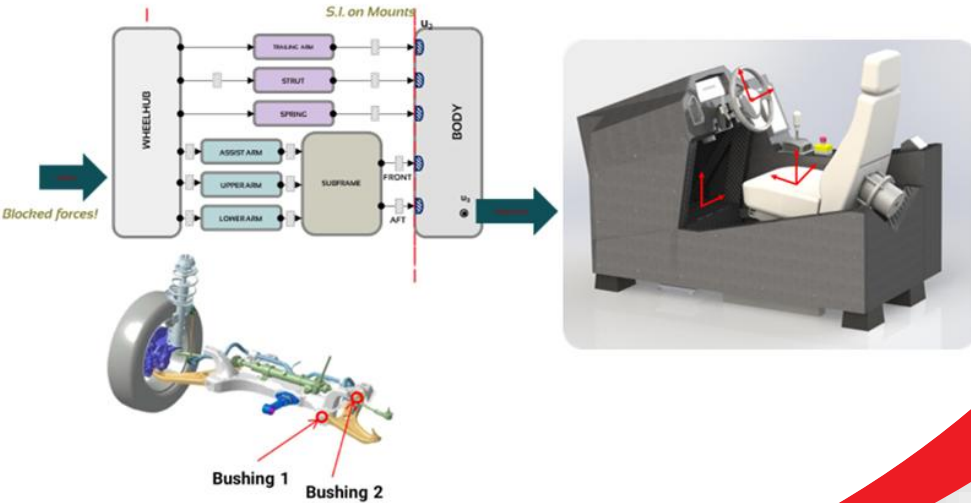




 **VIBES**.technology

 **VI-GRADE**

HYUNDAI
MOTOR GROUP



ENHANCING ROAD NOISE EVALUATION:

**STIFFNESS INJECTION AND SUBJECTIVE ASSESSMENT
IN A MULTI-ATTRIBUTE NVH SIMULATOR**

PRESENTERS:

ERIC PASMA

 **VIBES**.technology

GRAHAM FRANKS

 **VI-GRADE**

Component TPA and stiffness injection

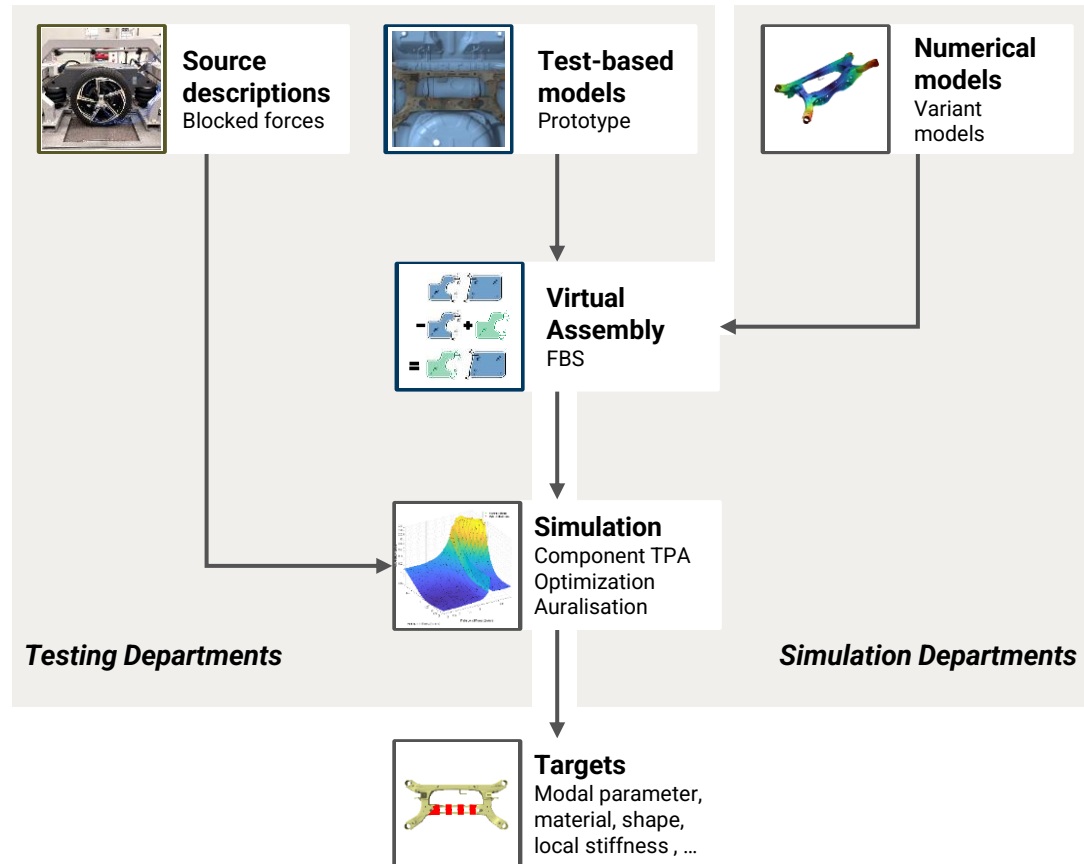
*How can we **improve road noise NVH performance** in a late phase of the development?*

*How can we **balance attributes** line Ride & Handling and NVH?*

*How can we **reduce the testing efforts** and get results quickly?*



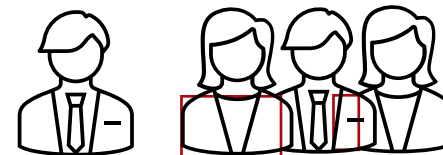
Integration in development processes



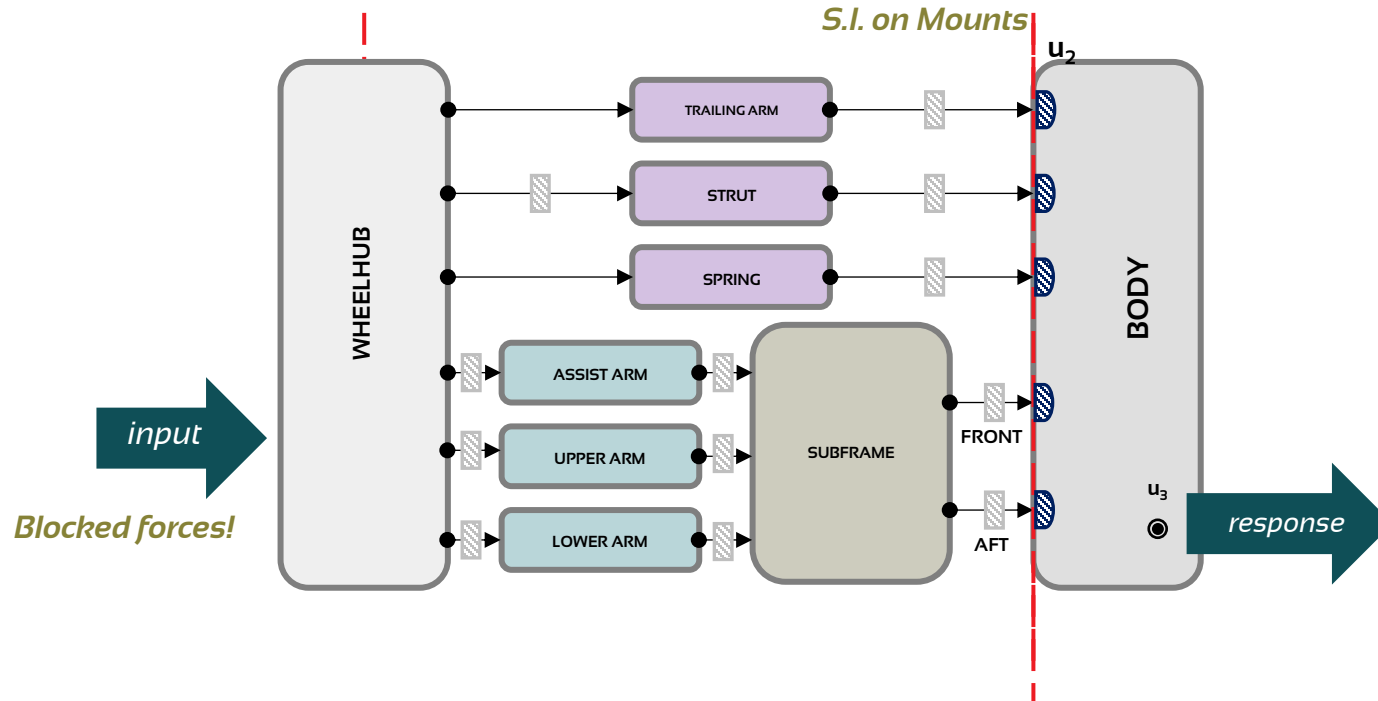
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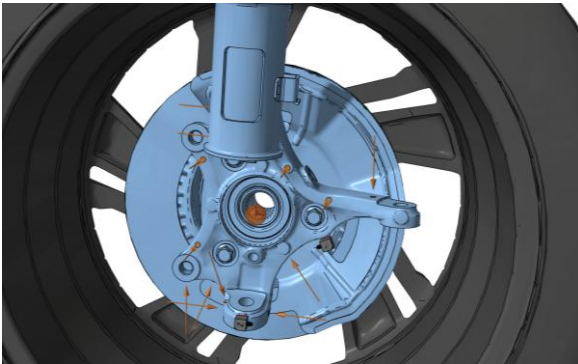


Suspension topology & VPT FRF measurements



Wheel hub blocked force characterization & validation

VPT FRFs for in-situ blocked forces



DIRAC

Component TPA validation

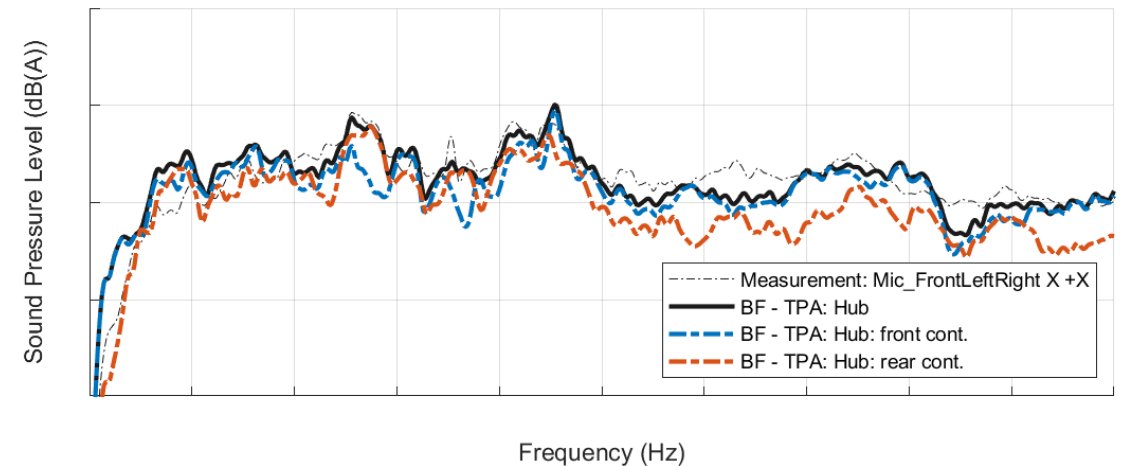


SOURCE

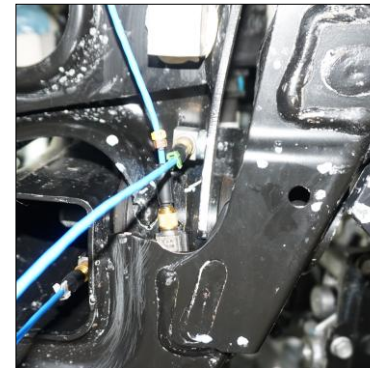
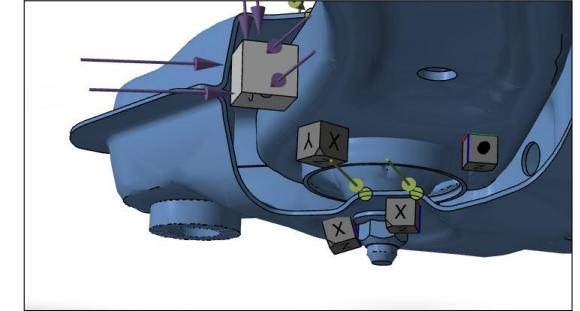
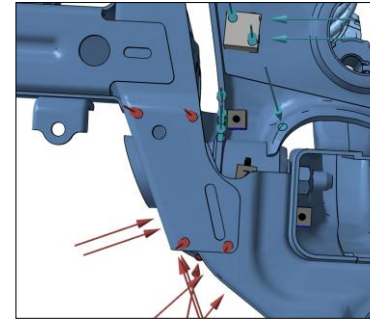
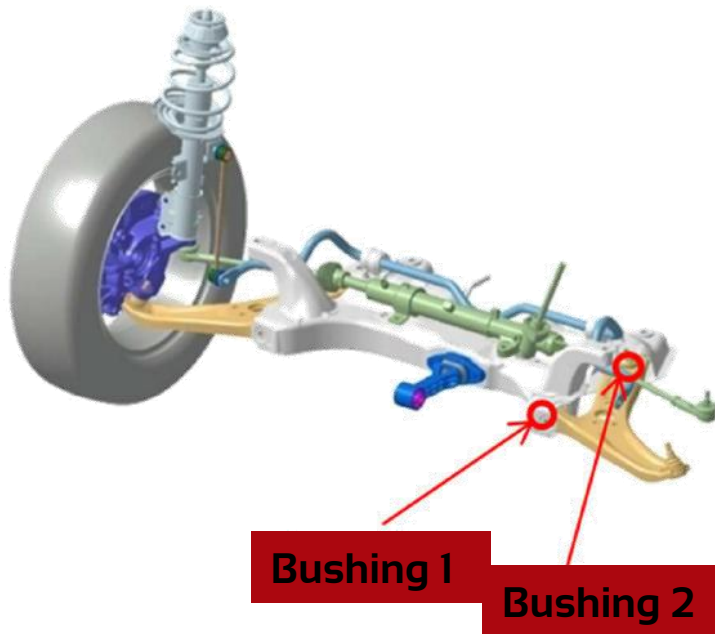
Virtual point transformation

- ▶ Transformation to 6 degrees of freedom
- ▶ Local rigid assumption
- ▶ FRF Measurement @ the connection points

Driver Inner Ear Response



VPT FRF measurements on the active and passive mounts for the Stiffness Injection Model

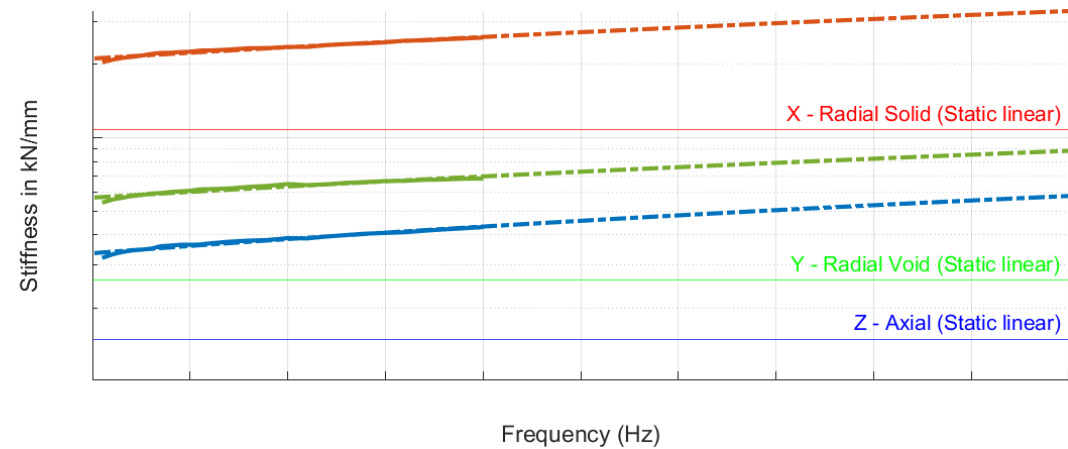
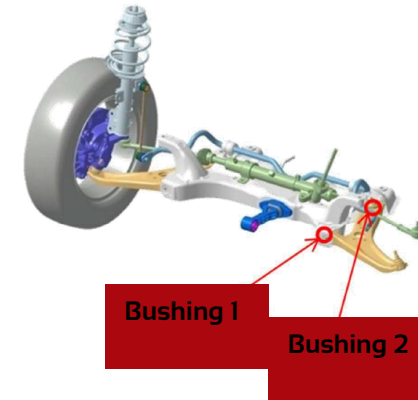


VPT measurement on the vehicle on active and passive side of the mount

Nominal bushing data to acquire relative stiffness changes

Cases based on nominal stiffness values for relative changes:

1. Stiffness variation on bushing 2
2. Rotate the bushing 90 degrees (extreme case)

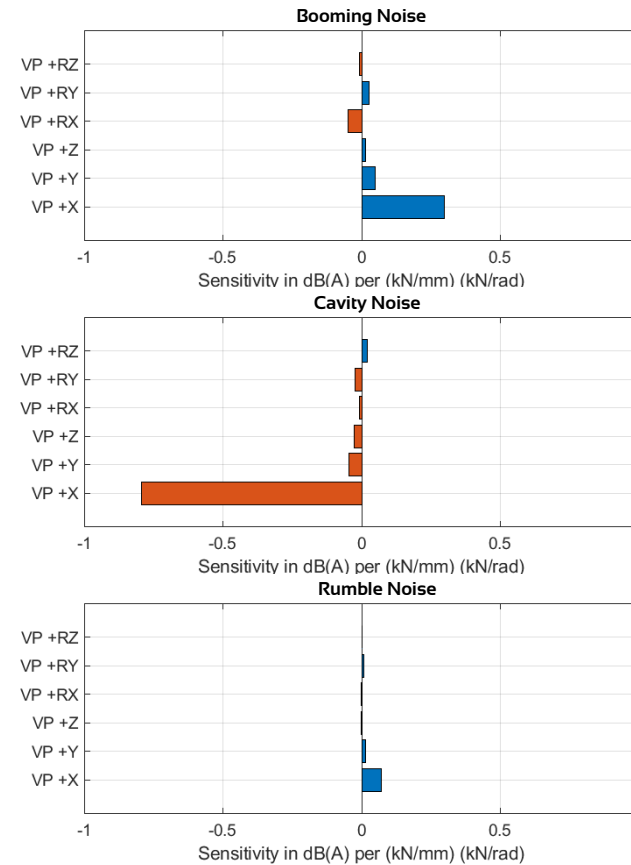


Sensitivity analysis of the mounts with respect to SPL

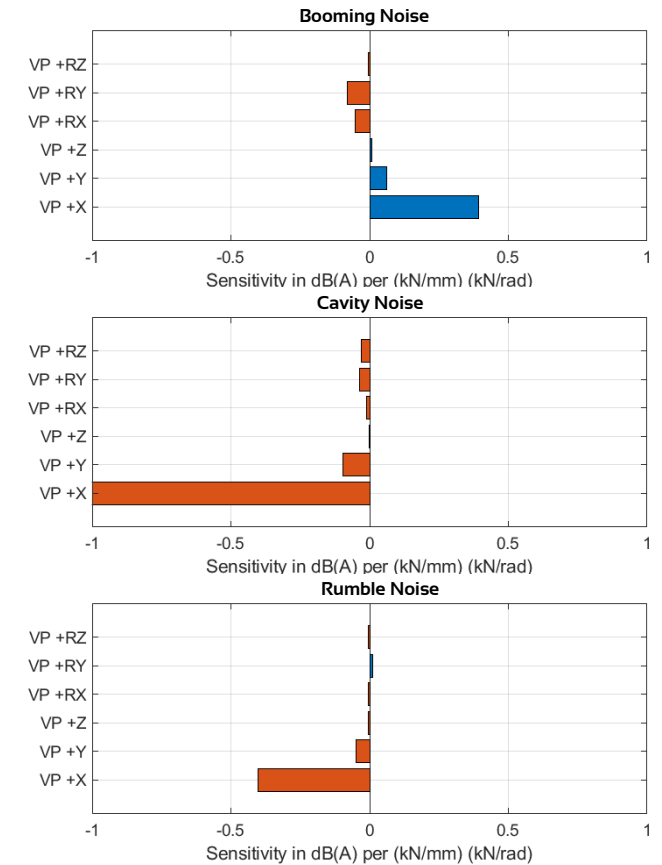
Mount Sensitivity analysis

- ▶ Change of the response in dB(A) due to change of bushing stiffness.
- ▶ *Linear superposition principle based on finite difference of 1 (N/m)*

Driver's ear



Passenger



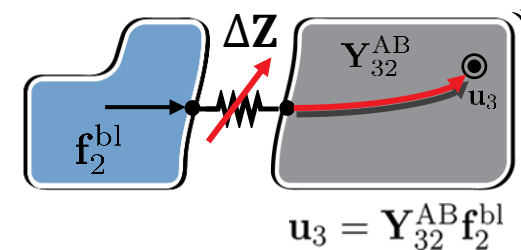
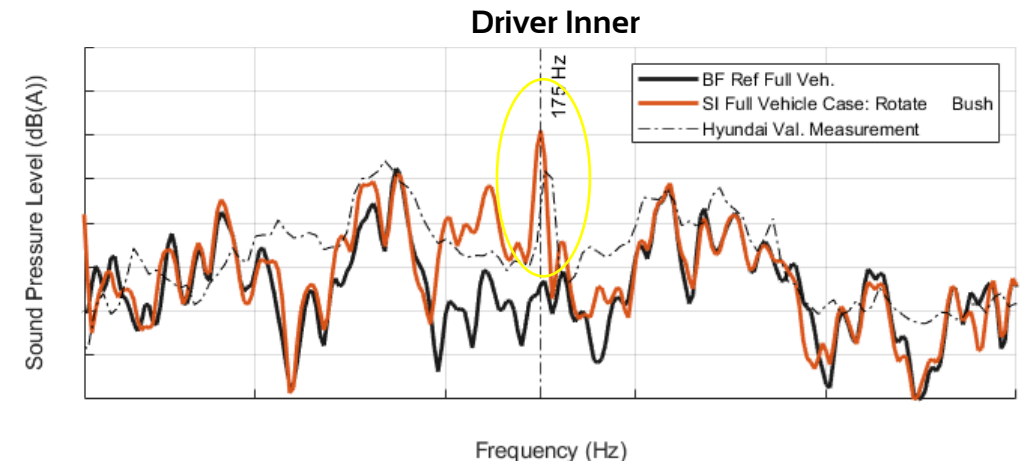
Prediction of SPL when rotating a bushing virtually 90 degrees (extreme case)

Conditions

- ▶ Rough Road, constant speed run
- ▶ Rotating the bushing virtually by 90 degrees on the estimated stiffness values.

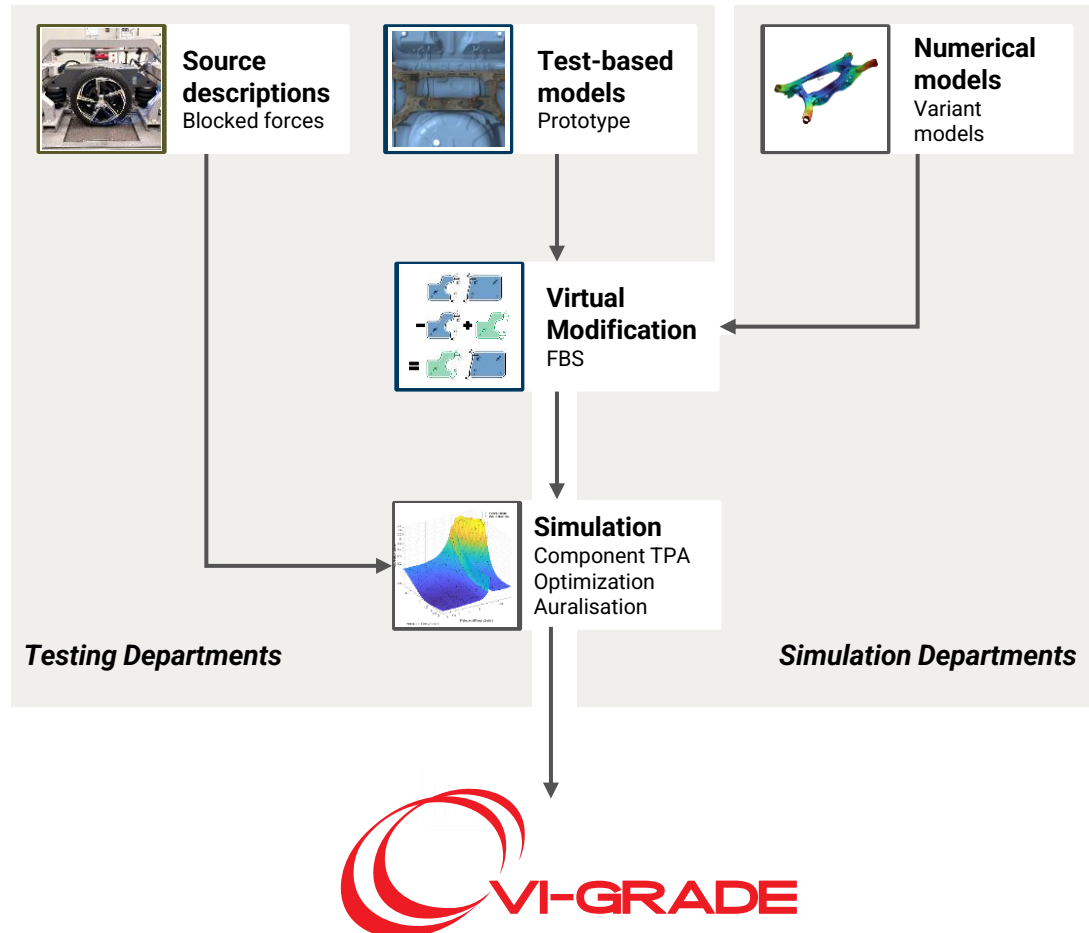
Validation

- ▶ The same peak is observed in the SI-prediction as measured by HMTEC.



- Stiffness Injection can change the vehicle virtually!
- Prediction matches the validation very well

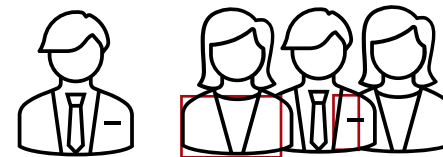
Integration of modular NVH development with sound simulation



How can we **improve road noise NVH performance** in a late phase of the development?

How can we **balance attributes** line Ride & Handling and NVH?

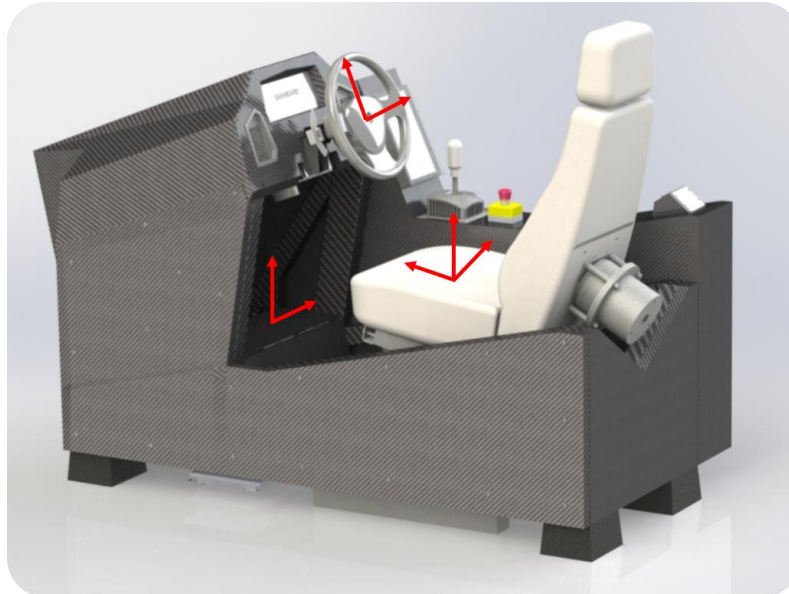
How can we **reduce the testing efforts** and get results quickly?



BRINGING THE TPA RESULTS TO LIFE !

SOUND & VIBRATION REPLAY - COMPACT NVH SIMULATOR

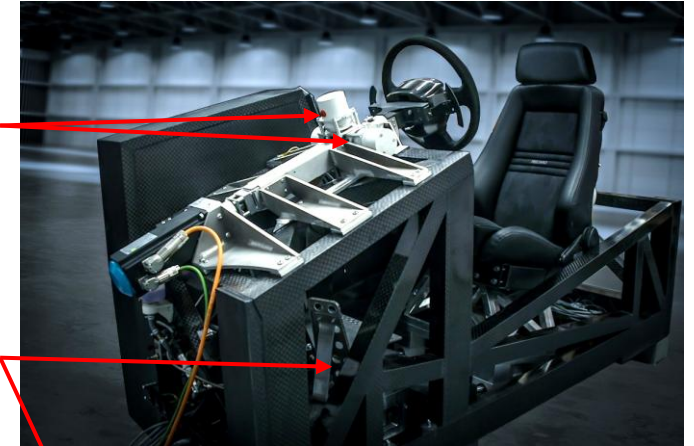
- A Multi-sensory driver-in-the-loop NVH Simulator Providing immersive Sound, Vibration, Visuals
- Calibrated / synchronized sound and vibration at primary driver contact points
 - Stereo Sound
 - 7 Independent Vibration DOFs:



+ Acoustic Playback

Vertical / Lateral
Steering Shakers

Vertical / Lateral
Heel Point Shakers



Vertical / Lateral
Seat Pad Shakers

Longitudinal Seat
Back Shaker

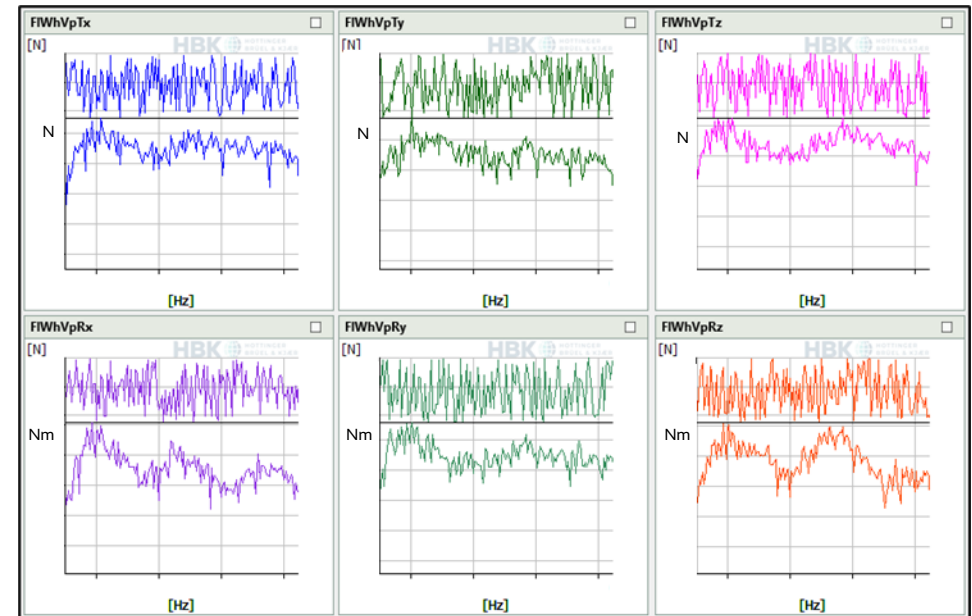
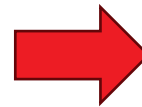
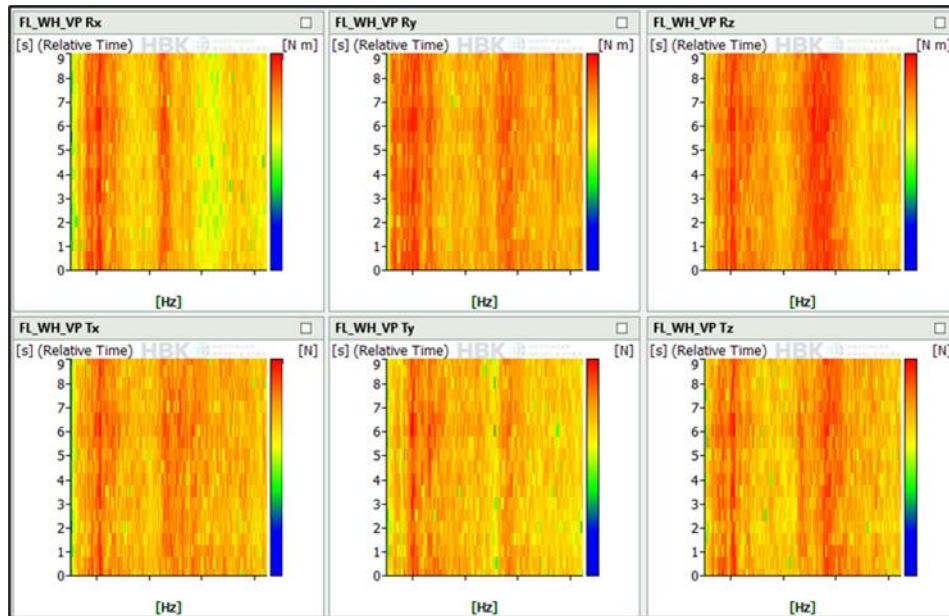


DATA INPUT - FORCE:

COMPONENT TPA WITH SIMULATED STIFFNESS INJECTION AT LOWER ARM MOUNT

LH Front Hub Blocked Force Data

- Supplied at 60kmh and 120kmh for a 10 second period as an FFT vs time data set
 - Rough road surface, stochastic in nature – so linear average obtained for all time blocks to yield an equivalent single complex function for each of the 6 DOFs: X, Y, Z, RX, RY, RZ, for the LH front hub



DATA INPUT – COUPLED FRFS:

COMPONENT TPA WITH SIMULATED STIFFNESS INJECTION AT A-BUSH

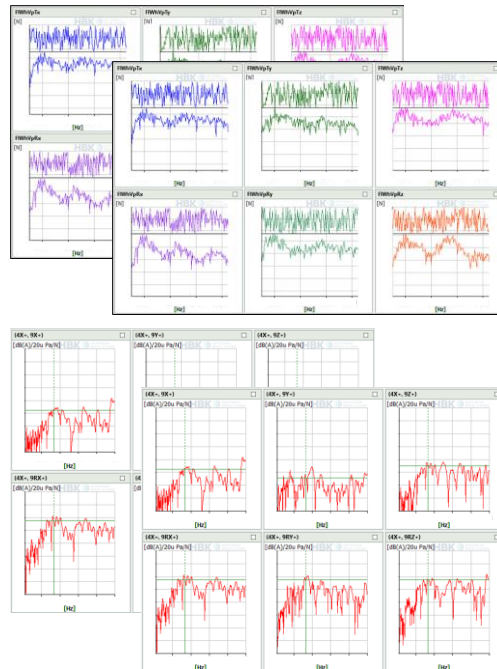
Transfer Function Data

Assembled transfer function matrix, two cases:

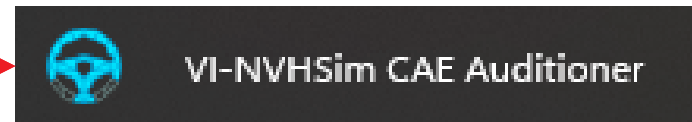
- Baseline
- Stiffer mounts, bushing #2

60 & 120kph
Hub Forces

Baseline
& Stiffer
FRFs

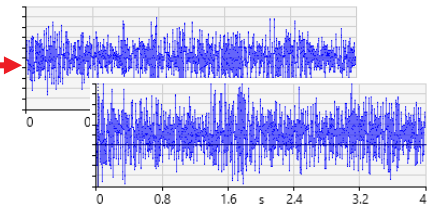


Contributions 'Auralised'

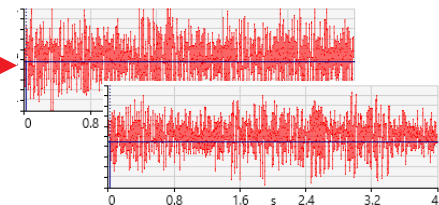


Time Domain Contributions

Noise



Seatrail Vib'n.



VIBRATION CHANNEL MAPPING:

AVAILABLE OUTPUT CHANNELS TO NVH COMPACT DEGREES OF FREEDOM

Available response channels mapped to the compact NVH Simulator vibration channels in the following manner:

Floor Vibration

- Seat Rail response vibrations were applied directly at the floor points:
 - Seat rail Y  **Compact NVH, Floor Y**
 - Seat rail Z  **Compact NVH, Floor Z**

Steering Vibration

- To add contextual steering wheel vibrations, a set of blocked force transfer functions were obtained from measurements on another (similar) vehicle. These are played at a reduced level so as not to cloud the perception of the simulated seat and floor vibration (or may be switched off in the simulation if desired).
 - Steering Wheel Y (surrogate TF)  **Compact NVH, Steering Y**
 - Steering Wheel Z (surrogate TF)  **Compact NVH, Steering Z**

TRANSMISSIBILITY MATRIX

APPLICATION OF MATRIX

The Compact NVH requires vibration produced at the seat to driver **interface**, rather than the seat-rail

Solution:

Transmissibility matrix $[\hat{T}_{ir,k}]$ calculated from operational data (surrogate vehicle data)

- We may then apply $[\hat{T}_{ir,k}]$ to estimate the contact point responses

Contact Point Output :

$$\{\hat{G}_r\} = [\hat{T}_{ir,k}] \{G_i\}$$

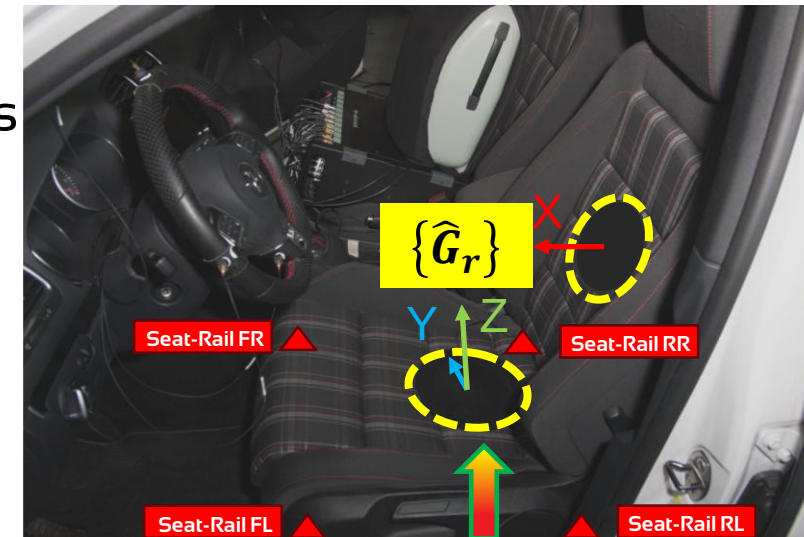
Seat rail mounting indicators
- Input from TPA

So that we have **Seat Tactile Response** response vibration at:

Compact NVH Seat Back X

Compact NVH Seat Base Y

Compact NVH Seat Base Z

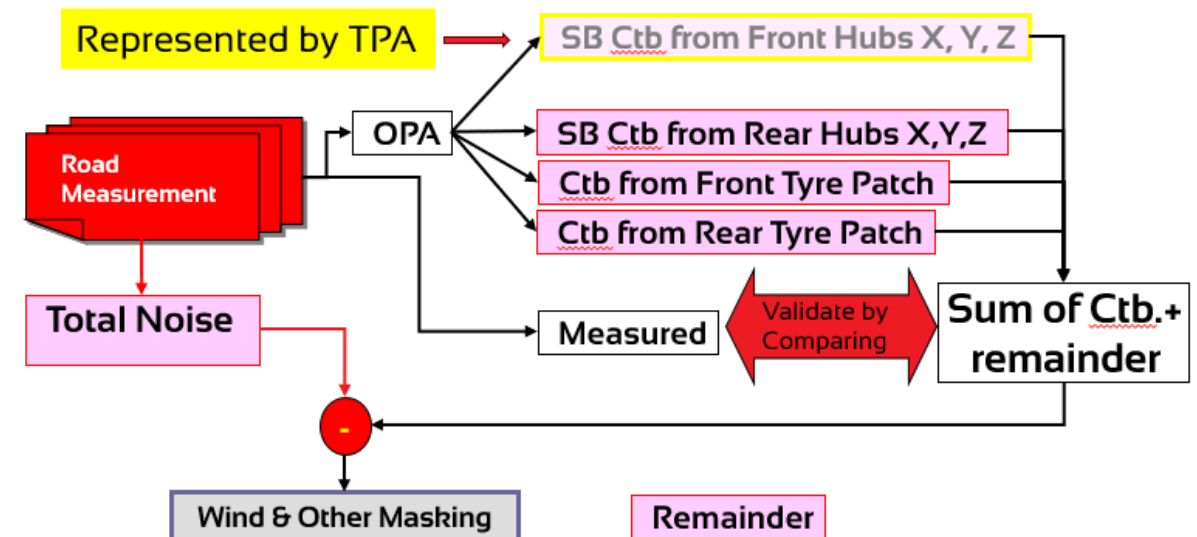
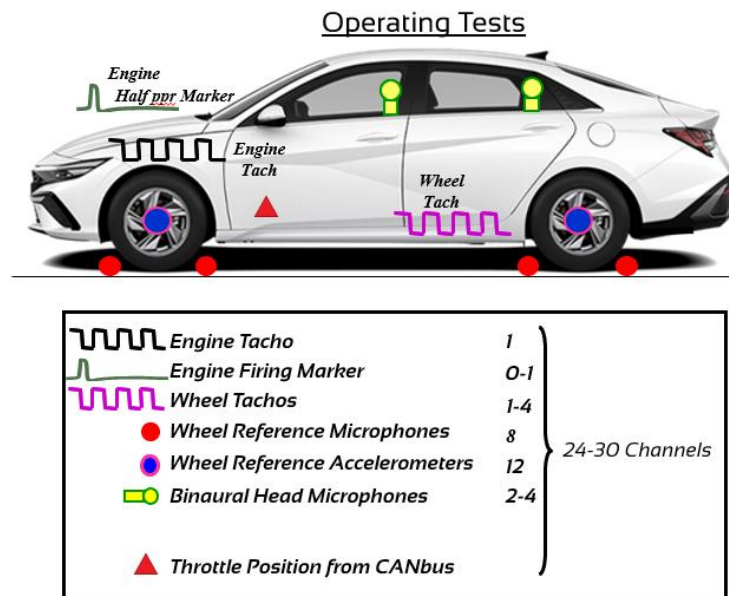


T-Matrix from operational data

ADDITIONAL HIGH FREQUENCY NOISE

SURROGATE VEHICLE DATA

- The Component TPA process provided data up to 1kHz, for the **LH front hub SB inputs**.
 - Vibration and SB Noise for Compact NVH from front hubs (est. as LH Hub+3dB)
- Additional contextual sound required for Compact NVH*
 - SB Noise from rear hubs*
 - Airborne and wind noise components*
 - Data obtained from Operational Path Analysis (transmissibility approach) of surrogate vehicle:*



EXPERIENCE NOISE & VIBRATION IN A MULTI-ATTRIBUTE SIMULATOR

DEMO ON COMPACT NVH SIMULATOR

60 & 120 kmh, driving on rough road:

- 1. Baseline Condition***
- 2. Stiffer Bush 2***