

TPA and NVH Prognosis - Application to Mercedes Benz Car Development of New Hybrid Methods Coupling Digital Simulation with Prototype Testing Results

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ABSTRACT

Digital NVH development has become a common tool for any acoustic engineer. Vehicles in their early development stages are nowadays mainly described and validated as digital models. However there still remain needs for improvement in the domains of acoustic and vibration prediction, as instance: refining models, addressing intricate systems, and CAE resistant phenomena. In a background of increasing modularity and process transfers, hybrid methods coupling with testing results, have shown a great potential for improving the quality of NVH prognosis and development quality.

Mercedes-Benz passenger car division has developed, tested and introduced a new engineering tool, based on the classical TPA applications coupled with hybrid simulation techniques. This toolbox is used to enhance the prognoses of acoustic interior noise and vibration comfort.

The actual NVH development process for engines and vehicles is described with main quality gates and objectives, showing when established or new methods come into use. In order to reach an effective operational level of the toolbox, it was necessary to standardize and automate thoroughly the whole acquisition and processing chain. This meant defining a standard for data acquisition and structure, setting procedures for signal processing and analysis, and developing new measurement methods.

The following examples are described: Automated measurement procedure for the reciprocal determination of transfer functions. Procedure for direct evaluation of input dynamical forces and airborne noise measurements acquired at engine test benches. In order to demonstrate the potential of mentioned methods, an application to the NVH development of an engine and the achieved end results are presented, illustrating the systematically project maturity evaluation, the virtual integration of engine and powertrain in some existing vehicle types, as well as the interactive virtual testing of different power train types, variants are other possibilities.

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INTRODUCTION

Present development processes lead to a high degree of car digitalization. This includes not only the geometrical description definition of vehicles and parts (CAD), but includes also aspects as NVH, crash, reliability, handling and fuel consumption. Comparing to a classical hardware prototype development process, the digital prototype (DPT) has specific process steps, where the digital geometry is frozen and also all functional data. A build up of a full digital vehicle for all function starts und describes after calculations the stage of maturity of the vehicle function in the development process. Figure 1 shows the full vehicle development process leading from early concept definition,

through digital development, up to the hardware car development.

Similar processes have been well established for the development of engines and whole powertrains. To improve project maturity and quality, the introduction of a new vehicle in combination with a new engine should be avoided. As a consequence, there appears automatically an offset between car and engine development process timing which can be used also for NVH. Digital vehicle data in the early stage of process are often combined with also digital engine models. Although a high level of quality has been achieved by improved CAE models. Some further improvements can be achieved by using the time offset between vehicle and engine development. As an example data from engine test benches

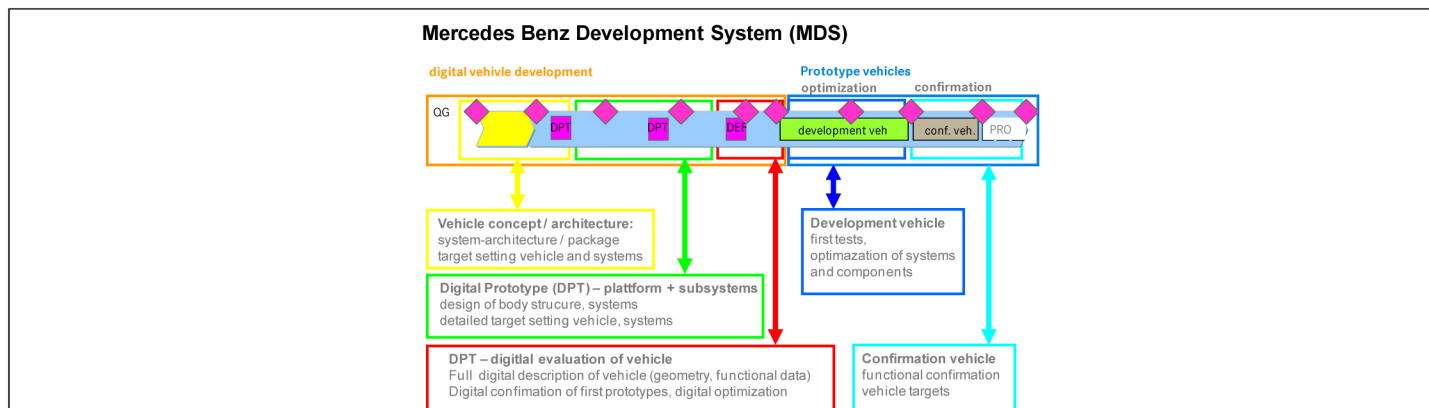


Figure 1. development process - Mercedes Benz cars

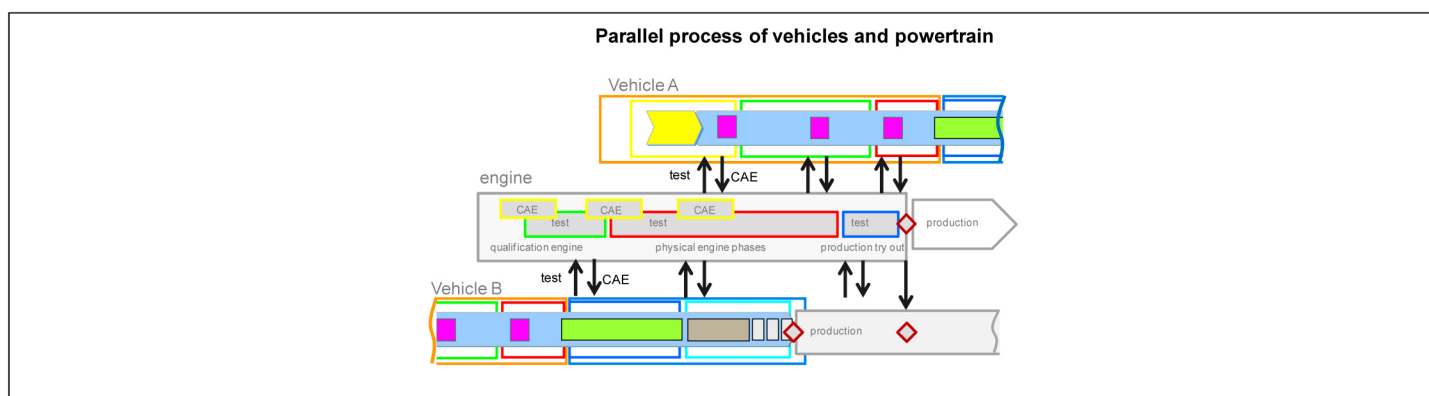


Figure 2. Challenge of development process vehicle and powertrain

can be combined with a digital vehicle model. Furthermore, the engine development can profit from the coupling of engine test bench data with measured vehicle transfer functions, allowing for instance the evaluation of the relevance between forces after engine mounts and airborne noise in vehicle. This allows a NVH prognosis of the introduction of a new engine and their acoustic in an existing car. The whole process can be started also in the earliest stage of an engine development from engine concept stage and intensive during digital development to improve engine structural dynamics. For example [figure 2](#) shows the development time offset on the digital and a possible experimental data flow of engine and vehicle development.

The use of the new methods to improve the NVH development of engine and vehicle is now well established. The term ‘NVH-Prognosis’ has become a general description for this process with coupling NVH measurement and simulation data during the engine or vehicle development. Some of them are described in literature [1] and in the following chapters.

The prognosis process can follow the two general processes: The “Vehicle-” or The “Engine-Process” with the relevant time tables and ‘quality gates’ beginning with concept phases.

Associated to the development process steps the prognosis process is divided for each development step in three main parts: Input, Activity and Output. Every part is described with standardized tasks which define the acquisition and formatting of experimental and computational data as well as how they should be processed. Furthermore the useful coupling of data and feasible prognoses analysis are defined step by step.

The project start or concept phase begins with investigations of the predecessor vehicle and relevant benchmark vehicles with their engines using the TPA tools. This encompasses: Quantification of the engine excitation forces, description of the wheel/road interactions, evaluation of transfer functions, evaluation of the aeroacoustic effects, etc. The data acquired allow a precise TPA especially for the drivetrain induced noise and vibration. The aim of the NVH-Prognosis is to control achievement of targets and if necessary to help finding appropriate countermeasures for improvement.

The quality of the input data tends to improve and changes during the process steps in the project. Starting with approximations of the vehicle characteristics as target values of systems (e.g. Transfer Functions), it is possible to combine the data later with FEM simulation results, to deliver

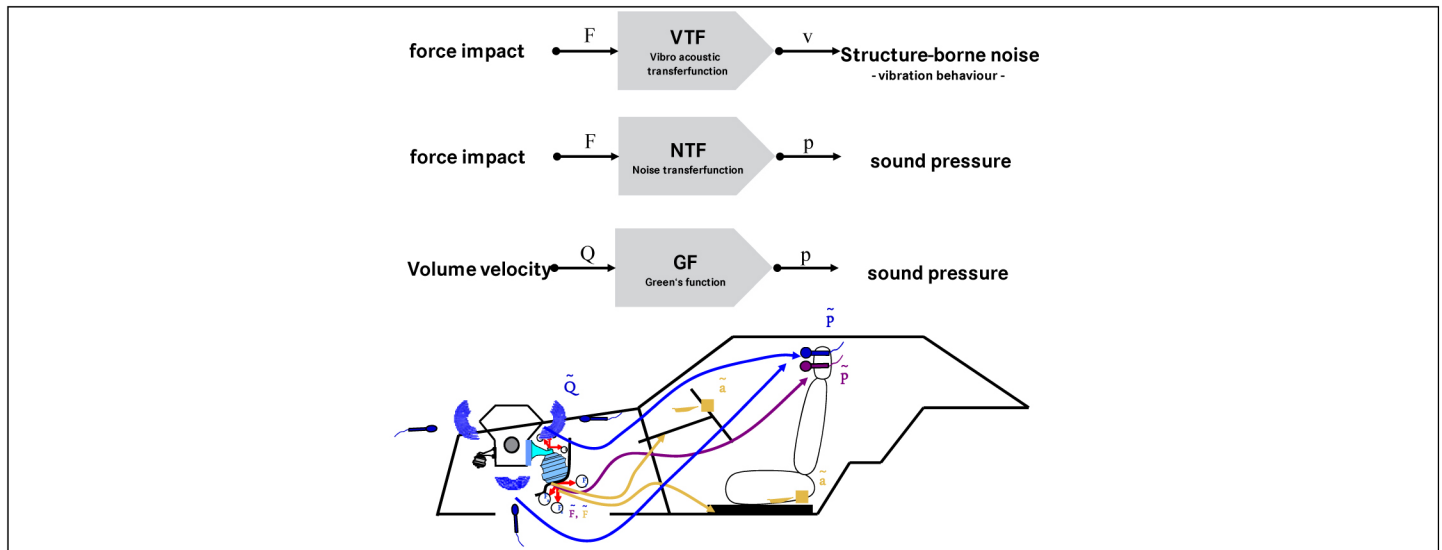


Figure 3. necessary paths for TPA - using reciprocity

predictions e.g. in combination with measured engine excitation. Prototypes allow the deliverance of the first measured data. This is not only a determinant milestone for the evaluation and validation of the prognosis quality and its ability to foresee the relevant solutions, but also the turning point between prognosis and analysis.

This process is now an integral part of the NVH-development and integrated in the actual development of single vehicles, vehicle platforms and engine development.

APPLIED METHODS & MODELS, TRANSFER PATH ANALYSIS

The transfer path analysis is used usually for the analysis of vehicle interior noise as well as for the evaluation of vibrations at the main vehicle comfort reference points. In the classical TPA, the vehicle is described as a linear time-invariant system. System nonlinearities are avoided by choosing the right operating point. The linear acoustic vehicle model is constituted of sources, transfer paths and vehicle interior noise including vibrations at the comfort reference points. The actual sources encompass engine, powertrain, exhaust and wheel-track interactions.

The relation between customer perception and stimulation is described through the transfer paths (figure 3). Of those the three main ones considered are:

The relation between induced forces through e.g. engine mounting and the resulting vibration at the comfort reference points in the vehicle interior (steering wheel, seat) is described by the Vibroacoustic Transferfunction 'VTF'. The relation between the vehicle interior noise p and induced force F is given by the Noise Transfer Function 'NTF'. The sound volume flow Q emitted by the sound source is transformed in sound pressure using Green's Functions.

The relevant transfer functions are measured indirectly by using reciprocity measurements methods in the complete

vehicle. As instance the determination of the airborne sound sensitivity using the reciprocity method is achieved as follows:

A defined force impact F_1 is applied using an impulse hammer or shaker to each force application point in all 3 directions independently. Simultaneously the system response p_2 is measured with microphones in the vehicle for example at the driver ear. The ratio p_2/F_1 thus obtained yields the noise transfer function NTF. The indirect measurement allows to bypass the individual force excitations by inverting emitter and receiver. So is it possible with a defined sound volume flow Q_2 emitting inside the vehicle to measure the resulting velocity v_1 at the force application points of the car body. Equivalent principles can be applied to the determination of Green's Functions and of the vibroacoustic transfer function VTF.

The measurement methods and devices will be explained later on in more details.

In order to analyse the interior noise and vibration behaviour of the vehicle, the relevant excitations must be quantified.

QUANTIFICATION OF EXCITATION

The structure-borne noise excitation of the relevant sources succeeds through the force identification in complete vehicle or through the measurements at specially equipped engine test benches. Several force identification measurement methods can be found in the literature [for example 3]:

• Direct force measurement in complete vehicle

The mounts of the engine or the powertrain are replaced or added with force measurement sensors. The operating forces are then directly measured operationally on the road measurements or on the vehicle test bench. However the placing of force measurement sensors modifies the response