Introduction to vehicle NVH and Acoustics
Introduction to NVH
Powertrain NVH analysis
Interior vehicle NVH
Exterior acoustics
Conclusion
What is NVH?

- **Noise**
  - Audible disturbance mainly in the 20 Hz – 5000 Hz frequency range.
  - Characterized by frequency, level and quality

- **Vibration**
  - Motion sensed by the body mainly in the 0.5 Hz – 50 Hz frequency range.
  - Characterized by frequency, level and direction

- **Harshness**
  - Rough, grating or discordant sensations associated with the combined effect of noise and vibration.
  - Principally associated with road surface excitation
The Spectrum of NVH Phenomena

**Excitation**
- Powertrain
  - fore aft shuffle
  - idle
  - 2nd order
  - engine auxiliaries
  - powertrain bending
  - gear rattle & whine
- Road
  - blocks
  - highway
  - wheel unbalance
  - wheel hop
- Vehicle
  - whole vehicle
  - engine rigid body
- Human
  - motion sickness

**System Resonances**
- Engine rigid body
- Body
- Organ resonances
- Visual disturbance
- Acoustic cavity modes
- Drive shaft
- Chassis & subframe
- Hearing disturbance

**Design Attributes**
- Lateral & longitudinal motion
- Fatigue
- Vibration comfort
- Acoustic comfort

**Response**
- Fatigue
- Vibration comfort
- Acoustic comfort
NVH Applications overview

Powertrain NVH

Turbo noise

Wind noise

Pass-by Noise

HVAC

Panel Transmission loss

Sound System

Interior Acoustics

Parking sensor

Intake/exhaust

Door slam

Brake squeal
Overview of NVH Applications

What is the problem? quantitative analysis needed
- Analysis of vibration levels
- Analysis of noise level
- Assessment of human impact

Where does it come from?
- Spectral analysis: which frequencies contributes
- Spatial analysis: which parts of the structure contribute?
- Is it a source or transfer problem?
- Where are the actual sources?
- What is the noise transmission process?
- What is the influence of the structure itself?

What can we do about it?
- Engineering analysis
- Modification assessment
- Build models so you can work with simulations
Powertrain NVH analysis

Introduction to NVH

Powertrain NVH analysis
- Structure-borne and air-borne noise
- Sound Source Localization
- Powertrain integration
- Component analysis: Gear box, Turbocharger, injectors…
- ICE and Hybrid engine
- Electric motors
- Combined use of test solutions and simulation analysis

Interior vehicle NVH

Exterior acoustics

Conclusion
Powertrain related NVH

- Direct radiated noise
- Driveline integration
- Structure-borne noise
- Auxiliary noise
Fuel Economy programs impact NVH

Integrating for productivity

NVH Analysis

Online Angle Domain / Combustion Analysis

- Pegging
- PV diagram
- IMEP
- Customized metrics

Torsional Vibration Analysis

ECU Communication

CAN / FLEXRAY / CCP / XCP
Engine radiated noise

Measurement using Acoustic camera

Beamforming (50cm)

500Hz 1/3 octave

1250Hz 1/3 octave

4000Hz 1/3 octave

Simulation with acoustics solvers
Drivability optimization in context of fuel economy
Early concept phase investigations of powertrain/vehicle behavior

1D Simulation
- Combustion process and parameters
- Coupling to ECU
- Control models for gearbox, torque converter, active suspension

ECU

Combustion Pressure

Driver Input - Throttle

3D Simulation
- Detailed MBD model: powertrain, driveline, chassis and suspension
- Integrated controls for gearbox, active suspension

Driveability:
Tip-in – Tip-out, WOT Gear shift…

Combined Optimization Driveability
Combustion - Controls – Vehicle

Hybrid / Electric Car NVH Analysis

• New challenges posed by EV/HEV
  - Air conditioning noise becomes more apparent (not masked)
  - Gearbox: whining noise more apparent
  - Sound Quality of the interior becomes more important
  - Safety: EV are very silent; silent car, silent danger
  - Electrical Motor Noise: Tonal & High Frequency
  - Battery & E-motor heat management and related noise
  - Wind noise / Road noise becomes more important (not masked)
  - Different strategies for trimming in engine compartment
  - Hybrid PT, Range extender: ICE on/off transitions!
  - Inverter noise: high frequency tonal
  - Switch Mode converter noise: high frequency tonal
  - Different powertrain mounting strategies: E-motor, E-motor+ICE, E-motor+Generator

• How does an electric vehicle sound like?
  - Full load run-up 25 to 95 km/h

Sound Pressure Level

48th Order - Whine

Road Speed (DT1) vs. Sound Pressure Level (dB(A))

Frequency (Hz) vs. Sound Pressure Level (dB(A))
Introduction to NVH

Powertrain NVH analysis

**Interior vehicle NVH**

- Transfer Path Analysis
- Modal Analysis
- Component analysis: HVAC, Wind Noise, Sound system...
- Vehicle comfort
- Complementary offering between test, simulation and engineering services

Exterior acoustics

Conclusion
Interior related NVH

- Engine noise & vibration
- Wind noise
- Sound System
- Interior Acoustics
- HVAC
- Road Input
Source-Transfer-Receiver Model

Given a set of excitations in frequency domain ...

\{ Mechanical Structural \}

Source

\times

Given the structural model of a car or its components ...

\{ Air Structure \}

System Transfer

Predict and optimize the NVH Performance

\{ Sound Pressure Level Structural Vibrations \}

Receiver

End of page content.
Response and contribution analysis (1/2)

Which Path?

Which Mode?

Which Panel?

What shape? (ODS)
Response and contribution analysis (2/2)

Path Contributions

Over Paths?

Modal Contribution

Over frequency?
# Measurement and Analysis Methods for Wind Noise

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Exterior</th>
<th>Interior</th>
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</thead>
<tbody>
<tr>
<td>CFD results to Acoustic response</td>
<td>Build a detailed map of exterior flow generated noise including coherence to interior sound levels.</td>
<td>Reduce wind tunnel testing time, identify dominant sources &amp; plot results on CAD geometry.</td>
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</table>

## Simulation

**CFD results to Acoustic response**

- Exterior flow generated noise including coherence to interior sound levels.

## Exterior

**Build a detailed map of exterior flow generated noise including coherence to interior sound levels.**

## Interior

**Reduce wind tunnel testing time, identify dominant sources & plot results on CAD geometry.**
Sound system engineering

Sound source definition
- Frequency-dependent
  - Source Power
  - Directivity

Cabin
- Interior modeling including trim influence

Receiver
- Sound quality indicators (IACC, ILD, ITD, etc.)
- Auralization of results
Exterior acoustics

Introduction to NVH

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Interior vehicle NVH

Exterior acoustics

• Pass by noise simulation
• Pass by noise testing: Indoor, Outdoor, Certification
• Sound power analysis
• Exterior warning sounds
• Parking sensors

Conclusion
NVH Applications overview

- Pedestrian warning
- Door slam
- Parking sensors
- Pass-by noise
Pass By Noise homologation

- Key exterior noise qualification for vehicles
- Compliance with ISO standards and for competitive performance
  - Exterior noise test; 2 microphones and standard acceleration profile
  - Compliance to ISO standard
- Interior noise test with multiple microphones to analyze the problem
- Processing into octave spectra
- Identification of contributing frequencies and components

<table>
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<tr>
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<tbody>
<tr>
<td>Test Approach speed</td>
<td>50 km/h at entrance AA’</td>
</tr>
</tbody>
</table>
| Test Operating Condition | Full Load (WOT) | Combination of 2 tests:
  - Full Load (WOT)
  - Constant speed |
| Tested Gears | Gear 2 and 3 | Gear depend of mainly power to mass ratio
  Often gear 4 and even gear 5 need to be tested |

eVADER – Exterior sound of EV (EU Project)
System engineering approach - Sound Synthesis & Propagation

Speaker Directivity

Multiple speakers in bumper
Combined with sound environment
And Beam-forming (phase shift)

=> Directional warning sound field

EC Project eVADER - SCP1-GA-2011-285095
Electric Vehicle Alert for Detection and Emergency Response
Parking sensor
Pulse emission and reflection simulation

Parking Assistance

Ultrasonic 40 kHz pulse simulation

Ultrasonic sensors send out short pulse at particular frequency, which hits an obstacle and is reflected back to the sensor. The entire phenomenon is naturally run in the time domain both for computational efficiency and analysis capability.
## Solutions for Vehicle NVH Simulation

<table>
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<th>Interior Acoustics</th>
<th>Exterior Acoustics</th>
<th>Sub-systems</th>
</tr>
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<tbody>
<tr>
<td>Covering full frequency range using Simcenter 3D FEM, SEA+ and Ray Acoustics based solutions</td>
<td>Simcenter 3D, FEM AO, AML and BEM solutions to cover simulation for pass-by Noise, wind noise, door slam, external speaker noise, parking sensors</td>
<td>A multitude of sound sources warrant detailed investigation, such as intake/exhaust, HVAC systems, entertainment systems, tank slosh,…</td>
</tr>
</tbody>
</table>

### Powertrain Acoustics
Simcenter 3D solutions for engine and transmission, full offering linking acoustic simulations with motion and 1D simulation

### NVH Troubleshooting
What is the root cause? Source? Path? Transfer path analysis, panel contribution analysis, vibro-acoustic modal analysis

### Hybrid Engineering
Building fast and accurate full vehicle models using data from FE, Test, 1D, or others…
## Solution for Vehicle NVH in testing

### Target related testing
- Target setting & validation
- Orders, Octave, Sound Power, Mount force validation, radiated noise quantification, …

### Functional performance
- How to meet functional performance?
- Running mode, torsional vibration, angle analysis & combustion analysis, dynamic balancing, …

### Advanced Acoustics
- How to meet acoustic performance?
- Sound source localization and ranking, combustion noise analysis, sound transmission loss, …

### Model Validation
- Optimize Simulation models
- Modal testing & correlation, inertia data, load input assessment, …

### Powertrain Integration
- How to meet vehicle targets?
- Sound Quality & Sound Synthesis, Transfer Path Analysis & ASQ, In-vehicle recording, …

### Vibro-Acoustic Engineering
- What is the root cause? Source? Path?
- Transfer path Analysis - Acoustic Source Quantification - Vibro-acoustic modal analysis
Engineering services
Smart technologies. Unique solutions.

Highly skilled engineers
Process & technology

Multi-attribute engineering

Troubleshooting

Expertise & know how
Infrastructure & tools

Technology transfer

Co-development

Balancing performances

Vibration

Drivability

Noise

Fuel economy

Controls

Handling

Durability

Fuel economy improvement through control optimization

Road Speed (DT1)

Prominence Ratio FRRI:OUT:S WF 267 [0-6602.6 rpm]
Exterior acoustics

Introduction to NVH
Powertrain NVH analysis
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Conclusion
Siemens PLM Software delivers value across the Automotive NVH Process

• Enable a consistent, model-based engineering process
• Benefit from 30-years expertise
• Support accurate simulation and test solutions
• Provide access to a complete range of product performance solutions
• Enable faster and more frequent design/analysis optimization iterations
• Make design changes transparent and reduce change cycle times
• Reduce time to create product documentation and digital manufacturing data
• Support customer with best-in-class multidisciplinary team of experts
• Facilitate rapid communication of detailed design, analysis and manufacturing data across the supply chain
Simcenter solutions for Automotive NVH & Acoustics

- Legislation and regulation
- New powertrain concepts
- Lightweight structures
- Increase vehicle performance