EXPERIENCING NOISE AND VIBRATION FROM CAE SIMULATIONS IN AN INTERACTIVE MULTI-ATTRIBUTE DRIVING SIMULATOR

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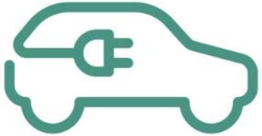
VI-grade

Current NVH Challenges

- Electric Vehicles

- Hybrid Vehicles



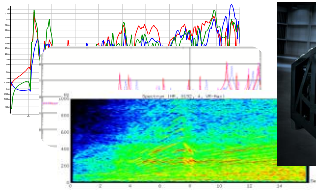
- Autonomous Vehicles

- Lightweighting

- Development Time/Cost

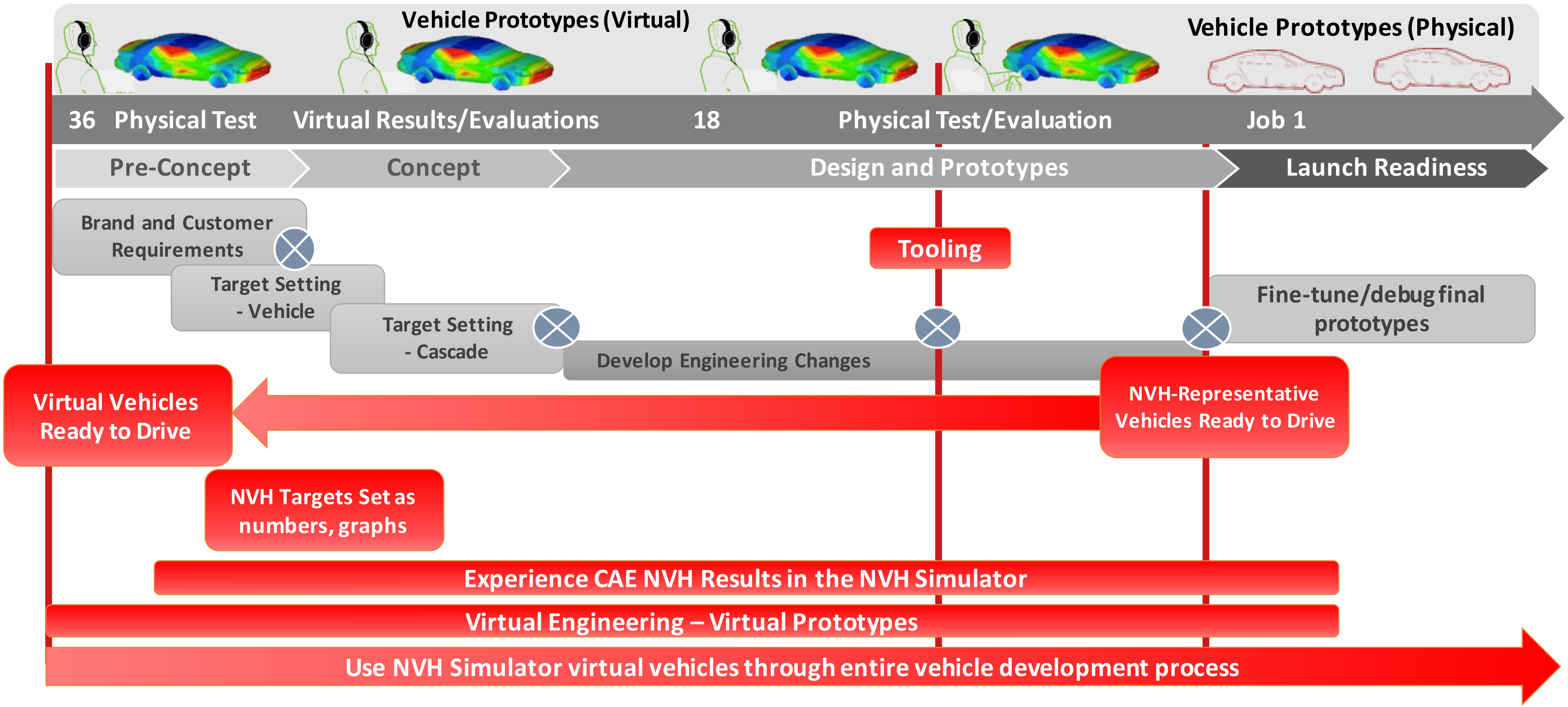
- Increased reliance on simulation
  - Early feasibility studies that decide future development path

- Facilitate development decisions via subjective experience of simulated vibration + sound
  - NVH Compact Simulators provide immersive vibro-acoustic environment.

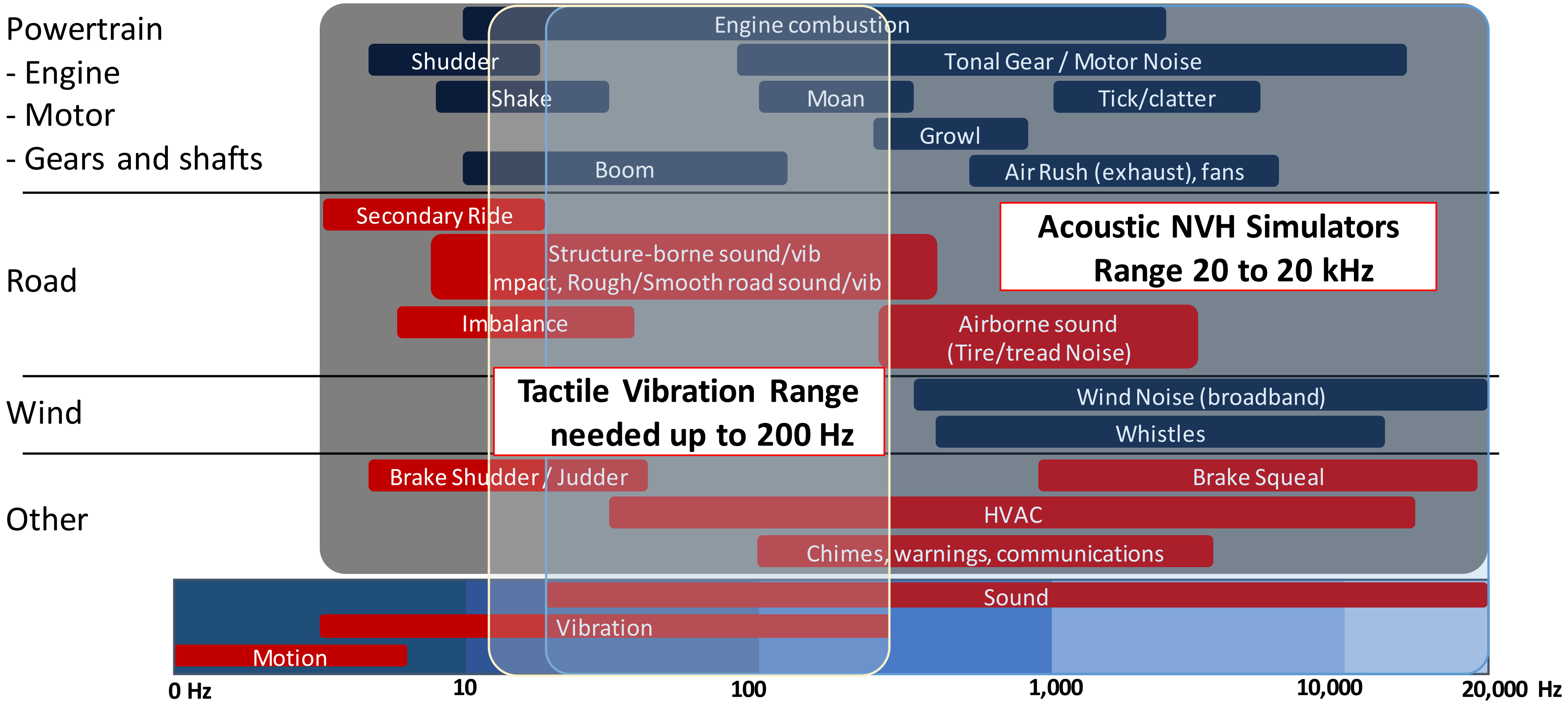


"Does it sound good?"
"Is it better than ______?"
"What does it sound like?"

Virtual Prototype Approach

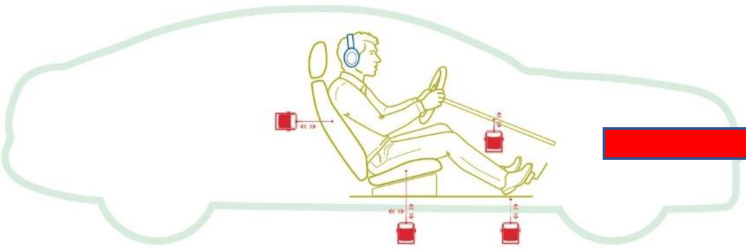


Multi-Sensory Simulator Vibration Operating Range Need



Multi-Sensory NVH Simulator

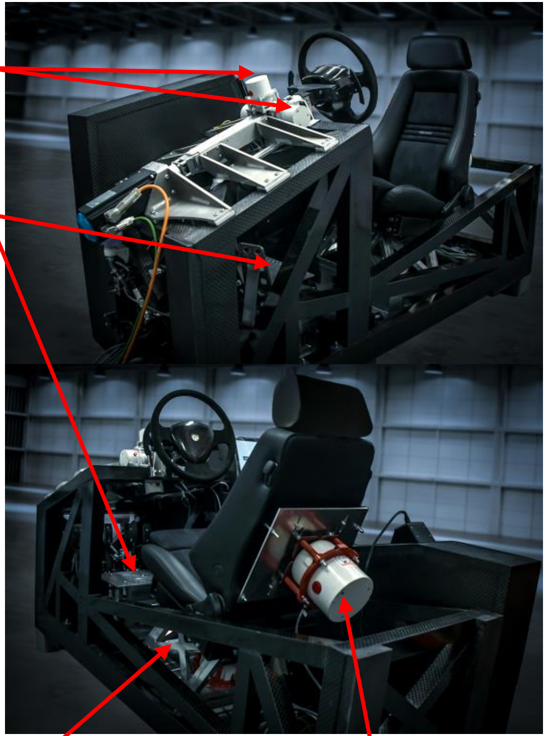
- A Multi-sensory driver-in-the-loop NVH Compact Simulator utilized
- Provides immersive Sound, Vibration, Visuals
- Multi-DOF, calibrated / synchronized sound and vibration at primary driver touch points
  - Stereo Sound
  - Heel, Seat Pad, Seat Back, Steering Vibration



Acoustic Playback

Vertical / Lateral Steering Shakers

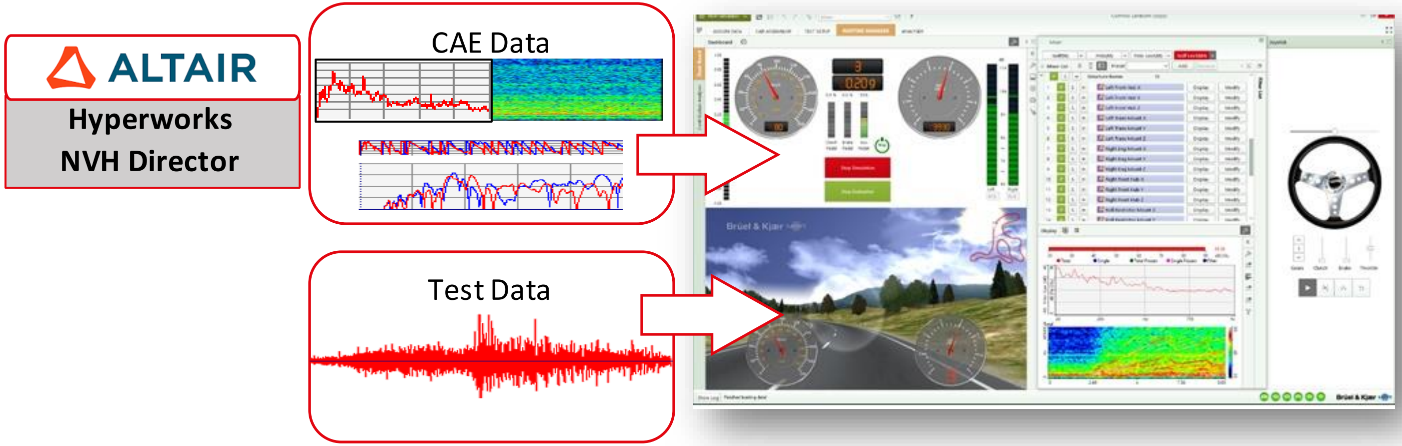
Vertical / Lateral Heel Point Shakers

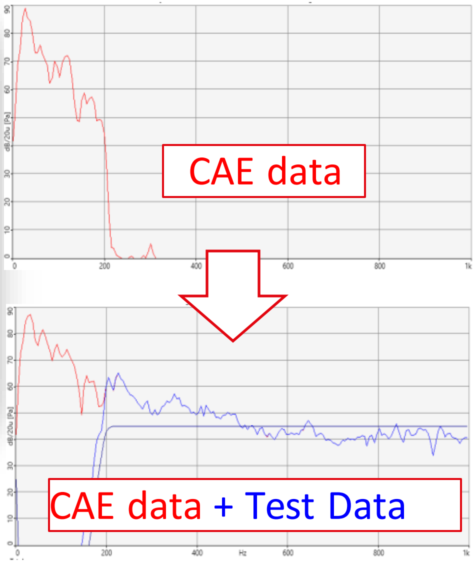


Vertical / Lateral Seat Pad Shakers

Longitudinal Seat Back Shaker

Hybrid Model Building w/ NVH Simulator



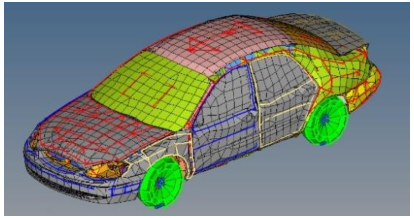


NVH Simulator

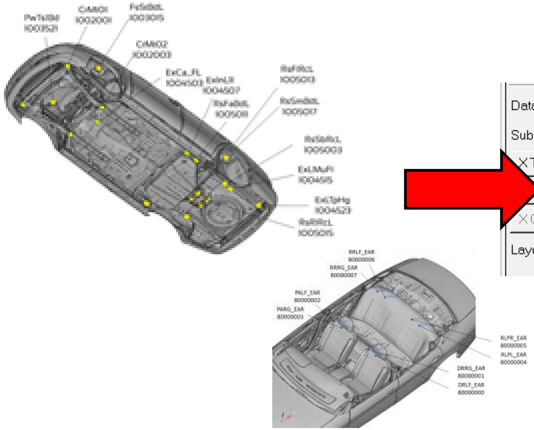
- Test + CAE hybrid model creation
- CAE data exported from NVH Director
    - Convert CAE data from native *.pch frequency-based format into timed-based observable sound / vibration
- Test-based data from vehicle analog for high frequency acoustic content

Finite Element Road Noise Model

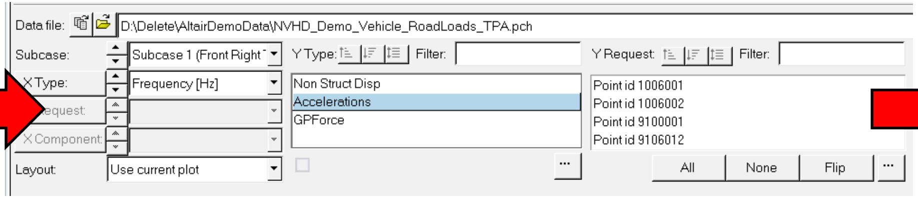
- CAE Model: Finite element full vehicle model with acoustic cavity
- Excitation: 4 Subcases: Road profile PSD displacement at each tire patch
- Operating Scenario: Coarse chipseal road surface at 70 km/h
- Results: Spectral domain source strengths / attachment point FRFs
- PCH format exported by Altair NVH Director



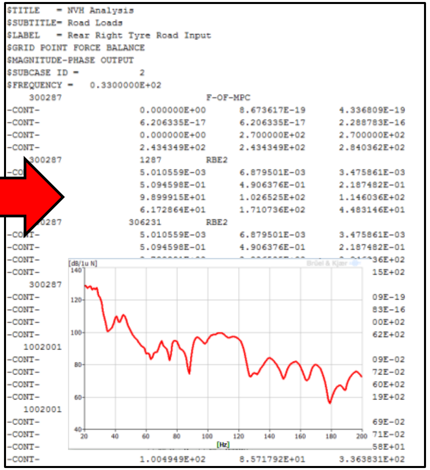
Input / Response Locations



NVH Director Export



*.pch File Output

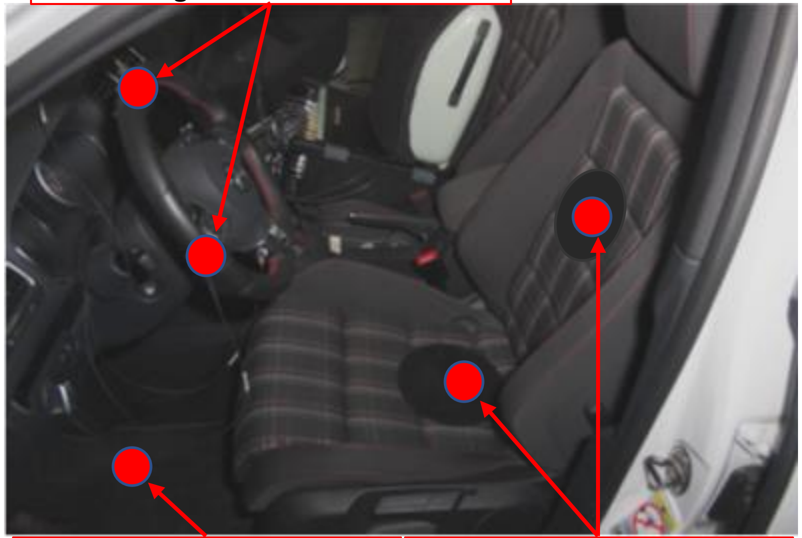


Physical Vehicle Data: Analog for High Frequency

- 19 channels of acoustic and vibration data measured on an analog vehicle
- Data will be used to fill the missing full vehicle performance gaps not calculated from CAE
  - Engine order vibro-acoustic content and high frequency road input vibro-acoustic content

Binaural Acoustics

Steering Triaxial Acceleration



Heel Point Triaxial Acceleration

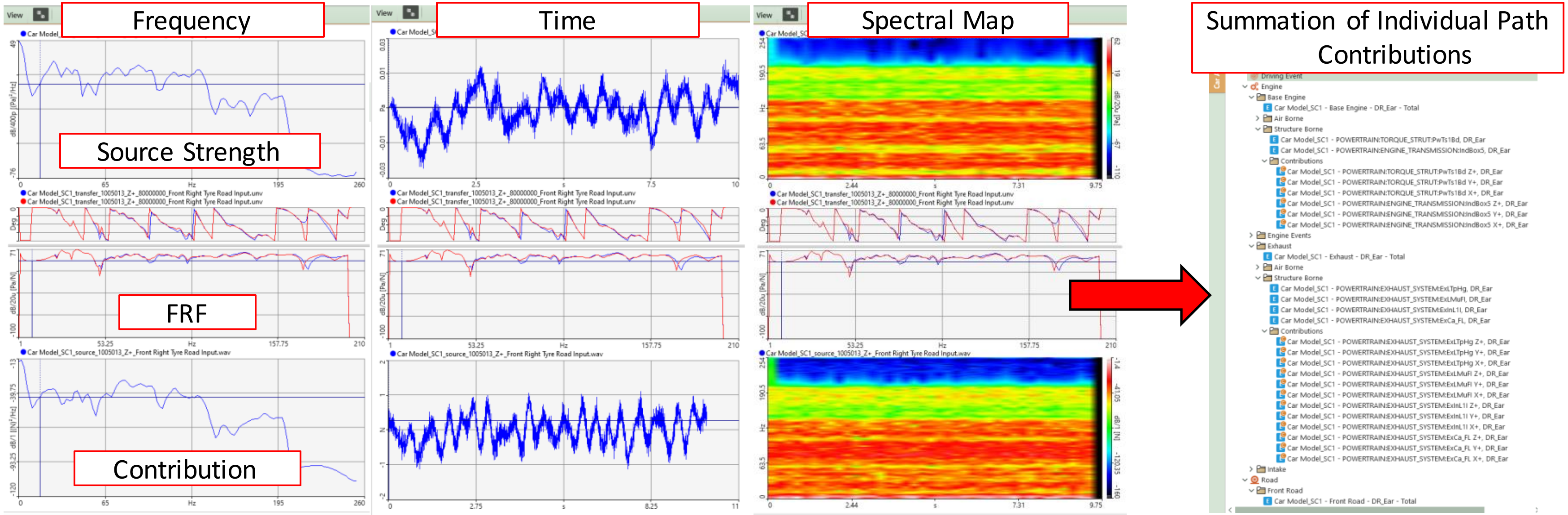
Seat Pad / Back Triaxial Acceleration

Engine Rotational Speed

Wheel Speed / Vehicle Speed

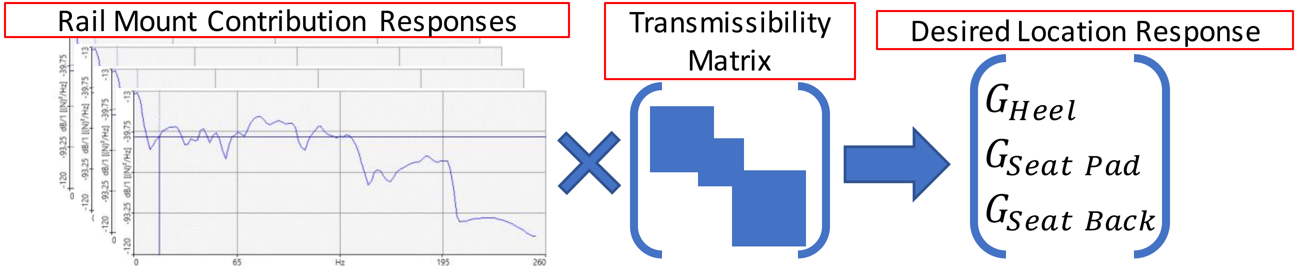
Model Building Method: Input Path Contributions

- Frequency-based component path contributions calculated.
  - Corresponding input force x transfer path products performed
- Path contributions converted to time domain
  - Frequency spectrum used as FIR filters on specific white noise “seed” data



Model Building Method: Seat / Heel Response

- Exported FRF data from FEA model wasn't ideal. Limited to acoustic, steering and seat rail mounting point responses
- Derived heel point, seat pad and seat back responses by utilizing a seat rail to seat pad / floor transmissibility matrix



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

$\{G_r\}$ = estimated vector of responses measured at the receiver positions $r = 1..R$

$\{G_i\}$ = a vector of responses measured at indicator positions $i = 1..I$

$$[\hat{T}_{ir,k}] = [C_{ir}][C_{ii}]^{-1}$$

$[\hat{T}_{ir,k}]$ = a *Transmissibility Matrix* between indicators and receivers from input force at *k*

$[C_{ir}]$ and $[C_{ii}]$ = cross-spectra matrices between receivers / indicators and indicators respectively

- Transmissibility matrix was estimated from operating measurements of a reference vehicle

Model Building Method: Transmissibility Matrix Testing

- On-road operating acceleration measurements made in reference vehicle.
- Seat pad / back acceleration measured using triaxial seat pad accelerometers
  - Redundant seat points measured to ensure robust matrix inversion
- Heel point acceleration measured using floormat fit with triaxial accelerometer
- Front / rear seat rail mount point acceleration measured with triaxial accelerometers

Redundant Vibration Receiver Points

Rear Seat Rail Indicator Points

Rear Seat Rail Indicator Points

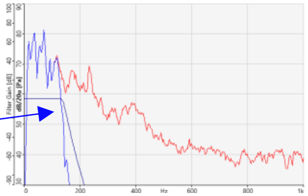
Driver Heel Receiver Point

Model Building Method: Final Model Assembly

- An occupant's mass and seating position will influence a physical seat's vibration response
- Transmissibility will change based on the occupant and seat.
- Two separate models were created for NVH Compact Simulator to provide an opportunity to subjectively evaluate:
  - Perceived seat vibration of 80kg male occupant
  - Perceived seat vibration of 55kg female occupant

CAE Road Input Vibration / Acoustic 10 - 200 Hz

- Rear Road
  - Rear Road - Steering Y
  - Rear Road - Steering Z
  - Rear Road - Driver
  - Male 80kg 70kph
    - Rear Road - Seat Z Calculator
    - Rear Road - Floor Z Calculator
    - Rear Road - Floor Y Calculator
    - Rear Road - Seat X Calculator
    - Rear Road - Seat Y Calculator
  - Female 55kg 70kph
    - Rear Road - Female 55kg 70kph - Seat Y Calculator
    - Rear Road - Female 55kg 70kph - Seat X Calculator
    - Rear Road - Female 55kg 70kph - Seat Z Calculator
    - Rear Road - Female 55kg 70kph - Floor Y Calculator
    - Rear Road - Female 55kg 70kph - Floor Z Calculator



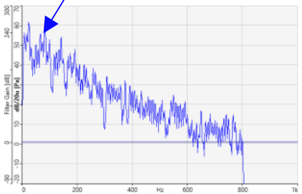
Reference Vehicle Road / Wind Input Acoustic 200 Hz – 20kHz

- Road
  - Golf 7 - Acoustic - Coarse Road + Wind

NVH Compact Simulator Model

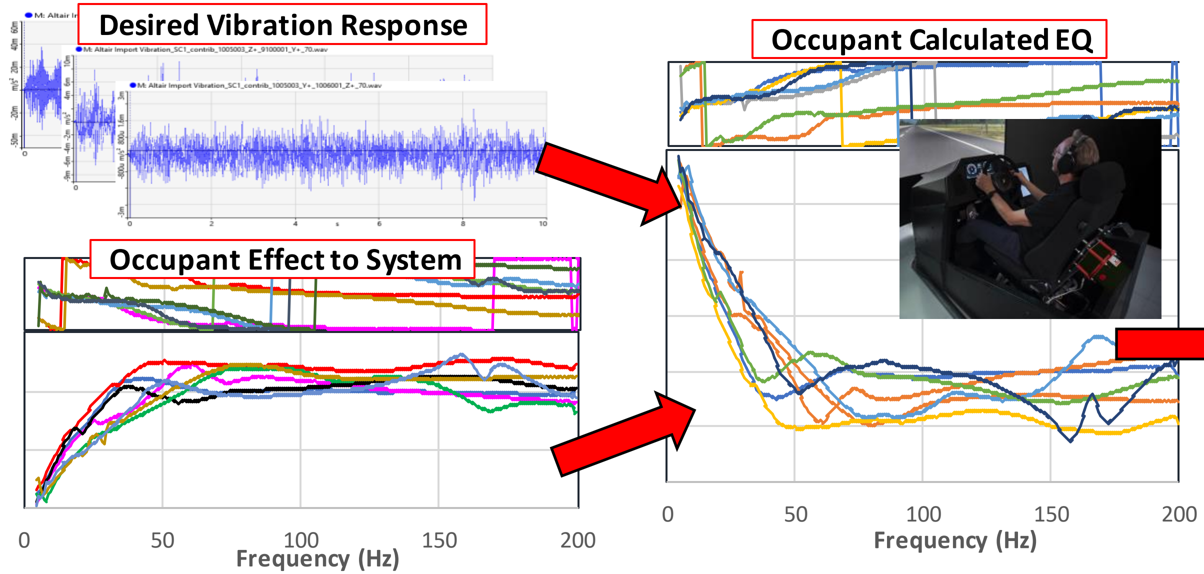
Engine Order Input Vibration 10 - 200 Hz Acoustic 0 - 20 kHz

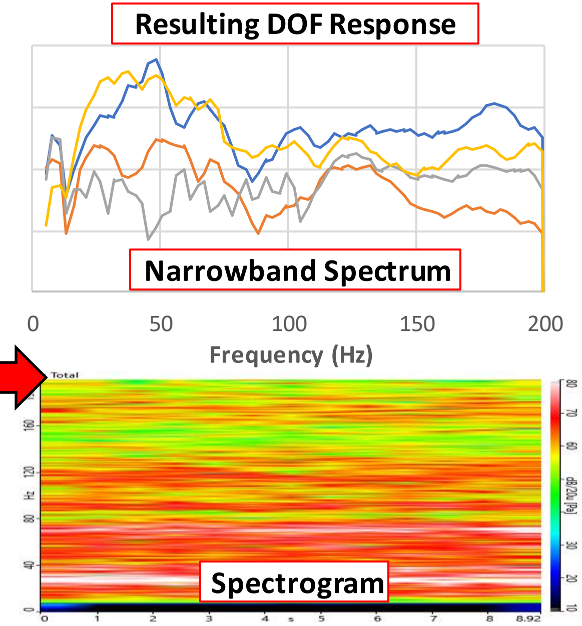
- Engine
  - Golf 7 - Engine - Driver
  - Golf 7 - Engine - Floor Y
  - Golf 7 - Engine - Floor Z
  - Golf 7 - Engine - Seatback X
  - Golf 7 - Engine - SeatBase Y
  - Golf 7 - Engine - SeatBase Z
  - Golf 7 - Engine - Steering Y
  - Golf 7 - Engine - Steering Z
  - Golf 7 - Engine Masking - Driver



Model Calibration: Operator EQ Application

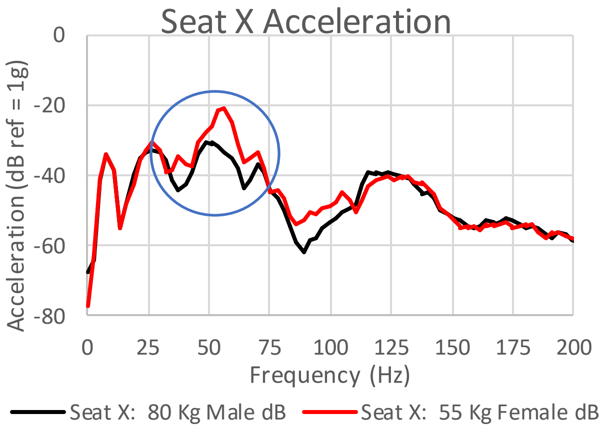
- Excitation degrees of freedom are filtered through customized EQ curves measured with occupant included in the system
- Essentially removes effect of occupant's influence on the desired vibration input to the system
- Unique EQ for each input degree of freedom

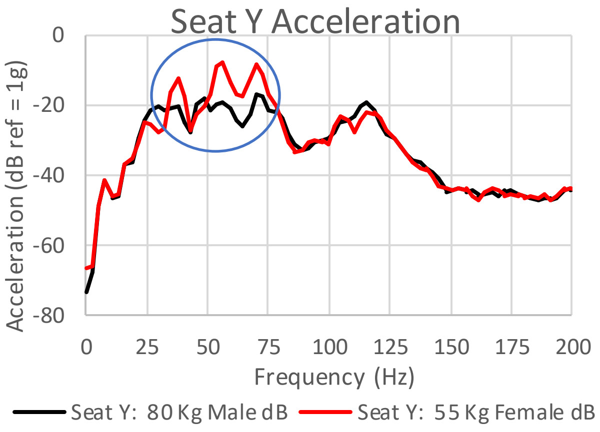


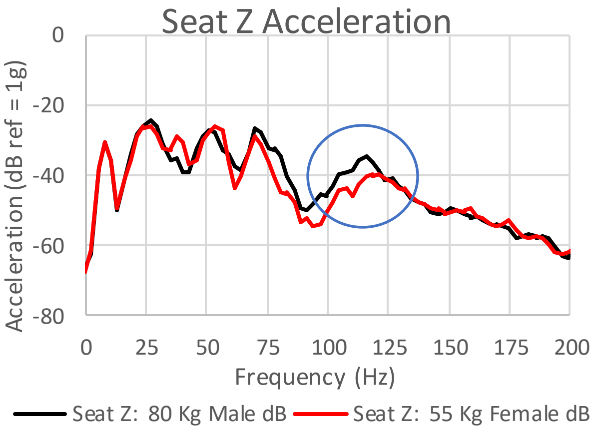


Results: Occupant Comparison

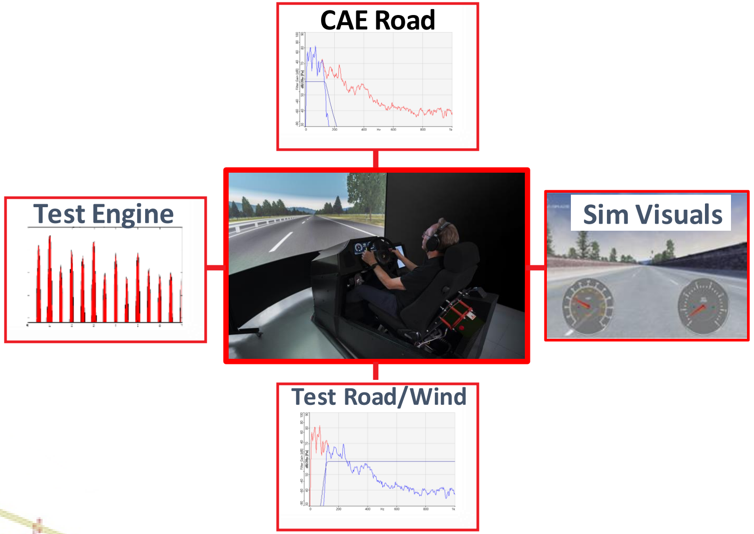
- Evaluated assembled hybrid model using multi-sensory NVH simulator by several operators.
- Simulated seat acceleration in the X and Y directions for a 55 kg occupant ≈ 10 dB higher than the 80 kg occupant.
- Simulated seat acceleration in the Z direction ≈ 10 dB higher for 80 kg occupant.
- Overall subjective perception change of combined seat vibration noticeable for all operators.







Benefits of Method



Multi-Attribute NVH Simulator

- Avenue to evaluate CAE simulation in context of total vibro-acoustic spectrum of a full vehicle

Seat-Rail x Seat Pad Transmissibility Transformation

- Operator has opportunity to experience vibro-acoustic perception of different sized occupants

- Evaluate performance of different seat designs without physically changing the simulator’s seat.
  - Seat / occupant effect modular to any model

Conclusions / Next Steps:

CONCLUSIONS

- Exported a constant speed road input FEA simulation data using project management tool
- Transmissibility matrices used to create seat vibration responses for two different occupants.
  - Transmissibility linked to seat/occupant system ∴ can be used with any seat rail vibration.
- Created hybrid NVH Simulator model with acoustic and tactile vibration components
  - < 200 Hz using CAE data, > 200 Hz using measured reference vehicle test data
- Evaluated model using Compact NVH Simulator in a constant speed scenario
  - Unique opportunity to subjectively compare vibration performance for different occupants

NEXT STEPS

- Expand model to include several constant speed cases to create drivable model.

Acknowledgements / Contact Information

Support from:

- Frank Syred - HBK
- Mark Allman-Ward - VI-grade
- Kelby Weilnau - VI-grade

Thank you for your attention:

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