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ACOUSTICS | NVH SIMULATOR

# A Path to the Digital Twin



# NVH Simulator – A Path to the Digital Twin

As manufacturers make actual prototypes increasingly rare due to tighter time and cost targets, simulation models are used more frequently in the NVH development process to evaluate part or component modifications. However, it is almost impossible to assess modifications to noise and vibration behavior based on simulation results alone. The perception of noise and vibration in a vehicle cannot be reduced to diagrams and numerical values – the human experience is the yardstick. In the following, Head acoustics shows how manufacturers can realistically evaluate NVH performance, even as they conduct fewer and fewer real-world tests.

An NVH (Noise, Vibration, Harshness) simulator interactively simulates driving noise and vibrations, **FIGURE 1**. Drivers operate the gear selector lever and the pedals as in the actual vehicle and hear the driving noise resynthesized in real-time. Depending on the selected simulator hardware, vibration is also applied, for example, to the seat and steering wheel. In contrast to listening tests with prepared sound samples, in the NVH simulator, the drivers themselves determine the operating state and can consciously trigger the noise and vibration phenomena that are relevant to them.

A driving dynamics model calculates the parameters required for the NVH simulation, such as speed(s), load(s), and velocity, from the driving inputs. The parameters of the driving dynamics model include the torque curve, transmission ratios, and air and rolling resistance. The simulator auralizes noise sources such as the powertrain, tire/

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road, and wind by resynthesizing them depending on the operating state (engine rotational speed, load, velocity) and outputting them aurally via a binaural playback system. Only in an NVH simulator can users modify noise sources using filters or even exchange them – for example, for the wind noise of a competitor vehicle – and change the volume at the push of a button while driving. The basis for the NVH simulator's acoustic models is measurement and/or Computer-Aided Engineering (CAE) simulation data adapted in scope and type for the respective application and the required level of detail.

## SIMULATOR VARIANTS

Different simulator systems have different immersion levels depending on the application and budget, **FIGURE 2**. The desktop simulator requires a PC, software, and a calibrated binaural playback system that ensures auditory accuracy, as well as USB pedals for intuitive longitudinal control of the virtual vehicle.

The so-called Sound Seat makes it possible to adopt a sitting posture similar to that in a vehicle. In addition to binaural sound, shakers reproduce vibrations at the steering wheel and seat. A vehicle cabin with mounted shakers and speakers equalized to the driver position (Sound Car) can further increase the authenticity level of the simulation.

A mobile simulator integrated into an actual vehicle offers the most realistic driving experience. The operating state variables such as speed, load, and velocity are not driving dynamics simulations but are collected from the vehicle's CAN bus. The noise playback of the virtual vehicle is done via Active Noise Cancellation (ANC) headphones to suppress the real driving noise.

An NVH simulator can also be integrated as a subsystem via programming interfaces or the CAN bus in a full vehicle simulator with a motion system. Noise is reproduced via headphones or loudspeakers. The NVH simulator thus enhances the immersion of the full vehicle simulator for application areas such as Advanced Driver Assistance Systems (ADAS), driving dynamics, or autonomous driving. Adding authentic driving noise helps test subjects feel and behave as if they were in an actual vehicle.

## THE PATH TO THE DIGITAL TWIN

Depending on the application and its development stage, varyingly complex paths to the digital twin with a corresponding level of detail are feasible. A significant difference is how the

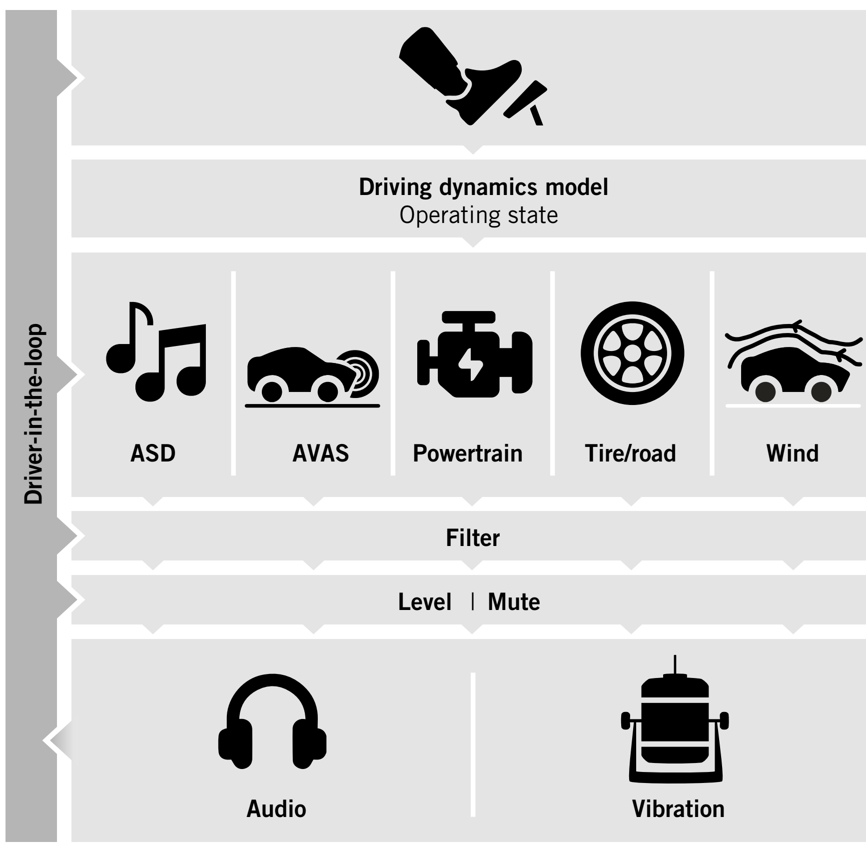


**FIGURE 1** Concept and structure of the NVH simulator software with the interfaces to the operator and possible noise and vibration sources (© Head acoustics)

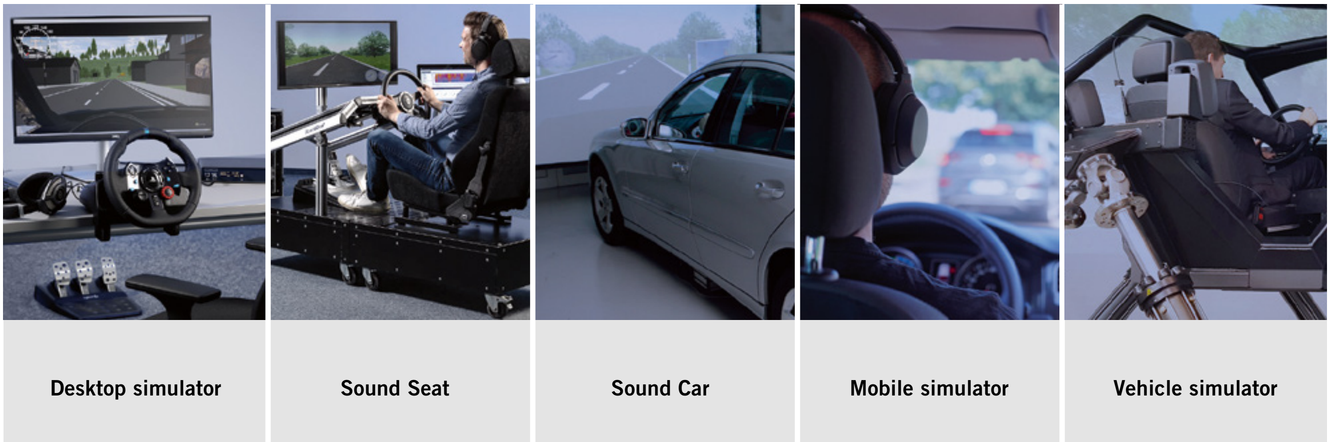


**FIGURE 2** A NVH simulator is scalable from a desktop application to a mobile simulator to a subsystem in a vehicle simulator (© Head acoustics I Cruden)

required data sets are generated and subsequently combined in the NVH simulator. Measurements, simulations, or, in the case of hybrid approaches, combinations of both can serve as the basis for these data sets, **FIGURE 3**. The fastest path is to prepare a data set of a (prototype) vehicle's wind and tire noise measurement, which is recorded with a binaural headset microphone or artificial head and can be used for benchmarking, jury testing, or target sound setting, for example. The collected acceleration data enable vibration playback during simulation. The experimental characterization of the noise and vibration source "powertrain" is performed with the vehicle on a chassis dynamometer. The relevant operating conditions, typically run-ups over the entire speed range at ten to twelve loads, are recorded accurately and reproducibly. If needed, tire and wind noise can be separated with the Operational Transfer Path Analysis (OTPA) [1]. This requires additional sensors during the test track vehicle measurements. From these measurement data, the NVH simulator creates data sets that it not only reproduces during the virtual drive but also resynthesizes in real time according to the current operating state in such a way that no transitions or artifacts can be heard.

A detailed, measurement data-based Transfer Path Analysis (TPA) model provides even deeper insight at the component or path level [2]. In this context, an NVH simulator offers strong added value. With it, all participants experience even complex TPA results in a comprehensible and interactive way.

Together, they can evaluate "what-if" scenarios and quickly identify critical paths with the most significant potential for efficiently improving a noise phenomenon, for example, the transfer of the $27^{th}$ order via the gearbox mount, **FIGURE 4**. In addition, even at an early stage of development, powertrains operated only on the test bench can be virtually calculated into a vehicle using TPA [3]. Data from an engine test bench can be experienced in the NVH simulator using real-time TPA and evaluated together with the tire and wind noise [4].

An NVH simulator can also serve as a bridge between testing and CAE simulation. In CAE simulations, absolute statements on noise development are still tricky, especially without a validation object. In practice, it has proven beneficial to build a CAE model based on measurement data of a real object, validate it and calculate the acoustic effects of changes in the virtual model. This information can either be used directly in the NVH simulator or applied to the measurement data in the TPA process to make the virtual changes perceptible. The TPA method is also suitable for combining a simulated component's noise and vibration excitation with measured transfer functions.

The vision is an entirely virtual vehicle based exclusively on simulation models. Here, the creation effort, validation, and the achievable frequency range are (still) the limiting factors. However, a purely virtual NVH simulator can help auralize numerical TPA models early and support landmark

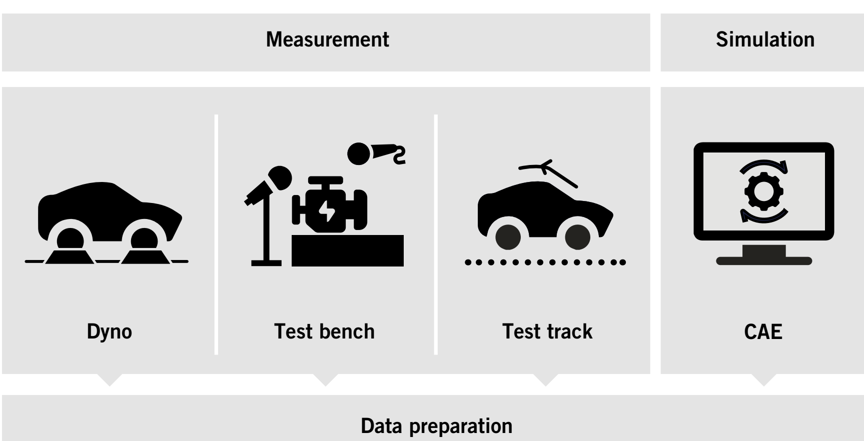


**FIGURE 3** Depending on the application and development phase, different data can be used in the NVH simulator (© Head acoustics)

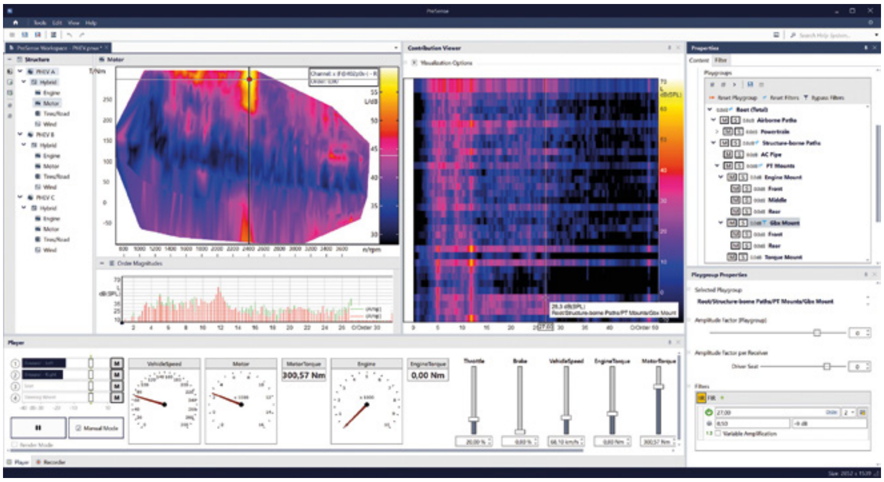

**FIGURE 4** In the NVH simulator, virtual modifications can be carried out while driving using targeted filters and checked for effectiveness (here: effects of a reduction of the transmission mount's contribution for the 27th order by 9 dB, screenshot) (© Head acoustics)

decisions. The numerical TPA fully simulates the source excitation and transmission in CAE software. In addition, data sets based on measured and simulated data in a hybrid approach can provide information on whether, for example, undesired tonal noise components of a simulated electric powertrain combined with the measured masking noise are perceptible.

## ACTIVE SOUND DESIGN

Active Sound Design (ASD) is not only used in electrified vehicles. In most cases, the vehicle's loudspeaker system is intended to reproduce artificial engine sounds, thus creating the "right" driving sound that arouses emotions, reflects the brand image, and corresponds to the vehicle's market positioning. The NVH simulator brings the creative world of ASD and the technological world of driving sounds closer together: With an NVH simulator, sound designers can carry out the creative process in the proper context from the very beginning, **FIGURE 5**. Already in the concept phase, thanks to an NVH simulator, they gain an understanding of the vehicle performance and the actual vehicle noises that occur to develop a coherent soundscape with their compositions.

Third-party systems for sound generation can also be integrated via software and hardware interfaces [5] so that NVH engineers and creatives can contribute with their familiar tools for sound generation. For this purpose, the NVH simulator sends the operating conditions to the sound design software or hardware, receives the resulting ASD sound, simulates the transmission behavior of the loudspeakers, and reproduces the result together with the driving noise. This way, the effects of different sound systems can be simulated efficiently.

The sound designers need neither prototype vehicles nor a test track. In the NVH simulator, they can drive a wide variety of scenarios in the shortest possible time in an uncomplicated, safe, and reproducible manner and design sounds interactively. The genuine driving noises are still present. Any tonal noise components that may occur can be combined with the ASD, cleverly masked, or integrated as sound elements to generate an optimal sound and driving experience. The actual vehicle is only used in the validation phase for the final tuning.

Another area of application is the development of Acoustic Vehicle Alerting Systems (AVASs), whose sounds serve as a warning system for people and other road users in the vicinity of the vehicle. Loudspeakers outside the driver's cabin emit the warning sound to the surrounding area, but what is the impression for the people in the vehicle? With the transfer functions from the AVAS loudspeaker to the interior, it is possible to investigate whether passengers find the AVAS sound annoying or whether it harmonizes with a possible ASD interior sound already during the design phase. The methodology can also be applied to the design of warning and notification sounds. From turn signals to ADAS, it is crucial to design and evaluate signal sounds in context. For example, it is easy to answer the question of whether the turn signal can still be heard at top speed or whether the warning sounds attract sufficient attention.

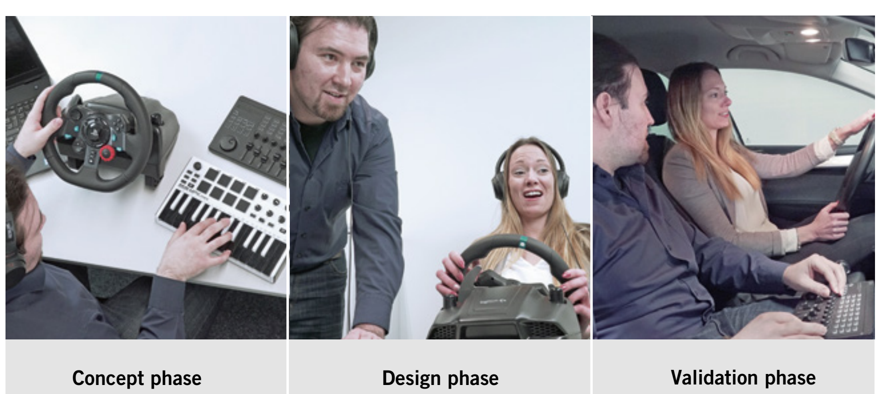


**FIGURE 5** Integration of the NVH simulator into the development phases of ASD (© Head acoustics)

## CONCLUSION

An NVH simulator offers different paths to the digital twin by making NVH performance perceptible, enabling ASD in the vehicle context, and increasing immersion in a full vehicle simulator. Depending on the development phase and the required result accuracy, simulation and test data are used for this purpose. Due to its scalability, it can be adapted to the requirements of the development process, from simple desktop solutions to complete vehicle applications. Aurally correct playback and the best possible auralization quality are crucial for the simulation quality: Are the sounds authentic and free of artifacts, that means, indistinguishable from the original? A good integration with NVH measurement technology and methods and competent support in know-how transfer for the dataset creation contribute to the success.

The NVH simulator is a good development tool to support users in the face of tighter cost and time targets and the resulting ongoing minimization of physical prototypes. It makes measurement and simulation data audible and tangible in early stages of development via an interactive driving noise simulation. Everyone can evaluate NVH performance instead of just analyzing diagrams and numerical values, which would require a high level of expertise. The data can be shared globally between different locations, and decision-makers can flexibly and efficiently perform virtual test and assessment drives at their site.

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