DIGITAL INDUSTRIES SOFTWARE

Road noise engineering

Mitigating the most dominant noise sources in electric vehicles early in the development process

Executive summary

Without the masking of a combustion engine, road noise is more prominent in electric vehicles (EVs) and has become the dominant source of noise for drivers and passengers, especially at low speeds. Road noise is present in almost all driving conditions; however, predicting road noise can be notoriously difficult and has become a critical issue for engineers working on EV noise, vibration and harshness (NVH).

This white paper describes an innovative approach to road noise engineering using a virtual prototype assembly (VPA). This allows for predicting road noise earlier and throughout the vehicle development process without needing a physically assembled vehicle or prototype.

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Introduction

Due to increasing vehicle diversity, it is infeasible to conduct test-based validation of component integration for all possible vehicle configurations. Instead, the industry is looking to digitalize its development processes to save development time and cost. In addition to reducing the number of physical prototypes for test-based NVH engineering, vehicle NVH departments are shifting priorities from powertrain NVH to road and wind noise performance.

Solving road noise is a complex engineering challenge. Unlike engine noise, which comes from a single, well-defined source, road noise originates from road-to-tire contact. The roughness and profile of the road and the compliance of the tires influence four noise sources (assuming a four-wheeled vehicle). Additionally, tires interact with the suspension system, subframe and vehicle body, which impacts road noise performance. From an engineering point of view, the increased level of complexity is obvious compared to engine noise.

In addition to the engineering complexity, the supplier and original equipment manufacturer (OEM) relationship also comes into play. Most OEMs do not manufacture their tires and may even have multiple tire suppliers for the same vehicle, which can further complicate the issue. First, there are various types of tires for the same car, with each combination having its own noise characteristics. Second, you will need to work with suppliers to agree on the target performance and key parameters for each tire. Ideally, the targets are consistent with a clear agreement of responsibility between the OEM and supplier.

All of this creates the need for a modular methodology that allows you to assess road noise performance virtually without needing to physically build the assembly and combine invariant data from the sources. Using component-based transfer path analysis (C-TPA) enables the transformation from physical to virtual prototypes. It allows the combining of subsystem and component models based on test and/or simulation data for virtual road noise prediction. The subsystems are passive systems such as trimmed bodies, suspension systems and subframes, and active components that introduce loads into the vehicle. When considering road noise, the active components are the wheels and the road loads coming through them. The critical aspect of these components is you can independently define them from the physical vehicle application, meaning they are universal for any vehicle model.

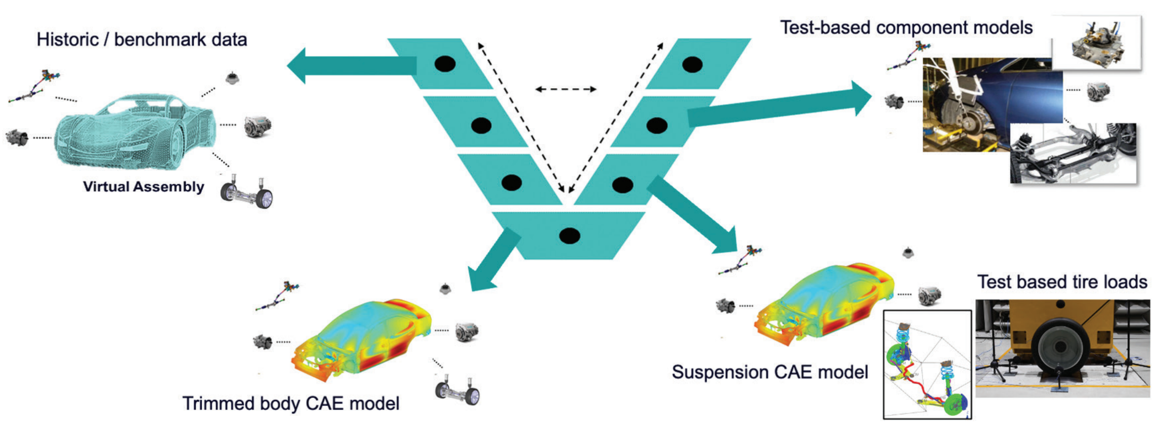

Figure 1. Virtual assemblies for NVH prediction at any stage of development.

This approach can help you create virtual assemblies to effectively predict road noise in the vehicle development process without needing a physical vehicle or prototype. Thus, you can create road noise solutions early in the design process.

People often use the words wheel, tire and rim as synonyms. However, they are not interchangeable. The visual in figure 2 gives an example of a correct representation. For lack of a better word to encompass all three components, we will use the term tire. In this document, the wheel includes both the tire and the rim, unless specified otherwise.

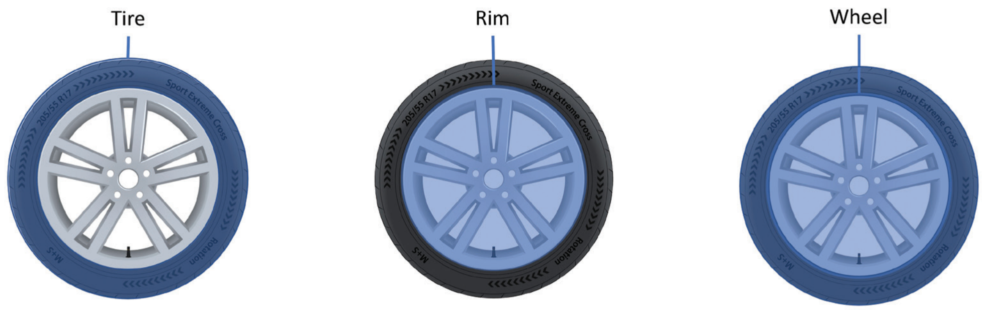

Figure 2. Correct representation of a wheel, tire and rim.

Approaches for predicting road noise

Most methods for handling road noise performance fall back on a source-transfer-receiver approach. This approach decomposes the road noise at its source – like tire excitations – and its transfer into the so-called passive components.

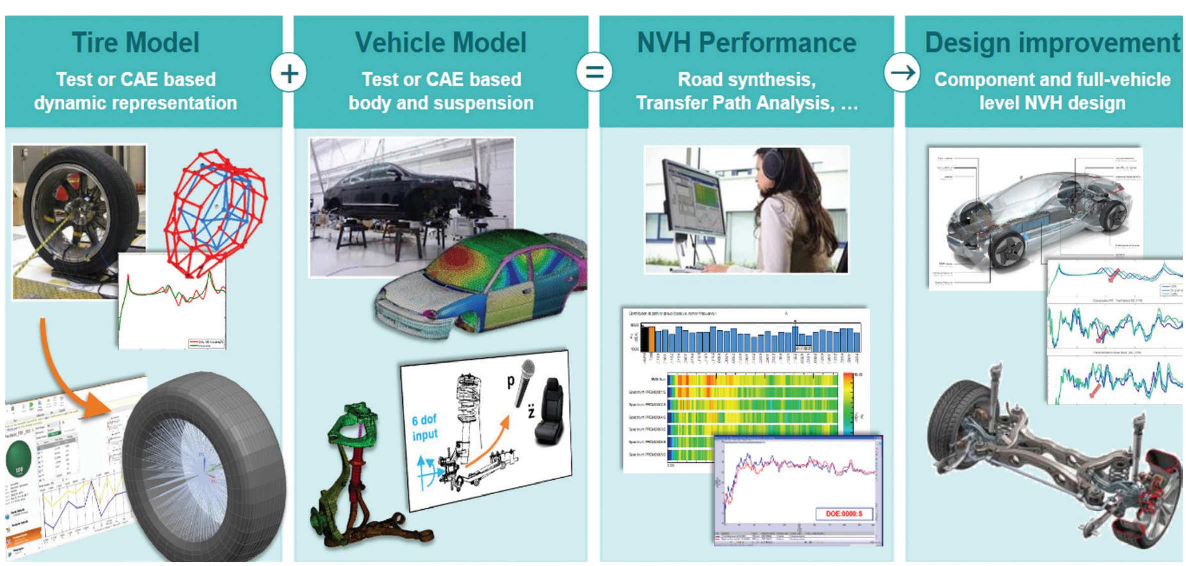

Figure 3. Gaining insights into road noise design improvements with a source-transfer-receiver approach.

Two main methods are:

- Traditional TPA is an established methodical approach for qualifying and quantifying vibro-acoustic transfer paths. It can lead to faster troubleshooting, better product refinement and lower road noise levels in the passenger compartment. You can apply this approach to a specific vehicle assembly configuration, especially on physical full vehicle prototypes
- C-TPA is a noise source identification methodology that focuses on components rather than the assembled product. It is a virtual prototyping methodology to characterize noise source components independently from the receiver structure while assessing the coupling after assembly. Thanks to using combinations of invariant subsystems, users can maximize their ability to virtually explore assembly alternatives. This helps make this approach a common practice

Before elaborating further on the two main approaches to predicting road noise, it is important to introduce the key enabler for predicting system NVH.

The true value of C-TPA lies in its ability to break down traditional collaboration barriers. For example, between test and computer-aided engineering (CAE) engineers, component departments, or OEMs and suppliers. However, with many stakeholders there is a risk of user error as each domain expert will use their own established methods, conventions and tools to characterize their components. Therefore, a key element for success is implementing a streamlined and holistic process called VPA. This process ensures the correct exchange of component characterizations, no matter their origin, allowing users to widely adopt C-TPA in the NVH development process.

VPA enables engineers at any development stage to virtually assemble a vehicle prototype, evaluate NVH characteristics and assess the impact of vehicle design by changing or updating components. By using VPA you can implement a fail-safe process for C-TPA and the use of data from different groups of people.

Further, you can use VPA assemblies on the NVH simulator to allow auralization of the road noise – with or without the other noise sources – and translate the VPA results into design key performance metrics (KPI), such as sound quality.

Traditional transfer path analysis

TPA has traditionally played a crucial role in the full vehicle NVH analysis and optimization process. Using TPA enables the identification of the contributions (loads) of the individual component sources and the body or chassis sensitivity to the total interior noise level. Designers have used TPA for decades to lower road noise levels in the passenger compartment by using test and/or CAE analysis to identify the dominant path or component and verify modifications.

TPA for road noise analysis requires identifying the road input for each tire, which is usually defined as the forces at the wheel centers to eliminate the tires. In addition, measuring or calculating the frequency response function (FRF) between the wheel centers and the target locations, typically the driver and passenger ear locations and seat track vibrations, is necessary for completing the TPA model.

Read the TPA white paper.

Figure 4. Engineers instrumenting the vehicle body for measuring FRFs at suspension mount locations.

The key to traditional TPA is the so-called contact forces, which are only relevant for the specific vehicle tire combination. Since it also requires determining the road loads on the vehicle, you can only effectively use it once prototypes are available. As a result, you can apply traditional TPA for trouble-shooting problems late in the development process.

Component-based transfer path analysis

C-TPA allows you to predict the NVH performance of an assembly using independent component characterizations, which you can virtually couple using frequency-based sub structuring (FBS). You can characterize source components by invariant loads – called blocked forces – and impedances at their output connection interfaces. Further, you can characterize receiver components by impedances and transfer sensitivities between their input and output connection interfaces.

Blocked forces are the loads a source exerts on the clamping points during clamped conditions and are invariant from the receiving structure. This is what allows us to re-use such loads for noise predictions in any receiver. For road noise, you can identify those blocked forces on the wheel's center level.

By applying these blocked forces, which represent the tire loads in the case of road noise, to a vehicle model, you can predict the noise generated by the

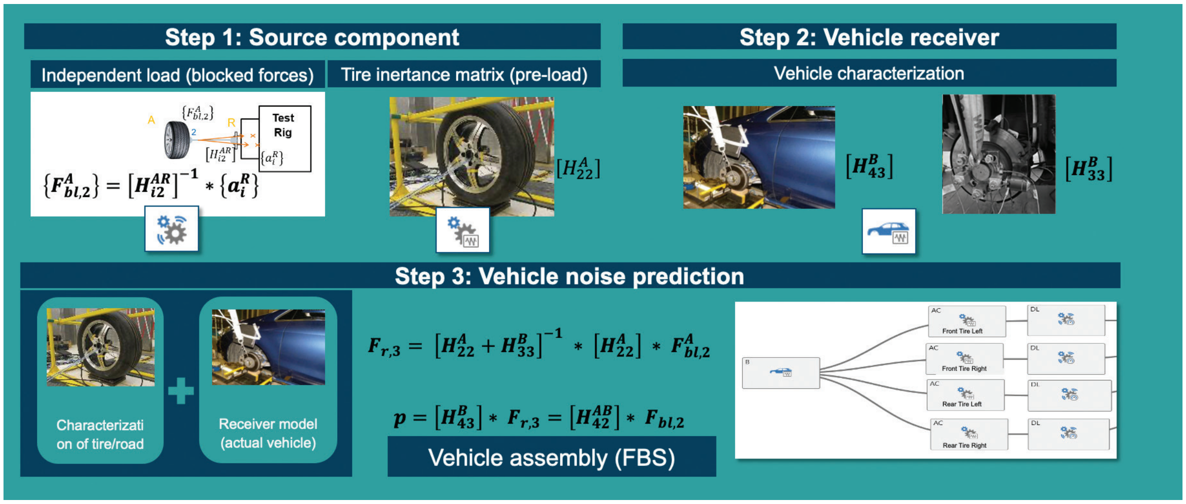

Figure 5. Applying component-based TPA and FBS for road noise.

tires. C-TPA couples the passive side (body and suspension) to the active side (wheel) using the connection impedances on both sides. The technique for coupling components is FBS. The results are like a traditional TPA model; however, you can calculate them using invariant component models.

Read the component-based TPA white paper.

Identifying tire loads

When applying C-TPA, it is crucial to couple the source and receiver at the exact same location. This requires a clear definition of the connection point location. A typical location choice is the center of a mount for mount connections, or the center of the tire.

In many cases, it is important to not only identify translational excitation (forces), but also rotational excitation at connection points. As for tires, it is imperative to identify the blocked forces and moments at the wheel's center.

C-TPA and FBS require FRFs from those connection locations. Applying measurements to get FRFs often come with additional challenges:

- First, the necessary connection locations might be difficult or impossible to excite. For example, the center of a mount
- Second, it is often unlikely to directly excite rotational degrees of freedom (DOF)

As a result, you need to acquire FRFs in locations around the points of interest and transfer them to that point of interest (often named virtual point) using virtual point transformation (VPT). For tire applications, you can typically select four to five excitation point locations for FRF data acquisition and transform them toward the virtual point, located at the wheel center to knuckle connection.

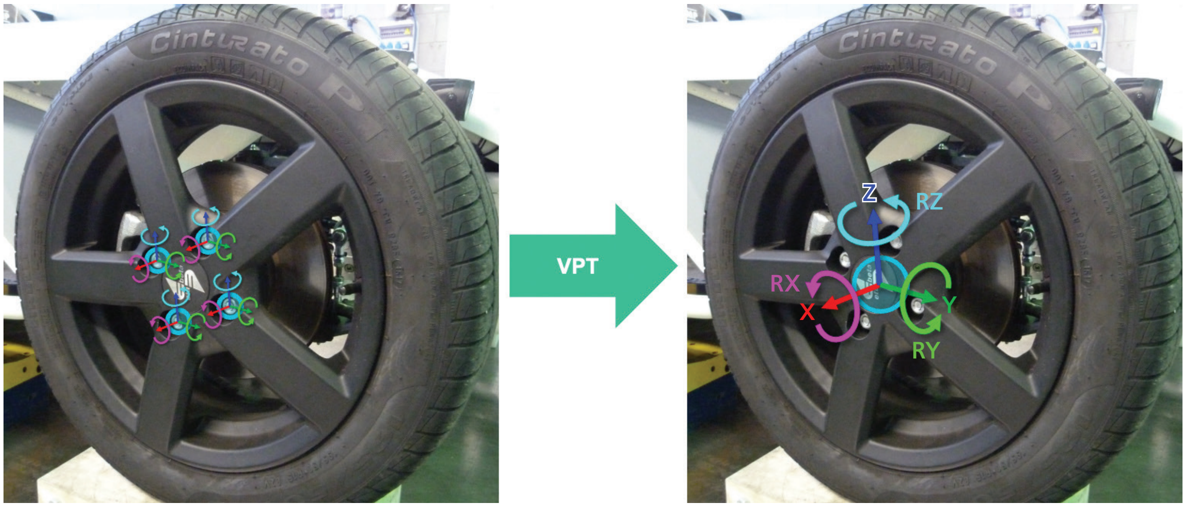

Figure 6. Applying virtual point transformation on a tire.

By leveraging VPT, you can use geometric information to transform the data toward the virtual point. Small errors in instrumentation can lead to large errors in the transformation. This can include errors:

- In the geometric location of excitation and measurements point entered in the software
- From unrepeatable excitation during FRF measurements. For example, a slight change in direction or location of hammer impacts
- Due to insufficient excitation of all DOF

The following elements can significantly reduce these challenges:

- Prepare measurement locations using computer-aided design (CAD) models to create virtual instrumentation and warrant correct geometric information
- Leverage the Simcenter™ Qsources™ hardware shakers to accurately determine location and direction of excitation
- Use a special mounting structure for those shakers with Simcenter Qsources Integral Shaker (Q-TRX), which allows excitation of all DOF

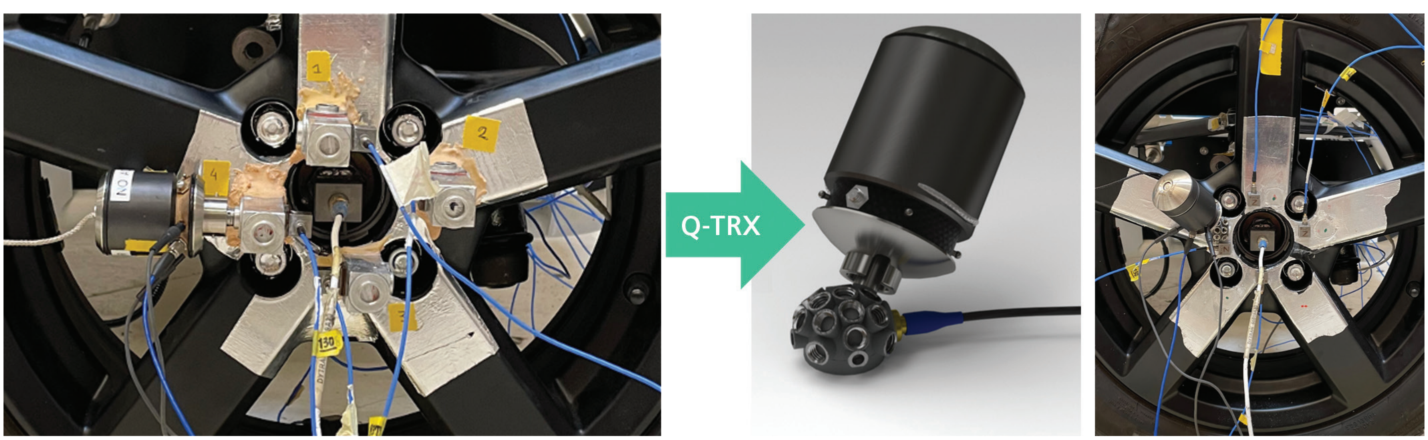

Figure 7. Using an integral shaker with Q-TRX to warrant repeatable excitation of all DOFs for VPT.

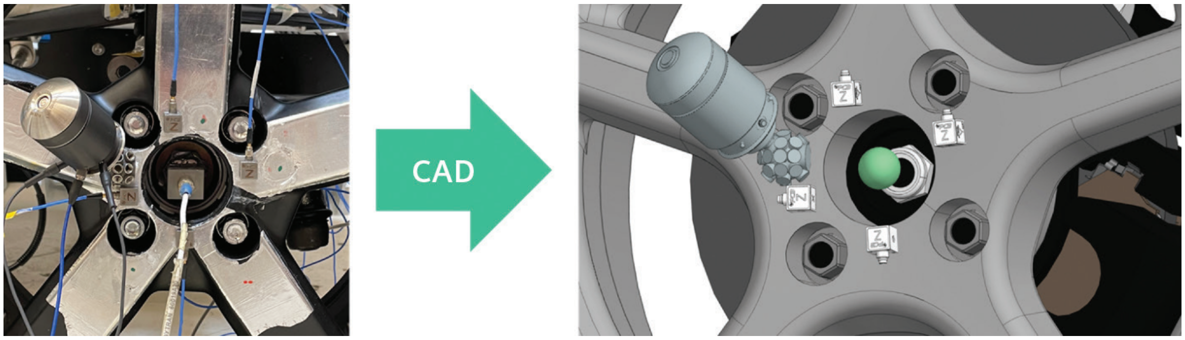

Figure 8. Showing the use of accurate geometric information from CAD-based virtual instrumentation.

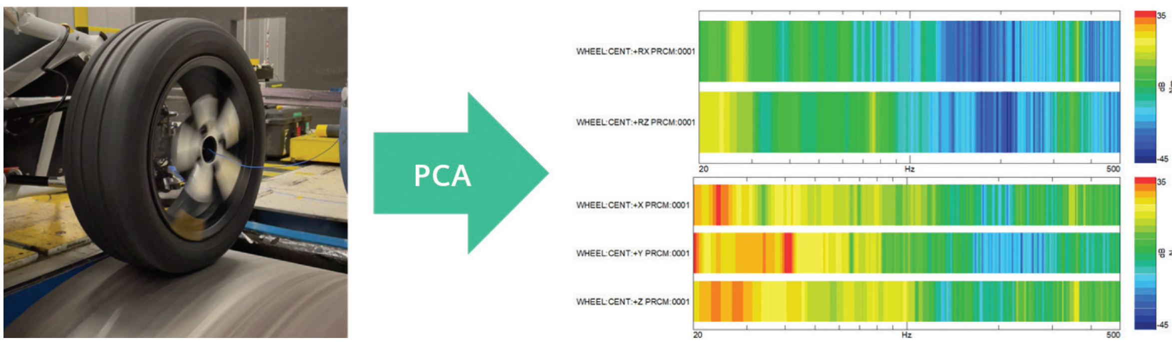

Figure 9. Calculating the wheel's center blocked forces and moments at a virtual point.

Simcenter is part of the Siemens Xcelerator business platform of software, hardware and services.

Next, after transforming the FRF data and combining it with tire operational data, you can calculate the wheel center's blocked forces.

One key factor is to consider the full wheel as a source component. As mentioned earlier, the effective noise source in a road noise analysis is the interaction between the wheel and the road surface. The vibration generated in the road contact patch will transfer to the wheel spindle and into the knuckle. From a full vehicle analysis perspective, you can consider the wheel as the source component. As a result, engineers need to determine accurate tire models to determine the load transfer from the road to the spindle.

OEMs can struggle to define unified, reusable tire models due to the variety of system targets, platforms, tools and maneuver tests. One solution is to use a tire modeling methodology that combines multi-domain applications and unified parameterization within a single tire model. Additionally, it includes models that are fit for specific purposes and helps ensure an optimal balance between accuracy and cost.

A typical tire modeling process consists of the following phases:

1. First, conduct a test campaign on a tire in a pre-loaded, nonrotating fixed or free test condition. Use FRF measurements featuring shaker and/or hammer excitation to acquire all the necessary data for describing the force transfer from the tire patch to the rim

2. Next, process the measured transfer functions between the tire patch and rim to transform the acquired output into an FRF model. That describes the tire dynamics for a displacement input at the contact patch that runs toward the acceleration response at the rim's center

Figure 10. A tire force rig of an AZL to test front and rear suspensions and tire-rim combinations on the same excitations.

For more information about figure 10 and how the German acoustic expert, AZL, used Siemens' solutions to realize early system optimization in vehicle development cycle, read the AZL case study.

The tire concept finite element (FE) model is an innovative development that extends the test-based tire model. In an FE tire concept model, you can describe the tire dynamics using a set of changeable concept parameters. Using Simcenter NASTRAN, this results in a detailed FE or parametric tire model with limited geometric and material parameters. For example, belt or sidewall stiffness. You can then tune them to match the measured FRF model as closely as possible.

The advantage of having a parametric tire model is you can experiment with parameters and evaluate their influence on road noise. From here, you can consider the "what if" scenarios and play with target settings.

From C-TPA to process implementation with VPA

Implementing C-TPA has the advantage of combining different sources of data for predicting road noise. In practice, this means that stakeholders (inside and outside the company), test engineers and CAE engineers will contribute to the creation of component data. Since you can often re-use and archive component data, it is important to have a fail-safe process in place that can manage this. Using Simcenter Testlab™ Virtual Prototype Assembly software, you have access to an environment for storing and managing architectures, subsystems and component models. It also allows easier reuse of data and analyses to build new vehicle configurations and rapidly evaluate various options.

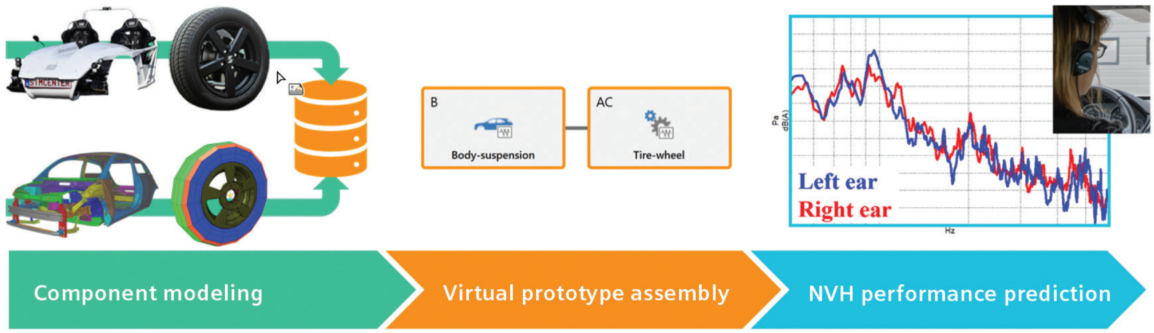

Figure 11. Implementing a virtual road noise prediction as a process with a VPA.

The VPA process allows users to create and publish test or CAE-based component models as VPA components, which you can only reuse in later assemblies. To achieve the consistent creation of VPA components by multiple users, the software helps users by providing templates that enforce correct naming conventions. This comes with built-in intelligence that allows you to seamlessly convert CAE data models with different naming conventions to the correct target VPA naming conventions.

Using Simcenter Testlab Virtual Prototype Assembly can help you build a knowledge base to maximize the use of the NVH data produced by an organization and data shared by suppliers. By managing this information centrally, users can easily search for published component models. You can also share modular components between suppliers such as tire manufacturers and system integrators, resulting in better communication and realistic target setting.

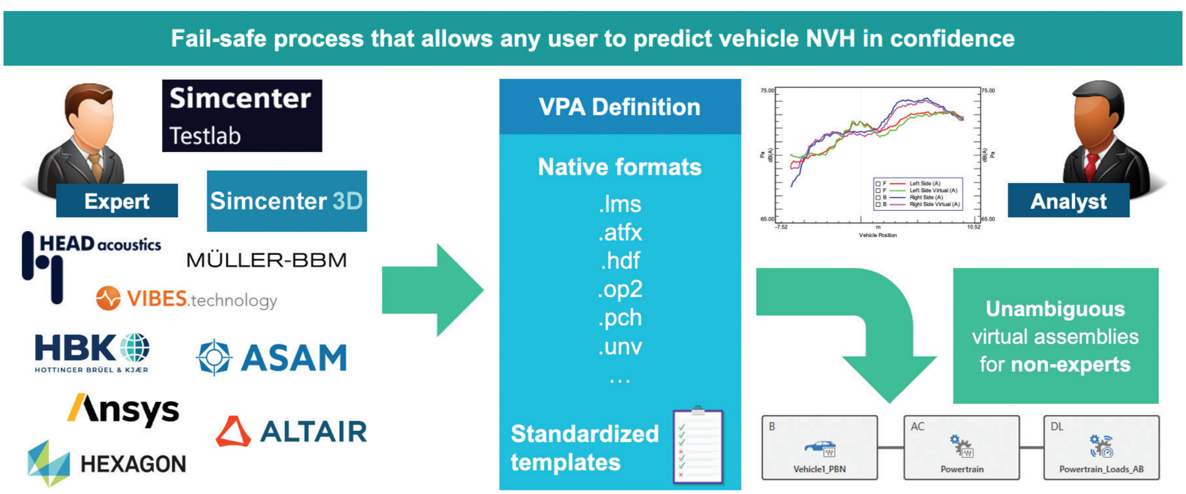

Figure 12. Creating and publishing VPA components for fail-safe re-use later in assemblies.

Users can retrieve components from the Simcenter Testlab Virtual Prototype Assembly component library and use them to create virtual assemblies. When running calculations, all the FBS calculations are performed automatically.

Further, each component of the assembly is represented using a visual building block and easily replace or updated at any point in time. This allows you to easily explore design variations or update the performance prediction of a vehicle under development at any time with the latest component models.

Engineers can effortlessly swap assembly or design alternatives and immediately see the NVH impact before the vehicle is physically available. For example, they can evaluate the effect of modifying the structural properties of the vehicle body, the suspension mounts, or alternative sets of tires.

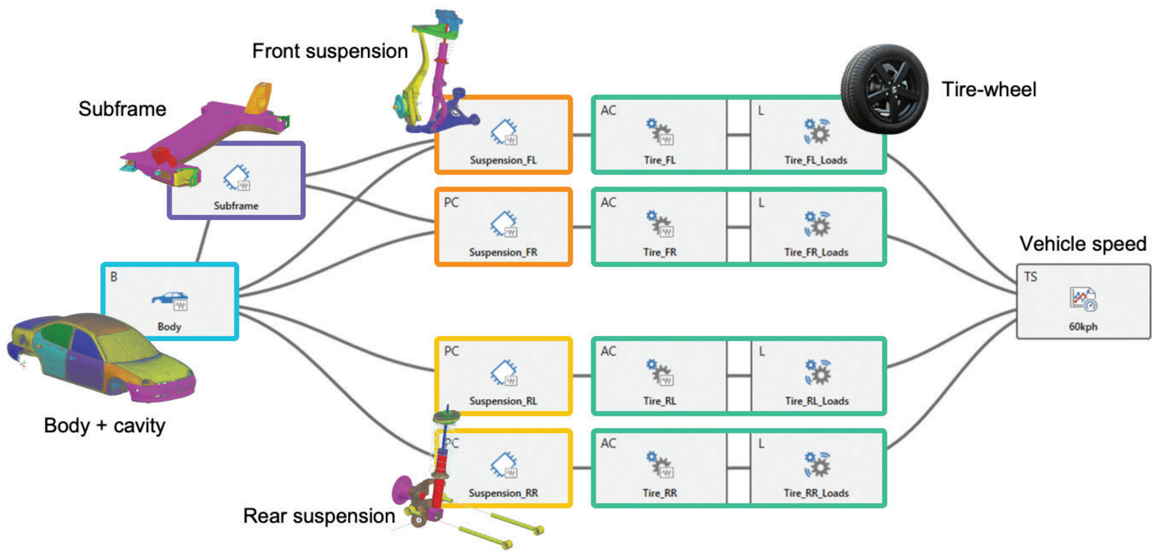

Figure 13. Example of a VPA for structure-borne road noise prediction that combines test and CAE-based component models.

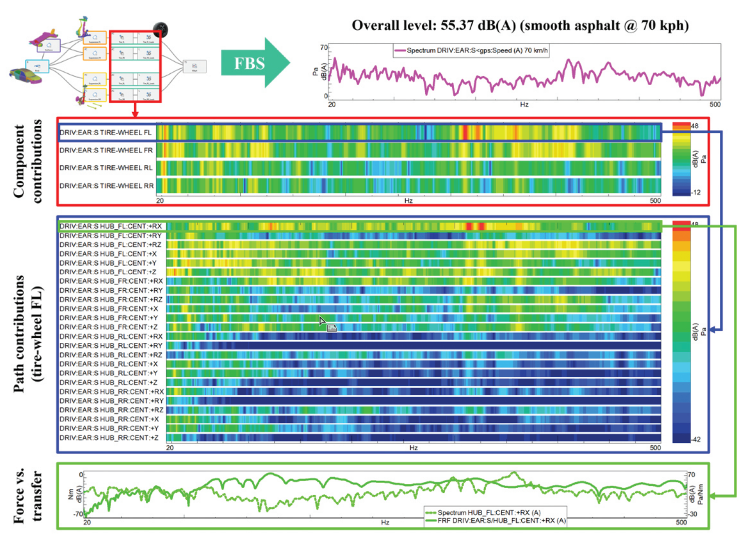

Figure 14. Typical results of a VPA calculation for road noise prediction.

Vehicle NVH simulator

Since EVs are quieter than conventional vehicles due to the lack of combustion engine noise, their sound quality requirements are critical. This means a subjective evaluation of the vehicle's actual noise is more important than absolute noise levels in decibels (dB).

To do this, you can import the VPA models into the vehicle NVH simulator, which converts the frequency-domain VPA models into signals for auralization. Some key advantages of this solution are that engineers can combine the road noise VPA models with other noise sources, such as powertrain and wind noise, to get a feel for the masking effect between components.

Having a full VPA model behind the road noise model can help you enable diverse engineering possibilities. For example, you can insert design variants with alternative component selections to assess their impact on sound perception.

Using vehicle NVH simulation technology, manufacturers can master sound perception early in the design process and find beneficial control strategies to balance conflicting performances. The role of control strategies can help optimize the balance between vehicle NVH and other attributes.

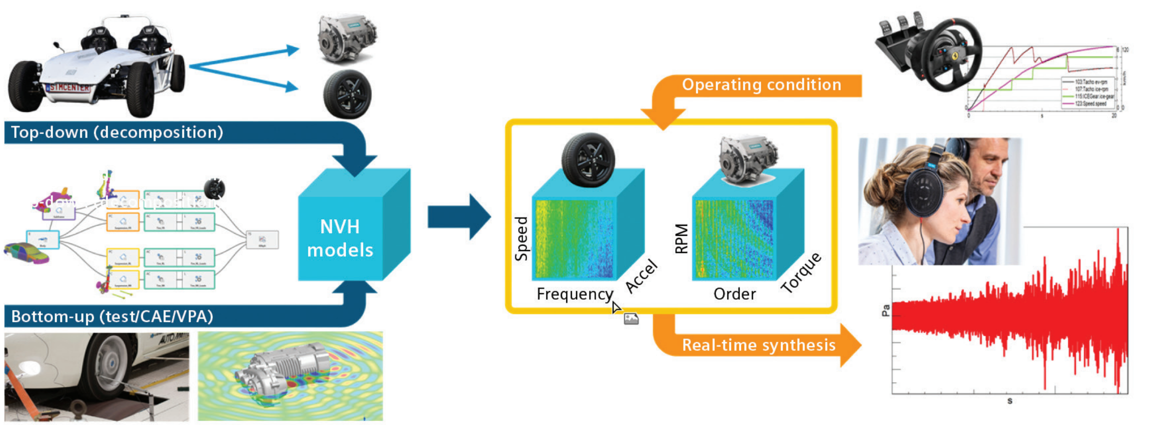

Figure 15. A combination of a VPA road noise model with noise sources from the powertrain and wind loaded on the NVH simulator.

Figure 16. Evaluating sound perception in the early design stages with the vehicle sound simulator.

Conclusion

Road noise in EVs has rapidly become a major concern for the automotive industry, leading to a greater need to properly predict and optimize a vehicle's road noise performance than it used to be with internal combustion engine (ICE) powered vehicles. Vehicle manufacturers and suppliers can use the technology and tools mentioned in this white paper to evaluate the road noise performance of EVs in a structured manner. This white paper brings together existing and/or simulated subsystems, provides insights into evaluating different design alternatives and offer tools for listening to the produced noise.

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