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Address NVH integration issues from concept to validation through model-based development (MBD)

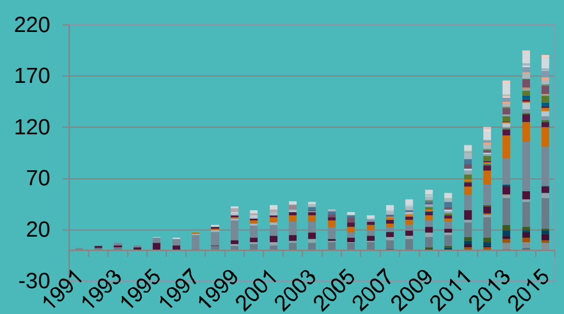
Wednesday January 23, 2019

Vehicle NVH Innovation Area

Challenges

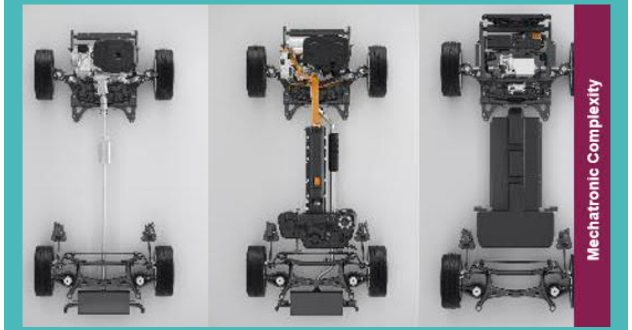
Vehicle Electrification

200+ (H)EV models. Increased engineering complexity

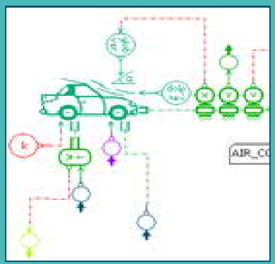


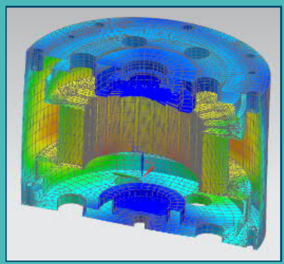
"OEMs and suppliers understand that NVH features can become the main differentiation factor among automotive companies."

Visiongain, NVH market report



Analyze electrical and mechanical design





Vehicle NVH Innovation Area
Challenges

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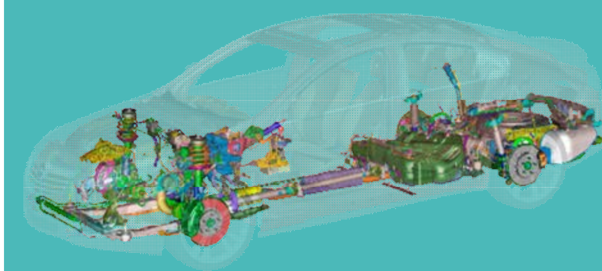
Driveline integration

Low-frequency torsional vibrations are amplified in the driveline

"Predicting systems behavior upfront significantly reduces the workload and allows us to focus efforts and resources on other priorities, such as brand image and value"

S. Watanabe
Powertrain NVH, Honda R&D

Ensure smooth vehicle integration



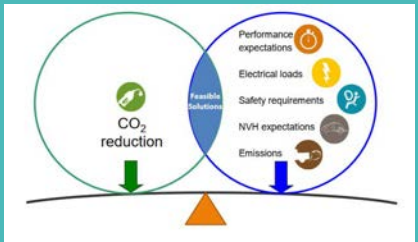
Vehicle NVH Innovation Area
Challenges

Balancing performances

Conflicting performance characteristics (NVH, energy management, drivability)

“Balancing CO2 reduction requirements and increasing customer expectations constrains the feasible solutions zone, requiring an integrated approach”

Tom McCarthy
Chief engineer PT Research & Advanced Engineering, Ford



Balance NVH with other attributes

Current vehicle NVH engineering process
Challenges

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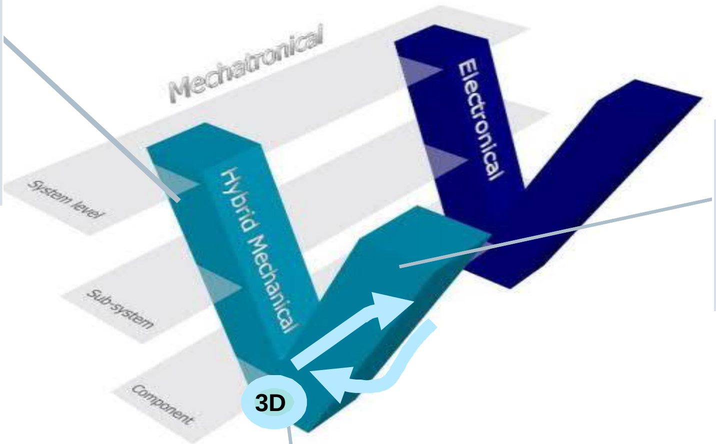
SPECIFICATION | DESIGN / ENGINEERING | VALIDATION | CERTIFICATION | TROUBLESHOOTING

Target setting and benchmarking
- Many new vehicle architectures and variants
- New fuel economy & safety regulations



Test-based validation
- Issues occur in prototype stage
- Limited design space for solutions
- Long time to solve

NVH CAE engineering
- Starts late in the process
- Needs detailed geometry
- Limited space for design changes

Addressing these challenges requires an integrated approach

What if we could add Model-Based Development to the process?

From CAD-centric to System-centric thinking

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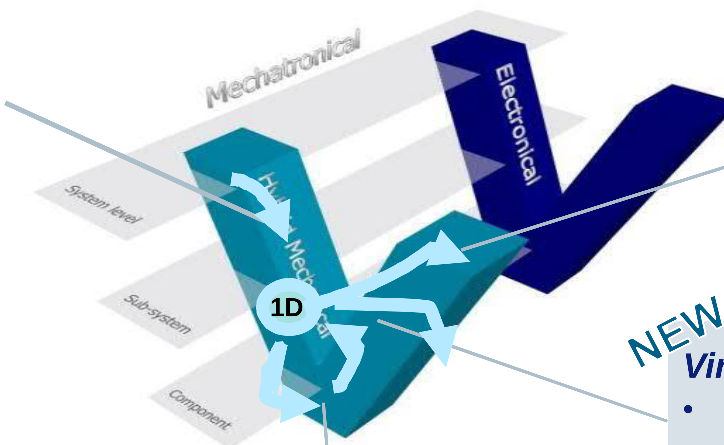
Target setting and benchmarking
- Shortens testing phase
- Multi-attribute target setting and evaluation
- Cascade system targets down to components



Validation
- Get insight in rotational dynamics
- Reduce prototype troubleshooting time

NEW
Virtual Verification
- Verify component performance at system level before prototype is available

NVH System Engineering
- Frontload design choices
- Feasible even without detailed geometry

From CAD-centric to System-centric thinking

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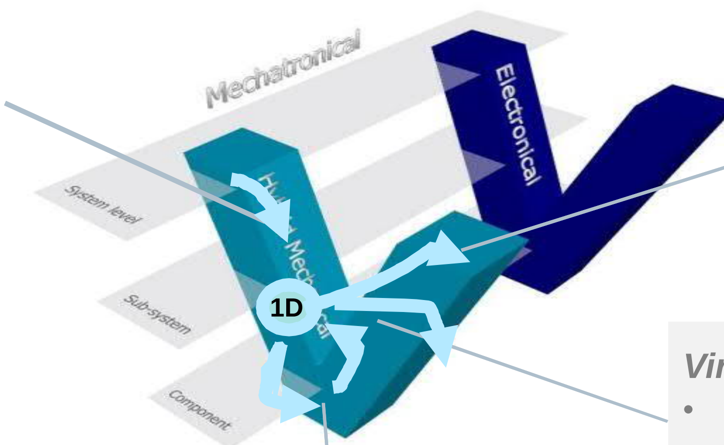

Validation

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- reduce prototype troubleshooting time

Virtual Verification

- verify component performance at system level before prototype is available

NVH System Engineering

- Frontload design choices
- Feasible even without detailed geometry

NVH System Engineering

Process deployment for NVH Investigation

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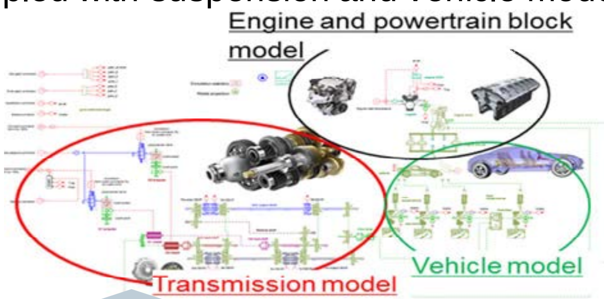
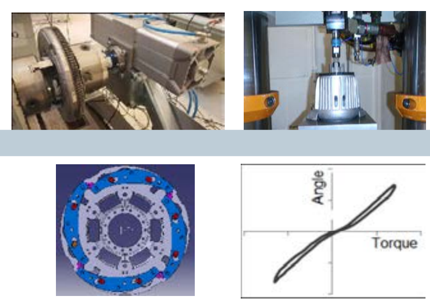
Torsional driveline model
Coupled with suspension and vehicle model



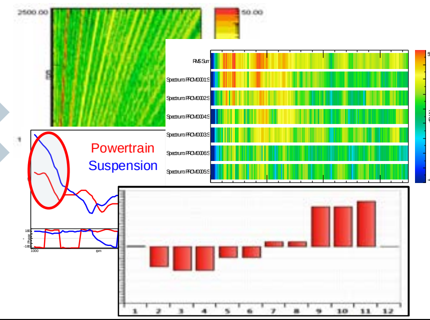
Update & Validate

Complement

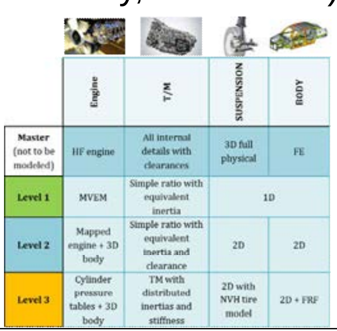
Component – system tests
Vehicle tests



Diagnose
Insights

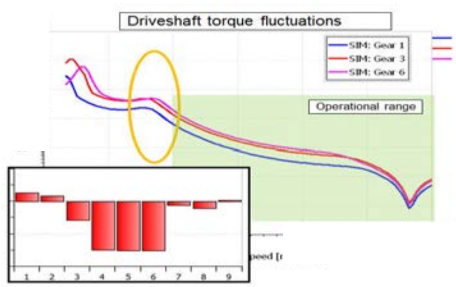


Scalable model complexity
f(accuracy, information)

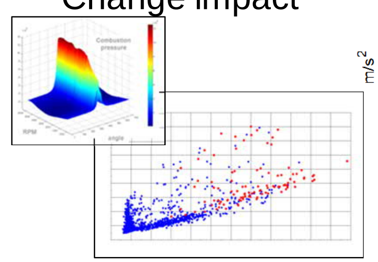


	Engine	T/M	SUSPENSION	BODY
Master (not to be modeled)	HF engine	All internal details with clearances	3D full physical	FE
Level 1	MVEM	Simple ratio with equivalent inertia	1D	
Level 2	Mapped engine + 3D body	Simple ratio with equivalent inertia and clearance	2D	2D
Level 3	Cylinder pressure tables + 3D body	TM with distributed inertias and stiffness	2D with NVH tire model	2D + FRF

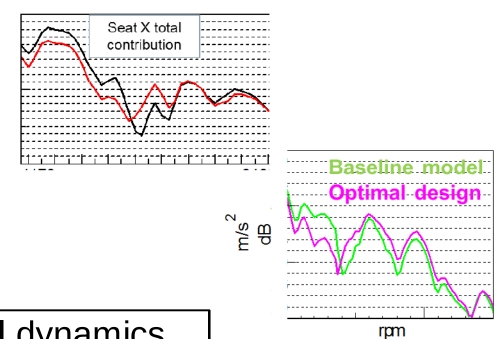
Sensitivity studies



Design exploration
Change impact



Modification studies



Model provides insight in rotational dynamics & coupling driveline and suspension dynamics

NVH System Engineering

How to incorporate 3D dynamics in system simulation

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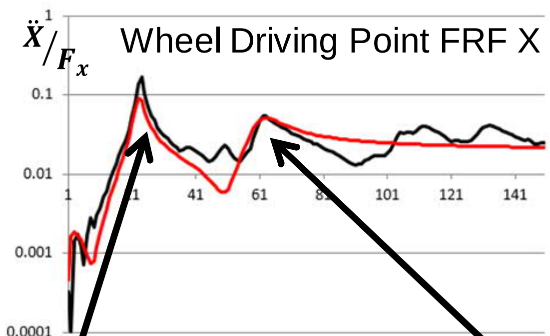
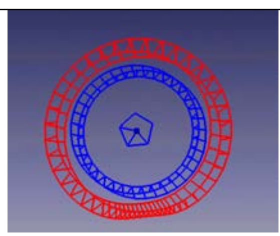
Suspension and Tire

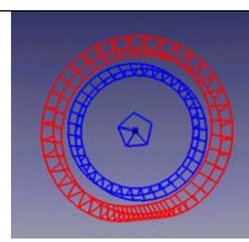
Relevant tire and suspension dynamics needs to be included for booming evaluation up to 80Hz



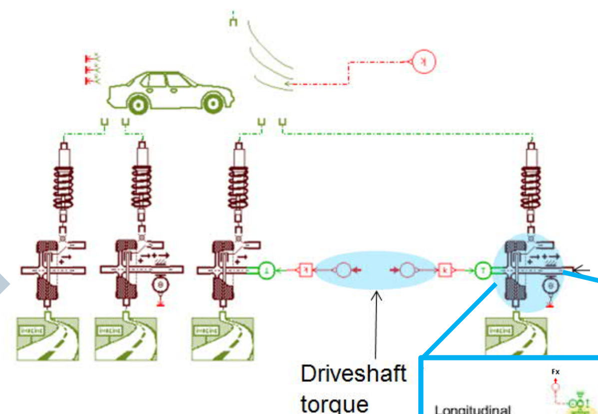
For-aft mode ~20Hz

Rotational mode ~60Hz

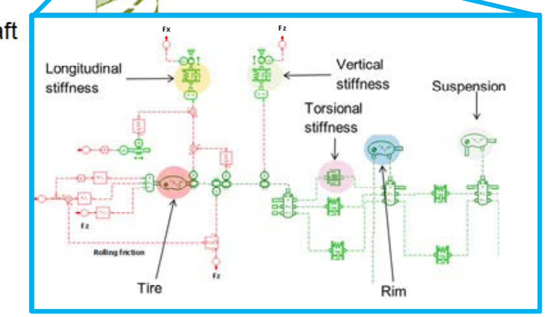




2D elements available in system simulation to include suspension dynamics



Detailed tire model for NVH

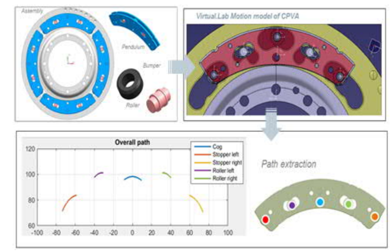


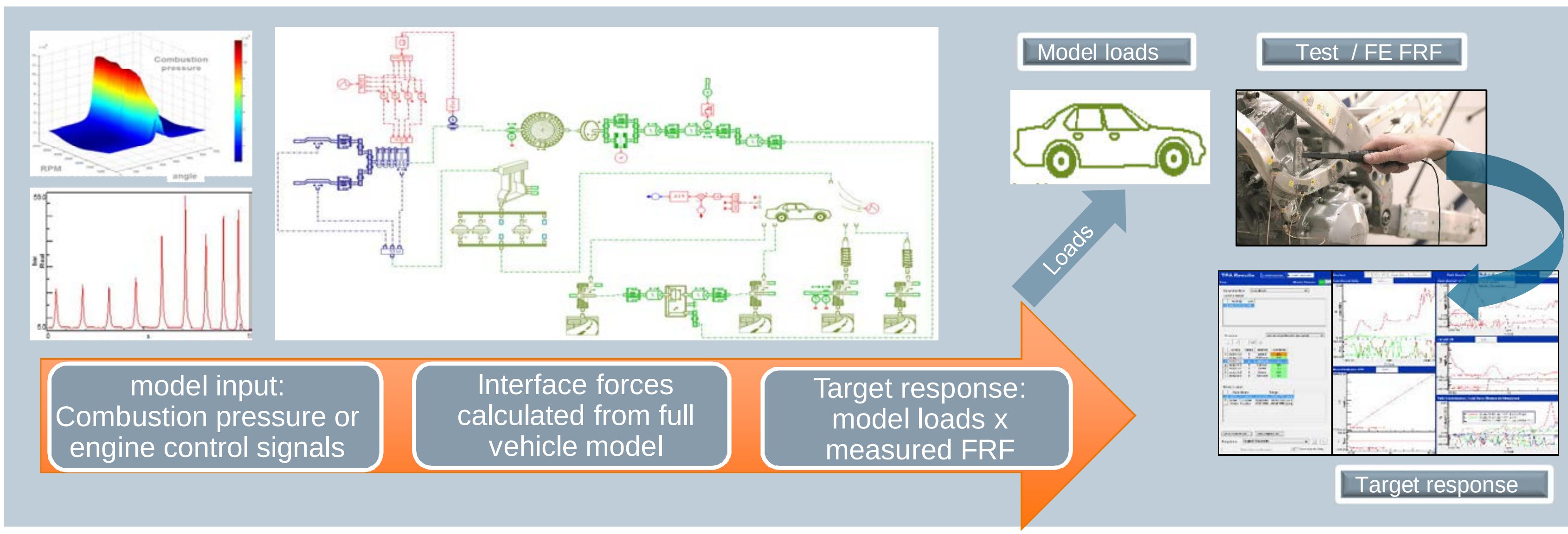
NVH System Engineering
Low-Frequency Booming Noise

- Shift Shock
- Clunk
- Judder
- **Booming**
- Squeal
- Engine Re-start
- 1D Rattle
- 2D Rattle
- Switching & slotting effects
- …

Solution

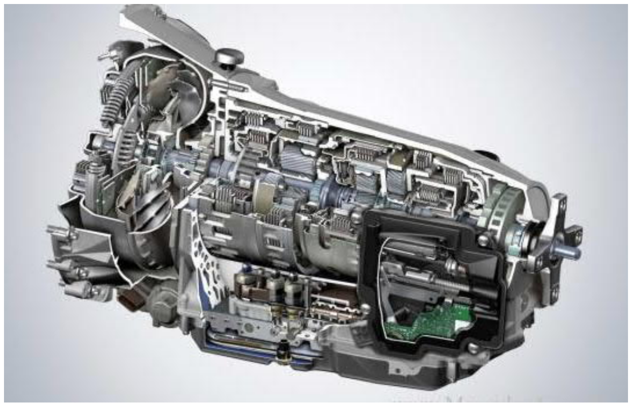
- MBD driveline coupled with Test or FE transfer function
- Closes the loop from engine inputs to interior noise
- Enables tuning/optimization of driveline parameters to reduce booming





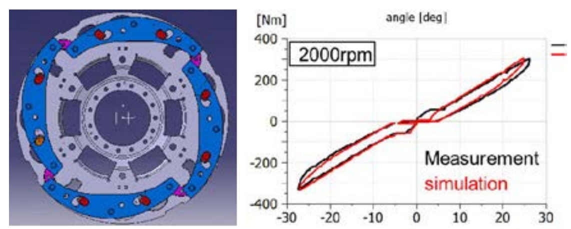
NVH investigation and improvement of a rear wheel drive vehicle

Using a model-based approach combining test and simulation methods

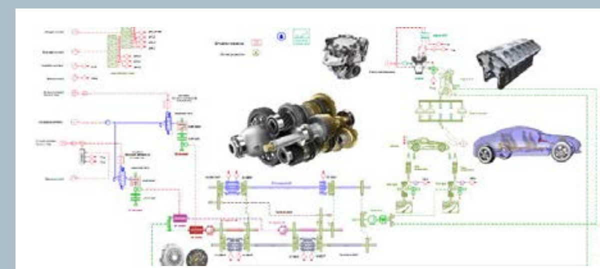


- **Reverse engineer competitor vehicle to understand driveline contributions for lock-up booming noise and vibrations**
- **Static and dynamic characterization of components based on full vehicle measurements**

Model-based approach by combining test and simulation



Reverse engineering of CPVA



Full vehicle modeling

- Using testing methods for gaining insight and obtaining parameters for modeling
- Using simulation to validate and update the sub-systems to create a full vehicle model

“The Simcenter Engineering team smartly combined operational measurements to gain insights into the vehicle behavior, noise sources and noise transfer paths, with simulation models to build a full vehicle model. We were able to evaluate the performance of the CPVA and reduce lock-up booming noise.”

Automobili Lamborghini
Creating a new driveline concept design using Simcenter 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

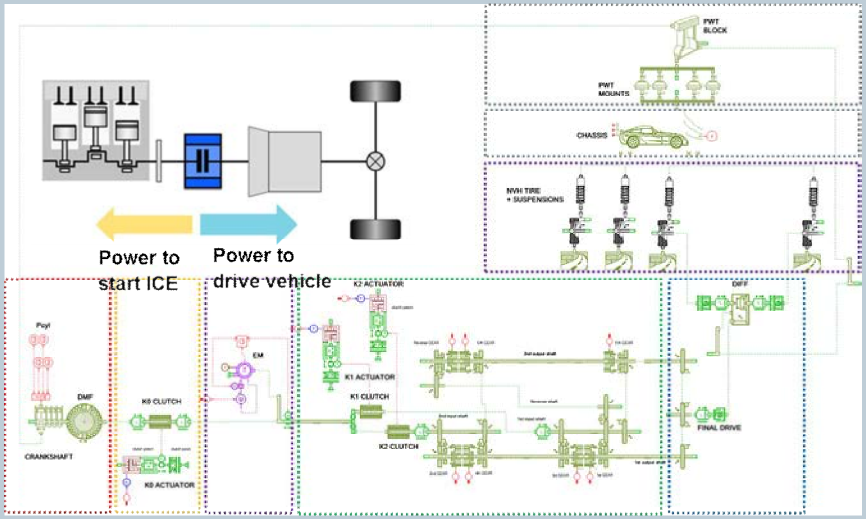
“The true power of Simcenter Amesim is demonstrated by how easy it is to evaluate different driving conditions, software or hardware changes and even different configurations”.

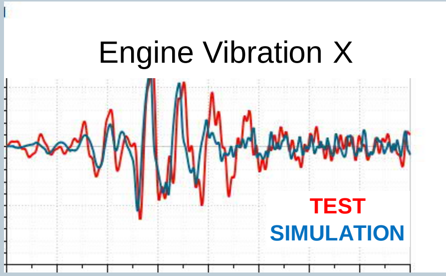
Ing. Claudio Manzali, R&D

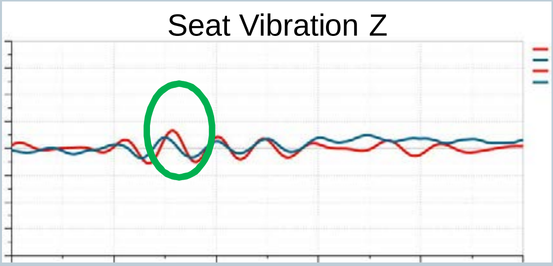
NVH System Engineering
Engine re-start shock for PHEV

- Shift Shock
- Clunk
- Judder
- Booming
- Squeal
- **Engine Re-start**
- 1D Rattle
- 2D Rattle
- Switching & slotting effects
- …

Solution
- MBD representation of driveline and vehicle
- Closes loop from engine inputs to chassis response
- Enables optimization of active control strategy







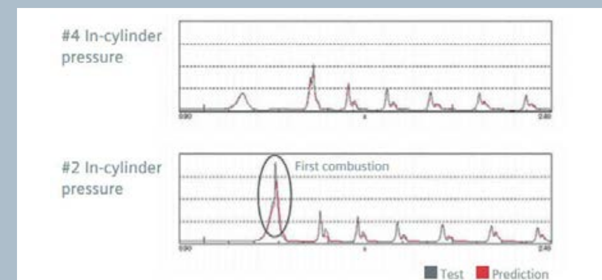
Honda Motor Company

Resolve hybrid engine restart vibrations

- **Solve hybrid engine restart vibrations**
- **Take into account the entire powertrain restart process and allow for varying in-cylinder pressure**
- **Reduce time to market**

Reduce vibrations at restart of hybrid engines while balancing fuel economy and performance

Test methods such as transfer path analysis, impact testing, modal analysis, and more



Results of in-cylinder pressure at engine restart using 1D prediction model

- Integrate the testing process for data acquisition and validation
- Build integrated engine and vehicle models for combustion, mechanics and controls

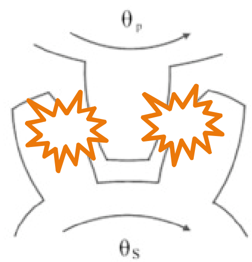
"Thanks to the Simcenter engineering expertise, we predict systems behavior upfront. The workload afterwards is significantly reduced, which allows us to focus our efforts and resources on other priorities, such as brand image and value." Satoshi Watanabe, Model-Based Design for Powertrain NVH

NVH System Engineering
Gear Rattle

- Shift Shock
- Clunk
- Judder
- Booming
- Squeal
- Engine Re-start
- **1D Rattle**
- 2D Rattle
- Switching & slotting effects
- Drivability

Rattle assessment

- Low Frequency excitation
- Torque zero passing in idle gears → impact



Rattle propagation

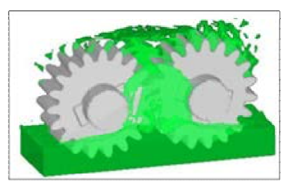
- Broadband noise
- Propagation through transmission casing and mounts

Rattle-free design

Focus on reducing losses, makes rattle-free design harder

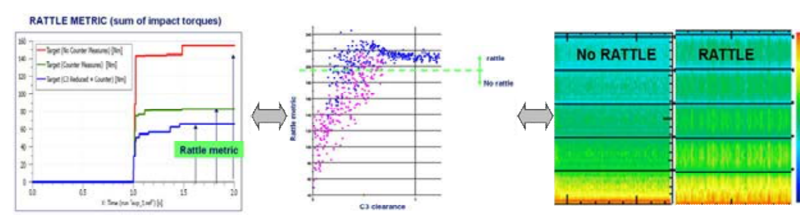
Bearing losses

Oil churning losses in Idler gears



Rattle metrics

- Difficult to objectively quantify rattle



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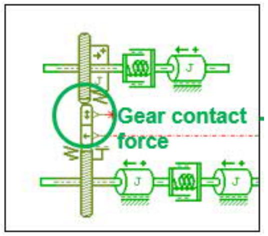
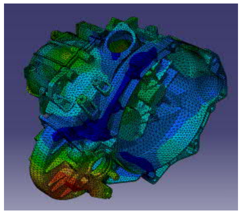
Rattle assessment

- System simulation driveline modeling
- Extract gear contact forces
- Detailed loss models in function of physical parameters
- Virtual troubleshooting



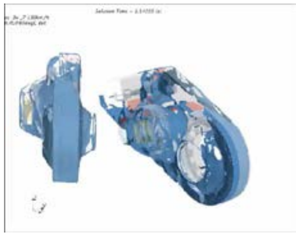
Rattle propagation

- structural FE models and acoustic models
- Coupling with gear forces for target prediction



Rattle-free design

- Multi-phase CFD analysis
- Coupling with lubrication modeling for boundary condition
- Balancing losses - rattle



Rattle metrics

- Subjective-objective correlation
- Sound quality analysis
- Metric development

gear impact forces ⇨ Gear train ⇨ Bearing ⇨ Casing vibration ⇨ Air ⇨ Airborne noise

From CAD-centric to System-centric thinking

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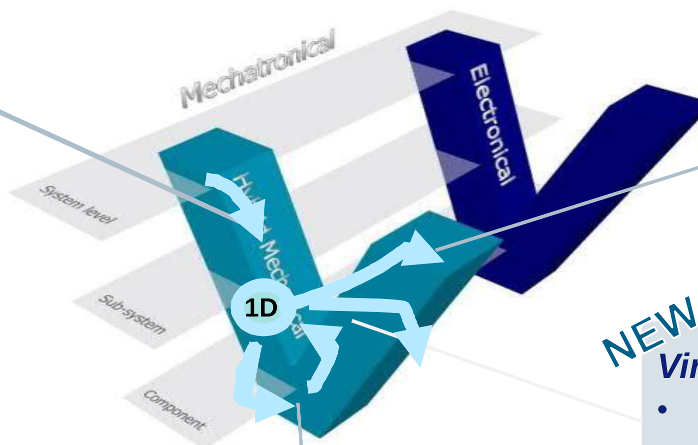
Target setting and benchmarking

- Shortens testing phase
- Multi-attribute **target setting and evaluation**
- **Cascade system targets** down to components



Validation

- Get insight in rotational dynamics
- Reduce prototype troubleshooting time

NEW

Virtual Verification

- Verify component performance at system level before prototype is available

NVH System Engineering

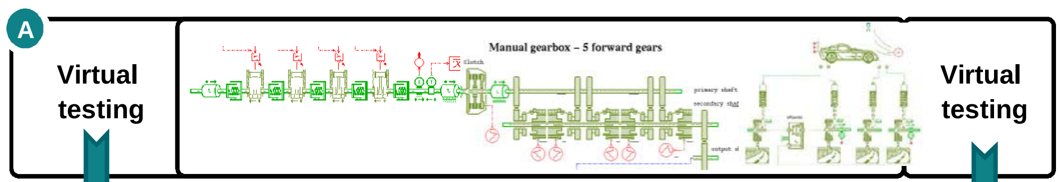
- Frontload design choices
- Feasible even without detailed geometry

Virtual Validation

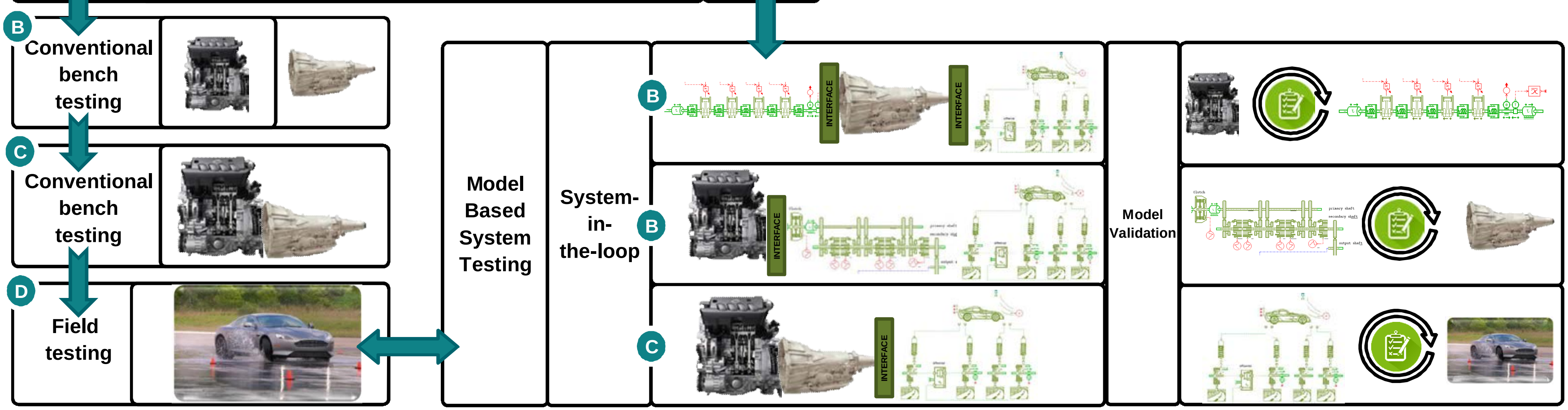
System-in-the-loop testing

System-in-the-loop testing in support of Model-Based Development

Consistent testing for shorter development cycle



- ✓ test component / subsystem / control unit in near-real conditions using a real-time simulation of the full system.
- ✓ full-system testing during all development phases: virtual (a), hybrid (b-c), physical (d)



Virtual Validation
Hardware-in-the-loop testing

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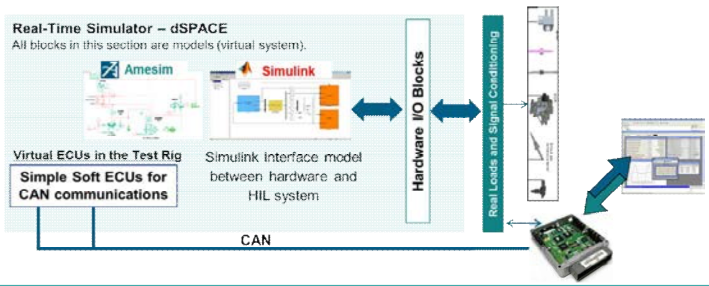
HiL for HEV control pre-calibration for MAB

Closed-Loop HIL



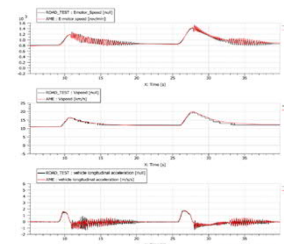
Validation – NVH

Tip-in Tip-Out – EV Mode

E-Motor speed [rpm]

Vehicle speed [kph]

Vehicle acc. [m/s²]



CUSTOMER REFERENCES

2016 9th EUROSIM Congress on Modelling and Simulation

Published Paper

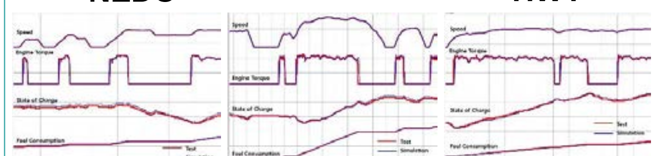
Development of a Hardware In the Loop Setup with High Fidelity Vehicle Model for Multi Attribute Analysis

Jae Sung Bang, Tae Soo Kim, Suk Hwan Choi
Eco-Vehicle Control System Development Team
R&D Division, Hyundai Motor Group
Seoul, South Korea
aeromec@hyundai.com

Raphael Rhote-Vaney, Harikrishnan Rajendran Pillai
MBSE Engineering Services
Siemens PLM
Livonia, USA

Validation – Energy efficiency

NEDC **FTP** **HWY**



The errors between the test data and the simulation data is **less than 2%**!

From CAD-centric to System-centric thinking

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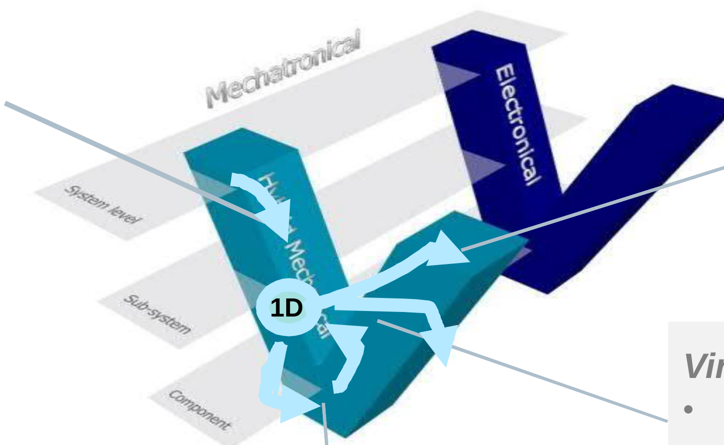


Validation

- Get insight in rotational dynamics
- Reduce prototype troubleshooting time

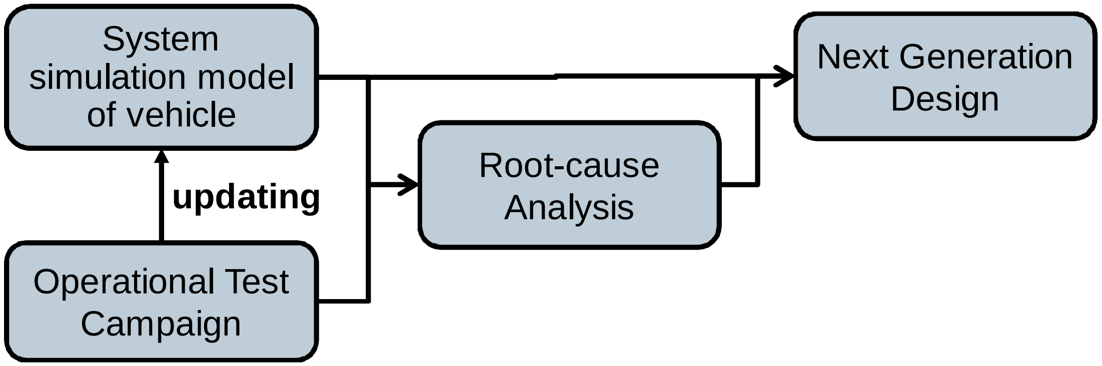
Virtual Verification

- Verify component performance at system level before prototype is available

NVH System Engineering

- Frontload design choices
- Feasible even without detailed geometry

Validation
Enhance test-based troubleshooting

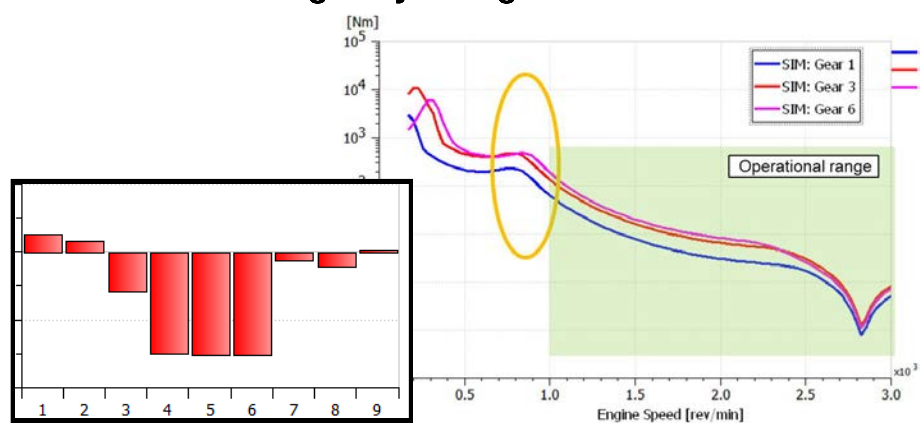


Combine **test data** analysis and **system simulation to**

- Tackle the issue in the driveline
- Reuse in next generation vehicle design

Test, simulation, CAN/ECU overlaid for root cause analysis

Additional insight by using simulation model



Validation

Synchronizer gear rattle at low frequencies

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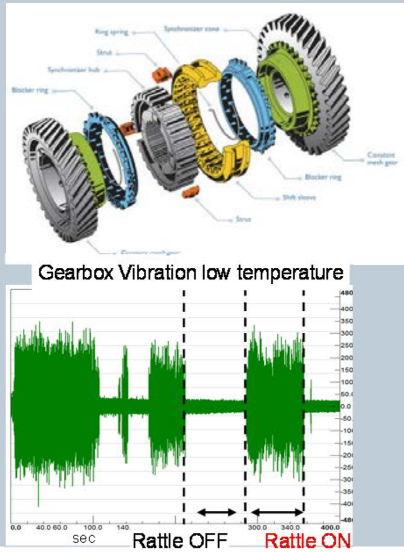
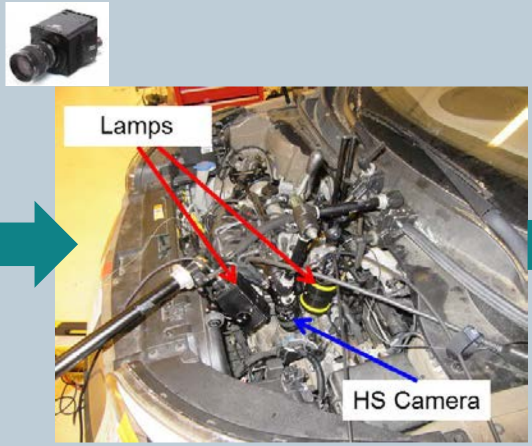
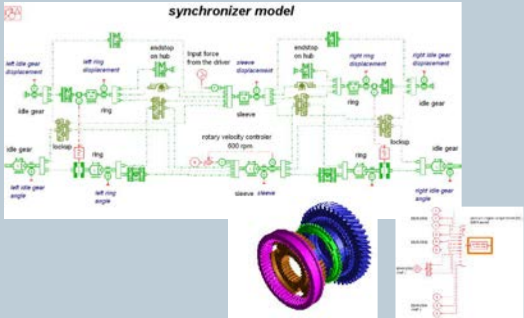
- Shift Shock
- Clunk
- Judder
- Booming
- Squeal
- Engine Re-start
- 1D Rattle
- **2D Rattle**
- Switching & slotting effects
- Drivability

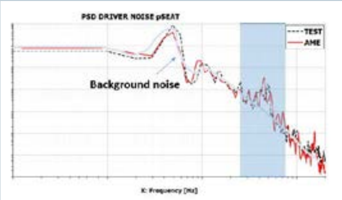
Solution

- Detailed MBD model of the transmission
- Combined test and system simulation troubleshooting
- Unexpected NVH issue can be included in next generation design verification









From CAD-centric to System-centric thinking

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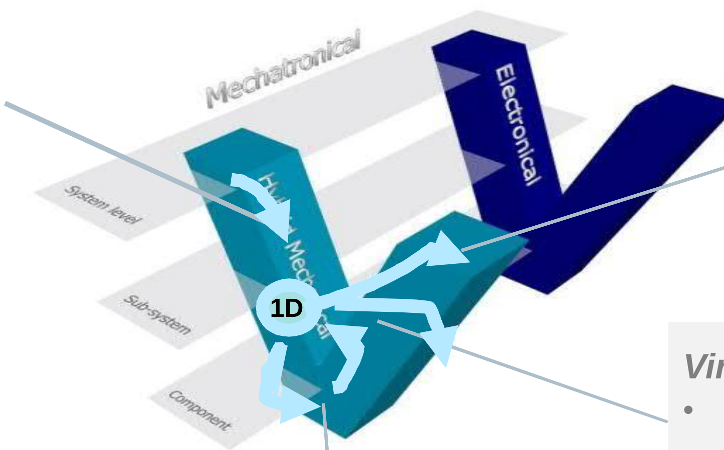
SPECIFICATION | DESIGN / ENGINEERING | VALIDATION | CERTIFICATION | TROUBLESHOOTING

Target setting and benchmarking
- Shortens testing phase
- Multi-attribute target setting and evaluation
- Cascade system targets down to components



Validation
- Get insight in rotational dynamics
- Reduce prototype troubleshooting time

Virtual Verification
- Verify component performance at system level before prototype is available

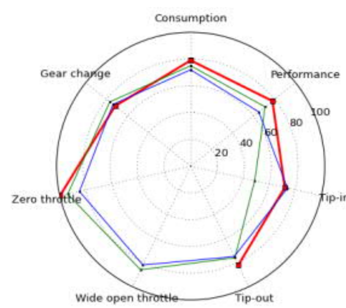
NVH System Engineering
- Frontload design choices
- Feasible even without detailed geometry

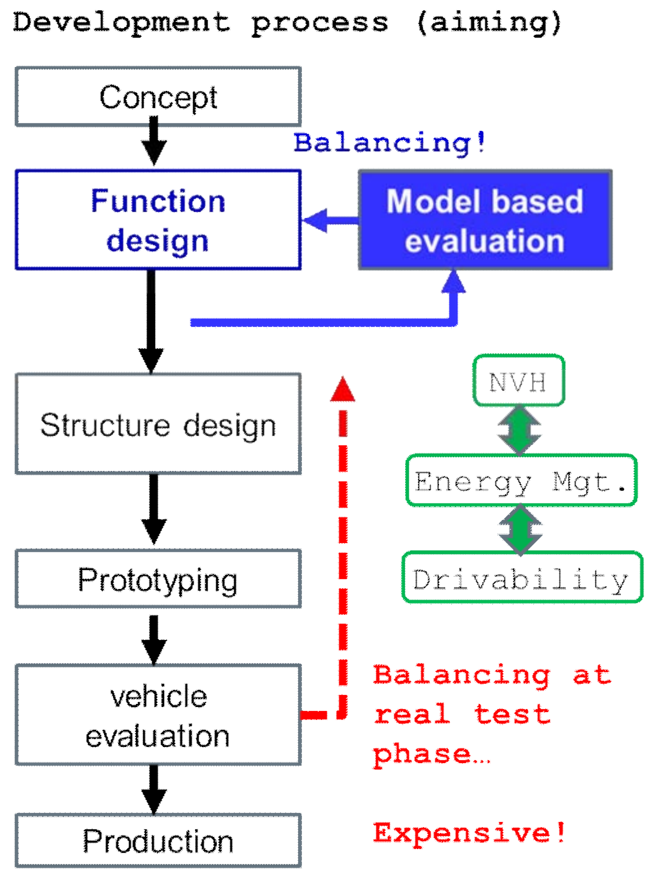
Target Setting and Benchmarking
Why Multi-Attribute Balancing

Challenge: balance conflicting attributes → modifying the vehicle in refinement stage is too costly

- Better energy efficiency is required → Some measures often degrade NVH performances (downsizing engine, idling stop, lower speed at Lock Up, weight saving,…)

Solution:
- Deploy **multi-attribute testing** campaign for target setting
- Develop **unified modeling approach** for performance balancing at early stage





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Target Setting and Benchmarking

Multi-attribute testing

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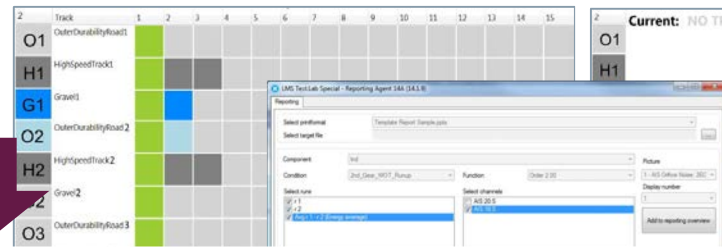
To synergize

Unified setup

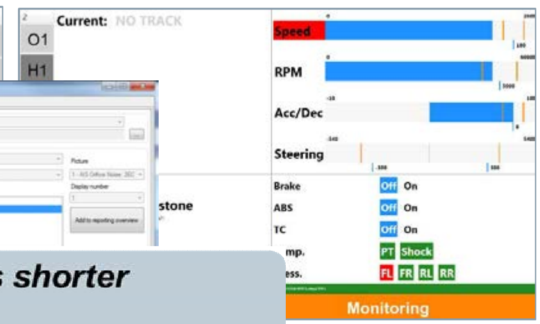
	Durability	Handling	Comfort	Drive-ability	LF NVH	Asset turnover ratio [# coverages / 1 use]
Spindle forces	YES	YES	YES	YES	YES	5
Suspension acceleration	YES	YES	YES	YES	YES	5
Frame acceleration	YES	YES	YES	YES	YES	5
Frame strain	YES	YES				2
Cabin acceleration & mic						
Driveline rpm torque						
CAN						

To automate

Scheduling & Monitoring

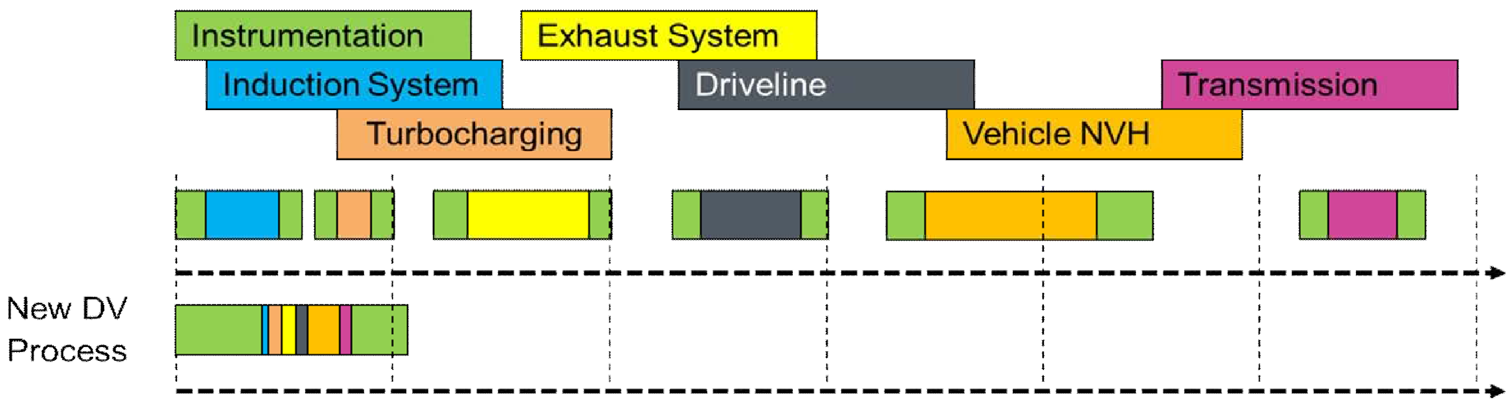


GPS Based acquisition



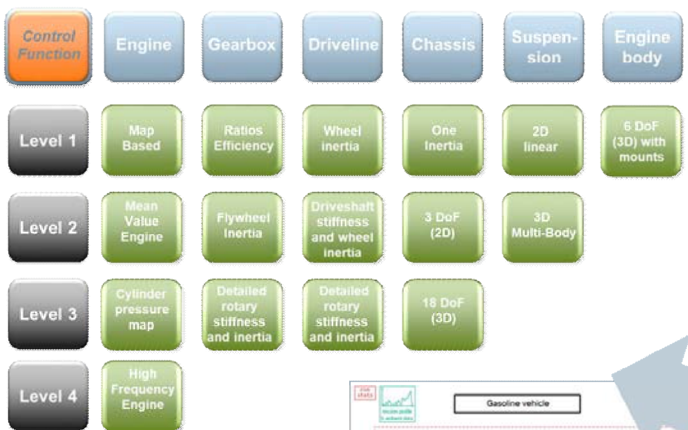
mated quality
ks & reporting

Customer statement "Our new design verification process is now 5 times shorter and the processing of data has gone from 2 weeks to 3 hours"

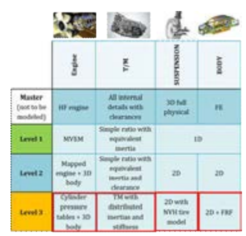


Target Setting and Benchmarking
Unified modelling approach

Scalability concept

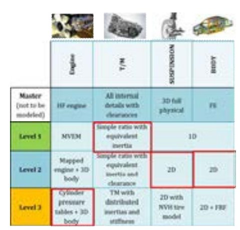


Booming



	Engine	T/M	SUSPENSION	BODY
Master (not to be modeled)	HF 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

Engine Start



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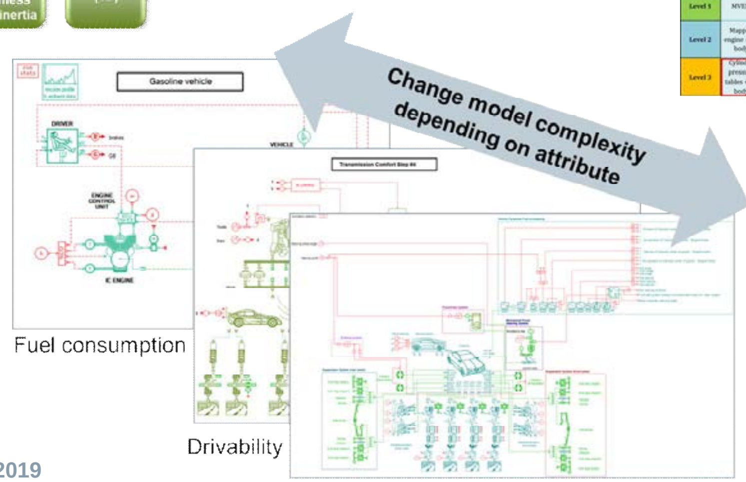


Fuel consumption

Drivability

Vehicle dynamics

Unified parametrization

Cross-department data gathering

Global parameter list

Model parameters

Simulation specific parameters

Tip-In model

Start model

VEM model

Booming model

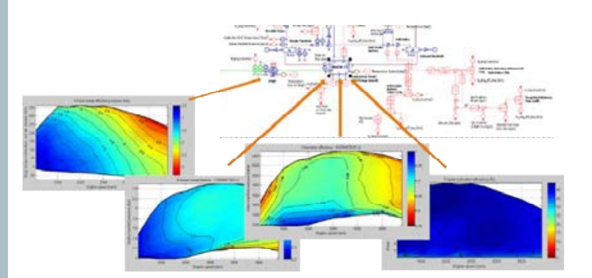
Ensure parameters consistency between models

Mitsubishi Motor Company

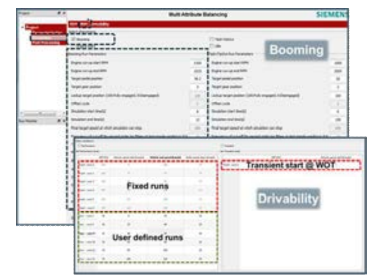
Technology development to allow multi-attribute evaluation

- **Satisfy multiple performance at the early stages of vehicle development**
- **Evaluate design parameters and control settings on different attributes**
- **Reduce risk of issues during validation**

Multi-attribute balancing of NVH, drivability and energy management



Full vehicle model with scalable complexity



Multi-attribute balancing tool

- Generate a unified system simulation environment to evaluate different performances
- Build a library of full vehicle models and a centralized data management tool

"Simcenter Engineering services helped us to apply performance balancing at the early stages of development, contributing to prevent development reworking."

Paper at SAE

Conclusions
Added value of Model-Based Development for NVH

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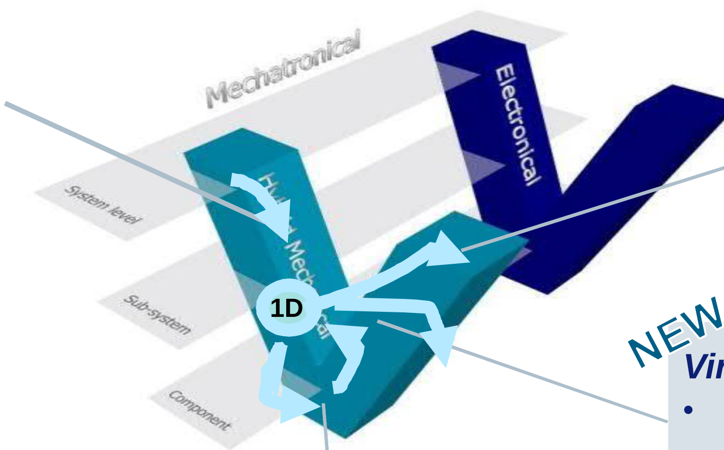

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NEW

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Strengthening its position as technology partner

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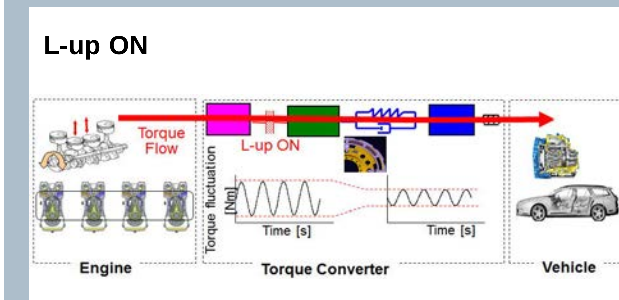
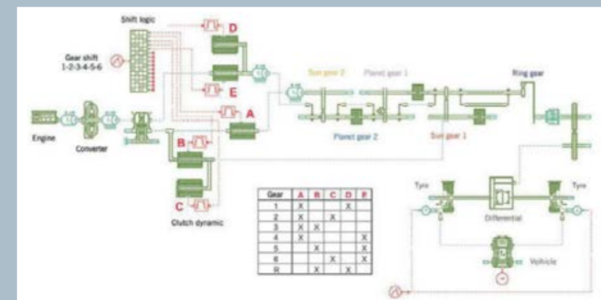
- **Gained 50 percent time reduction when troubleshooting a new NVH issue**
- **Significantly reduced overall development time**
- **Recognized as technology partner of automotive OEMs, resulting in competitive advantage**

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 Simcenter Engineering are now part of our standard development process, such as transfer path analysis.”

Hiroki Tsuji, Group Manager, Core Component Engineering Department

Thank you! Want to know more?

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Read more	Explore, share and learn
Watch videos	**Contact the expert**