Downsizing Powertrains
NVH Implications and Solutions for Vehicle Integration
Downsizing Powertrains
NVH Implications and Solutions for Vehicle Integration

- Downsizing trends and NVH impact
- Traditional Approach for NVH studies
- New Integrated approach

Examples:
- Low Frequency Booming Noise
- Clunk
Addressing the challenges

Continued focus on fuel economy & emissions

NVH & driving pleasure impacted by fuel economy

Multitude of options to be evaluated

New materials – new engineering challenges
Technical impact of the fuel economy race

**Introduction of new technologies for transmissions**
- Stop & start, Hybridization, Robotized Automated Manual Transmissions (AMT), Dual Clutch Transmissions (DCT), Continuous Variable Transmission (CVT), Increase of gear ratios up to 10 in AT, CPVA (Centrifugal Pendulum Vibration Absorber)
- Dampers technologies on pendulum, DMF, Variable stroke pumps, ...
- Control strategies to reduce LU opening, CVT clamping pressure, increase energy recovery, ...

**Growing stresses in the driveline**
- Weight reduction, reduced size of components
- Downsizing/down-speeding engines increases acyclism

**Attributes balancing requirement**
Defining the best compromise between fuel economy, performance, drivability and vibration/acoustics is requested to improve brand value
Reducing CO₂ at the price of NVH and driving comfort?

<table>
<thead>
<tr>
<th>Drivers for new vehicle development</th>
<th>Light Weight</th>
<th>New P/T &amp; Driveline Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission &amp; Fuel Economy</td>
<td></td>
<td>Downsize ICE / Hybrid mode</td>
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<td>→ Higher torque irregularities</td>
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<td>→ Driveline integration issues</td>
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<td>EV-mode operation</td>
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<td>→ No LF ICE masking</td>
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<td>→ LF and HF issues</td>
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<td>Multi-Attribute Balancing</td>
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<td>Body Weight vs Body Stiffness</td>
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</tbody>
</table>

- P/T Booming
  - Clunk, rattle
  - Non-speed related
- Tip-In/Out
  - Key-On/Off
  - Mode switch
- Increased Road Noise
- Electric Motor Noise
- HVAC & Auxiliary Noise
- Static Stiffness
  - Handling
  - Ride comfort
  - NVH
Integrated Design and Verification: Full Vehicle NVH
Front Load and Virtualize Decisions
Model Complete Systems – Predict and Verify

Target Setting & Concept Finalization
Concurrent & Integrated Design and Verification
Improved Systems Integration & Virtualize Testing
Optimize Test and Validation, with Correlation to the Virtual

Pre-Program
Detailed Design
Virtual Verification
Physical Verification

Benchmarking
Target Setting
Load Identification

PWT, Chassis & Platform Concept

Verify sub-system behavior
System Verification
Physical Test

Release for mule
Release for prototype
Release for pre production
SOP

TEST
CAE

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Siemens PLM Software
## Analysis requirements for vehicle integration performance

<table>
<thead>
<tr>
<th>Requirements vs. Frequency</th>
<th>0.1</th>
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<th>10</th>
<th>100</th>
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<td>Driveability</td>
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<td><strong>Road / Suspension</strong></td>
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<td><strong>Excitation model</strong></td>
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<td>Map-based response</td>
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<td>Dynamic torque calculation</td>
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<td>Increasing component</td>
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<tr>
<td>parameterization</td>
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</table>
CO₂ reduction effect on NVH

**CO₂ Reduction**

- Reduce vehicle weight
- Compromised stiffness/NVH pack
- Reduced isolation
- Increase interior noise & vibration
- Present
- Past

**NVH cause & effects from CO₂ reduction**

1. Improve engine efficiency
2. Increase driveline efficiency
3. Increased combustion related noise
4. Reduced isolation

**Engine Speed**

- Lock-up open
  1. Increase engine power
  2. Lower number of cylinder
  3. Expand L-UP condition

**Vibration**

- Present
- Past
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Examples:
- Low Frequency Booming Noise
- Clunk
## Traditional technologies for NVH studies

<table>
<thead>
<tr>
<th>Method</th>
<th>Insight</th>
<th>Limitation</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Path Analysis</td>
<td>Separate root cause of vibration / noise</td>
<td>Time consuming, single configuration</td>
<td><img src="Image1.png" alt="Source" /> <img src="Image2.png" alt="Transfer" /> <img src="Image3.png" alt="Target" /></td>
</tr>
<tr>
<td>Operational Deflection Shapes</td>
<td>Visualization of forced response, ability to select key components</td>
<td>Vehicle level only, no rotational dynamics</td>
<td><img src="Image4.png" alt="Vehicle" /></td>
</tr>
<tr>
<td>Full 3D</td>
<td>Detailed optimization possible</td>
<td>Exploration of rotational dynamics not easy</td>
<td><img src="Image5.png" alt="Vehicle with Detailed Optimization Possible" /></td>
</tr>
<tr>
<td>1D Driveline</td>
<td>Detailed rotational dynamics</td>
<td>Full vehicle dynamics not easy to include</td>
<td><img src="Image6.png" alt="1D Driveline Diagram" /></td>
</tr>
</tbody>
</table>
Traditional driveline NVH evaluation approach

Limitation

Classical approach → Assumptions
- Modification prediction → Limitation in low frequency booming range

- Clutch stiffness especially with DMF
- Influence of the preload
- Non-linear mount stiffness
- Influnce of the preload
- Change shaft stiffness
- Change suspension stiffness
- Modify rotational mode
- Modified input
- Modify suspension mode
- Coupling with rotational mode
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New integrated approach

From two different worlds...

“A model can solve the question. My model is correct, your test data is wrong.”

...To polyvalent engineers combining 1D simulation, 3D simulation and testing capabilities

“Let’s combine the available technologies to provide the best answer for the customer”

“Test is the answer. My measurement is correct, your model is wrong.”
Context / Expectations from customer - Booming

General trend: increasing pressure on fuel economy
- Downsized engines
- Advanced torque lock-up strategies (for the case of automatic transmissions)
- Cylinder deactivation

Consequences
- Use of the engine at lower RPMs
- Higher torque irregularities due to lower cylinder number
→ Higher booming noise and vibration

Questions
- How are competitors dealing with booming noise?
  - What is the efficiency of the driveline rotational damper?
  - How are torsional vibration transferred to the cabin?
  - What is the root cause of the high torsional vibration?
  - Is there any coupling of structural modes to rotational dynamics?
  - What is the real added value of a CPVA or a DMF?
Performance of driveline damper

Full vehicle test diagnosis

Full vehicle model diagnosis

Evaluate the performance of the damper (CPVA, DMF…)

Identify the problem and pinpoint the main contributors

Objectivize the decision making process for next driveline design

Provide information about components not available from supplier
Characterization of lock-up damper
Lock up and damping performance analysis

What is the effective range of the lock-up damper?

How efficient is the lock-up damper?
Full vehicle diagnosis using test based load identification in time and frequency domain, ODS, EMA
Reverse engineering
Obtaining model parameters not available to the customer

Benchmark vehicle
→ No parameters

Component testing

Suspension/body characterization

Driveshaft characterization

Torsional damper static and dynamic characterization

Powertrain mounts stiffness

Full vehicle model creation
⇒ Full component visibility

Siemens PLM Software
Calculation of acoustic target response based on combustion pressure excitation

Combustion pressure maps as model input
Interface forces calculated from full vehicle model
Target response calculated based on model loads + measured FRF

Model loads
Test FRF
Target response

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Context / Expectations from customer – Multi-attribute balancing

General trend: higher competitor pressure on vehicle market
- Different attributes in different departments: design decisions can impact other teams, cross department communication not always easy
- Need to save vehicle development cost

Consequences
- Front loading multi-attribute study to early development phase
- Balance between fuel economy, performance and vehicle comfort required
- Need accurate models that can handle different attributes

Question
- How to balance the comfort/fuel economy request?
  - How to frontload multi-attribute balancing?
  - How to properly define a unified modelling environment?
  - How to provide objective evidence that performance is not compromised?
  - Where should we direct our investment strategy for Fuel Economy/NVH?
LMS Engineering answer – Multi-attribute balancing

- **Full vehicle unified testing campaign**
- **Multi level modeling strategy**
- **Multi-attribute optimization loop**

- Evaluate the vehicle performance for each attribute
- Get the right detail level for the attribute to be studied
  - Balance the model complexity with the end user need
- Understand the coupling effect between the attributes
- Define the best design strategy for attribute co-optimization
Multi-attribute evaluation (unified testing)

Multi-physic measurement
→ Heavy instrumentation (>200 channels)

Data processing for model input and validation
→ Vehicle diagnosis

Metric evaluation for multiple characteristics
→ Target setting

Multi-attribute evaluation
→ cross coupling between the attributes
Balance between accuracy and complexity

<table>
<thead>
<tr>
<th>Engine</th>
<th>Transmission</th>
<th>Suspension</th>
<th>Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master</td>
<td>High Frequency engine</td>
<td>All internal details with clearances</td>
<td>3D full physical</td>
</tr>
<tr>
<td>Level 1</td>
<td>MVEM</td>
<td>Simple ratio with equivalent inertia</td>
<td>1D</td>
</tr>
<tr>
<td>Level 2</td>
<td>Mapped engine + 3D body</td>
<td>Simple ratio with equivalent inertia and clearance</td>
<td>2D</td>
</tr>
<tr>
<td>Level 3</td>
<td>Cylinder pressure tables + 3D body</td>
<td>TM with distributed inertias and stiffness</td>
<td>2D with NVH tire model</td>
</tr>
</tbody>
</table>

Calculation time vs Accuracy of the model

Level 1 vehicle

High complexity vehicle
Automatic optimization processes to gain insight in design

Selection of sensitive parameters from Design Of Experiment

Multi objective optimization

Customization → GUI fit for every user level

Best solution for multi attribute balancing
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Aisin AW
Relying on LMS Engineering to strengthen its position as technology partner

- Gained 50 percent time reduction when troubleshooting a new NVH issue
- Significantly reduced overall development time
- Recognized as technology partner of automotive OEMs, resulting in competitive advantage

Reducing booming, judder and gear noise

<table>
<thead>
<tr>
<th>L-up ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
</tr>
<tr>
<td>Time [s]</td>
</tr>
</tbody>
</table>

Energy flow lock-up booming

- Deploy a full vehicle model based approach for the prediction and elimination of clutch judder
- Employ full vehicle modeling approach combining test, 3D and 1D simulation methodologies

“Many NVH techniques we learned from LMS Engineering services are now part of our standard development process, such as transfer path analysis.”

Hiroki Tsuji, Group Manager, Core Component Engineering Department

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Page 26
Aisin AW
Process lock-up booming investigation

1) Testing
Measurement of input & validation data, data for load identification

2) Test based diagnosis
In-depth test investigation including transfer path analysis (TPA) and operational deflection shapes (ODS)

3) 1D Driveline modeling
1D model consists of engine model and transmission model

4) 3D Vehicle modeling
- Powertrain block & mounts
- Subframe
- Chassis
- Front & rear suspension
- Driveshafts & tires

5) Simulation, correlation and model based diagnosis

- Forced response
- Coupled simulation
- Vehicle body – test
- Powertrain internals – 1D
- Linear analysis
- Optimize target vibration
Automobili Lamborghini
Creating a new driveline concept design using LMS Imagine.Lab Amesim

- Designed the torsional vibration characteristic of the Aventador LP700-4 driveline
- Supported torsional vibro-acoustic driveline optimization

Designing the Aventador LP700-4 torsional vibro-acoustic driveline

- Model easily complex dynamic systems using prepackaged components
- Generate models in function of the phenomena the user intends to investigate

"The true power of LMS Amesim is demonstrated by how easy it is to evaluate different driving conditions, software or hardware changes and even different configurations”.

Ing. Claudio Manzali, R&D
Simcenter solutions for Automotive NVH & Acoustics

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