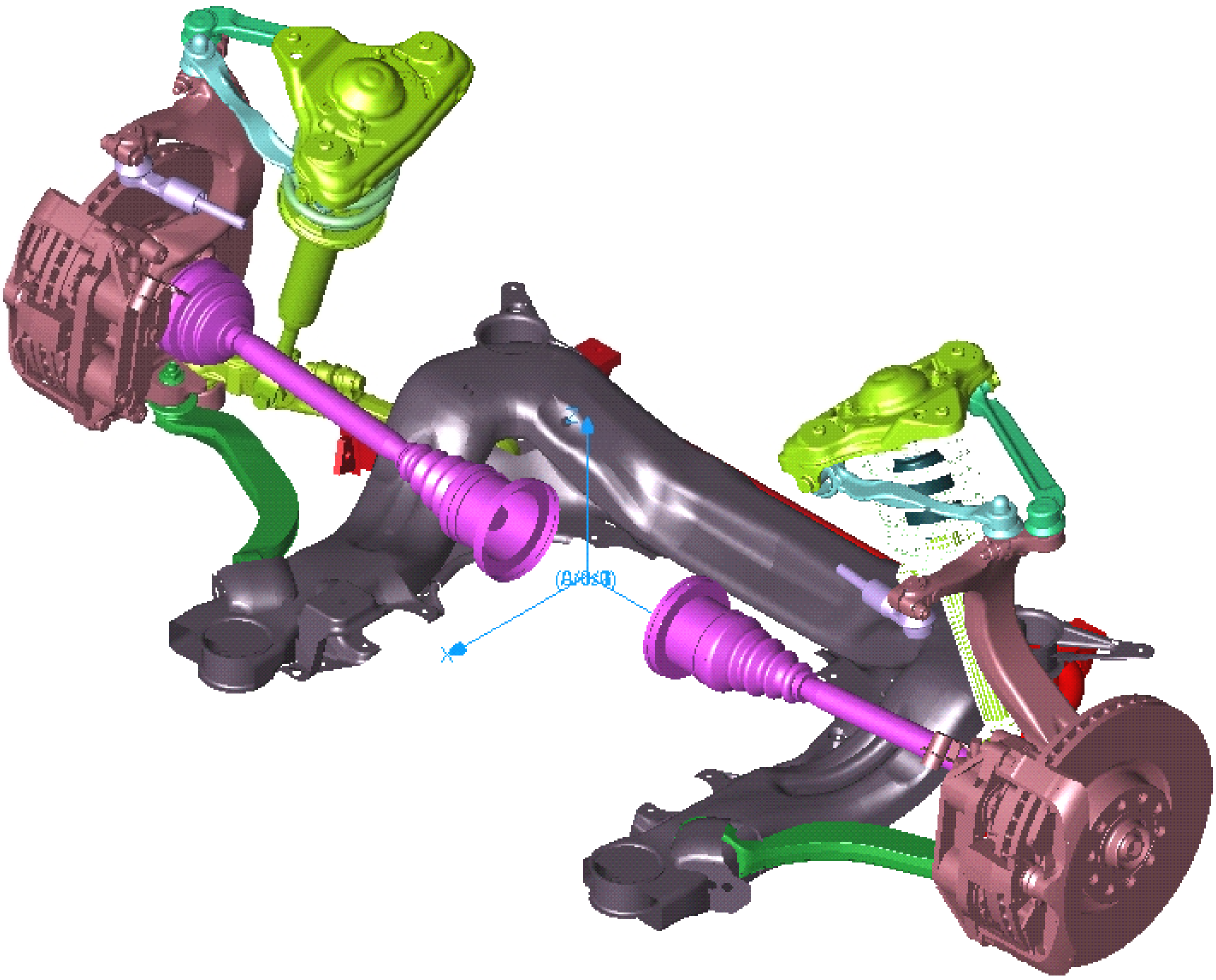

Figure 4: Static envelope of the front axle of the Audi A6

The movement information for all suspension parts is obtained from an elastokinematic suspension analysis in ADAMS/Car. Audi uses a customized version of ADAMS/Car including the Audi-specific KINELA functionality and postprocessing for the analysis and design of suspension systems.

The ADAMS/Car model contains a detailed representation of the suspension system including all relevant elasticities and nonlinear bushings. A series of synthetic load-cases and prescribed motions are applied to the suspension model representing real driving conditions. The resulting positions of the suspension parts are provided for the DMU system through special requests. The total movement envelope encloses 65 calculated single positions.

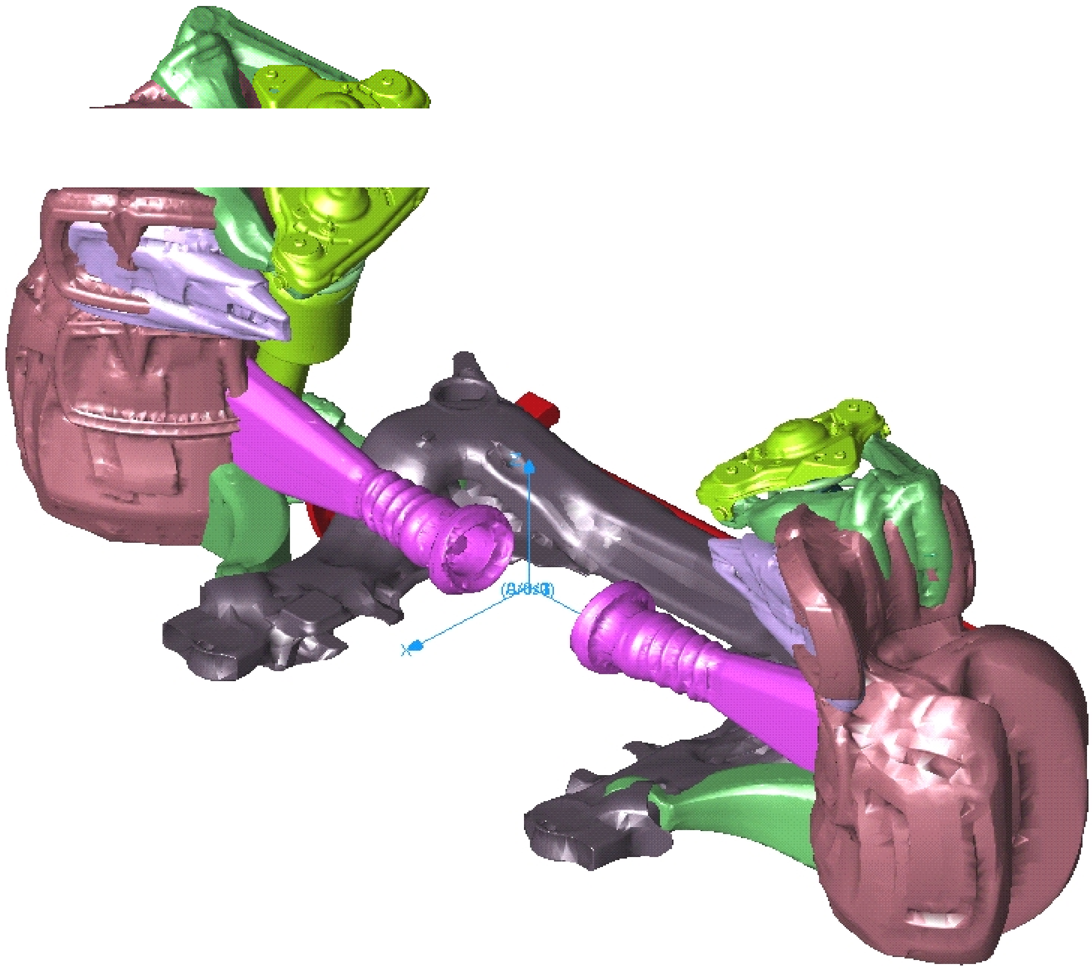

Figure 5: Dynamic envelope of the front axle of the Audi A6

Engine Envelope

Another example of a typical movement envelope is the engine envelope shown in figure 6. It represents the V6 engine in the Audi A6. This envelope was generated in the DMU system 'Virtual Workshop' using 10 mm cubes with VOX-Pack and is about 4 megabyte in size. The computing time was 53 hours.

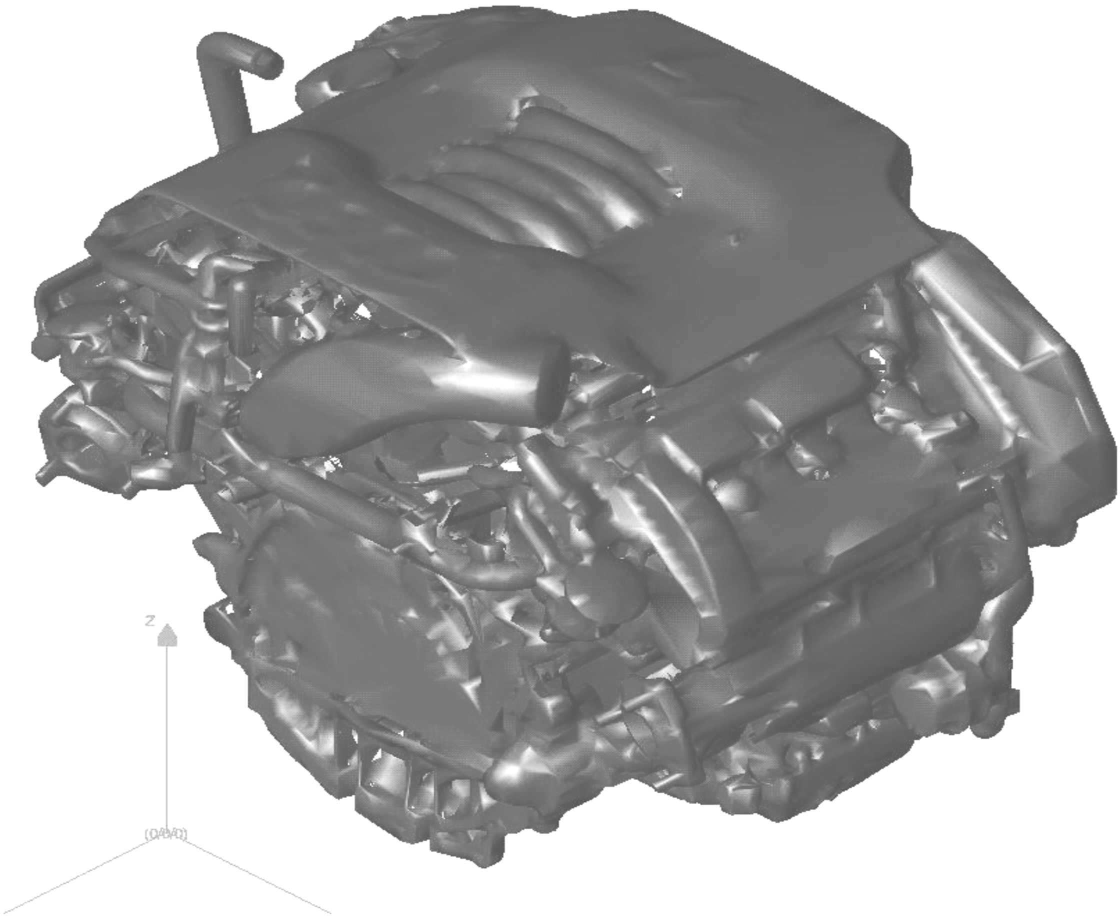

Figure 6: Dynamic envelope of the V6 engine of the Audi A6

Movement information data of the aggregate is obtained from full vehicle simulations in ADAMS/Car at specific driving maneuvers. Figure 7 shows a simulation model of the Audi A6 quattro, a typical example of a model used for simulating engine movements. The model is modularly composed of ten subsystems in ADAMS/Car. The front and rear suspension systems are modeled in much detail, including all relevant elastic elements. Particular emphasis was placed on the modelling of the power train and the aggregate mounting in the vehicle.

For determining engine movements, specific driving maneuvers have to be investigated, which contribute to the maximum range of displacements. For this example, a snap start maneuver and load alteration events at different conditions were simulated and the resulting movement data was used to generate the illustrated envelope.

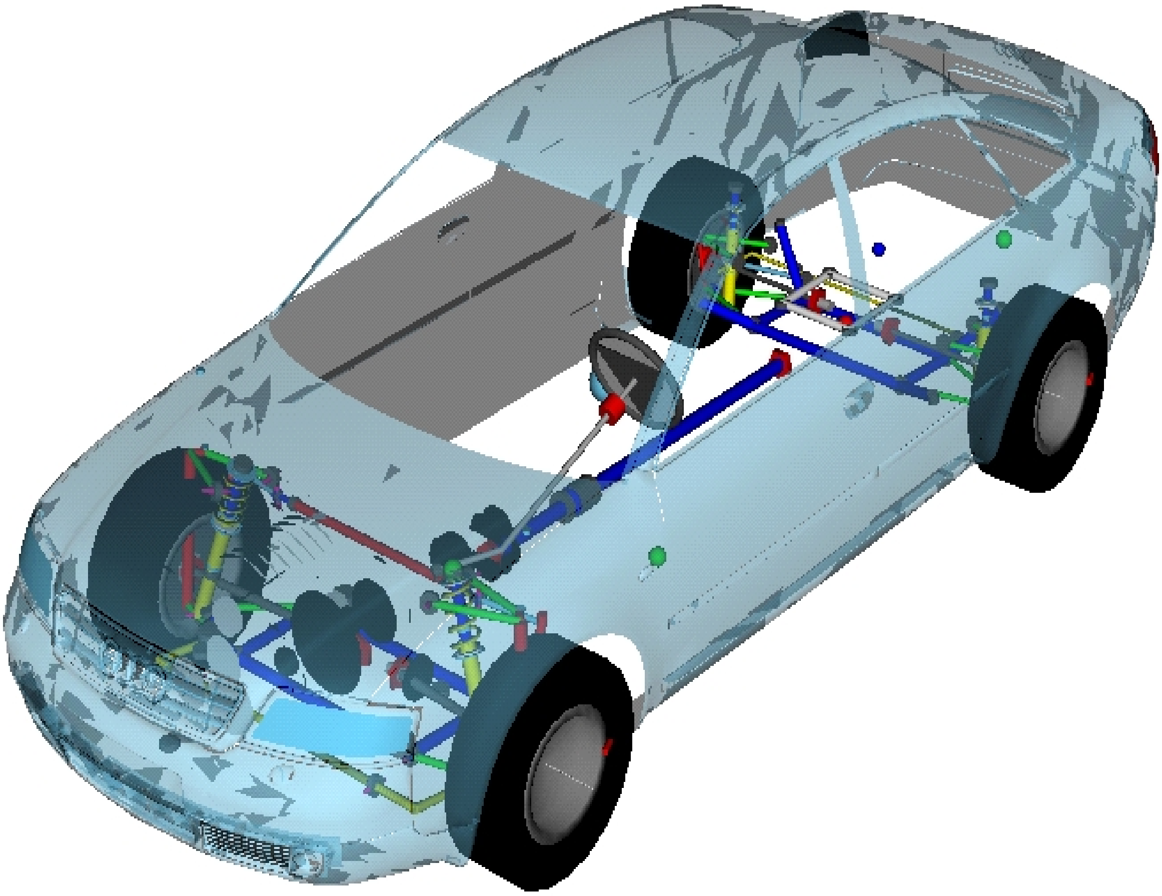

Figure 7: ADAMS/Car vehicle model for simulating engine movements

Conclusion

The coupling of DMU and multibody simulation allows including movement information of vehicle parts and assemblies in the DMU representation, thus leading to a higher quality level in DMU analyses.

Currently this technology is applied in certain vehicle projects. The objective is the standardized and consistent use throughout all vehicle projects at Audi.

An appropriate representation of flexible parts in DMU such as exhaust pipe system and hoses will also be a task for the near future.