AUTOMOTIVE APPLICATION

Vehicle Interior NVH Testing

ACOUSTIC SENSORS FOR PREMIUM NVH DATA

GRAS Sound & Vibration

GRAS

Vehicle Interior NVH Testing

Vehicle interior noise, vibration and harshness (NVH) involves a number of different tests – all related to noise inside the vehicle originating from road, body, chassis and components of the vehicle.

The main focus areas are:

- TOTAL INTERIOR NOISE
  A way of testing the general experience of a vehicle's acoustic comfort.
- ROAD NOISE
  Testing related to how road excitation contributes to the interior noise both structure-borne and airborne – depending on well-defined road surfaces and tires.
- THE SOUND PACKAGE
  An area that affects most of the NVH areas.
- COMPONENT NOISE
  Concerns all additional systems like the heating, ventilation and air conditioning (HVAC) system, power windows, etc. These are mostly electrical or driven by the engine belt, and sometimes hydraulic
- BRAKE NOISE
  A chassis-related noise and a big problem for car manufacturers.
- COMPUTER MODEL VALIDATIONS
  Testing on prototype parts or vehicles.

ACOUSTIC TEST TYPES WITHIN VEHICLE INTERIOR NVH TESTING

Total interior noise is a good measurement for benchmarking and a measurement often used by automotive magazines for comparison of different car models. It concerns the overall noise level inside the vehicle at its full speed range and is a way of testing the general experience of a vehicle's acoustic comfort.

Articulation Index (AI) is often used as a good index for sound insulation and sealing as well as speech intelligibility.

Road noise is one of the most annoying interior noises in a vehicle. Road excitation contributes to the interior noise both structure-borne and airborne. Requirements are normally based on subjective evaluation, benchmarking and experience. The requirements include noise level and frequency balance. Extra focus is on tire cavity resonance noise around 200-250 Hz and tread noise.

The sound package is closely related to most of the NVH areas. The first step is to make sure that the body is sealed as much as possible. This reduces high-frequency leakage and increases the overall NVH performance. Structural damping and heavy-layer isolation mats must be optimized for best performance and lowest weight and cost. Finally, acoustic absorption material at critical locations is used to improve the acoustic interior comfort.

Component noise is often divided into two areas: customer-actuated sounds and system-actuated sounds. Customer-actuated sounds are directly related to an action like opening or closing a door or power-operating windows and will likewise provide user feedback. System-actuated sounds are controlled independently of any action from the driver or passengers and the reason why the sound is not always easy to understand. The HVAC system is one of the dominating noise sources in the vehicle during cool down or heat up and needs a lot of careful design work.

Brake noise is a chassis-related noise and an area of great concern for OEMs across the world. The noise is caused by friction-induced vibrations, which make the brake system radiate noise. This will in turn cause a lot of irritation and disturbance to the car owner and any person near the vehicle when it occurs. The brake noise can lead to poor results in surveys of customer satisfaction and high warranty costs. Therefore, the development of brake systems with minimum noise issues are highly prioritized in the automotive industry. Brake noise is a very complex problem and the research in this area is in continuous progress.

On top of that, the electrification of vehicles requires new brake design as well as increased focus on noise since the auditory masking from the engine disappears. However, the traditional braking systems will be used to a lesser extent in an electrical vehicle. A regeneration process takes place during deceleration used to provide battery charging which in many cases will be sufficient to control the vehicle speed without using the brake pedal. (For more information on brake testing, please refer to specific brake application literature from GRAS).

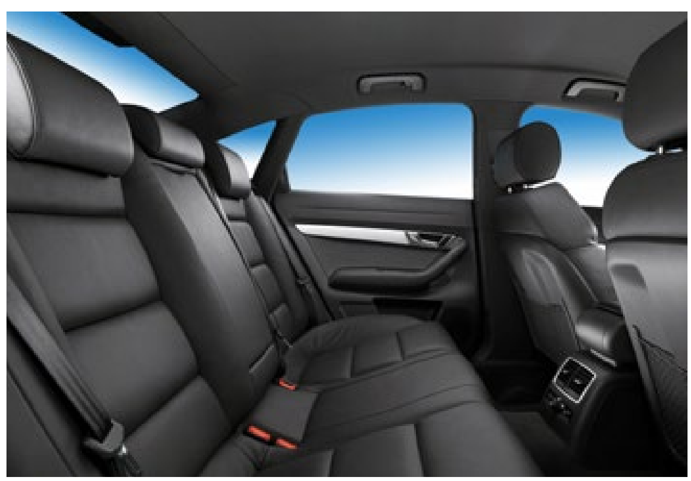
Three test levels

It is important to develop validated test procedures that are fast and easy to perform, and it is good practice to use a standardized selection of transducer types and transducer positions to be able to run several tests efficiently at the same test time. These procedures should also be as generic as possible to allow variation of system design. The engineers need to stay updated on new concepts and perform benchmarking.

Tests are performed at three main levels, vehicle test, system test and component test. Computer model validations can be an integral or separate part of these tests. The tests are used for development, requirement verification, troubleshooting and computer-aided engineering (CAE) correlations.

Vehicle test

A vehicle verification test typically includes two to four microphones at ear level inside the vehicle distributed between the driver's and passenger seats. The test conditions are specified in detail. Tests are performed both on test tracks, on a NVH chassis dynamometer, in the NVH laboratory or in a hemi-anechoic test cell.



Vehicle testing involves testing a range of noise generating sources:

- The **total interior noise** test is performed on a smooth road test track while accelerating from low to high speed. The test also includes analysis of sound pressure level (SPL) and AI versus speed.
- **Road noise** is tested at dedicated NVH test tracks with well-defined road surfaces like smooth, coarse or grooved. Analysis of SPL, third octave band spectra, narrow band spectra and AI is done at different vehicle speeds. External microphones or intensity probe with windshield can be used for measurement of near-field tire noise.
- **Sound package testing** at vehicle level is done indirectly by the vehicle tests.
- **Component noise** is tested during typical usage conditions, but isolated with no other sounds. The tests are performed in a vehicle in a hemi-anechoic test cell.
- **Brake noise** is evaluated with microphones at ear level and in the wheelhouse while driving on a dedicated test route with all possible braking and different environmental conditions.

System test, acoustic transfer function (ATF)

System testing requires the usage of a lot of different acoustic sensors. These tests are mostly performed in a NVH laboratory, either with a complete vehicle or for a system or component only.

System/component level test examples include:

- **ATF** from engine bay to interior to verify sound package. Noise transfer function (NTF) test to measure the structural noise paths. These tests are done with the vehicle in a hemi-anechoic test cell.
- **Noise source contribution from different surfaces** like floor, dashboard and doors is measured with a microphone or intensity probe. This can be done for a full vehicle in the laboratory on a NVH chassis dynamometer or using speakers as noise source, but also on a test track. An acoustic camera can also be used to locate noise sources and detect leakage. Subsystems like a vehicle front structure or door system are installed in an anechoic/reverberation suite, and the contribution from different areas is measured with a sound intensity probe. These tests are used for optimization of the panel treatment.
- **Sound absorbtion and sound transmission loss (STL).** The properties of the acoustic materials used in the sound package are tested in the NVH laboratory. Sound absorption coefficient is tested in a reverberation test cell or in an impedance tube. STL is tested with the test object installed in an anechoic/reverberation suite. The reverberation chamber acts as the diffuse sound source, and the STL is calculated from measurements of the SPL in the reverberation chamber as well as the sound intensity in the anechoic chamber.

Component test

Component testing also requires the usage of many different acoustic sensors. As with the system test, these tests are mostly performed in a NVH laboratory with a complete vehicle or for a specific system or component.

Component noise testing include:

- **Component noise at system level, like the blower noise of a complete HVAC module or the operating sound** of an electric sunroof module, is tested in an anechoic or hemi-anechoic test cell. The system is operated at correct operating conditions, but not the correct boundary conditions to the vehicle.
- **Separate components of a system,** like a small electric motor or solenoid, are also tested in an anechoic or hemi-anechoic test cell and under as valid operating conditions as possible. SPL or sound power and frequency, or order analysis as appropriate, are used to detect the noise corresponding to the component.
- **Brake squeal noise** is tested at system level for a full vehicle corner in a dedicated brake squeal dynamometer.

Computer model validation

A lot of the design decisions and verifications are done before any prototype part or vehicle is manufactured. The body and chassis design has a big impact on vehicle NVH performance, especially for powertrain and road noise, and needs to be verified at an early stage. Measurements from existing cars or systems are used to correlate the simulations. Mule vehicles (existing cars modified with new concepts) are also used.

General measurements include modal analysis and transfer function measurements, NTFs and ATFs. Impact hammer, shakers and volume velocity sources are used for excitation. Furthermore, the standardized vehicle verification tests are used for computer-aided engineering (CAE) model verification.

CHALLENGES COMMON TO VEHICLE INTERIOR NVH TESTING

There are a number of general challenges within vehicle interior NVH:

- Testing time should be short since the access to prototypes is limited.
- Microphone positioning should be done fast and easy, and in a way to record repeatable results.
- The microphones should be placed so that they minimize structure-borne sound.
- Microphone holders and cables should not introduce any rattling noise.
- The installation should be safe for the test engineer to perform during vehicle testing.
- Calibration verification should be easy to perform.

Reliable equipment is critical since testing is often performed at a test track offsite. Microphone field type is important since the noise is often analyzed above 5 kHz. In addition, time data can be stored for later playback for subjective noise comparison.

Specific challenges within total interior noise and road noise testing
The selection of chassis concepts is a critical early decision. Tuning of bushings, wheel size selection and tire selection are big integration areas where handling, design, comfort and cost need to be carefully balanced. Fine-tuning of bushings, chassis settings and tire selection can to some extent be done quite late in a project. Rear end rush (road noise coming from rear air evacuation, rear window, C-pillars, luggage compartment) is important though difficult to extract from measurement results with omnidirectional measurement microphones. Additional microphone positions can be used to analyze the sound field.

Specific challenges common to sound package testing
Packaging, weight, cost and production issues have a direct impact on the possible solutions, so optimization is important.

Specific challenges for component noise testing
Component noise is becoming more and more important. Low sound levels and good sound quality without disturbing tonality is the design target, especially for electrical vehicles because of less auditory masking. Correlation between component, system and vehicle tests to CAE is complicated because of the wide frequency range. Cooperation between the design and test team and sometimes the supplier for the component or system is essential to be able to perform a valid test. Improper test conditions cannot be saved by good test equipment.

Specific challenges for brake noise testing
Brake noise requires long test cycles in extreme environmental conditions, so this means that ruggedized and reliable equipment is a must.

SELECTING THE RIGHT MICROPHONE

The transducers should be able to withstand exposure to harsh environmental conditions such as strong vibrations, shock, drop, extreme temperatures and wet or dusty conditions without sacrificing performance or lifetime.

Low SPL performance and full audible frequency range is required. Low SPL is especially important for ATF tests. Free-field or random-incidence microphones are most often used and the choice depends on the test procedures.

Vehicle interior and component/system level noise measurements
GRAS provides solutions that can be used at the different project levels and under a wide variety of measurement conditions encountered in vehicle interior testing.

146AE CCP Free-field Microphone Set can be positioned in the car cabin at ear level to measure the interior noise coming from road, body, chassis and other car components. With the help of the RA0504 GoPro Adapter, the 146AE can be mounted on the wide variety of GoPro mounts and clamps available on the market. This will help make the microphone positioning inside the car quick and easy.

The 146AE can be used to test the properties of the acoustic materials used in the sound package or to measure component/system noise both in an anechoic, hemi-anechoic or reverberant chamber. The 146AE can be positioned in the different measurement points using the AL0006 Microphone Tripod in combination with the RA0093 ½" 5-click Microphone Holder or the AL0008 ½" Microphone Holder. The AL0008 also requires the use of the AL0005 Swivel Head. This combination will eliminate the possibility of introducing external rattle noise due to poor microphone mounting.

When a random-incidence microphone is needed, the 146AE can be used together with the RA0357 Random-incidence Corrector ring to change its response from free field to random incidence (diffuse field).

The 146AE is a robust microphone that will be able to withstand dusty and humid environments, very high and low temperatures as well as shocks and drops.

The power-on LED indicator in the 146AE will help the test engineers to swiftly check that all the microphones are working correctly. In addition, the transducer electronic data sheet (TEDS) capabilities of this sensor will contribute to the fast setup of multi-channel systems.

RECOMMENDED MICROPHONES AND CALIBRATORS

Vehicle Interior and Component/System Level Noise Measurements

	146AE	1/2'' CCP Free-field Microphone Set
	RA0357	Random-incidence Corrector for 146AE
	RA0504	GoPro Adapter
	AL0005	Swivel Head
	AL0006	Microphone Tripod
	AL0008	1/2" Microphone Holder, POM
	RA0093	½" 5-click Microphone Holder, Stainless Steel
Calibration	**42AG**	Multifunction Sound Calibrator, Class 1

Vehicle interior sound source location
Array microphones like the 40PH and the 40PL CCP Free-field Array Microphones are cost-effective, free-field acoustic sensors designed to be mounted on large or small array modules like the PR0002 Array Module for the analysis of sound fields. These types of microphones can be used in vehicle interior testing for measuring and locating noise sources using techniques like beamforming, near-field acoustic holography (NAH) and acoustic cameras. The 42AG Multifunction Sound Calibrator can be used for calibration of array microphones too.

A sound intensity probe like the 50GI-RP CCP Rugged Intensity Probe can be used for near-field tire noise measurements (mounted with the included windscreen) or to analyze noise source contributions from different surfaces like floor, dashboard and doors on system/component testing. The 51AB Phase Calibrator according to IEC 61043 is used for level and phase calibration of the intensity probes.

RECOMMENDED MICROPHONES AND CALIBRATORS

Vehicle Interior Sound Source Location

	40PH	CCP Free-field Array Microphone
	40PL	CCP Free-field Array Microphone, High Pressure
	PR0002	Array Module
	50GI-RP	CCP Rugged Intensity Probe
Calibration	**42AG**	Multifunction Sound Calibrator, Class 1
	51AB	Phase Calibrator according to IEC 61043

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About GRAS Sound & Vibration

GRAS is a worldwide leader in the sound and vibration industry. We develop and manufacture state-of-the-art measurement microphones to industries where acoustic measuring accuracy and repeatability is of utmost importance in R&D, QA and production. This includes applications and solutions for customers within the fields of aerospace, automotive, audiology, and consumer electronics. GRAS microphones are designed to live up to the high quality, durability and accuracy that our customers have come to expect and trust.

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