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LMS solutions for NVH, acoustics and comfort

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The new age of NVH, acoustics and comfort

The pressures on NVH engineering are constantly increasing. Legislation continuously dictates tougher noise and vibration limits; hybrid and electrical vehicles introduce an entirely new noise environment; fuel efficiency dictates new, lighter structures and downsized engines. And of course, customer expectations for driving dynamics and comfort are rising. NVH and driving dynamics as differentiating brand values have become more important than ever.

Optimizing fuel economy strongly impacts NVH behavior. Fuel economy is directly influenced by weight reduction. The focus on new materials such as composites and related bonding in body systems, as well as weight reduction in chassis and power-train components, all dictate NVH and acoustic performance. Design options for fuel economy can result in the degradation of vibration behavior unless properly addressed. Weight reduction programs can affect transfer paths causing driveline induced booming issues. Driveline induced transient vibrations as well as transmission gear whine and rattle issues become more dominant.

In the absence of low frequency interior engine noise, the interior sound quality of electrical vehicles is dominated by high frequency sounds. Auxiliary noises of small motorized parts, the HVAC system, fan noise, invertor and battery cooling noise and transmission whine are all more prominent. Road and wind noise also deteriorate further the interior sound quality.

Limited expertise and few databases exist in the industry for NVH benchmarking, sound quality and target setting for hybrid and electrical vehicles. These are just a few of the new challenges and opportunities in NVH development.

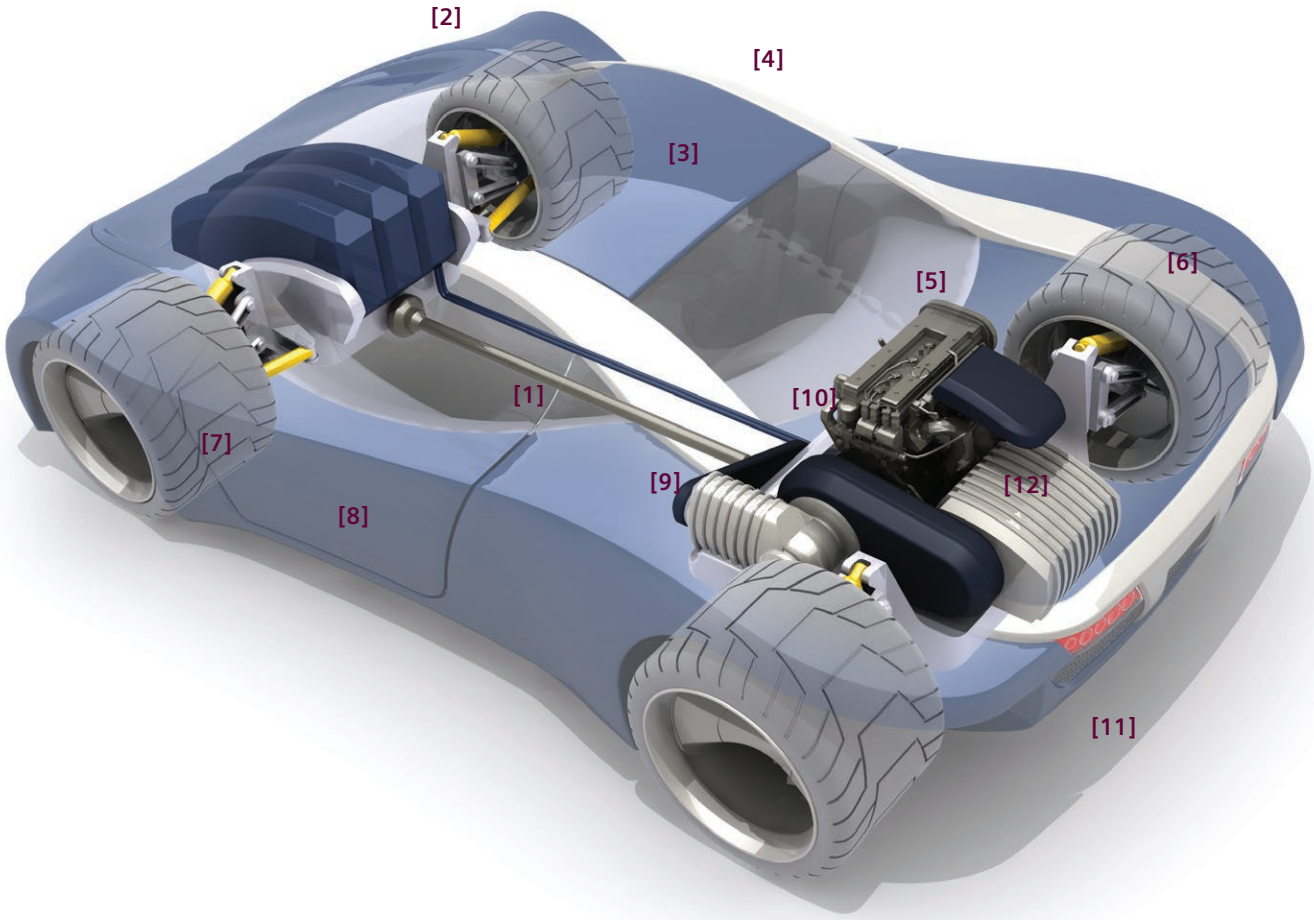
NVH, acoustics and comfort performance impacted by eco-challenges

Building more eco-friendly vehicles ranks high on the development agenda of automotive manufacturers and suppliers.

Very often, this ambition is linked to the successful introduction of hybrid or full electric technology. However, in the case of traditional cars – which are likely to remain the major bulk of vehicles produced in the foreseeable future – it implies downsizing the internal combustion engine (ICE) as well as further weight reduction.

All these new concepts strongly impact the noise, vibration and harshness (NVH) behavior of the vehicle under development:

- Fuel-economy-driven measures on engine design result in acoustic and vibration degradation, resulting in particular quality issues, such as impulsive noises in the injector system and high frequency whine in turbochargers.
- Weight reduction and ICE downsizing programs strongly affect noise and vibration transfer paths, causing driveline originated booming issues. In addition, torque lock-up strategies as well as start-stop features create transient vibrations.
- Without low frequency ICE noise, the interior sound quality for electrical vehicles (EV) is affected by high frequency sounds induced by small motorized parts, the HVAC system and fan as well as by transmission whine, while road and wind noise are likely to further degrade the acoustic experience.
- Noise from the electrical motor and inverter, as well as the battery cooling system, represent new challenges as do transient effects from switching drive modes in hybrid electric vehicles.



[1] Driveline and powertrain integration
- Driveline torsional vibration
- Mount optimization
- Shaft unbalance and booming
- Transitory behavior of hybrid engine and range extender
- Drivability
- Steering feel

[2] Exterior noise
- Door slam sound quality
- Pass-by noise regulations
- Drive-by reflections

[3] Interior acoustics
- Sound quality
- Trim optimization

[4] Body stiffness
- Structural and acoustic transfer

[5] Engine
- Combustion, cylinder and bearing forces load path analysis
- Engine radiation
- Injector tick noise
- Turbocharger noise
- Chain noise

[6] Ride comfort and road noise
- Tire noise
- Structure-borne transfers
- Body flexibility
- Steady and transient states

[7] Brakes
- Brake squeal
- Disc dynamic judder

[8] Component acoustics
- Air conditioning noise
- Battery heat management noise
- Inverter and electronics noise

[9] Gearbox
- Gear rattle, whine
- Transmission casing radiation

[10] Engine integration
- Structure-borne and airborne transfers
- High frequency tonal electric motor noise

[11] Exhaust
- Structural and acoustic excitation of pipes and muffler
- Shell radiation
- Tailpipe orifice noise
- Floor plate radiation

[12] Intake
- Intake orifice noise
- Shell radiation
- Turbocharger noise

LMS NVH solutions

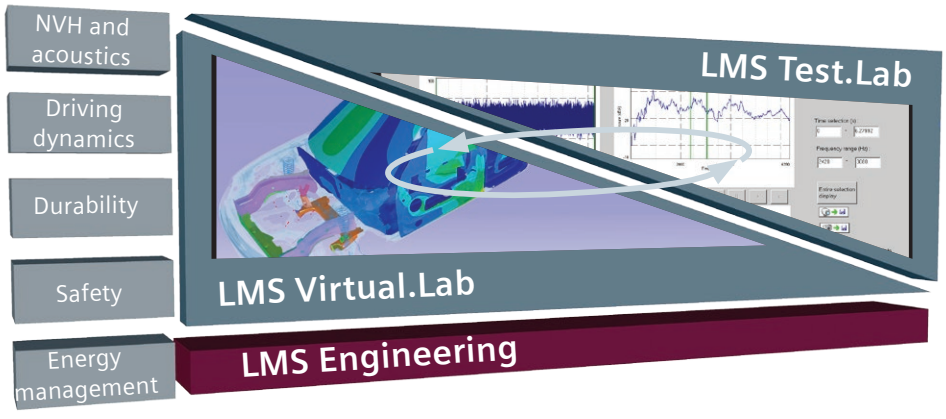
Backed by world-class test and simulation – software, engineering services and facilities

In close collaboration with industry-leading OEMs, LMS has further reinforced its position in NVH eco-engineering optimization as it provides:

- A solid, hybrid test-simulation development process, supporting effective frontloading of design decisions that dramatically reduce the development timeline and cost; it banks on the unique LMS™ software correlation capability for prototype-testing results and CAE simulation
- A market-leading NVH and acoustics testing platform, securing fast and accurate data acquisition in the laboratory, on the chassis dynamometer and on the road with unmatched support for test preparation, result analysis and postprocessing
- A state-of-the-art simulation platform for effective multi-attribute optimization including NVH and acoustics

In addition, LMS has a proven track record of successfully executing engineering projects, helping customers with:

- Engineering services, providing automotive manufacturers and suppliers with additional insight into industry best practices with respect to NVH optimization processes and methodologies
- Solving NVH-related challenges as part of a troubleshooting task or a full co-development project with a specific focus on technology transfer, development process improvement and on-the-job training

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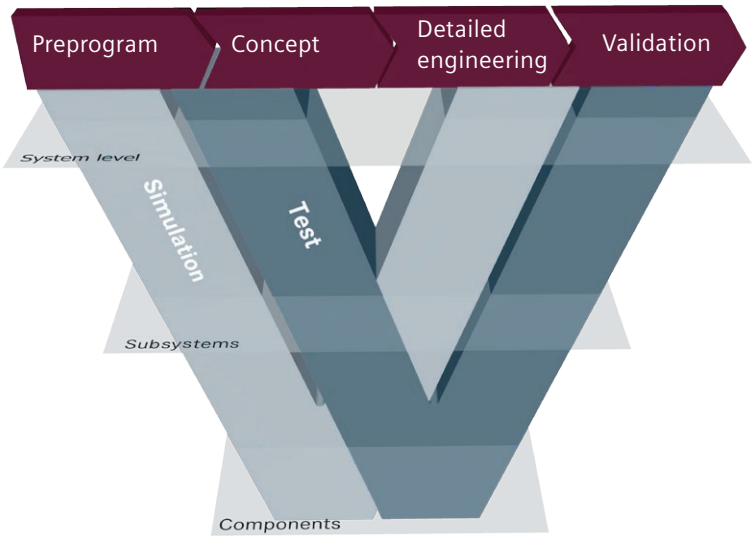
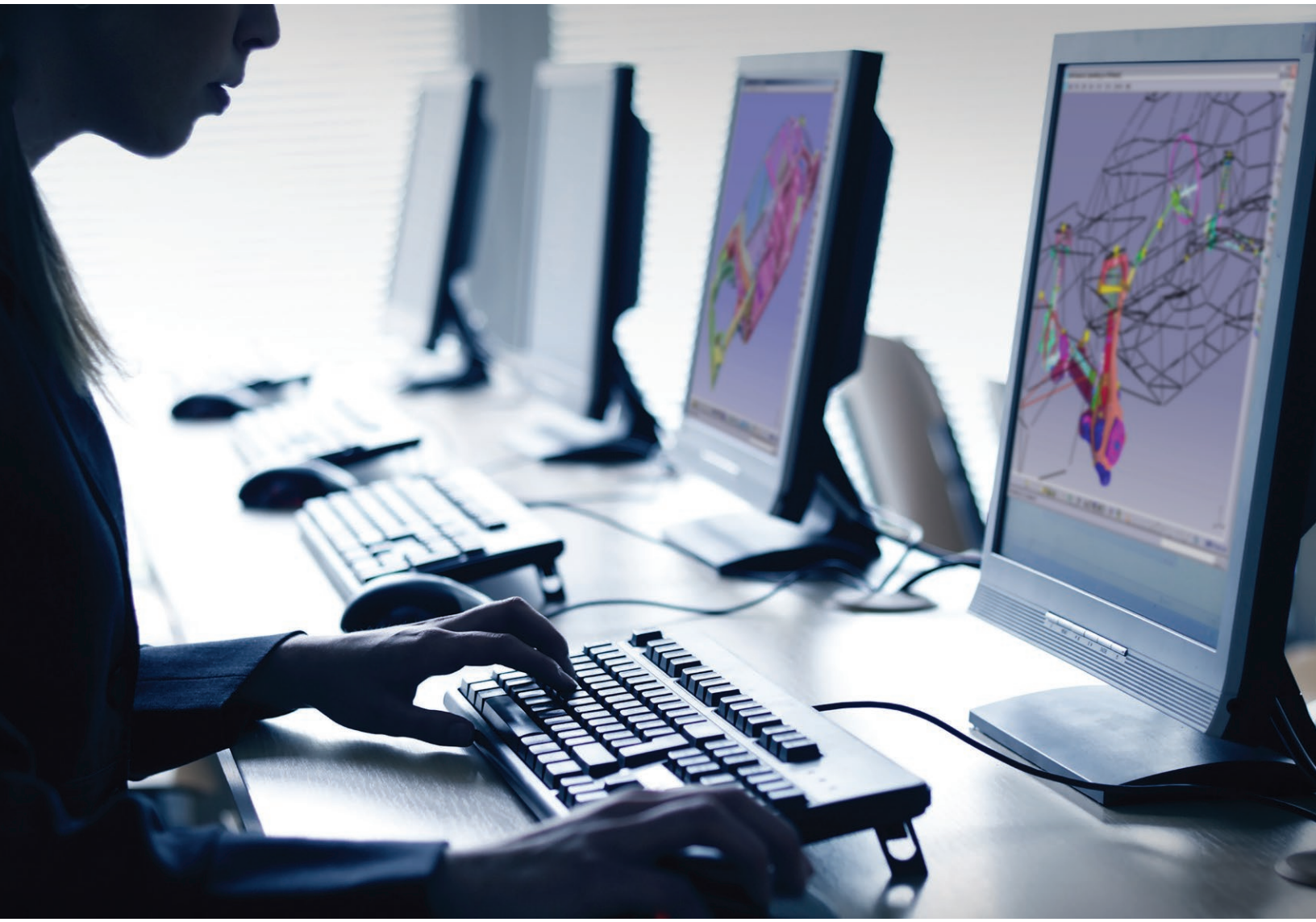
A solid NVH test-simulation development process

Many customers adopting our hybrid engineering approach have achieved 30 to 50 percent faster time-to-market cycles when introducing new eco-related design concepts.

We have pioneered a unique hybrid test-analysis engineering approach that integrates simulation processes with test results. As part of this process, test-based models of previous designs and competitive products are combined with virtual models of newly designed components and subsystems. This innovative approach enables:

- Frontloading NVH and comfort decisions for accurate assessment of different green design concepts and performance-related architectural choices.
- Increased productivity and efficiency: efficient subsystem engineering and reliable full-vehicle performance certification are achieved thanks to test-based refinement.
- Best-in-class simulation and/or testing technology during each development step for component, subsystem and vehicle design NVH and acoustic performance optimization.





A unique portfolio of test and simulation solutions to support the multi-attribute engineering process

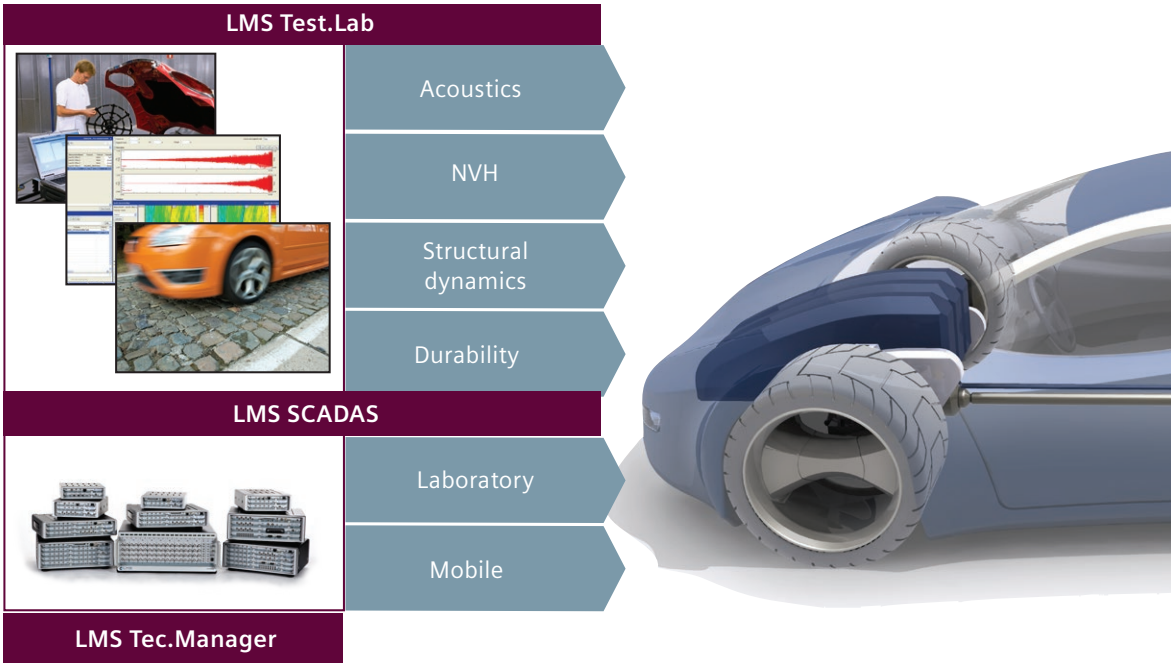
A market-leading platform for test-based engineering solutions

Testing experts can count on the productivity and efficiency of the comprehensive LMS tool set for integrated NVH and acoustics engineering. LMS Test.Lab™ software includes solutions for vehicle, engine and driveline applications. All LMS testing solutions are created to be used with the LMS SCADAS™ hardware, ranging from compact mobile units, autonomous smart recorders up to high channel count laboratory systems.

For hybrid analysis, the LMS Test.Lab suite offers the capability to correlate test-based model information with the results from simulation platforms such as LMS Virtual.Lab™ software and LMS Imagine.Lab™ software.

LMS Test.Lab supports ASAM/ODS as an industry standard for broader test data exchange while LMS™ Tec.Manager software provides a collaborative data repository environment for test data.

Responding to customer NVH eco-challenges brings new capabilities onboard the LMS Test.Lab suite, ranging from



specific developments in the LMS SCADAS hardware range to support multi-rpm tracking systems and more complex drive systems to specific engine, engine component and driveline testing and analysis procedures as well as new sound assessment and localization and sound quality technology.

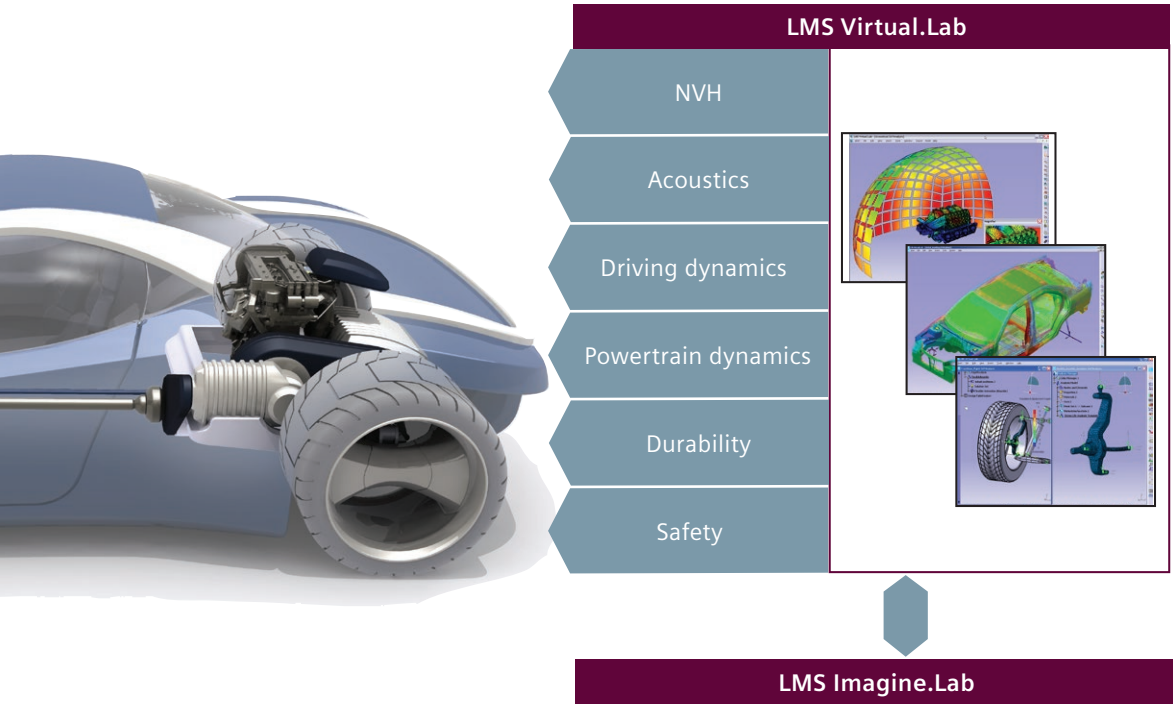
A state-of-the-art simulation platform for multi-attribute optimization

LMS Virtual.Lab offers an integrated 3D CAE simulation software suite to simulate and optimize mechanical systems performance. LMS Virtual.Lab covers all the process steps and required technologies to perform an end-to-end design assessment for multiple attributes. Next to general structural analysis, it supports multiple industry-standard FE solvers and CAD-integrated model assembly. We provide a range of dedicated simulation tools for acoustics, NVH, durability, safety and multi-body dynamic simulation for system synthesis and refinement, banking on best-in-class solver technology and superior process integration.

We continue our focus on developing its market-leading LMS Virtual.Lab Acoustics technology, where – next to extended application support for eco-trends – investments in superior acoustic solver technology are delivering value to customers who need to cope with broadening frequency ranges for new and adapted drive systems.

With the need to reduce vehicle weight, the new context does require continued focus on appropriate body NVH and acoustic modeling and design improvement technology for both exterior and interior noise.

In addition, we are rapidly expanding the LMS Imagine.Lab platform for mechatronic system simulation, securing further frontloading of eco-related design decisions, even without a CAD-derived 3D geometry. For particular NVH issues, the LMS Imagine.Lab Amesim™ software actuator and vibration source modeling capability for powertrain and chassis applications complements work in the 3D and testing environment.



LMS NVH engineering

Based on its multi-disciplinary and multi-attribute vehicle expertise, the worldwide LMS services team is uniquely positioned to help automotive OEMs and suppliers.

LMS Engineering services helps customers explore solutions for development-related eco-NVH related issues, ranging from quick vehicle troubleshooting questions to full vehicle co-development. More specifically, LMS Engineering supports:

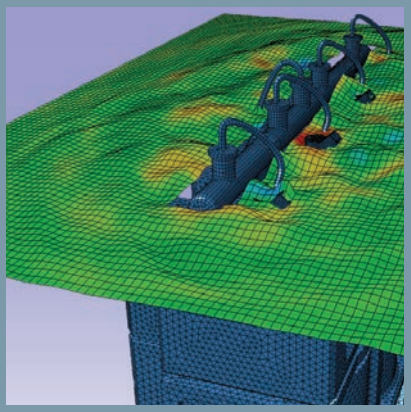
- Process re-engineering and technology innovation consultancy, taking advantage of our vast experience with industry best practices. Via technology deployment, we enable customers to implement these innovative processes while advancing their capability to carefully balance functional vehicle requirements.
- Full-vehicle and subsystem co-developments, where we take full responsibility for achieving performance objectives. We are uniquely skilled at balancing functional performance attributes, such as NVH, acoustics and comfort with fuel economy and weight reduction.
- Troubleshooting and design refinements that tackle problems which only appear during prototype testing. During this late development stage, a fast resolution is expected with full consideration for the implications and limitations of any substantial design change. In this case, we deliver an integrated and proven approach to late-development troubleshooting, using a mix of test and simulation techniques to avoid inefficient and time-consuming trial and error methods. The impact of different possible solutions is analyzed upfront and the optimal design change is validated through final prototype testing.

In addition to the proven development process, the LMS approach offers significant benefits over any other engineering solution as it secures deployment of the software tools and models for use in future projects. We maintain the delivered software, providing continuous support and release updates for the duration of the project. We have a culture of open technology sharing including models, data and milestone reports.

Furthermore, we organize regular onsite technology exchanges. This process of cooperation not only enables reaching the project targets, but it also deploys a simulation-based, vehicle-level methodology with a complete technology transfer.

Most importantly, we firmly believe in on-the-job involvement, securing a trusted customer relationship, which is key to the success of the program.

To date, we have a long list of references in deploying attribute methodology as part of vehicle development programs for both traditional and HEV/EV vehicles. We have successfully performed many NVH projects, integrating new eco-friendly technologies while continuing to improve vehicle drivability and performance.

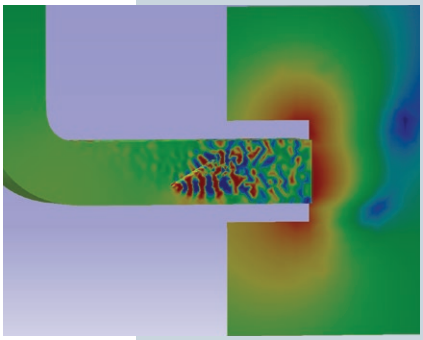


LMS Engineering has a wide variety of testing facilities at its customers' disposal:

- Chassis dyno in a large semi-anechoic chamber
- Structural test labs and semi-anechoic chambers
- Anechoic and reverb chambers
- Shaker test platform in an acclimatized space
- Tire-suspension NVH test rigs
- Engine and gearbox NVH test benches
- Proving ground access

Delivering an integrated approach to NVH eco-engineering

Eco-pressure in the industry is setting the stage for a renewed focus on adressing particular challenges arising on all NVH fronts from component and subsystem to the full-vehicle level. This eco-pressure affects vehicle manufacturers and suppliers alike.

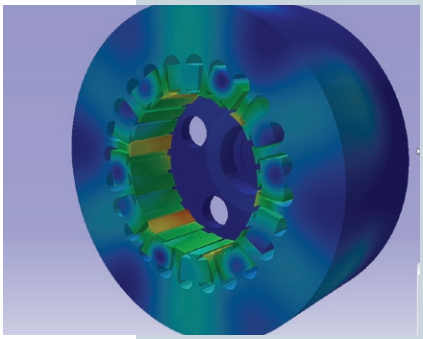


HVAC and cooling systems

HVAC noise is becoming a more prominent issue for hybrid and electric vehicles with the absence of traditional ICE noise.

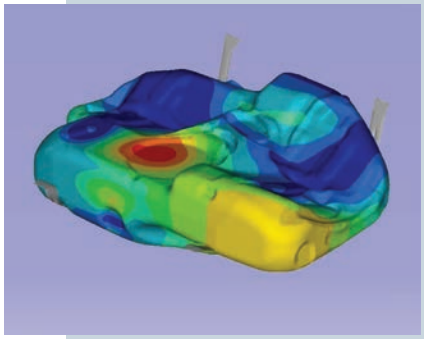
- Fans can create annoying tonal noise, and structure-borne or airborne noise is transmitted through the HVAC casing
- Air turbulence propagating from the HVAC ducts is another cause of significant noise
- The compressor in the refrigerant circuit causes high-pressure fluctuation as well

In order to prolong battery lifetime for hybrid and electric vehicles, the air from the vehicle interior is extracted and used to cool the batteries.Test-based source ranking technologies in combination with simulation-based technologies provide the right answers to vehicle integration issues and component optimization.



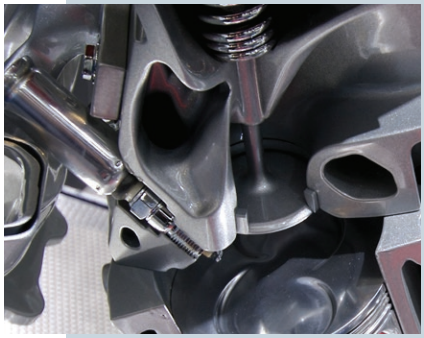
Electrical devices

Noise from electric motors clearly exhibits annoying harmonics in higher frequency ranges. Electromagnetic forces provide the necessary torque for the motor, but cause the motor to vibrate and radiate noise. For an electric motor, higher efficiency, enhanced torque and lower cost often conflict with improved noise performance. We provide solutions to assess and optimize the noise from electric motors as well as separate items like wipers, seats or window motion as well as power for the electronics.



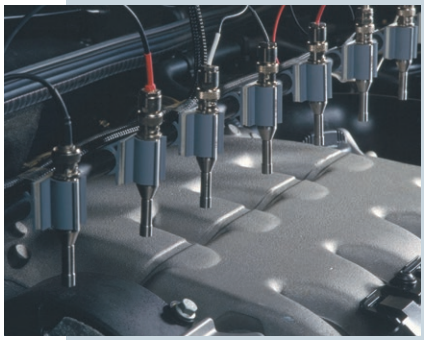
Fuel sloshing

Fuel sloshing occurs when a vehicle accelerates, creating noise that may be perceived as a quality issue by the customer. Start-stop features increase the focus on this noise aspect. To reduce slosh noise, a fuel tank has to be carefully designed. We provide the application expertise to combine CFD, structural FE and time-based acoustic simulation technology to support accurate noise prediction.



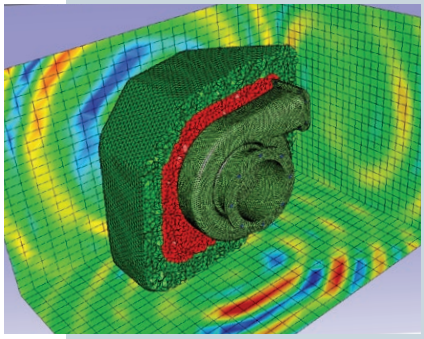
Engine dynamics

In order to increase fuel efficiency, refined engine system configurations, such as variable valve trains as well as new engine strategies (like variable displacement engines or cylinder deactivation) are being investigated and implemented. In-depth testing and simulation is needed to properly quantify and qualify the transient behavior. We provide integrated test and simulation solutions that allow fully synchronized acquisition and analysis, supporting in-depth engineering qualification.



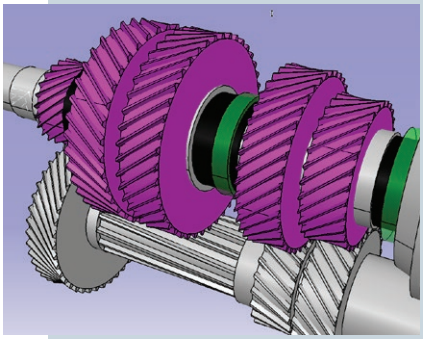
Injection systems

We offer dedicated solutions to support high-performance injection system development. Impact-like injector ticking noise is caused by needle-seat impact and impulsive waves, propagating from the fuel lines. Key to the LMS solution is the ability to accurately and efficiently model this excitation to analyze injector noise and vibration as a single component as well as the integrated injection system, including rails, hoses, connections and the engine. Likewise, the high-pressure injector pump is a major source of noise for which we provide solutions.



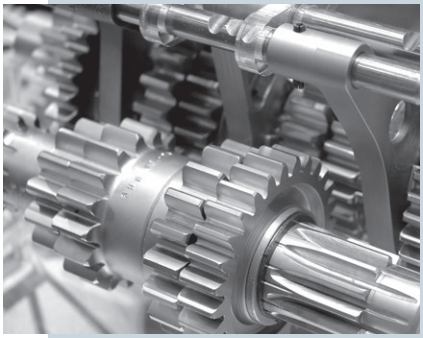
Turbocharger

Turbocharger-related noise is characterized by high frequency harmonics due to the high rotation speed of the impellers. Structure-borne noise is caused by complex rotor dynamics while airborne-noise is due to the pulsating air inside the turbocharger. Turbo resonators connected to the turbochargers reduce the high-pitched noise, often referred to as turbo whine. To reduce the noise, we provide solutions for both types of problems.



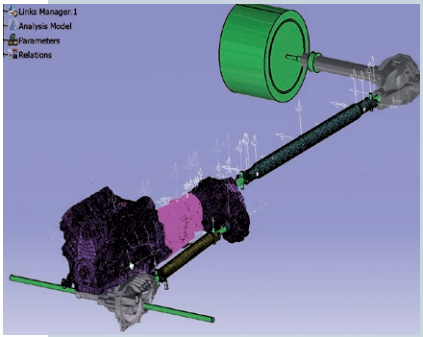
Transmission

Due to fuel economy requirements, torque variations in transmission systems are increasing, generating in particular gear rattle noise issues. Gear tooth whine issues are becoming more dominant, particularly in HEV vehicles because of more complex transmission technologies, such as planetary gear sets and dual clutch. We provide test and simulation solutions to predict the loads caused by gear interaction as well as solutions for acoustic radiation optimization of the transmission casing.



Driveline

One of the most important consequences of the ongoing downsizing trend is the increased torsional excitation of the vehicle driveline. This evolution, occurring as drivetrains are being optimized for weight and efficiency, leads to a number of comfort problems. It can also generate loads that far exceed nominal torques. We offer a complete range of test-based solutions to measure real-life rotational vibrations or driveline loads under any operating conditions.

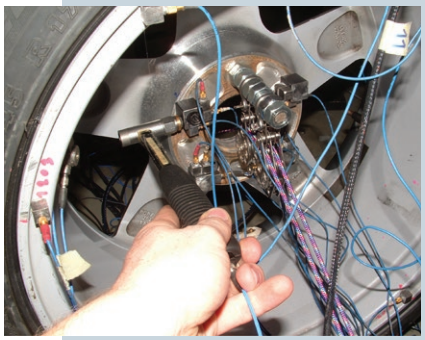


Driveline integration

Torque converter lock-up at lower RPMs and start-stop features can cause comfort issues due to transient vehicle excitation. Torque lock-up scenarios lead to particular nonlinear judder phenomena. Tip-in tip-out comfort is another relevant performance concern as new generation engines generate higher torque at lower RPMs and thus induce more driveline booming. We bring a scalable solution based on testing and CAE simulation, including, where relevant, engine and transmission control strategies. We provite adapted technologies supporting broad frequency range transfer path analysis, both for transient and steady-state engine and driveline integration applications.

Ride comfort

Low-frequency ride comfort is addressed through a combination of simulation and testing methodologies. During design validation, flexible multibody simulation models are used to address transient and steady-state ride comfort issues. In the prototype stage, modal analysis and transfer path analysis are used in combination with operational data analysis to further refine ride comfort behavior.

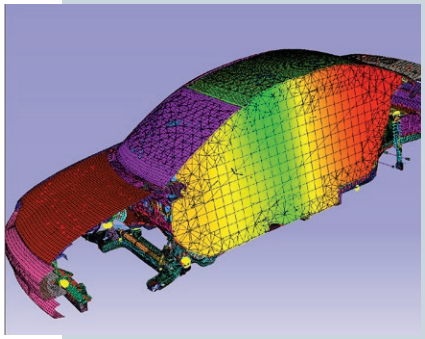


Road noise

Road noise is a major contributor to overall interior noise levels, especially at average vehicle speeds. For hybrid or electric vehicles, road noise is becoming even more important due to lower masking. Structure-borne and airborne road noise originate between the tire and road surface. It is propagated throughout the vehicle to the receiver. To address these NVH issues, we consistently apply source-transfer-receiver-based techniques. Identifying critical transfer paths upfront in the vehicle development process is possible using simulation to take advantage of LMS source-transfer-receiver insights based on physical prototypes testing.

Wind noise

When driving at average or higher speeds, wind noise, with its broadband frequency characteristic, is much more apparent in hybrid or electric vehicles compared to standard ICE cars. Car auxiliaries causing unwanted wind noise are primarily mirrors, wipers, pillars, sunroofs, and other flow-disturbing parts. Innovative component designs and alternative ways of connecting these auxiliaries to the car, resulting in less air turbulence, give rise to lower noise levels. We provide test-based acoustic array technology and acoustic simulation solutions to efficiently and effectively solve these flow-related noise problems both at the component and full-vehicle level.



Body design and acoustic package

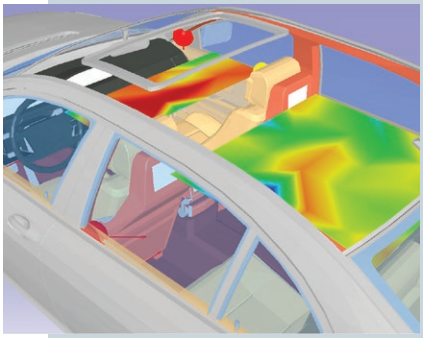
Balancing the weight and performance of a vehicle's acoustic package is a fine art and requires lightweight materials optimized to manage the higher range of frequencies. Lightweight materials contribute significantly to reducing the eco-footprint of the vehicle. We offer a range of advanced solutions for testing and predicting the effect of lightweight materials on overall interior and exterior noise. Test-based and simulation-based source data representing engines, intakes, exhausts and tires can be effectively combined with acoustic simulation models of the vehicle. As the frequency range for acoustic vehicle trim reaches 8kHz and higher, the simulation models become very large to compute. For this, LMS has developed unique technologies enabling full-vehicle acoustic simulations.

Benchmarking and sound quality

The balance between structure-borne and airborne noise contributions in different frequency domains varies drastically depending on the selected powertrain architecture. This creates new challenges for target-setting and benchmarking initiatives, in particular for hybrid and electric vehicles. Via competitive benchmarking, We have developed a structured process to cascade down targets to systems and components. During vehicle development, these targets are submonitored.

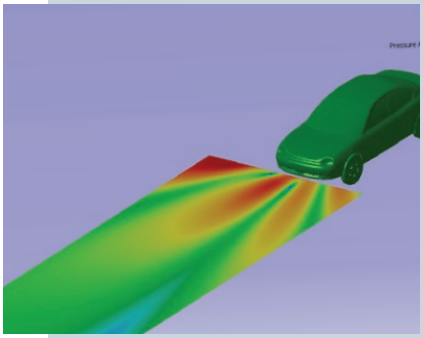
Pass-by noise

The growing concern regarding environmental noise has resulted in the new ISO362 standard for pass-by noise (PBN) certification, calling for an evolution in exterior PBN measurement solutions. The ongoing trend of engine downsizing and lighter material usage drives the need for more engineering insight in order to successfully run these tests. We advocate in-room pass-by noise testing in combination with sound source localization (SSL). This results in maximum design insight with regard to components contributing the most noise. Using computational methods to generate numerical estimates of the source-receiver-transfer path allows vehicle developers to obtain a pass-by noise estimate during the virtual prototyping stage.



Audio and multimedia

The ever-increasing quality demand for audio and multimedia systems requires an increased usage of simulation technology in support of the dimensioning and positioning of audio components. We have developed state-of-the-art technologies that aim at reducing development time and increasing in-vehicle audio sound quality by means of sound field simulation software.



Pedestrian safety

At low speed, an electric or hybrid vehicle is extremely quiet, representing a danger for pedestrians. To increase safety and conform to upcoming regulations, car manufacturers are putting sound alert systems into hybrid and electric vehicles. Sounds generated by these systems should aim at alerting and not annoying pedestrians. We provide solutions to engineer these sound systems. More specifically, one can investigate and optimize the directivity of the generated sound as well as the frequency and quality.

"The 'as installed group' where various LMS tools are used to solve key NVH issues is very vehicle-specific. To have global platforms and one signature DNA across all Ford vehicles, we had to go global. Today, we are working towards the same output on all our vehicles whether it is powertrain sound quality, brake feel or handling. We are going to be able to talk one language across all of our vehicles at any point in time."

Barb Samardzich
Vice President Ford of Europe
The Ford Motor Company

About Siemens PLM Software
Siemens PLM Software, a business unit of the Siemens Industry Automation Division, is a world-leading provider of product lifecycle management (PLM) software, systems and services with nine million licensed seats and 77,000 customers worldwide. Headquartered in Plano, Texas, Siemens PLM Software helps thousands of companies make great products by optimizing their lifecycle processes, from planning and development through manufacturing and support. Our HD-PLM vision is to give everyone involved in making a product the information they need, when they need it, to make the smartest decision. For more information on Siemens PLM Software products and services, visit www.siemens.com/plm.

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