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Ingenuity for life

Downsizing Powertrains

NVH Implications and Solutions for Vehicle Integration

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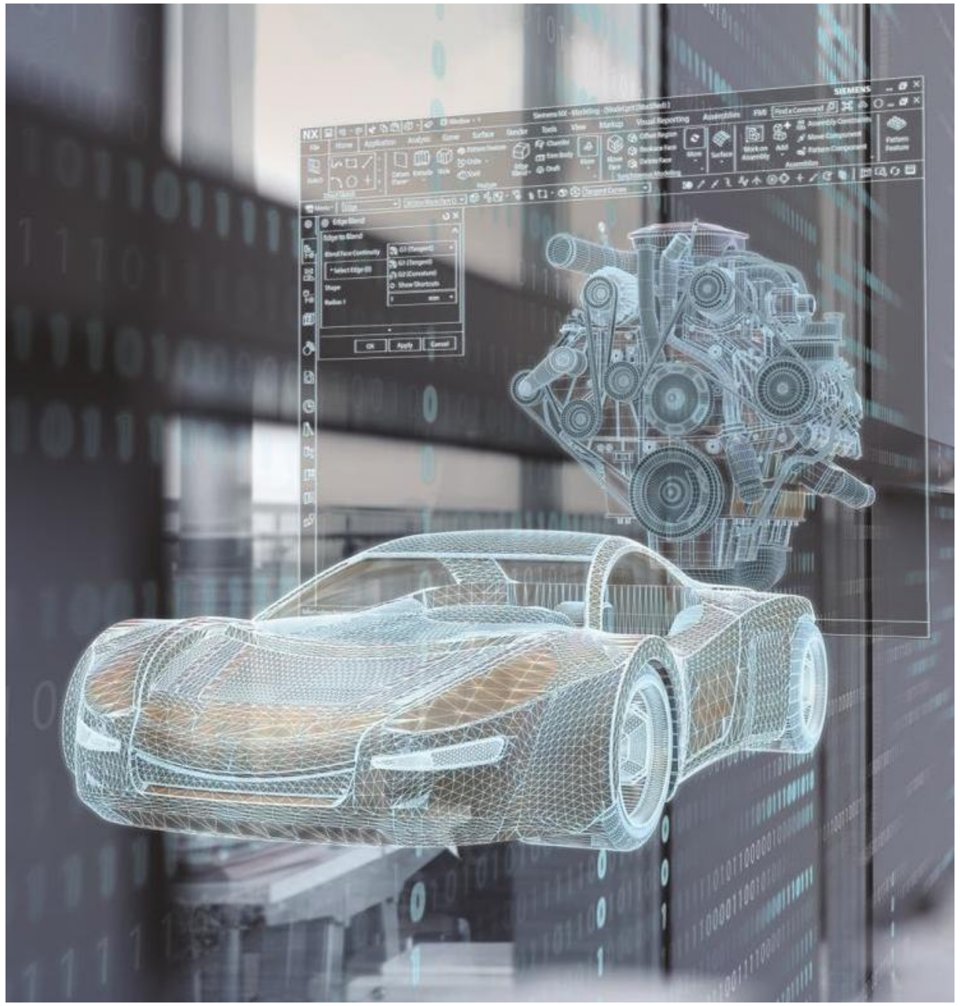
Realize innovation.

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

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Addressing the challenges

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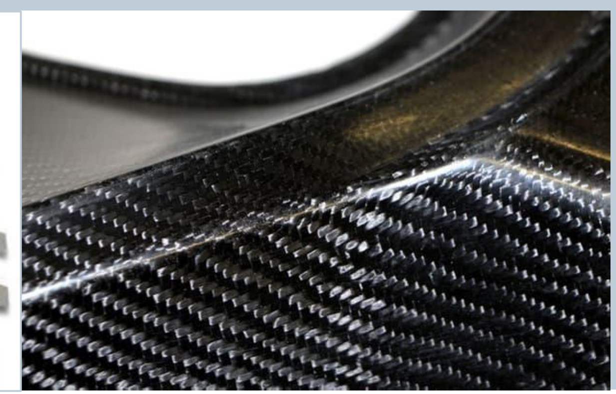
Continued focus on fuel economy & emissions

NVH & driving pleasure impacted by fuel economy

Multitude of options to be evaluated

New materials – new engineering challenges

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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

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Reducing CO_2 at the price of NVH and driving comfort?

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Drivers for new vehicle development
Emission & Fuel Economy

New P/T & Driveline Concepts

Downsized ICE / Hybrid mode
→ Higher torque irregularities
→ Driveline integration issues

- P/T Booming
  Clunk, rattle
  Non-speed related
- Tip-In/Out
  Key-On/Off
  Mode switch

EV-mode operation
→ No LF ICE masking
→ LF and HF issues

- Increased Road Noise
- Electric Motor Noise
- HVAC & Auxiliary Noise

Light Weight

Multi-Attribute Balancing
Body Weight vs Body Stiffness

- Static Stiffness
- Handling
- Ride comfort
- NVH

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Integrated Design and Verification: Full Vehicle NVH

Front Load and Virtualize Decisions

Model Complete Systems – Predict and Verify

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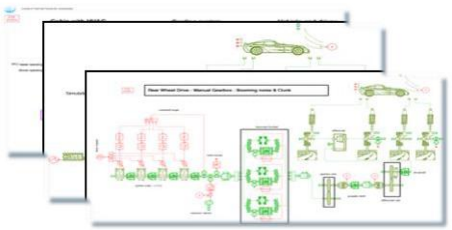
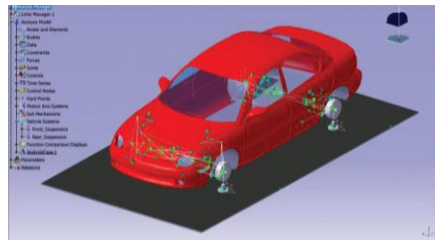
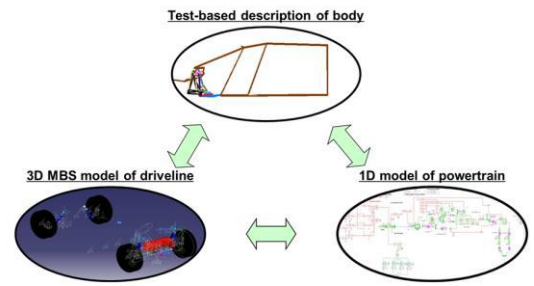


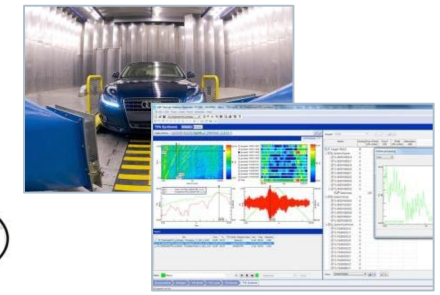
Target Setting & Concept Finalization



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**

TEST

CAE

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

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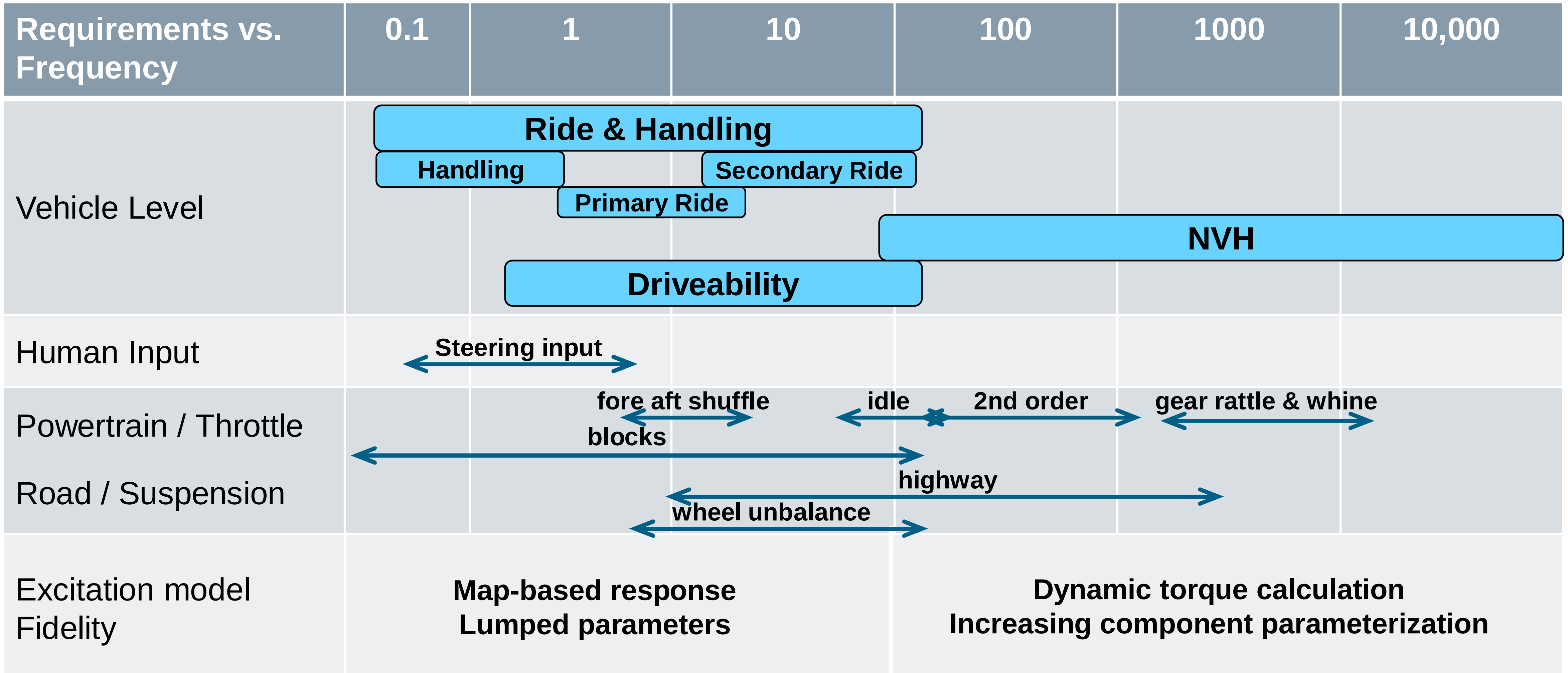
Analysis requirements for vehicle integration performance



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CO_2 reduction effect on NVH

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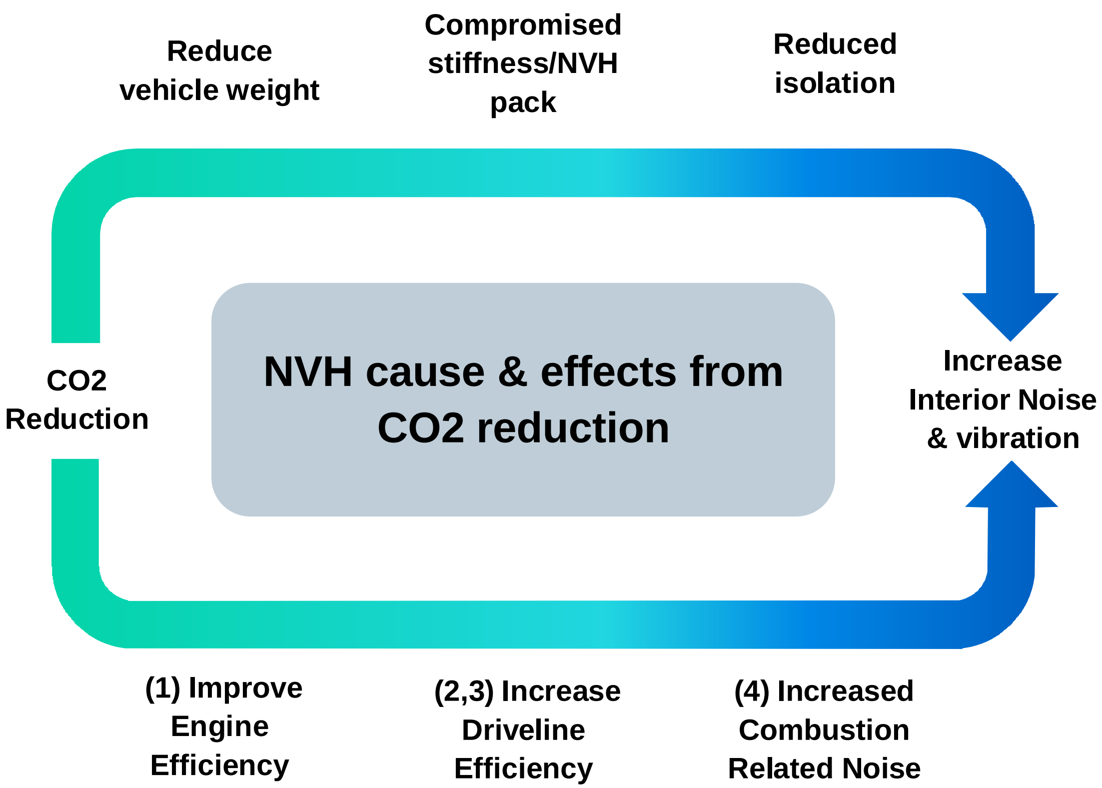

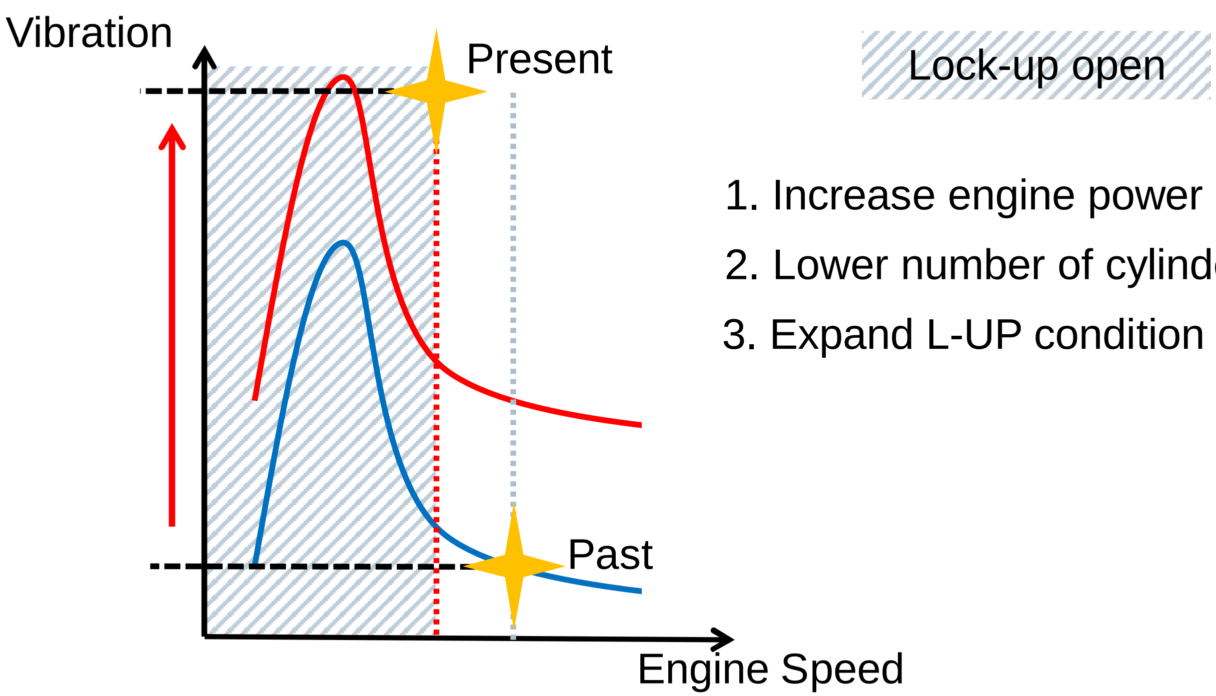

1. Increase engine power
2. Lower number of cylinder
3. Expand L-UP condition

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Downsizing Powertrains
NVH Implications and Solutions for Vehicle Integration

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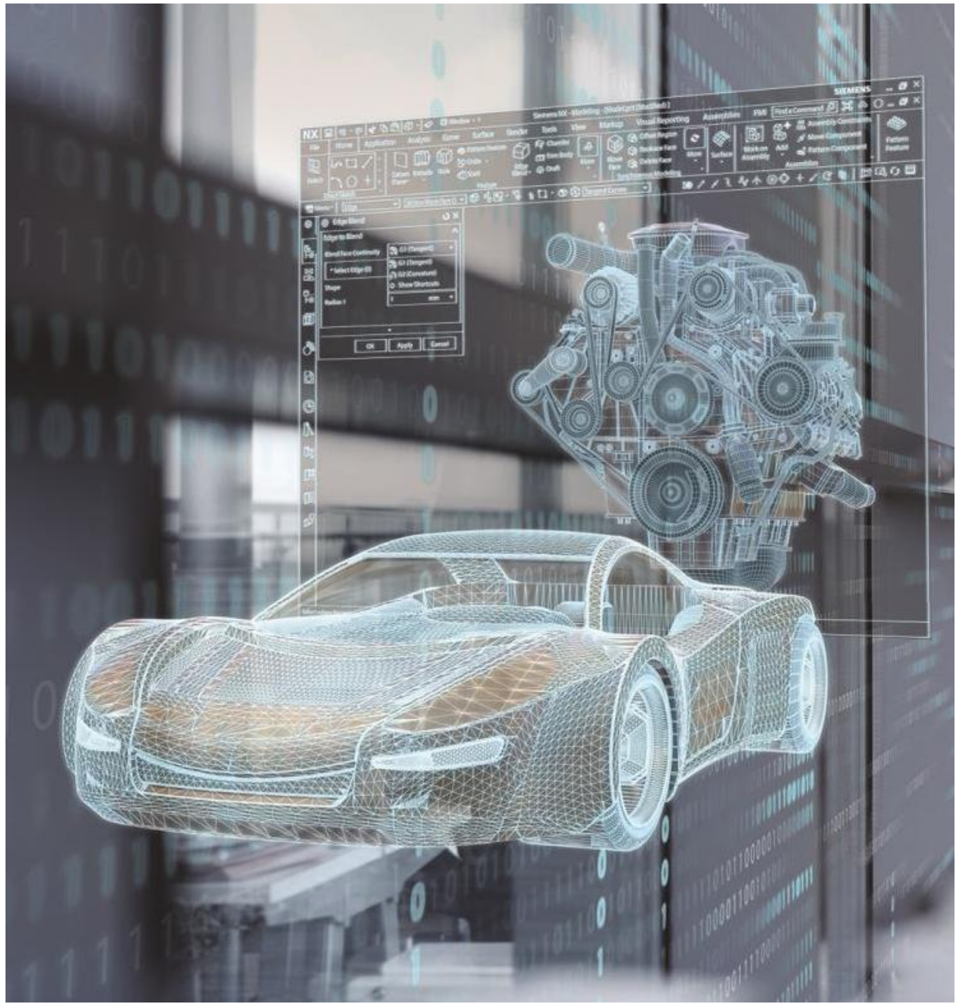

- Downsizing trends and NVH impact
- **Traditional Approach for NVH studies**
- New Integrated approach

- Examples:
  - Low Frequency Booming Noise
  - Clunk

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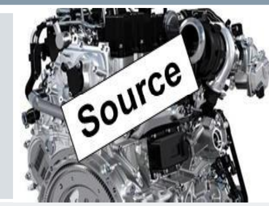
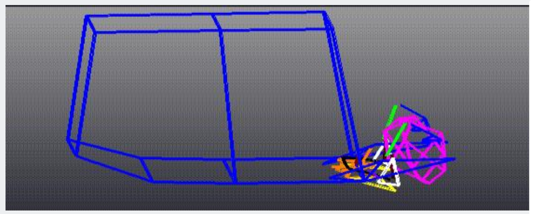
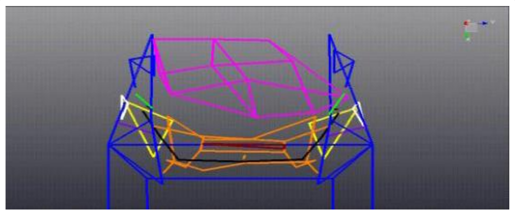
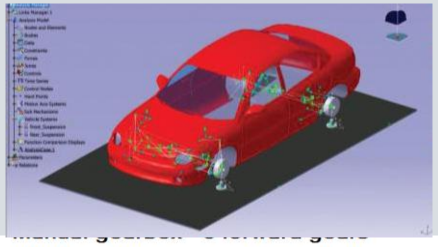
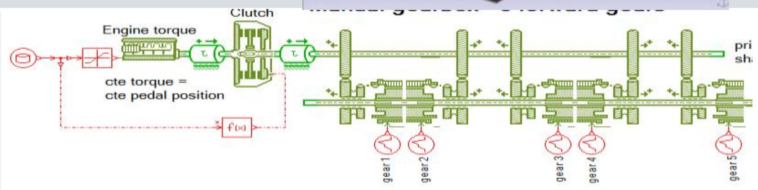
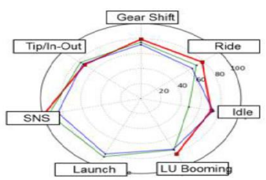
Traditional technologies for NVH studies

Method	Insight	Limitation	Picture
Transfer Path Analysis	Separate root cause of vibration / noise	Time consuming, single configuration	  
Operational Deflection Shapes	Visualization of forced response, ability to select key components	Vehicle level only, no rotational dynamics	 
Full 3D	Detailed optimization possible	Exploration of rotational dynamics not easy	
1D Driveline	Detailed rotational dynamics	Full vehicle dynamics not easy to include	 

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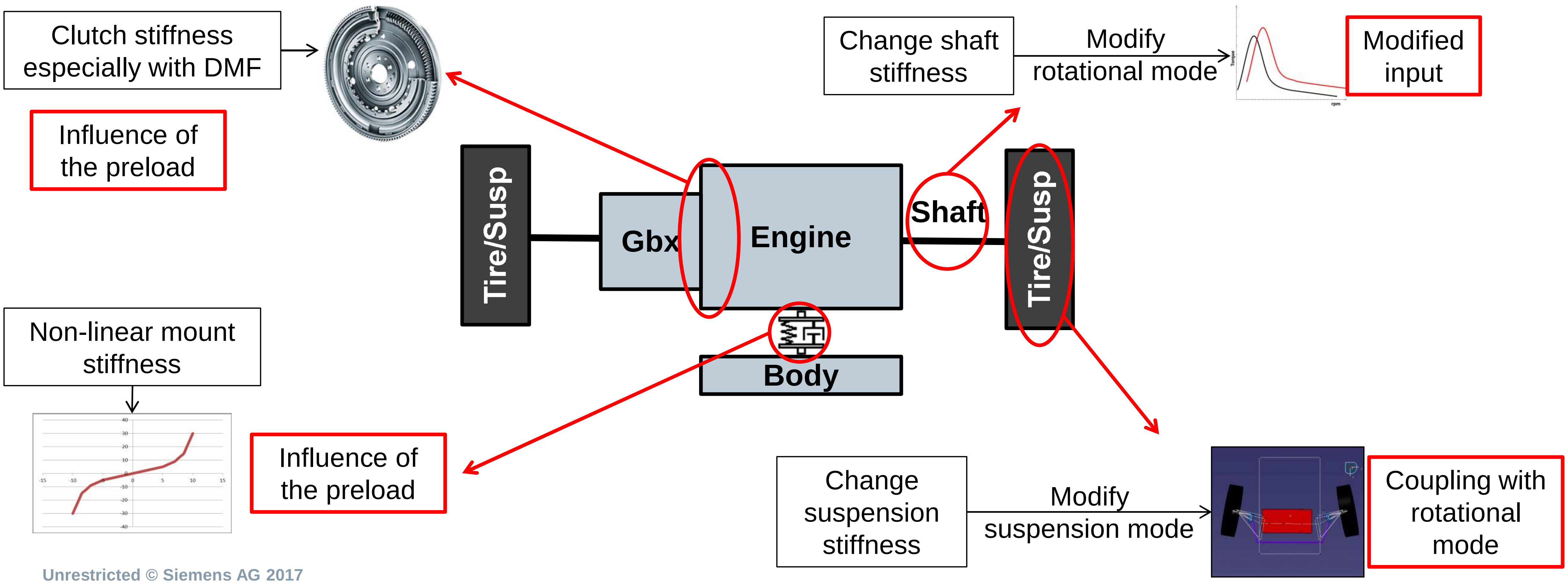
Traditional driveline NVH evaluation approach
Limitation

Classical approach → Assumptions

- Modification prediction → Limitation in low frequency booming range



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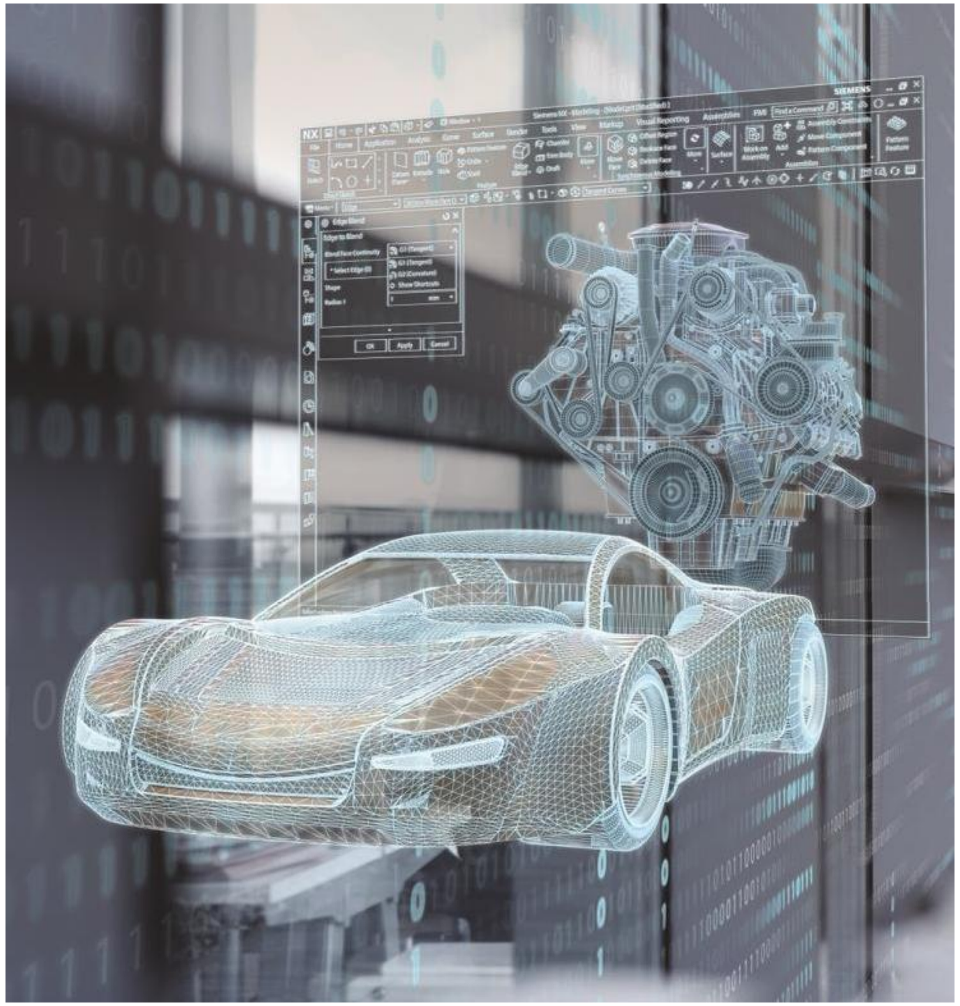
Downsizing Powertrains
NVH Implications and Solutions for Vehicle Integration



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

- Examples:
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  - Clunk

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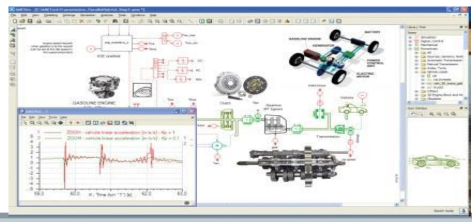
New integrated approach

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.”

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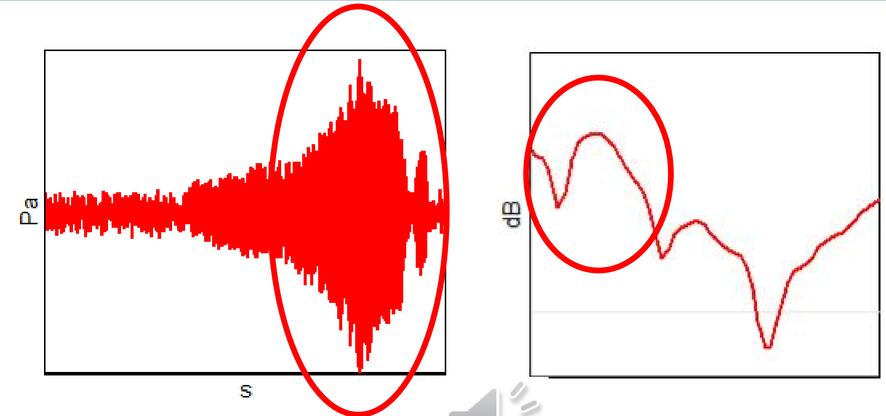
Context / Expectations from customer - Booming



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?

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LMS Engineering answer - Booming

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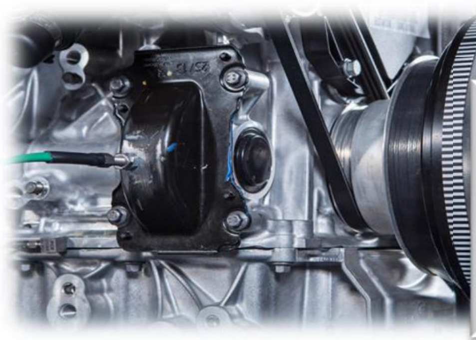
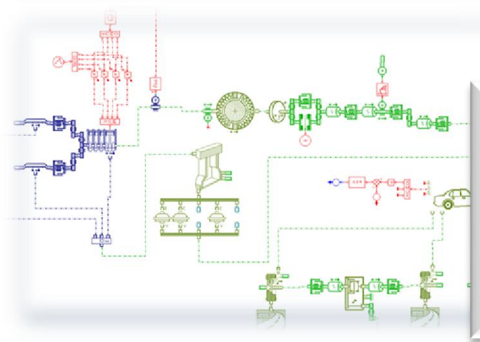


Performance of <u>driveline</u> damper

<u>Full vehicle</u> test diagnosis



<u>Full vehicle</u> 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**

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Characterization of lock-up damper
Lock up and damping performance analysis

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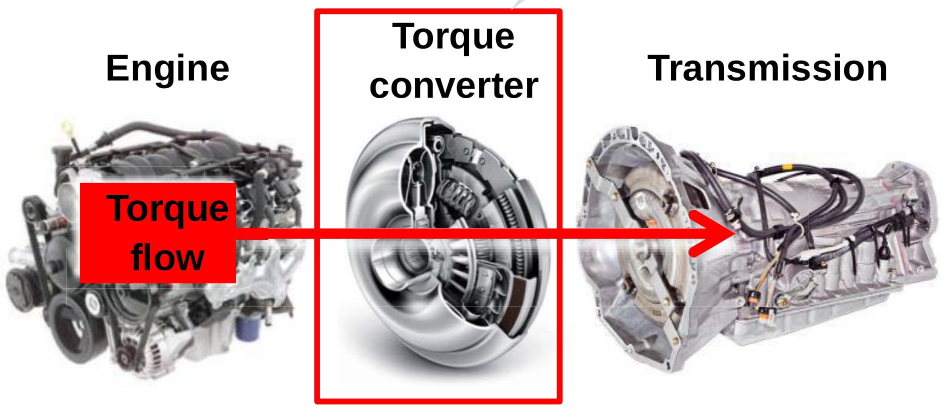
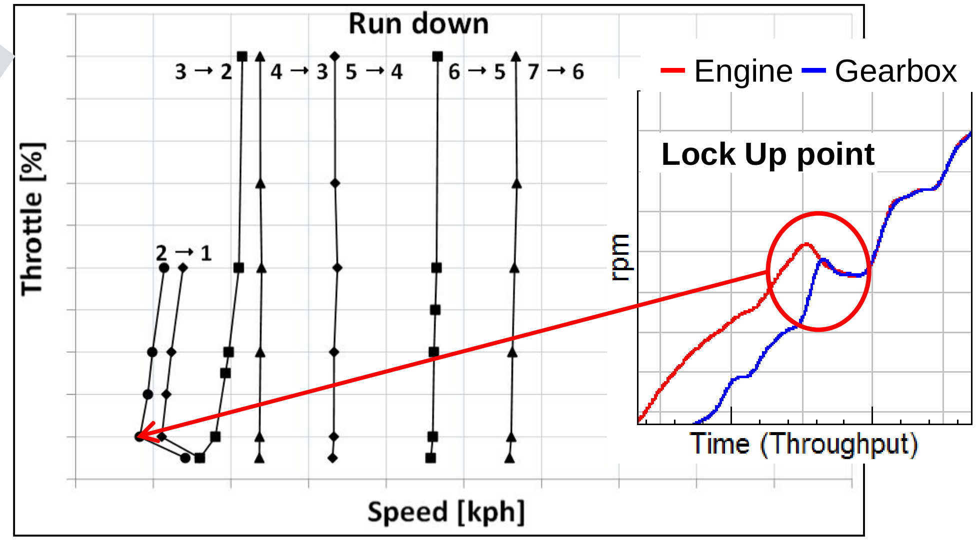
What is the effective range of the lock-up damper?

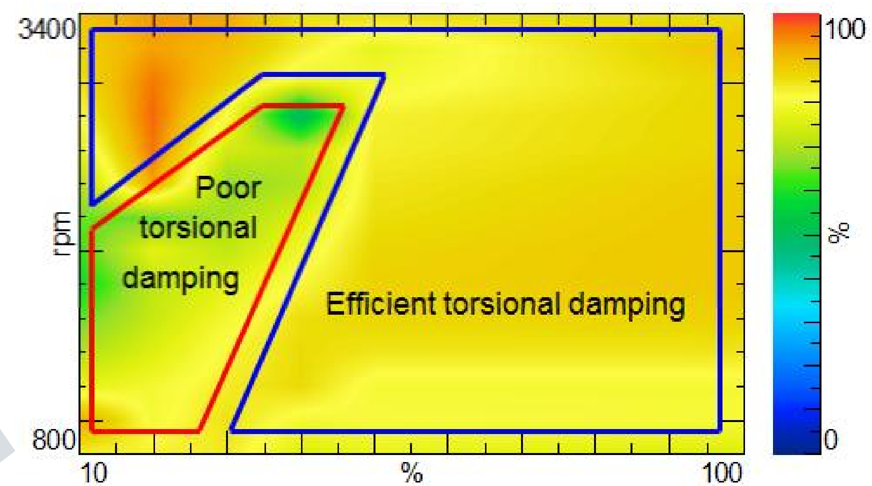
Lock up map





How efficient is the lock-up damper?

Damping map



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Full vehicle diagnosis using test based load identification in time and frequency domain, ODS, EMA

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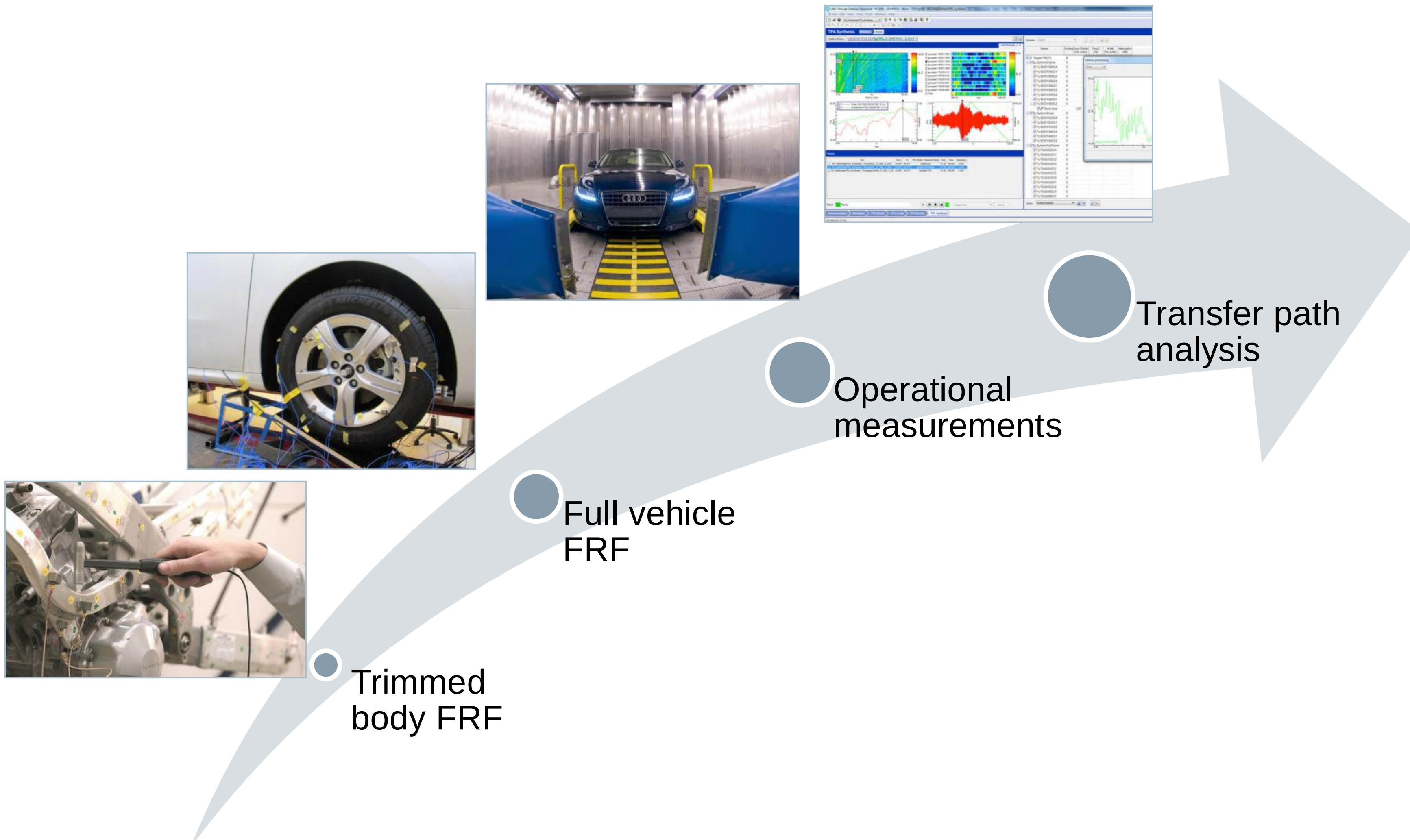

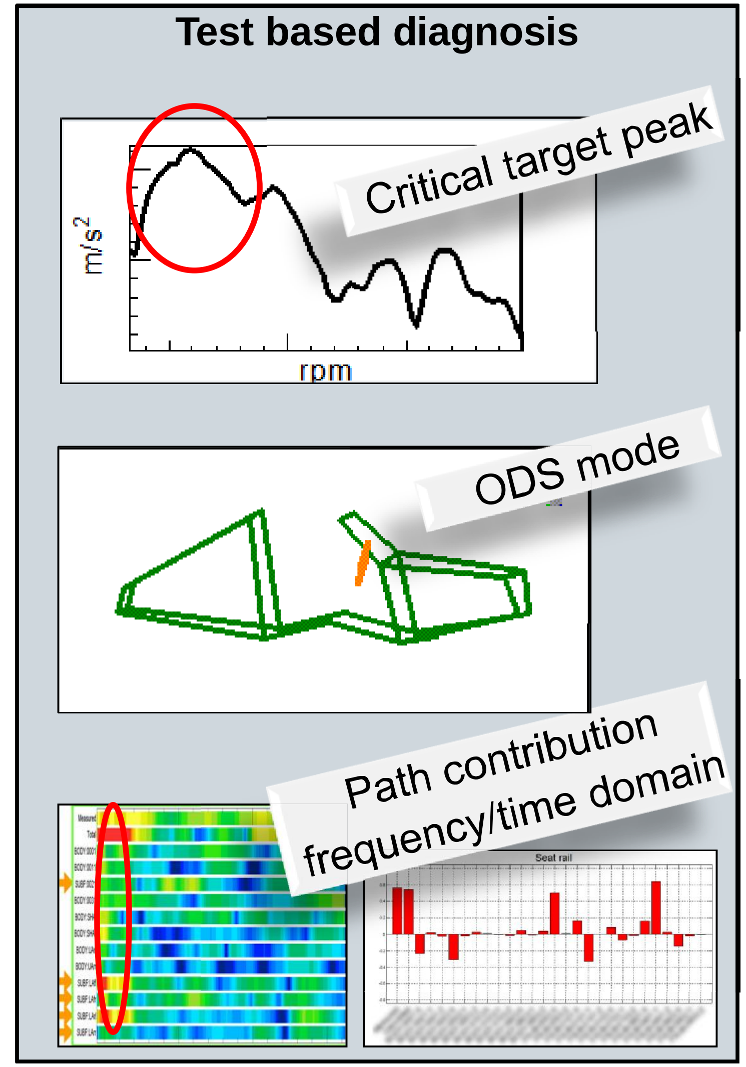

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Reverse engineering
Obtaining model parameters not available to the customer

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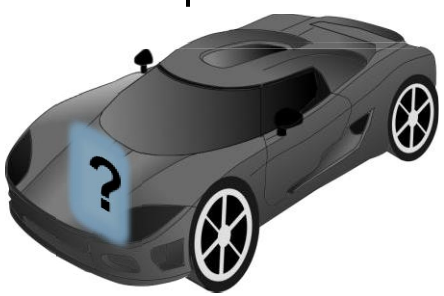
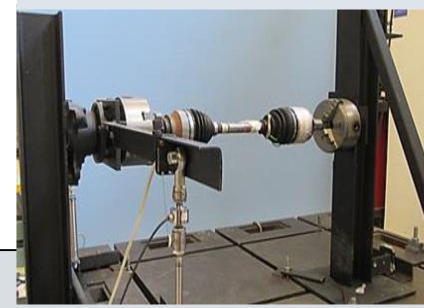
Benchmark vehicle
➔ No parameters

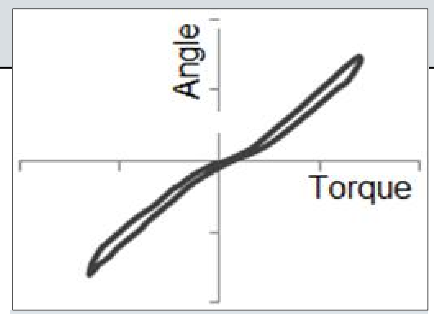


Suspension/body characterization

Driveshaft characterization



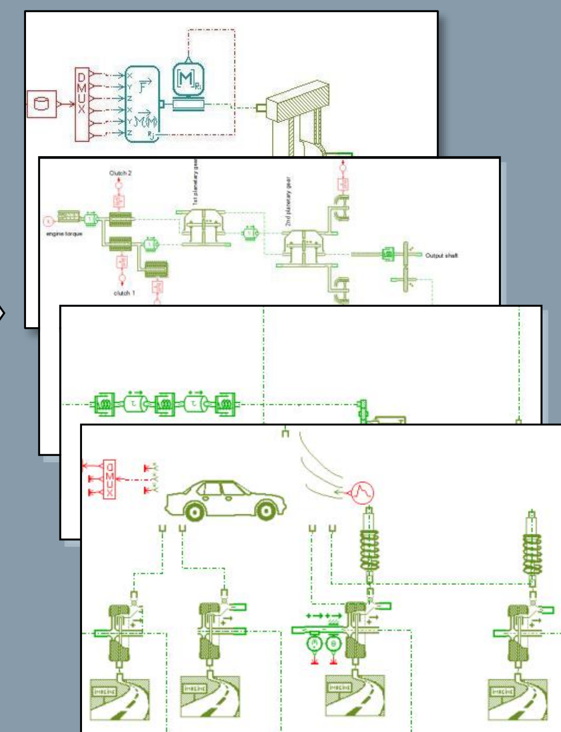
Component testing



Torsional damper static and dynamic characterization

Powertrain mounts stiffness

Full vehicle model creation
➔Full component visibility



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Calculation of acoustic target response based on combustion pressure excitation

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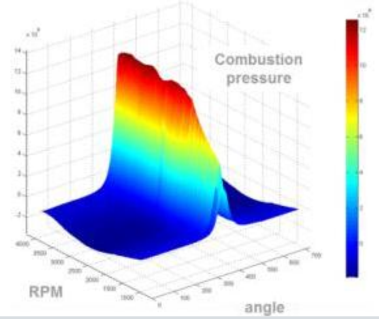
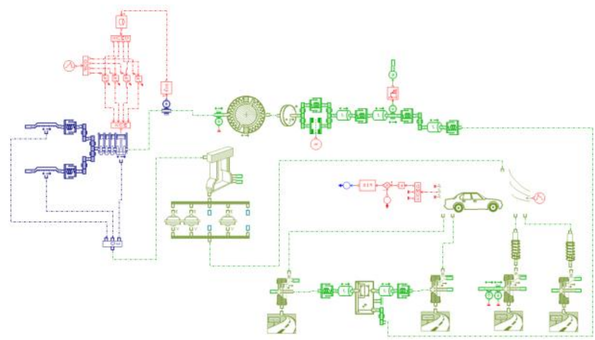
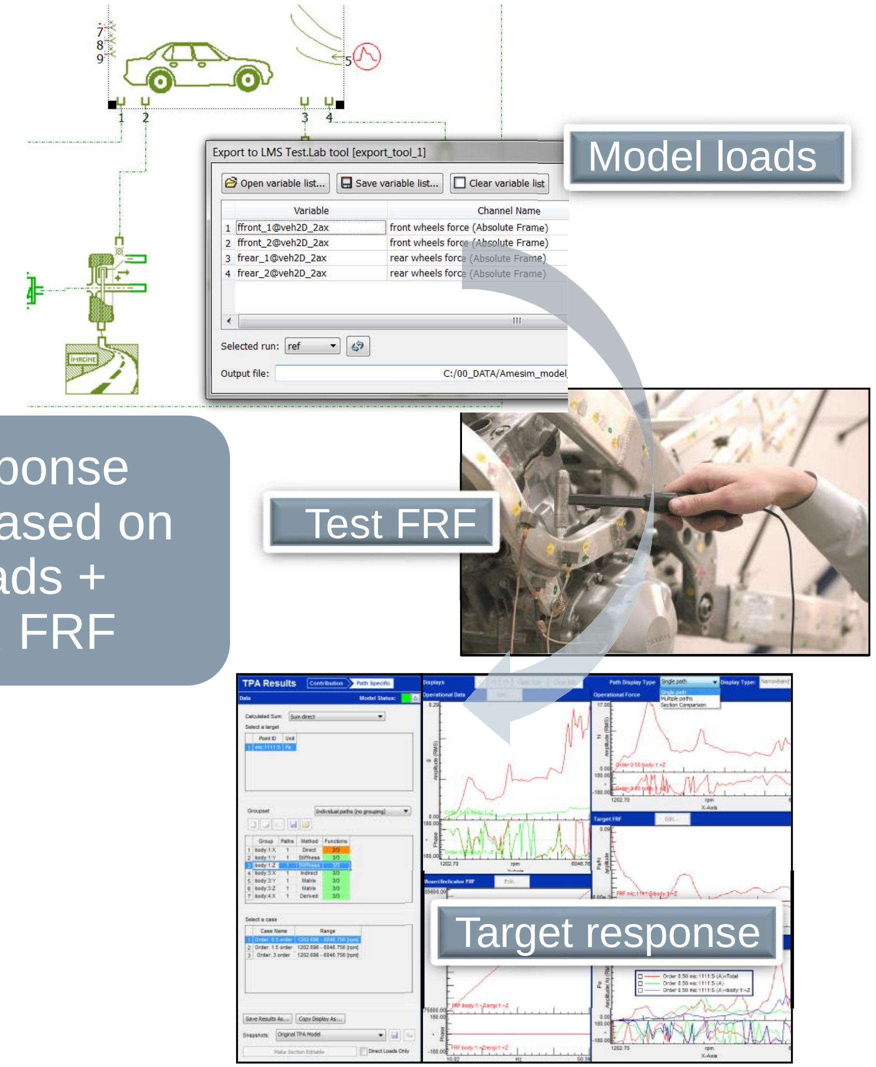


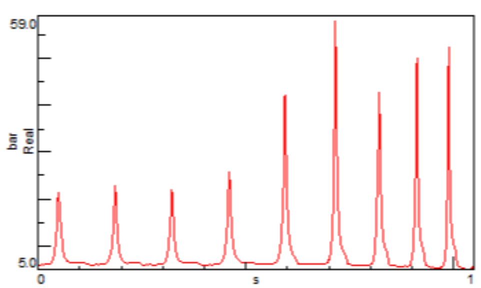


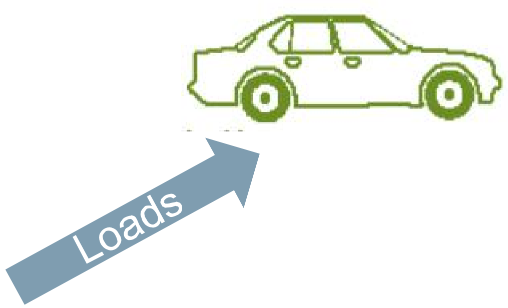


Combustion pressure maps as model input

Interface forces calculated from full vehicle model

Target response calculated based on model loads + measured FRF





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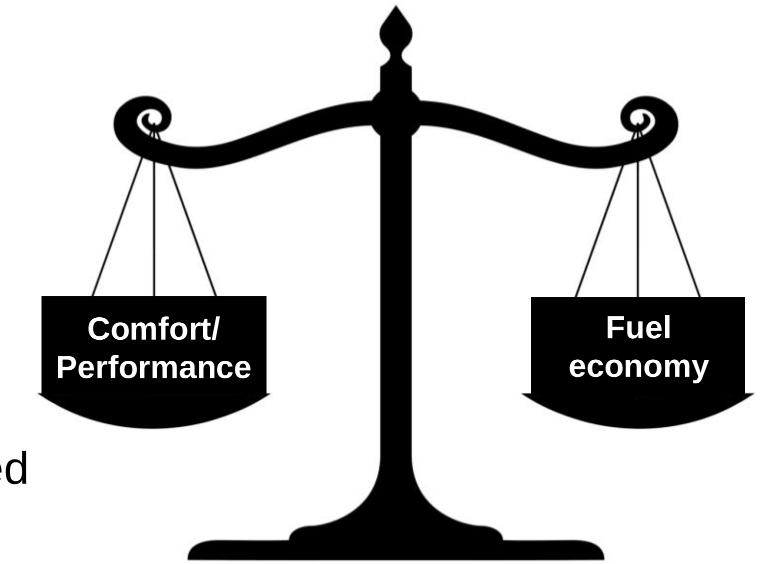
Context / Expectations from customer – Multi-attribute balancing

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?

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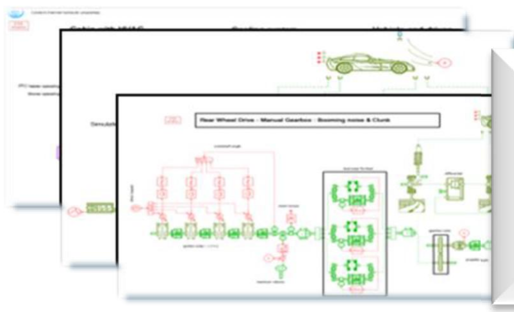
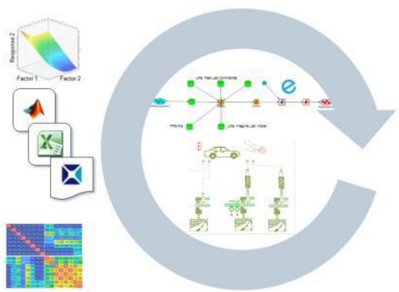
LMS Engineering answer – Multi-attribute balancing

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

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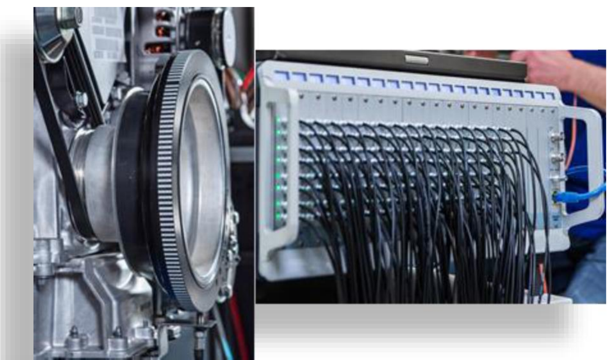
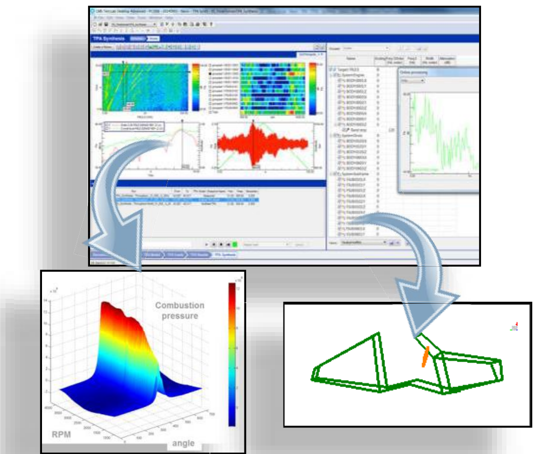
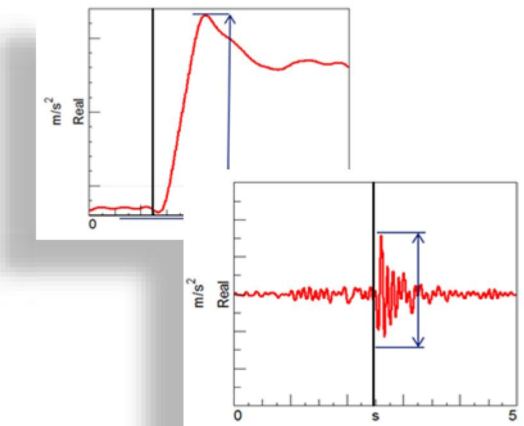
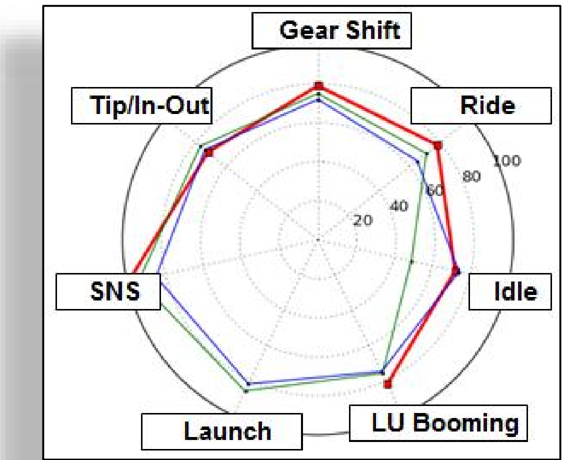
Multi-attribute evaluation (unified testing)









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

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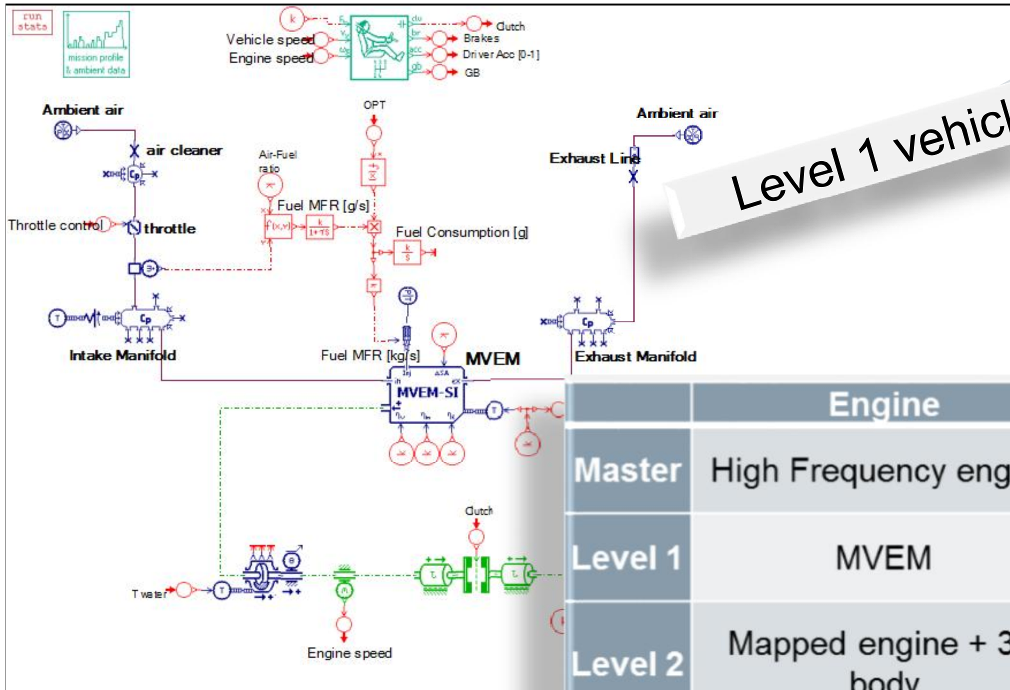
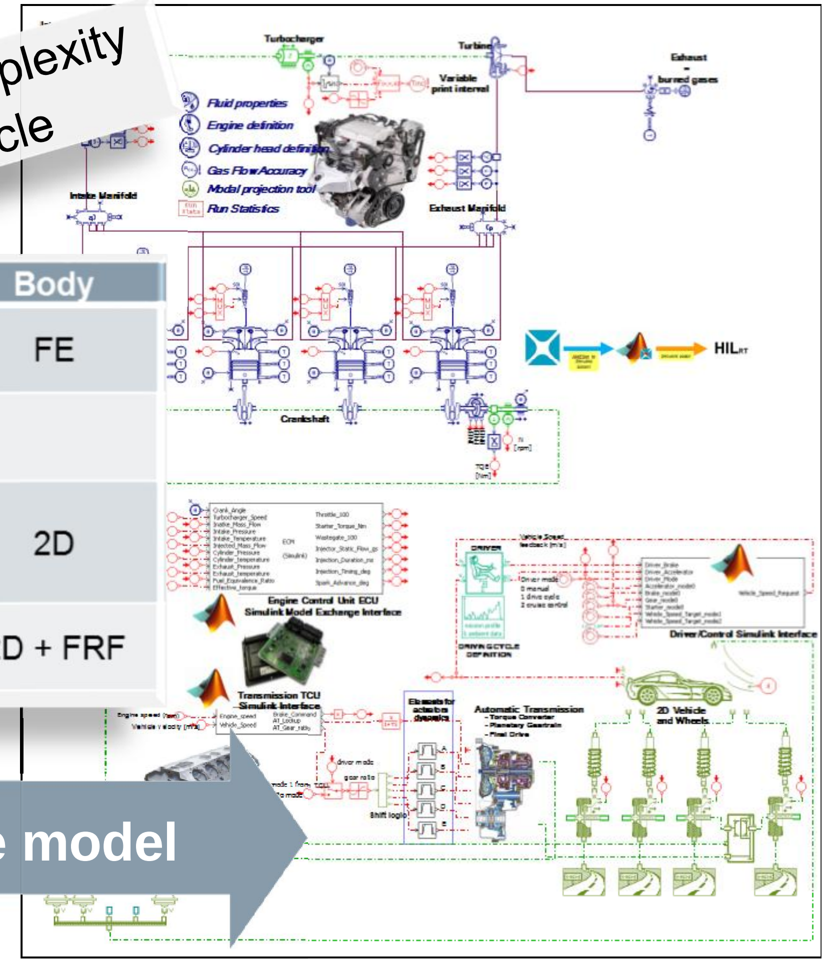
Balance between accuracy and complexity



Level 1 vehicle

High complexity vehicle



	Engine	Transmission	Suspension	Body
Master	High Frequency engine	All internal details with clearances	3D full physical	FE
Level 1	MVEM	Simple ratio with equivalent inertia	1D	
Level 2	Mapped engine + 3D body	Simple ratio with equivalent inertia and clearance	2D	2D
Level 3	Cylinder pressure tables + 3D body	TM with distributed inertias and stiffness	2D with NVH tire model	2D + FRF

Calculation time ? **Accuracy of the model**

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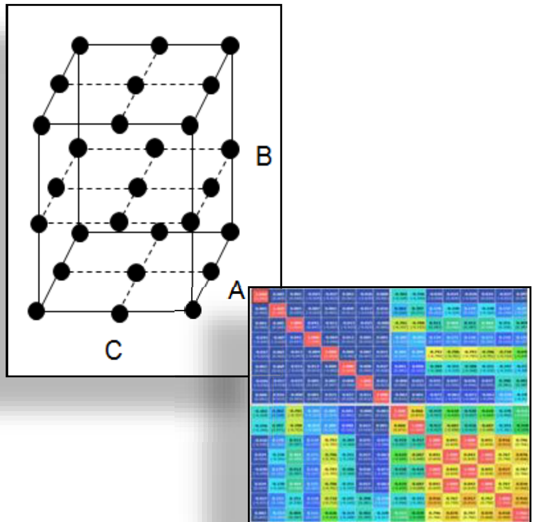
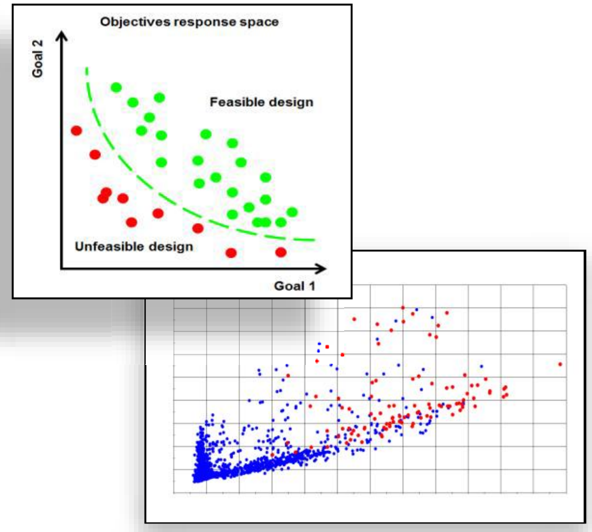
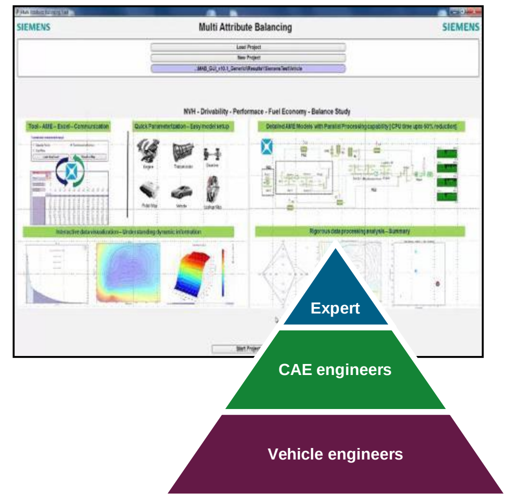
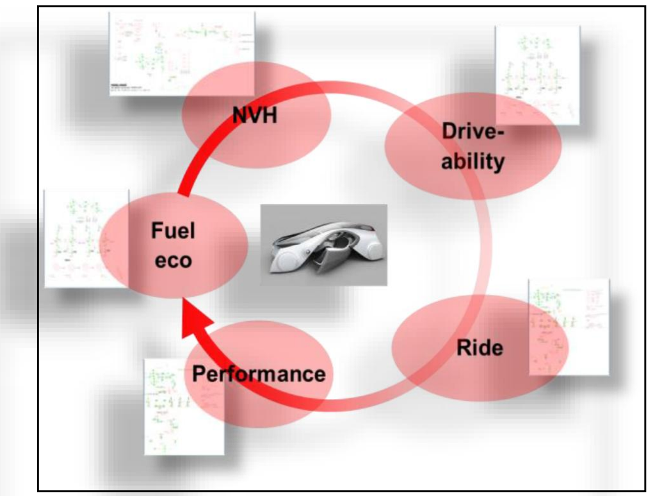
Automatic optimization processes to gain insight in design









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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Downsizing Powertrains
NVH Implications and Solutions for Vehicle Integration

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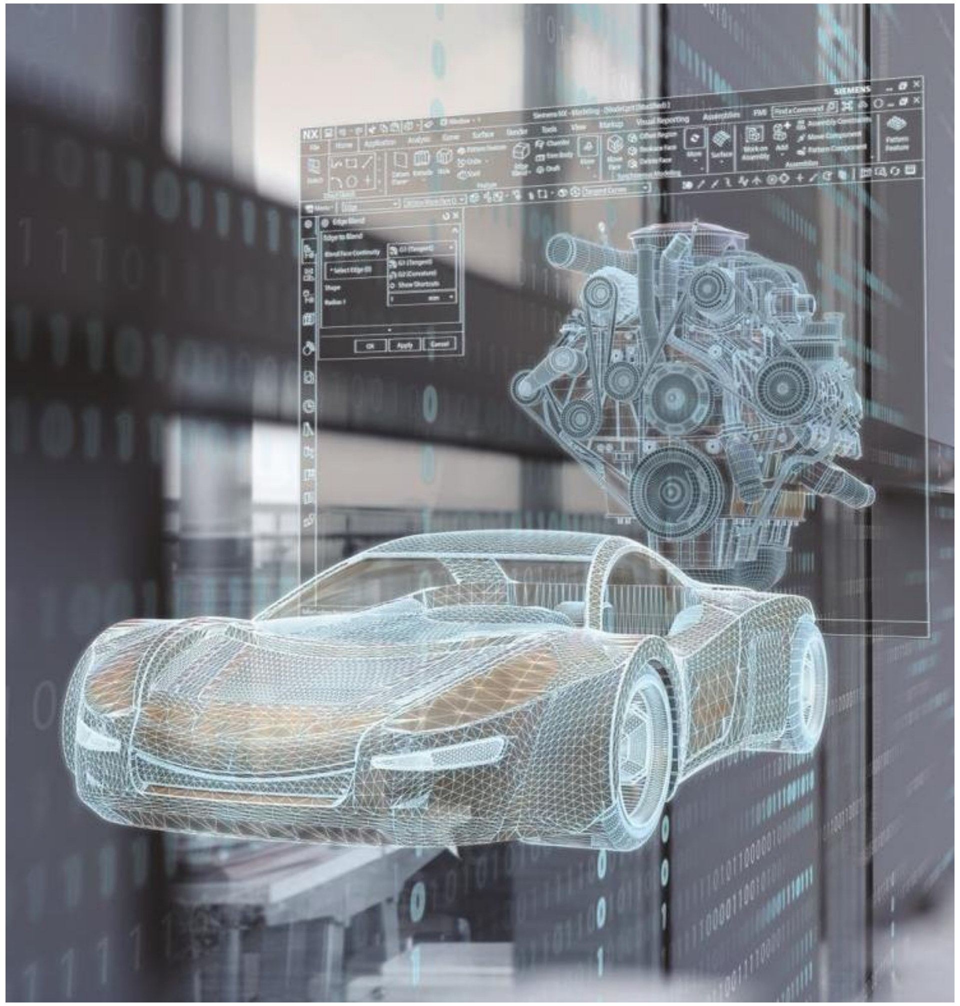

- Downsizing trends and NVH impact
- Traditional Approach for NVH studies
- New Integrated approach

- **Examples**:
  - Low Frequency Booming Noise
  - Clunk

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Aisin AW

Relying on LMS Engineering to strengthen its position as technology partner

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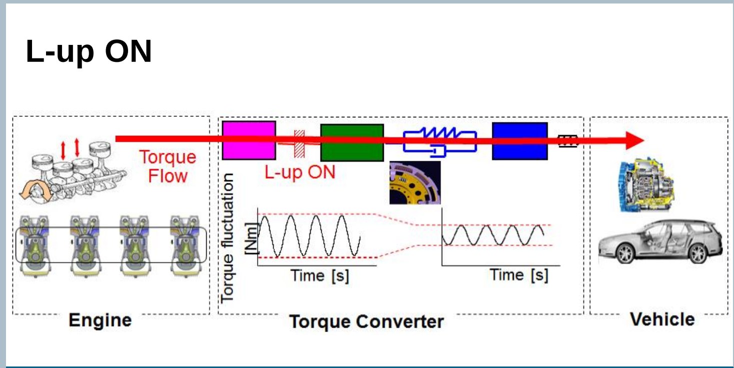
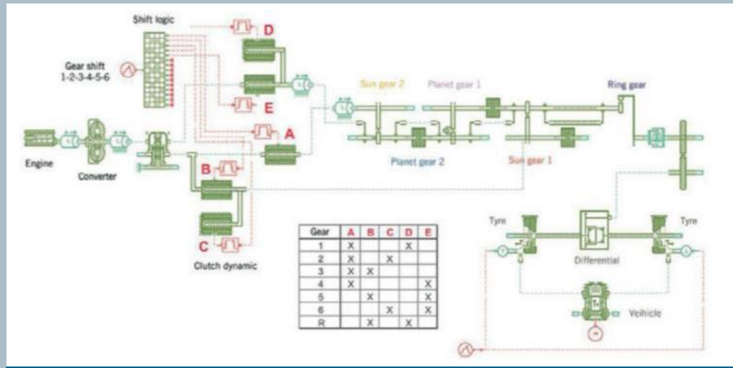
- **Gained 50 percent time reduction when troubleshooting a new NVH issue**
- **Significantly reduced overall development time**
- **Recognized as technology partner of automotive OEMs, resulting in competitive advantage**

Reducing booming, judder and gear noise



Energy flow lock-up booming



Full-vehicle simulation

- 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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Process lock-up booming investigation

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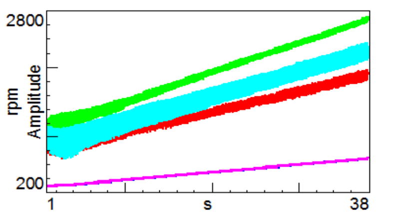
1) Testing

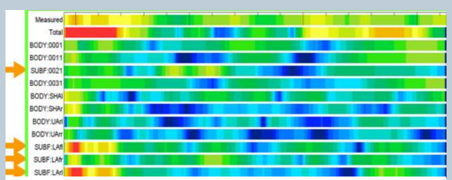
Measurement of input & validation data, data for load identification



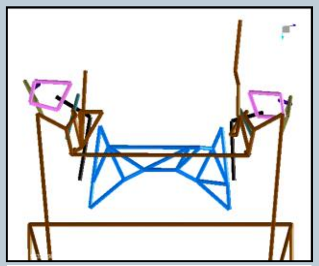
Internal transmission rpm

2) Test based diagnosis

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



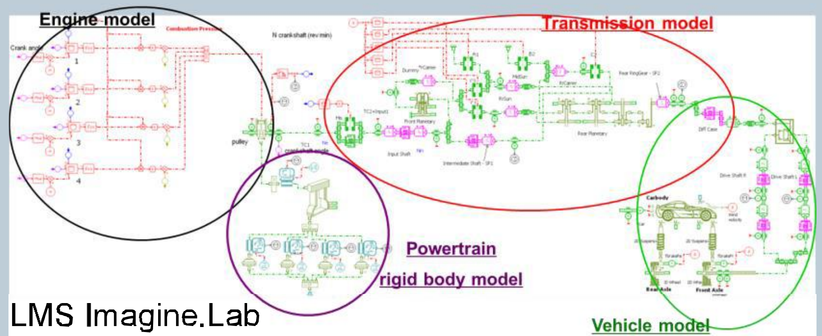
TPA contribution



ODS mode

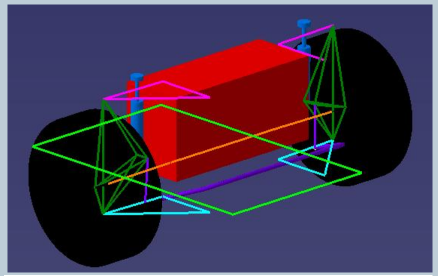
3) 1D Driveline modeling

1D model consists of engine model and transmission model



LMS Imagine.Lab

4) 3D Vehicle modeling

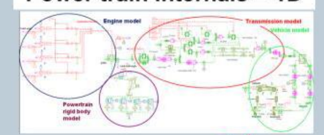


LMS Virtual.Lab

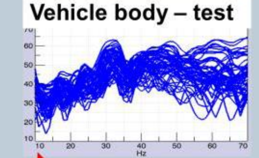
- Powertrain block & mounts
- Subframe
- Chassis
- Front & rear suspension
- Driveshafts & tires

5) Simulation, correlation and model based diagnosis

Power train internals – 1D

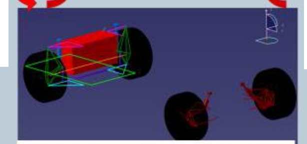


Vehicle body – test



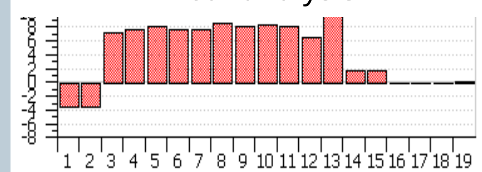
Coupled simulation

Forced response



Vehicle active part – 3D

Linear analysis



Optimize target vibration

Engine Speed

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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

Powertrain and gearbox noise optimization

Torsional behavior of the 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

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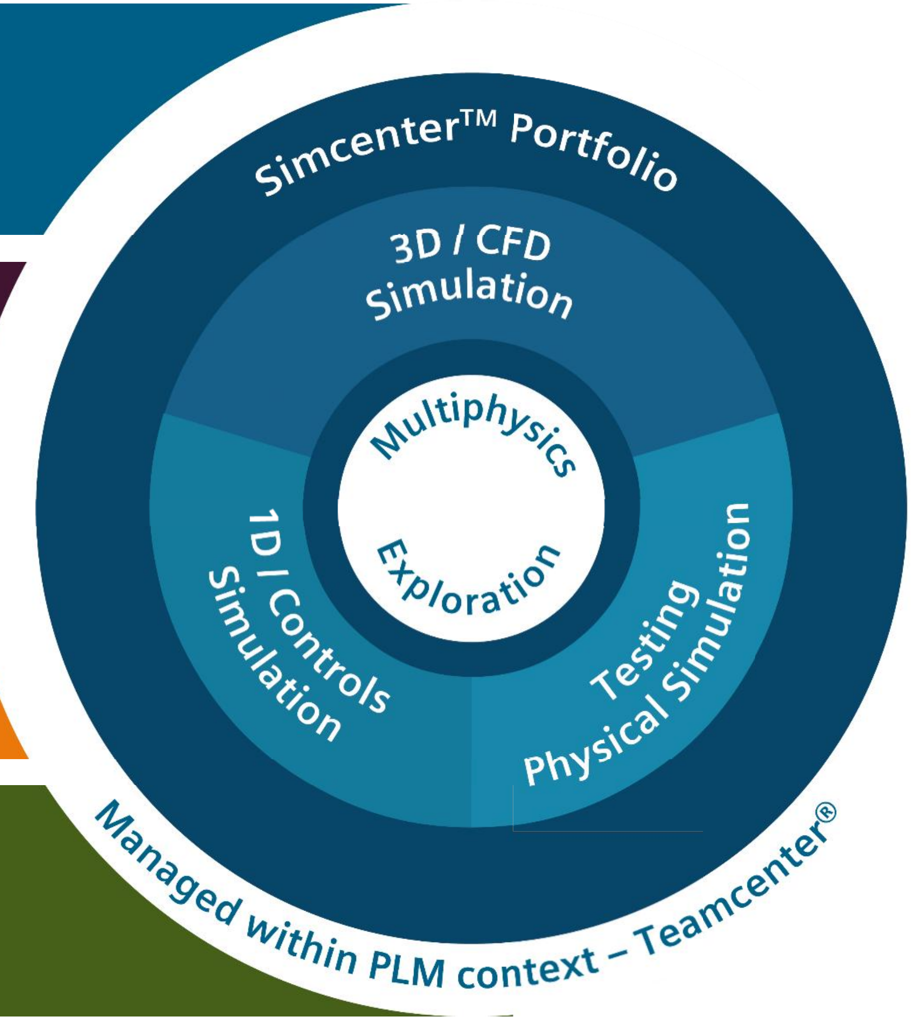
Simcenter solutions for Automotive NVH & Acoustics

SIEMENS

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



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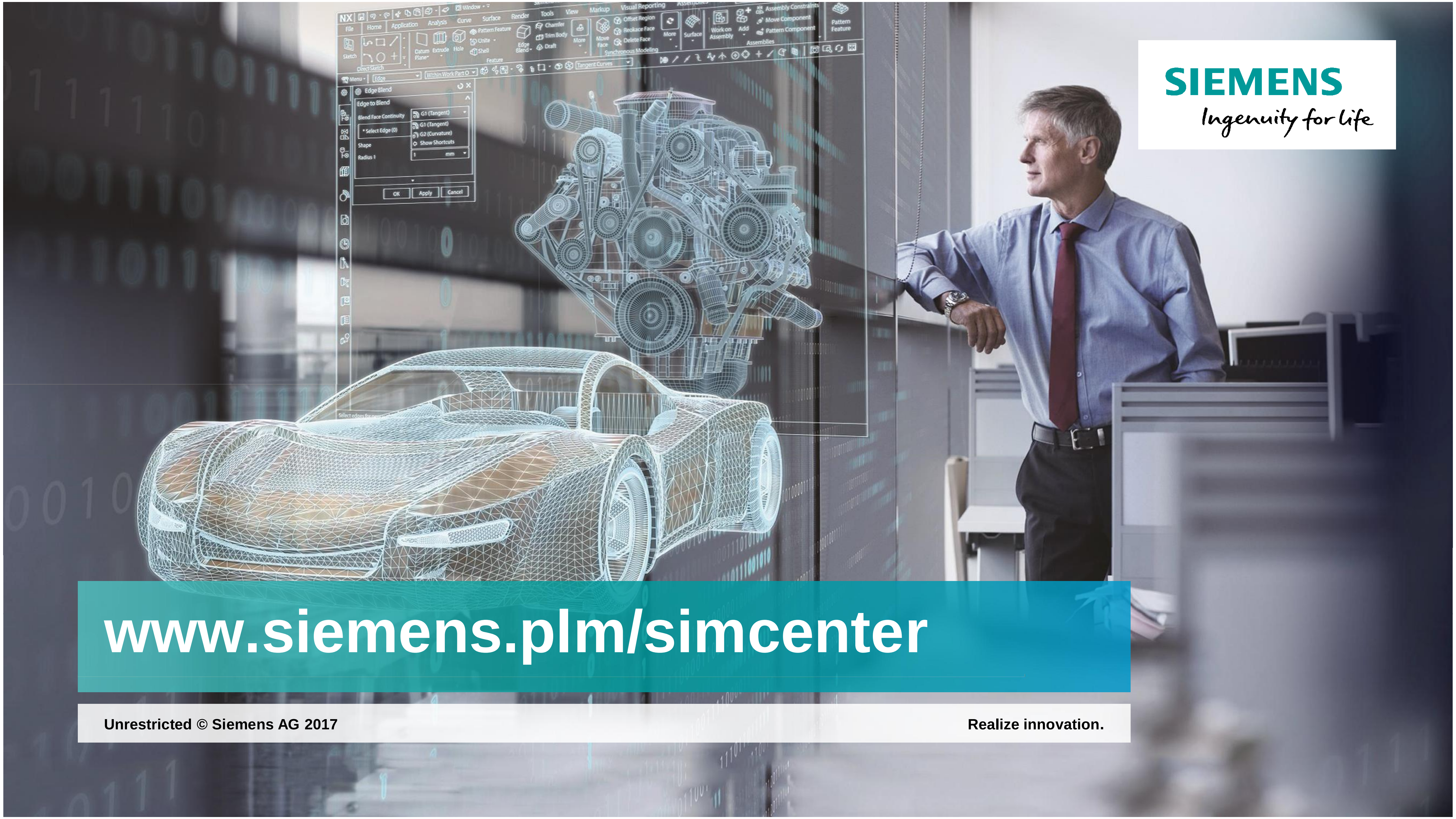

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