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# NVH-Driven Integration of Composite Brackets for Lightweight Vehicle Design

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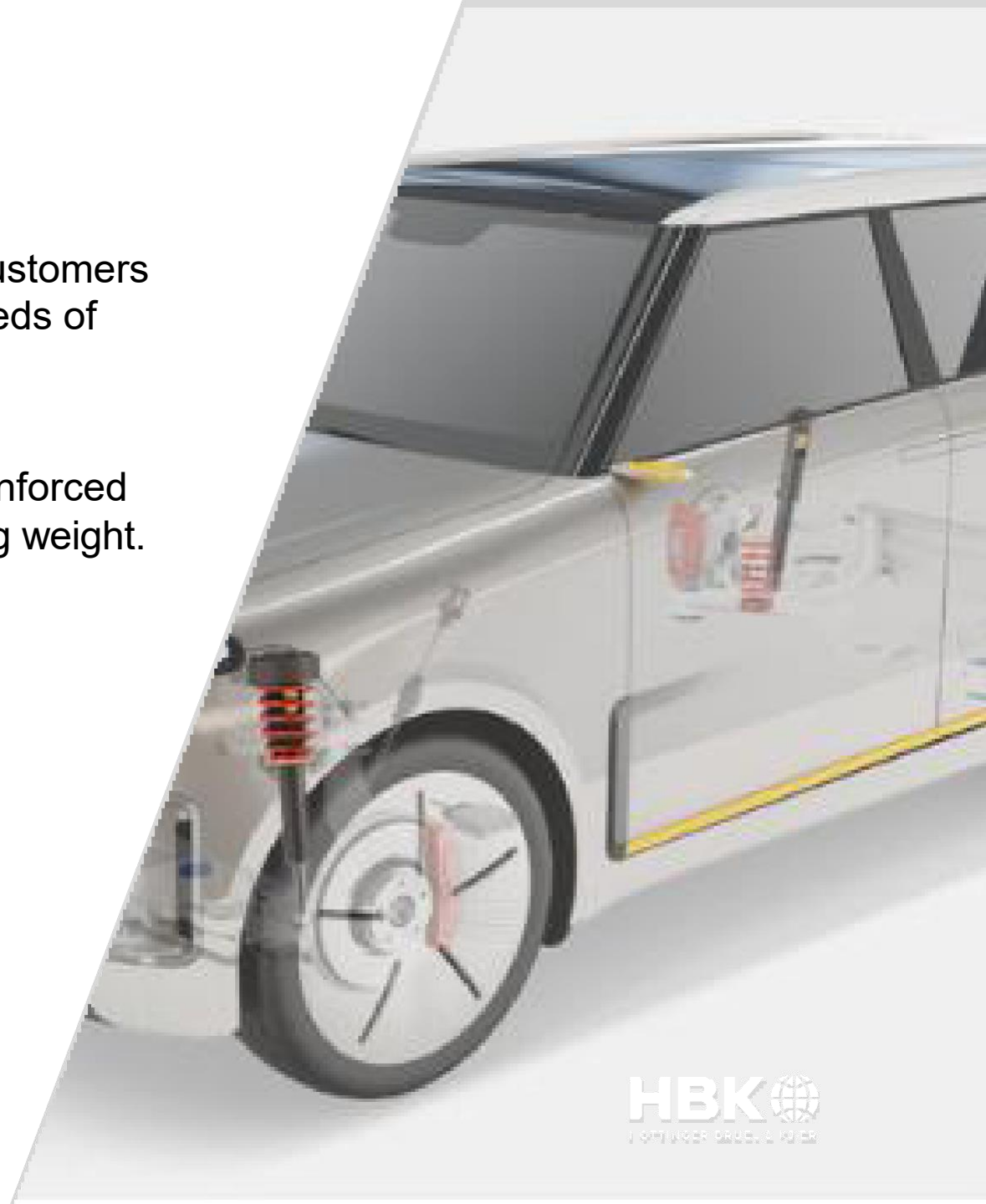
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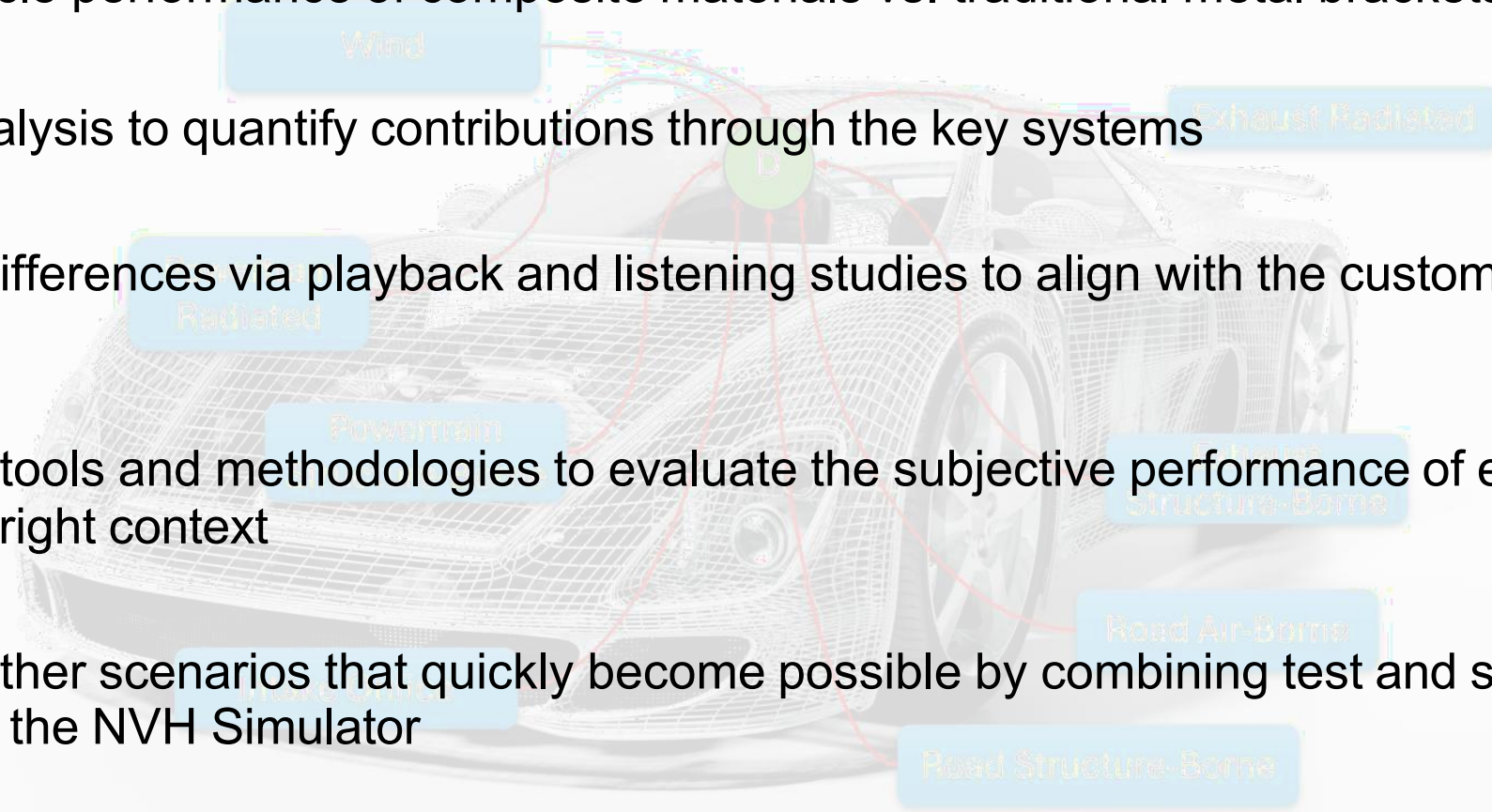
# The Need for Simulation

- ▲ BASF, through science and innovation, enables their customers in nearly every industry to meet the current and future needs of society.
- ▲ BASF materials, like Ultramid® polyamide glass fiber reinforced (GFR) composites, can be effective options for reducing weight.
- ▲ The challenge:
  - Demonstrate the sound and vibration performance of individual components within a vehicle can be difficult
    - Part manufacturer
    - Access to full vehicle data sets
    - Beyond 2d graphs
  - Needed a method to characterize and **effectively communicate** the acoustic performance of components.



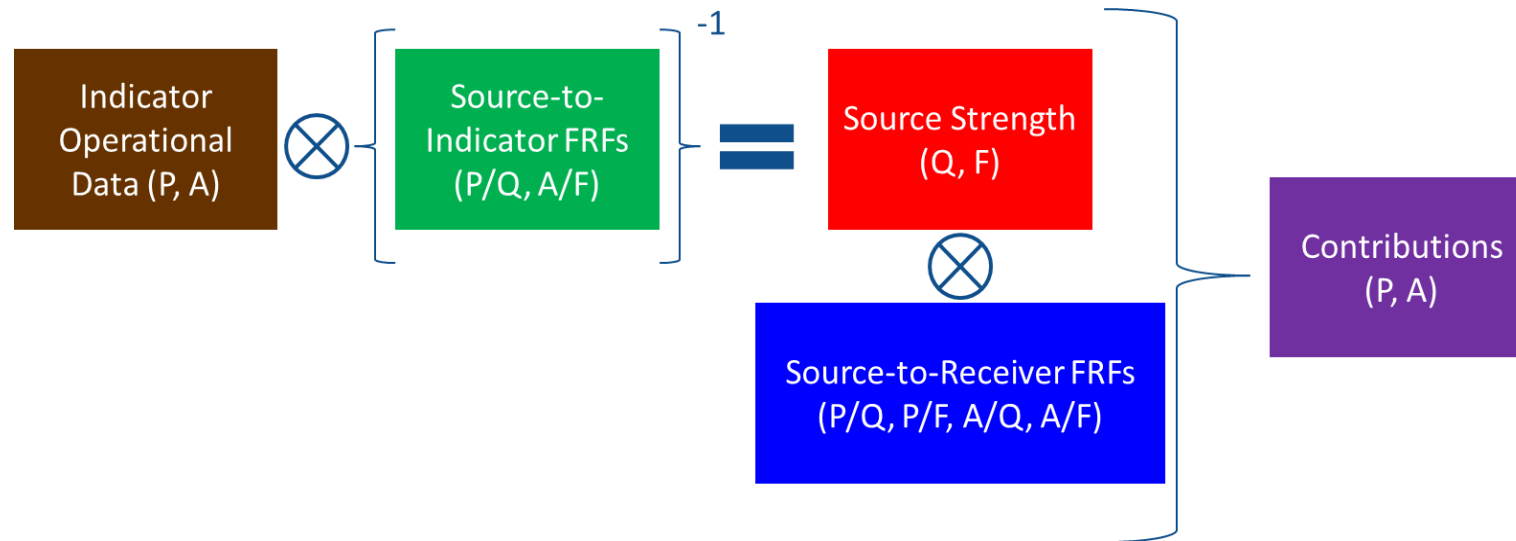
# The Approach

- ▲ Assess in-vehicle performance of composite materials vs. traditional metal brackets
- ▲ Utilize path analysis to quantify contributions through the key systems
- ▲ Demonstrate differences via playback and listening studies to align with the customer experience
- ▲ Showcase the tools and methodologies to evaluate the subjective performance of engine mounts, in the right context
- ▲ Demonstrate other scenarios that quickly become possible by combining test and simulation methods using the NVH Simulator



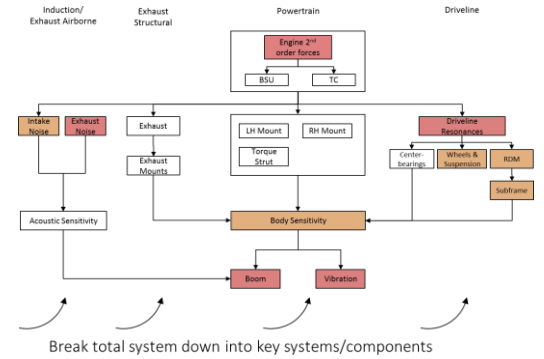
# Source Path Contribution (SPC) Methodology

- ▲ SPC analysis performed to characterize independent sources and paths of powertrain and road noise
- ▲ Output for each source:
  - Time-domain source strength (units of force, volume-velocity)
  - Frequency-domain sensitivity (transfer function from source to receiver)
  - Time-domain contribution (receiver signals from each source)
- ▲ Sum of Contributions to each receiver provides a measure of total sound captured by the model and allows for validation by comparison to the measured receiver signals



# SPC Data and Migration to NVH Simulator Model

- ▲ Utilize existing Transfer-Path-Analysis (TPA / SPC) models
  - For key components (engine, motor, exhaust, tires, gears, HVAC, etc.)
  
- ▲ Combine TPA / SPC model with contributions from other sources to provide full context for the customer experience
  
- ▲ Jury studies and listening evaluations
  
- ▲ Target setting and target cascading
  
- ▲ Assess and plan for performance prior to availability of hardware



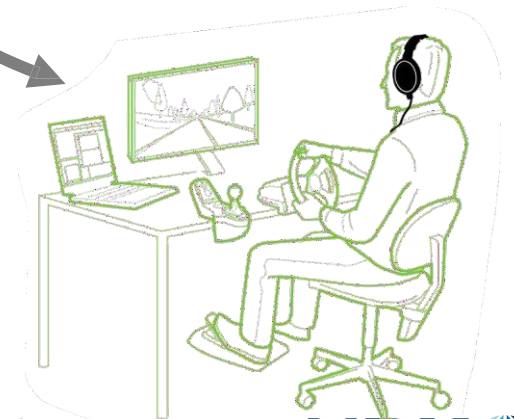
Road Noise



Gear Noise



Powertrain Noise



# The Study: Instrumentation Considerations

## Powertrain SPC study

- ▲ Transducer placement on the subframe/body structure instead of active side of powertrain component
  - Excludes participation from any rubber isolating elements
  - Easier to measure using hammer excitation
- ▲ Matrix inversion SPC approach
  - Inversion of transfer function matrix requires redundant (indicator) transducers per source location
  - Indicator to source ratio  $> 2x$
  - Instrumentation only on body side – only 1 set of transfer functions measured per vehicle & operational measurements repeated for each powertrain mount



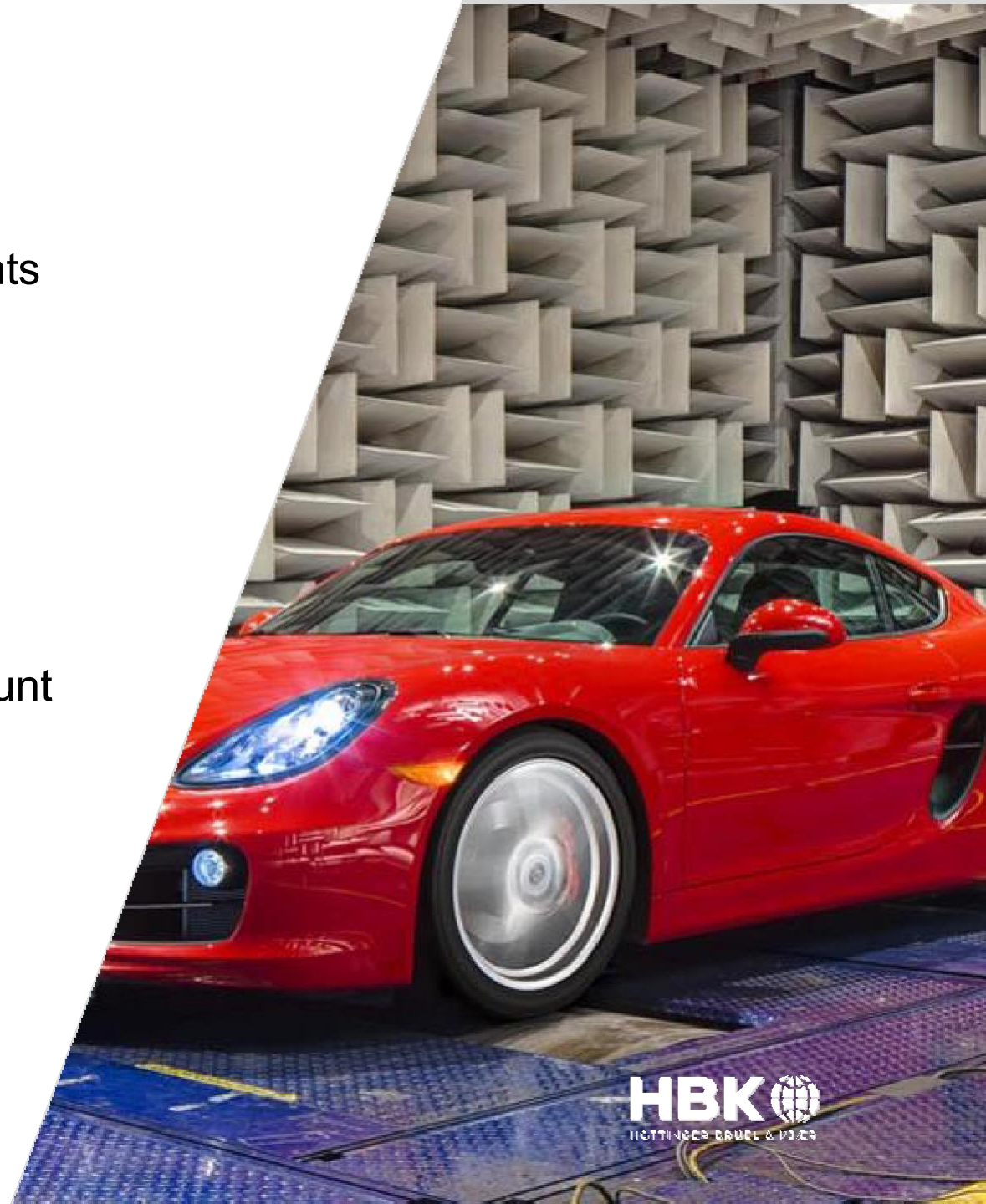
# The Study: Sensitivity Measurement Considerations

- ▲ Artificial excitation method for local and global transfer functions
- ▲ Impact hammer test for SB measurements in X,Y,Z directions for each mount
  - Powertrain components remain attached – proven to be time efficient and provide comparable results to disconnected method
- ▲ Volume Velocity source used for AB measurements
  - Airborne sources identified at each side/face of the powertrain
- ▲ Frequency range considerations
  - Higher RPM operation ranges of e-motor and switching frequencies of inverters requires higher frequency range requirements of SB and AB sensitivities



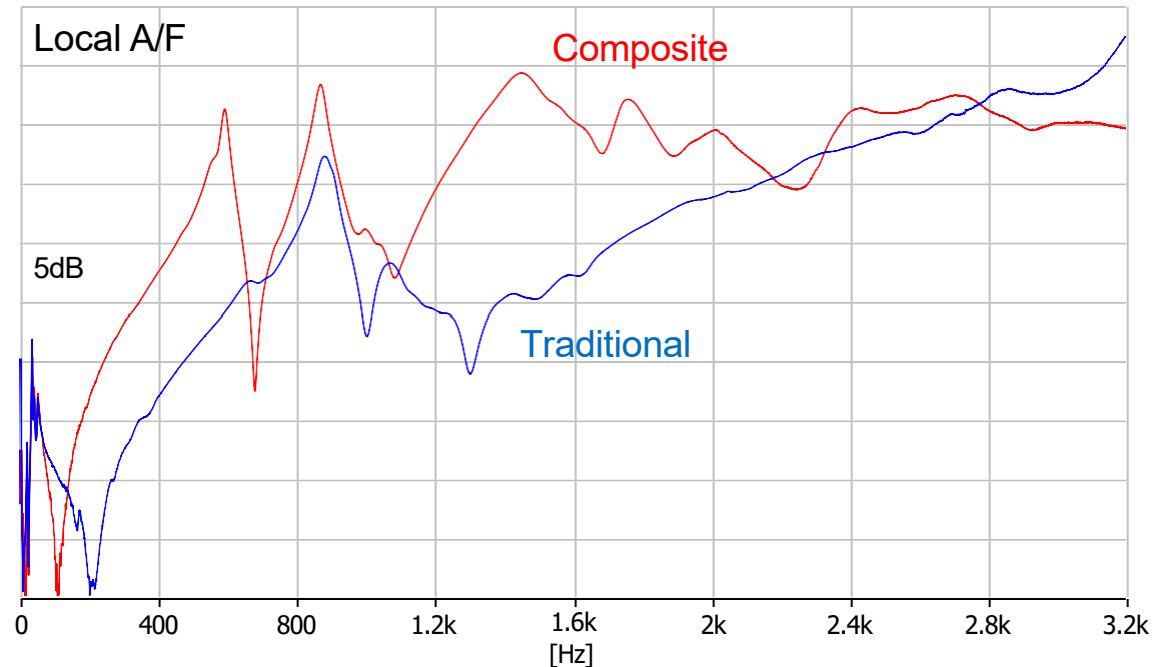
# The Study: Operational

- ▲ Powertrain SPC focus – Operational measurements conducted on a Chassis Dynamometer
- ▲ Several operating conditions measured
  - Several throttle / pedal % for one or more gears
  - Steady state measurements
- ▲ Operational measurements repeated for each mount (composite and traditional mount)



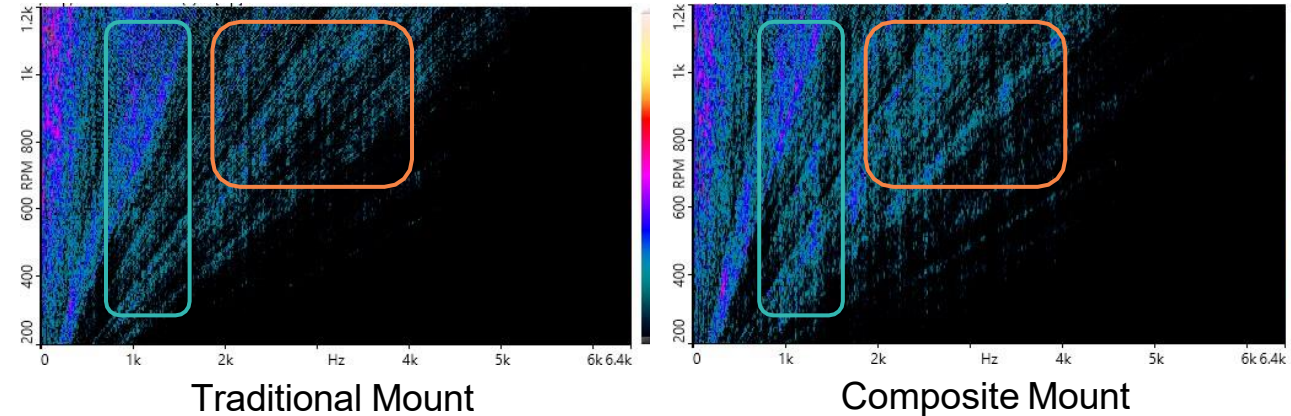
# The Results – Component Level Assessment

- ▲ One method to assess mount performance could be to study the structural response due to a force input at the component level
- ▲ Model hammer force input and local accelerometer response
  - Higher vibration response from the composite mount compared to the traditional mount
- ▲ Despite the higher response at the component level, it is unclear if this difference will have an effect on the end user during operation
- ▲ Need to understand the performance in context

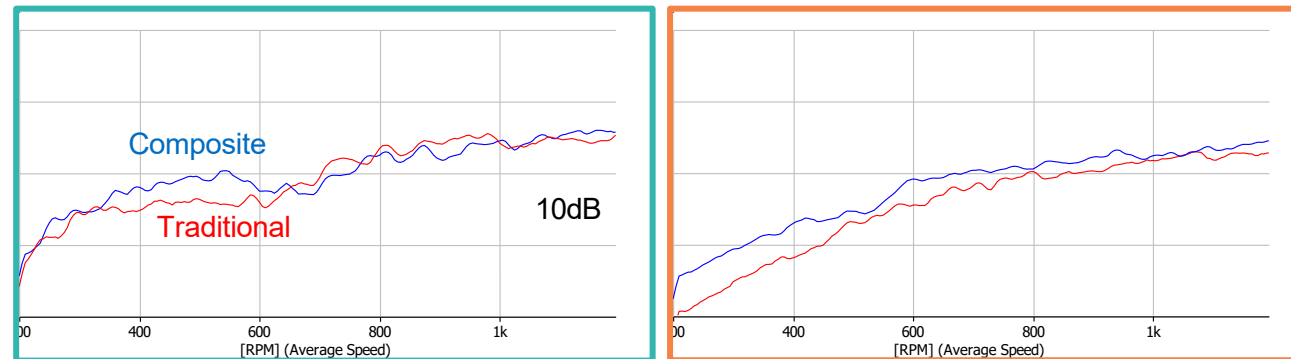


# The Results – Powertrain Contributions

- ▲ Determine the acoustic responses at the occupant position
  - Only powertrain contributions
- ▲ Path analysis (SPC) utilized to determine contributions through the mount bracket along with all other structural and acoustic paths
- ▲ Despite the higher response at the powertrain level, it is unclear if this difference will have an effect to the end user during operation
- ▲ Some mid / high frequency increases with the composite mounts
- ▲ Need to understand the performance including road and wind contributions



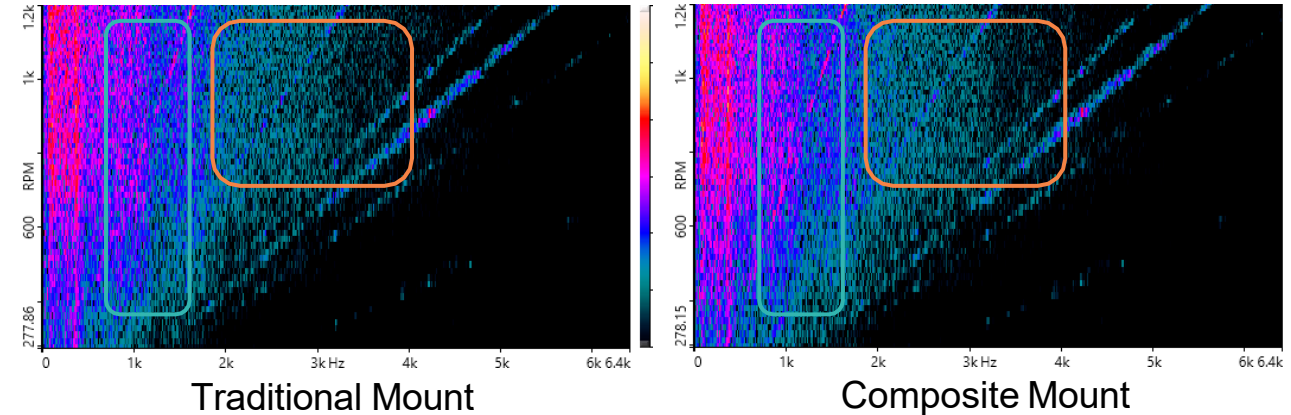
## Powertrain Only Contributions



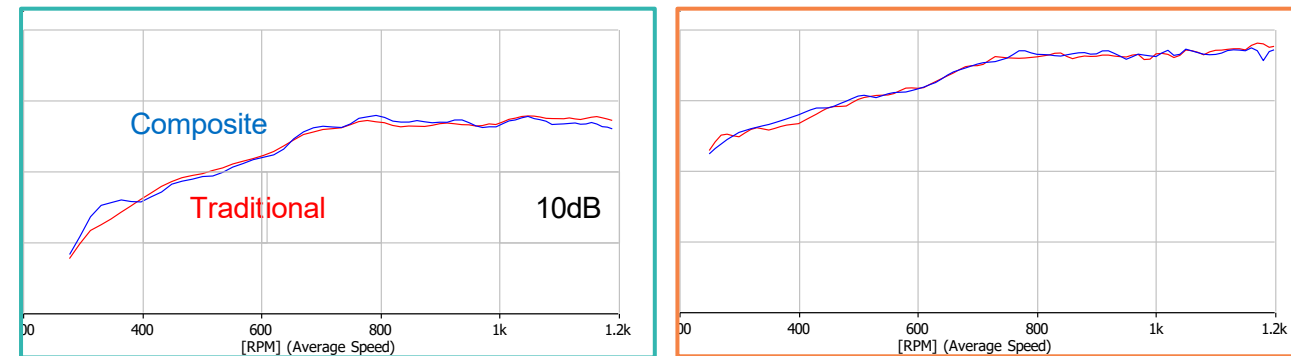
Frequency band extractions vs. speed

# The Results – Full Vehicle Contributions

- ▲ Determine the acoustic responses at the occupant position
  - Include powertrain, road and wind contributions
- ▲ Powertrain contributions combined with road / wind contributions using the NVH Simulator
- ▲ Road / Wind contributions mask powertrain contributions, including any effects from the composite mount
- ▲ Able to confirm these conclusions via data but also want to confirm via listening studies
  - NVH Simulator platform

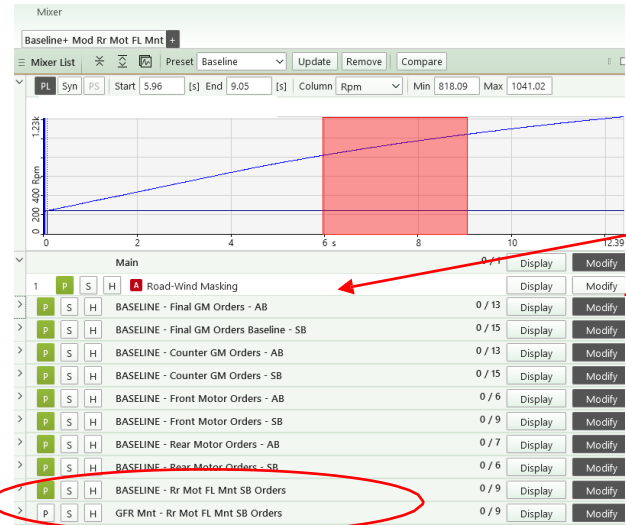


## Full Vehicle Contributions



Frequency band extractions vs. speed

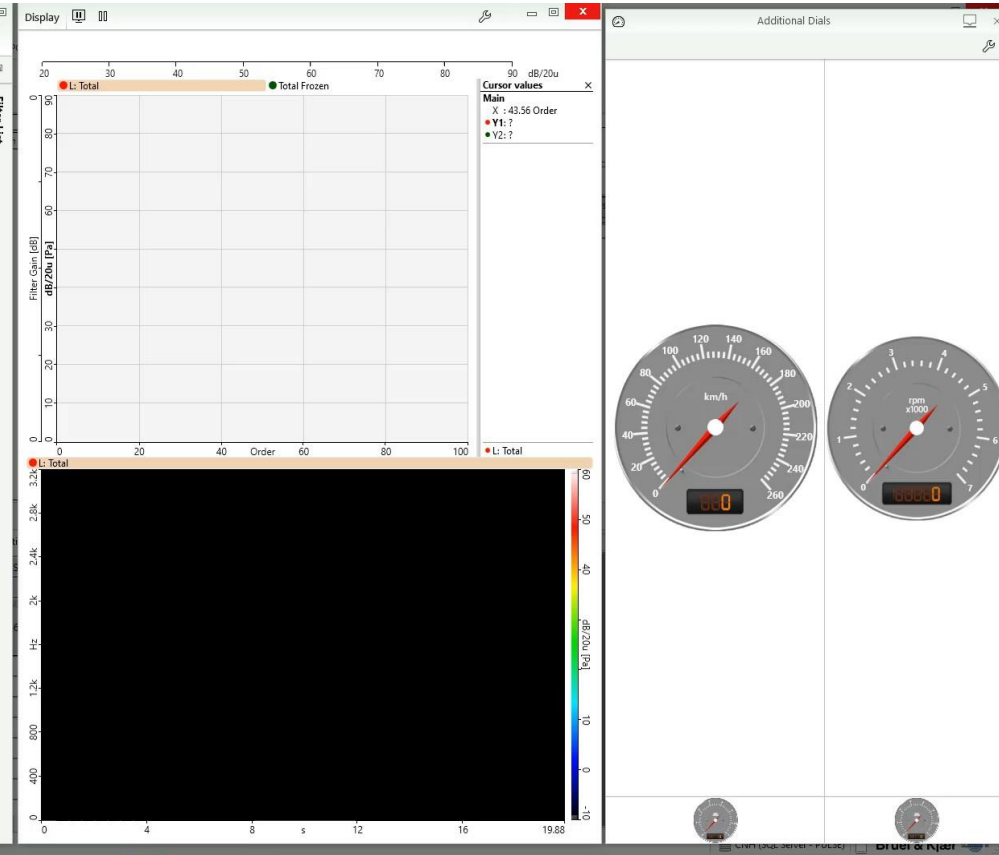
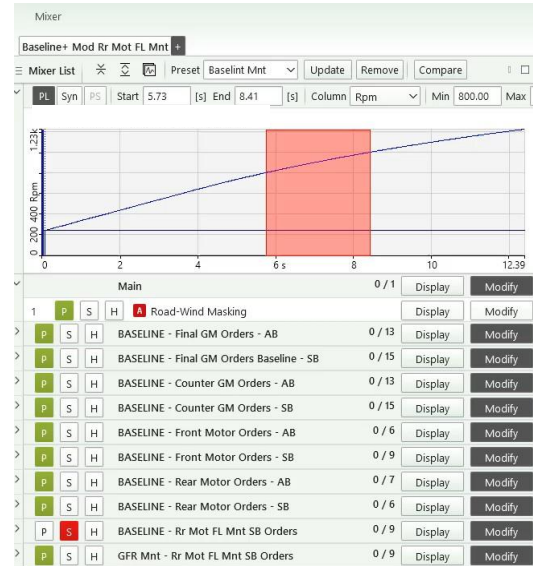
# Decision Making – Subjective Evaluations with NVH Simulator



Road & wind noise

SPC contributions separated into gear mesh and motor orders.

Mount contributions  
Composite vs. Traditional



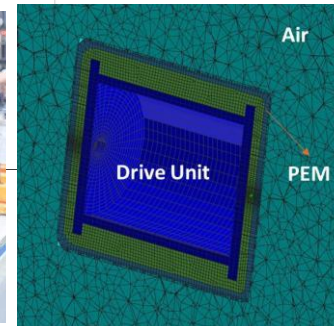
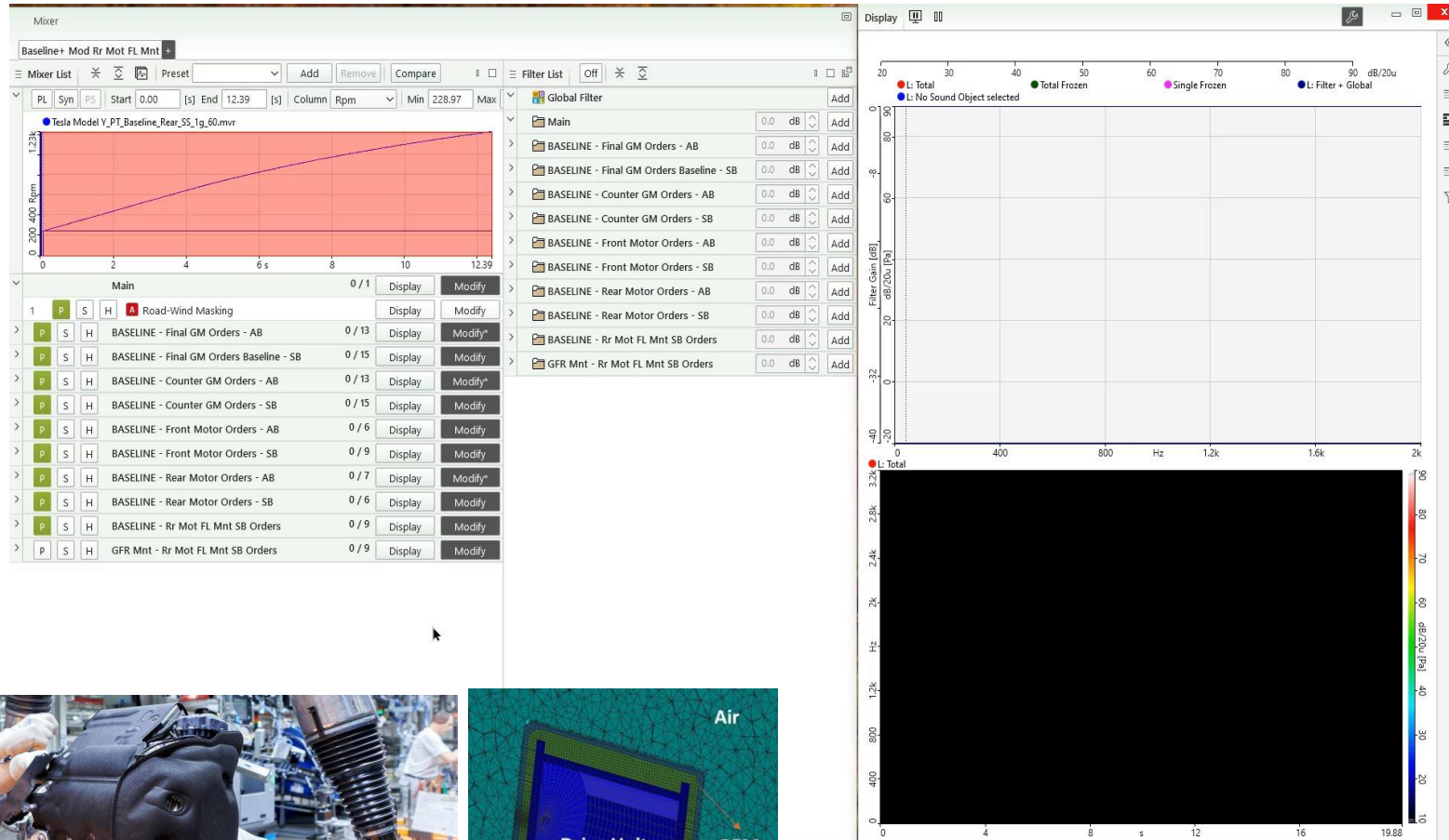
Actively playing groups are highlighted

Order	Component	Count	Display	Modify
1	Road-Wind Masking	13 / 13	Display	Modify
2	BASELINE - Final GM Orders - AB	13 / 13	Display	Modify
3	BASELINE - Final GM Orders Baseline - SB	15 / 15	Display	Modify
4	BASELINE - Counter GM Orders - AB	13 / 13	Display	Modify
5	BASELINE - Counter GM Orders - SB	15 / 15	Display	Modify
6	BASELINE - Front Motor Orders - AB	6 / 6	Display	Modify
7	BASELINE - Front Motor Orders - SB	9 / 9	Display	Modify
8	BASELINE - Rear Motor Orders - AB	7 / 7	Display	Modify
9	BASELINE - Rear Motor Orders - SB	6 / 6	Display	Modify
10	BASELINE - Rr Mot FL Mnt SB Orders	0 / 9	Display	Modify
11	GFR Mnt - Rr Mot FL Mnt SB Orders	9 / 9	Display	Modify

- ▲ Data and listening studies to demonstrate effects to the end user
- ▲ NVH can offer tangible weight and cost savings while maintaining no degradation to the end user experience

# Additional Study – Motor Encapsulation Simulation

- ▶ Motor encapsulation study to identify the effect on the total sound at the receiver
  
- ▶ Analytical team generated frequency domain predictions for the expected effects on the motor sound power
  - Motor excited with electromechanical force at the stator attachments
  
- ▶ Within the NVH Simulator environment:
  - Utilize motor acoustic source strengths
  - Filter to simulate analytical predictions for encapsulation performance
  
- ▶ Able to generate data and perform listening studies to demonstrate expected effects to the end user



# Summary

- ▲ Demonstrating sound and vibration performance of individual components within a vehicle can be challenging, especially for Tier suppliers
- ▲ Needed a method to characterize and **effectively communicate** the acoustic performance of components
- ▲ NVH Simulator toolsets can provide this capability to allow for interactive assessments of performance
- ▲ Able to demonstrate that materials, like BASF Ultramid<sup>®</sup> polyamide glass fiber reinforced composites, can be effective options for reducing weight while maintaining NVH performance to the end users

