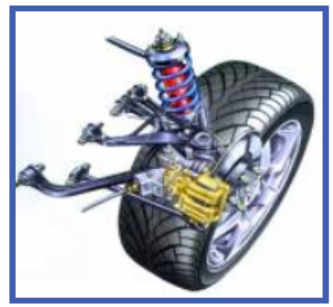
Bruel & Kjaer
Sound Engineering

The goal of Sound Engineering is to efficiently translate the subjective opinions of the customer into vibro-acoustic design targets for the components

"Voice of the customer"

Vehicle-Level Sound & Vibration

Subsystem/Component Targets & Designs



Contents

- Sound Engineering Introduction
- Automotive Sound Quality
- Source-Path-Contribution (SPC)
  - Interactive Tour http://www.bksv.com/flash/spc/index.htm
- NVH Vehicle Simulator
  - Video available on request
- Conclusions

Introduction: Start of a new vehicle programme

- Definition of programme objectives
  - Target customers
    - » Job, age, income,…
  - Attribute placement (competitive or best in class?)
    - » Attribute can be Noise Vibration Harshness (NVH), safety, handling, etc
  - Brand/model identity
  - Competitor set
  - Target deck
    - » a very large document. For many attributes, including NVH, there can be over 500 targets

- NVH is a difficult vehicle attribute to tackle
  - ”NVH adds weight, delays and cost!”

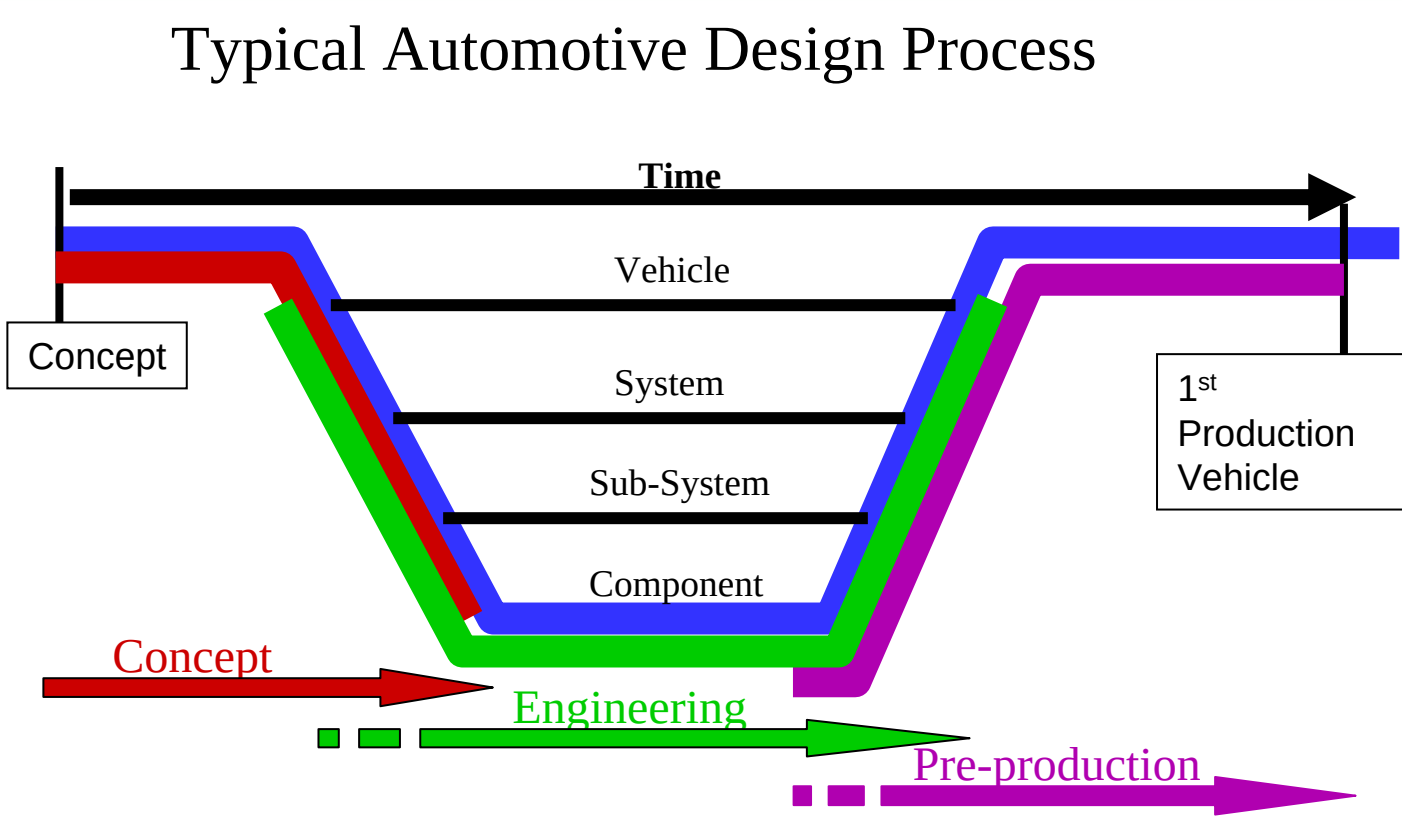
NVH processes in the automotive design process

Benchmarking

Target Setting

SPR Modelling / Simulation

Troubleshooting



SPR = Source Path Receiver

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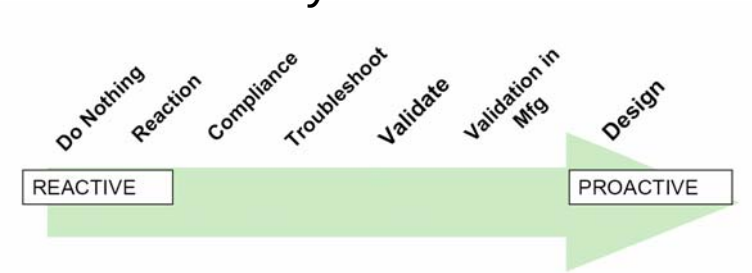
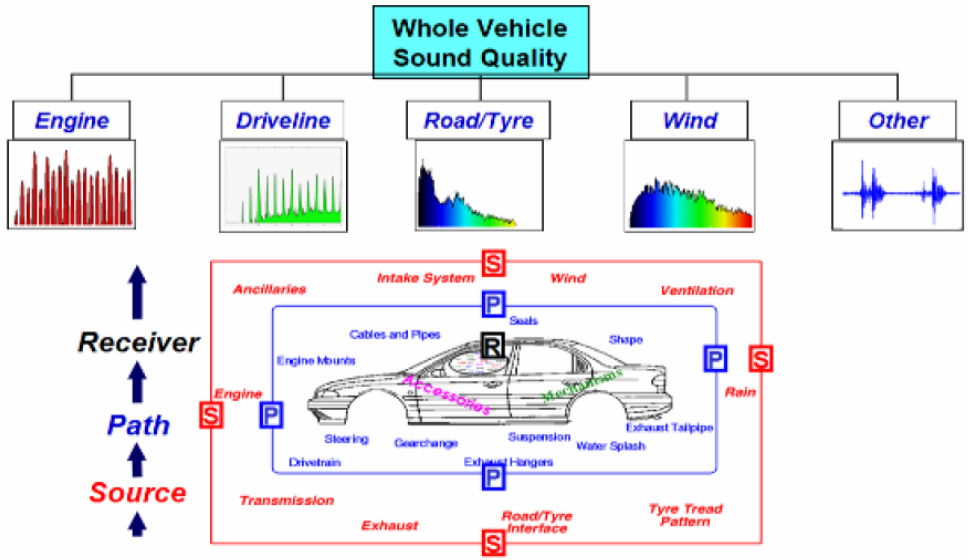
Sound Engineering: Introduction

- NVH Maturity model



- Automotive Sound Quality
- Source Path Contribution
- NVH Vehicle Simulator



- For use in:
  - Target Setting
  - Trouble-shooting
  - Benchmarking
  - Subjective evaluation

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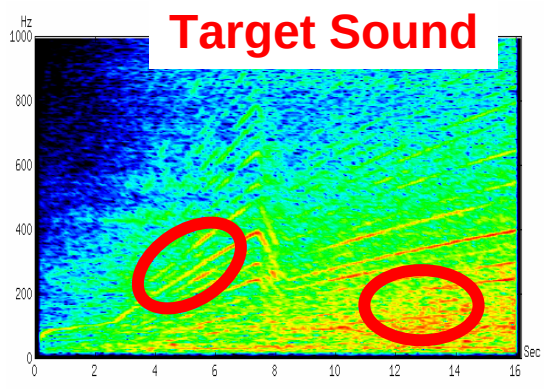
NVH Targets and Sound Engineering

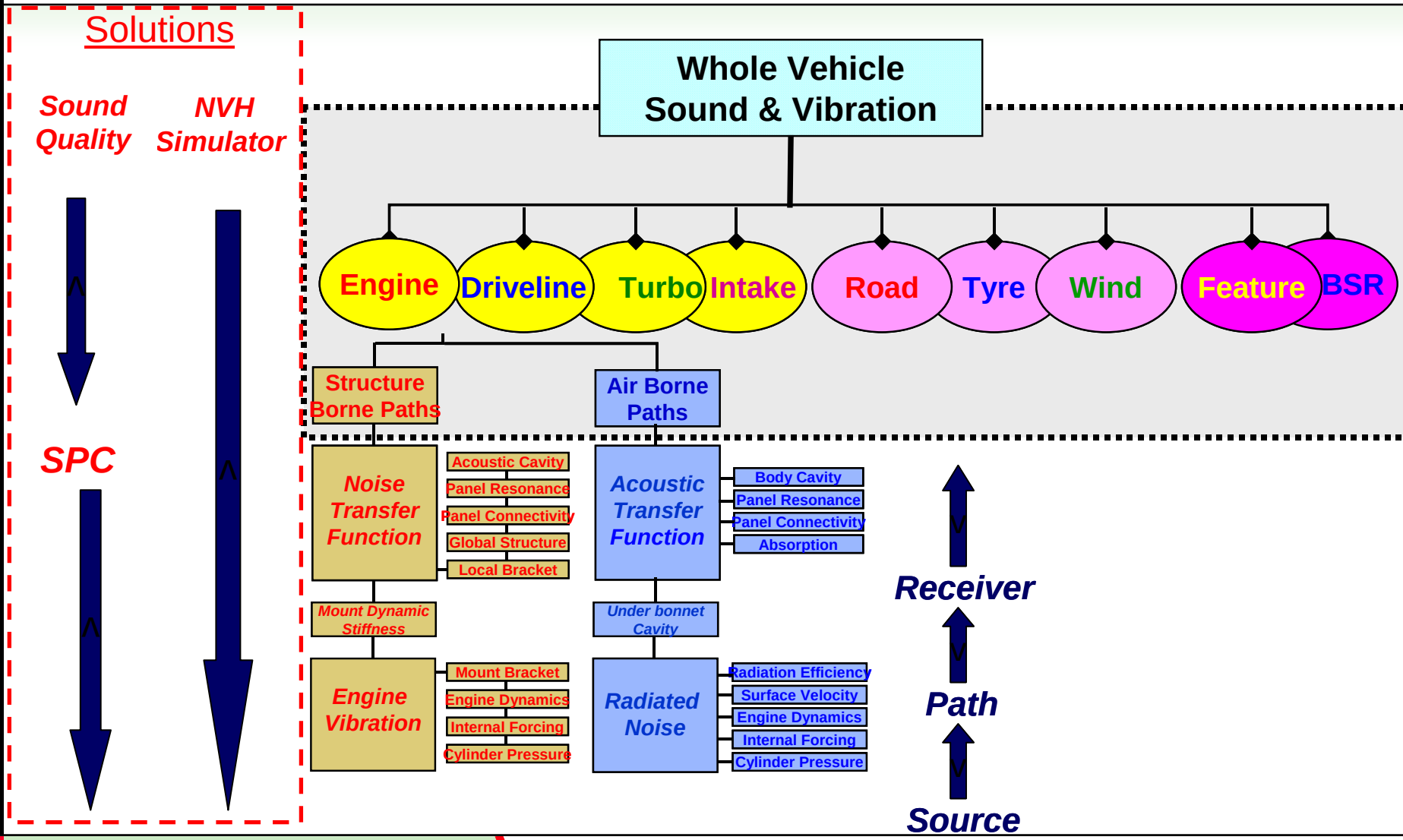
- There are different classes of NVH targets and concerns
  - Detectability
    - » Gear Tonal Noise
    - » Squeak and Rattle
  - Comfort / Tactile
    - » Shift-Feel
    - » Seat/Steering Wheel Vibration
    - » Passenger Shock & Vibration
  - Brand Image
    - » Engine Sound (Powerful, Refined, etc.)
  - Failure Related
    - » Electronics
    - » Critical Speed Avoidance
  - Regulatory
    - » Pass-by
- NVH has to be balanced with other attributes

POWERFUL *Elegant*

Sporty Refined



Sound Engineering Solutions



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Sound Engineering solutions

- Automotive Sound Quality
  - Basic sound decomposition, editing, filtering
  - Identify important sound charactersistics
- Jury Evaluation
  - Subjective sound quality jury evaluation
  - Statistical correlation of subjective preference to objective metrics
- Source Path Contribution (SPC)
  - Troubleshooting using source-path-receiver model
  - Benchmarking on source, path or receiver levels
  - Target cascade from vehicle (receiver) level to source and path level
  - Design and simulation of vehicle sound through source and path manipulation
- NVH Vehicle Simulator
  - Drive the design (full driving envelope)
  - Subjective evaluation of design before protoypes available
  - Subjective /objective correlation in the right context

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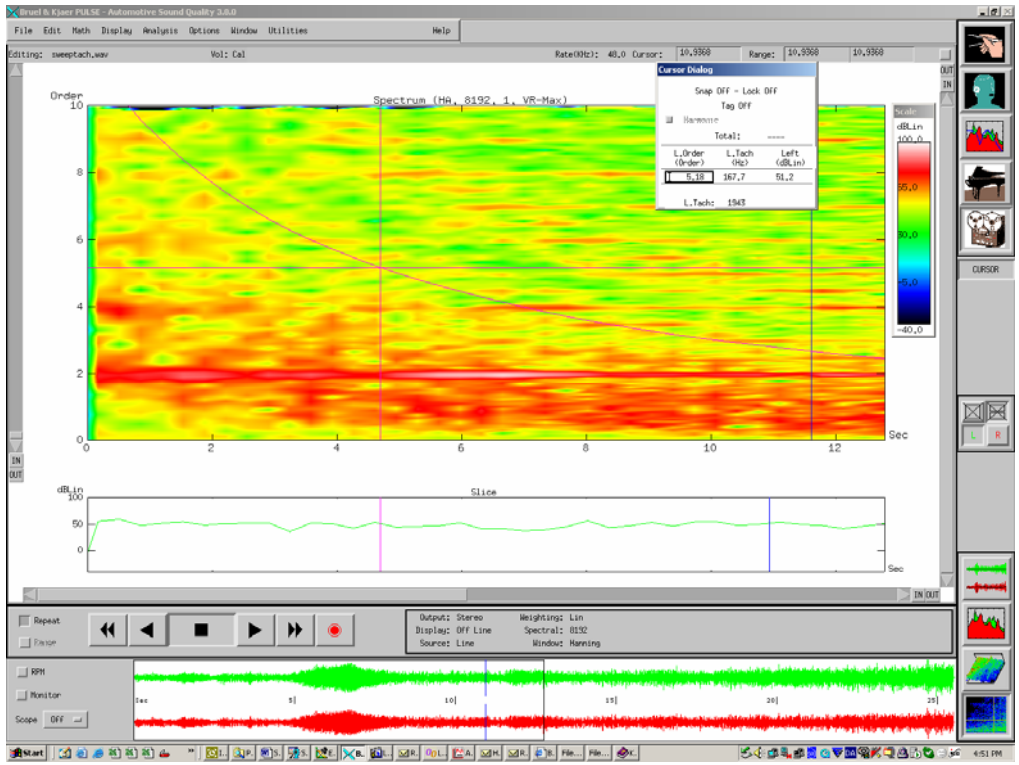
Automotive Sound Quality

- Well accepted by automotive industry
- Five complementary Sound Quality modules for
  - recording
  - analysing
  - auditioning
  - dissecting and synthesising sounds

Enables objective and achievable quality targets for products to be set in engineering terms.



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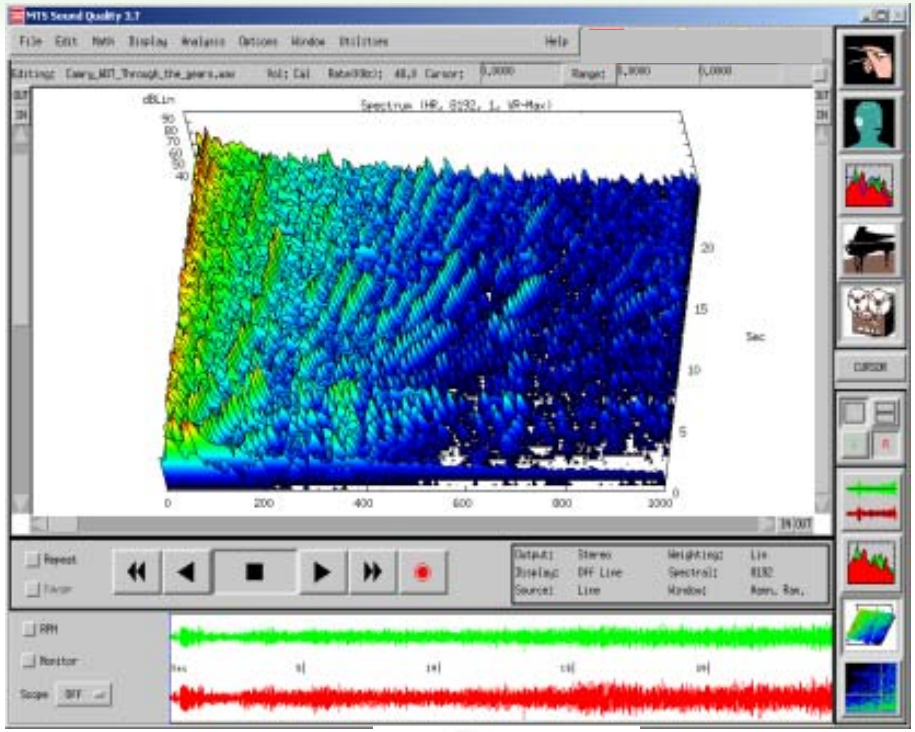
Automotive Sound Quality

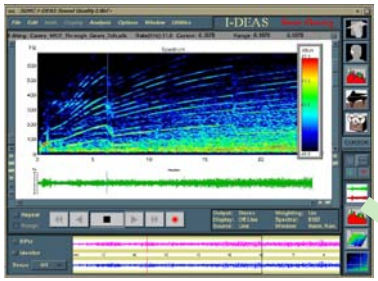
- Sound Recording & Editing
- Decomposition
- Synthesis
- Filtering
  - IIR & FIR
  - Real-Time Steady-State & Order Tracked
- Real-Time Displays
  - What You See = What You Hear
- Metric Calculations
  - Psychoacoustic
  - Environmental
- Compatible with all Binaural Recording Systems



Automotive Sound Quality – Jury Evaluation

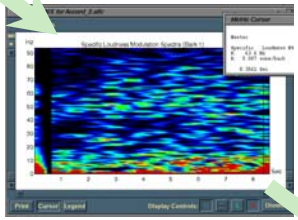
- Metric calculations enumerate the characteristic components of a sound.
- Metrics cannot describe the importance of the sound characteristics to human perception.

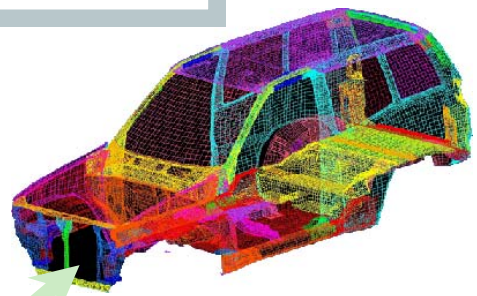
Jury Evaluation links Metric Values and customer opinions to provide NVH design targets



Sound Quality Evaluation Software

Metric Calculation





Design Targets

Jury Evaluation

Customer Expectation

Automotive Sound Quality – Jury Evaluation

- Integrated with Sound Quality
- Calibrated & Equalized Sound Replay
- Paired Comparison & Semantic Differential Methods
- Single Juror or Simultaneous Multi-Juror Testing
- Integrated with Microsoft Office Standard Tools:
  - Microsoft Powerpoint for Presentation
  - Microsoft Access For Data Storage
  - Microsoft Excel For Data Analysis
- Sophisticated Regression Analysis For Paired Comparison

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Key benefits – Automotive Sound Quality

- Rapid comparison of individual or various combinations of sounds.
- Recombination and synthesis of a total vehicle sound from individual components
- Listening to the individual contributions from a noise path analysis
- Synchronisation between sound files can be based on time or rpm.
- Sounds can be grouped into preset files and played individually or simultaneously.
- Multiple sounds of any length can be efficiently processed. The length of files is limited only by space on the hard disk.
- Graphical editing, maths and synthesis functions (mix, fade, envelope, create, draw).
- Flexible and comprehensive cursor functions allow simultaneous display of amplitude, frequency, order, rpm and time information.
- Real-time cursor order and frequency slicing in the associated display.
- Real-time filtering allows up to 128 stereo digital filters to be applied per sound and to modify the filter parameters while the sound is playing.
- Filters can be at nominally fixed frequency or locked to a rotational order.
- In addition to supplying the most commonly used metrics, open architecture features are available to allow the users to develop their own metrics.
- Time domain averaging for extraction of harmonic components from the total sound and editing of the individual harmonics. Harmonics can be separated in groups such as odd, even and half order or automatically removed from the sound source for decomposition.
- Vold-Kalman filtering can be used for high performance tracking of harmonic responses, or orders, of periodic loads in mechanical and acoustical systems.

Sound pressure mapping (approx.3000Hz to 4400Hz)

- 15.5 ~ 18 bark
- 5000 rpm

Loudness mapping (approx.3000Hz to 4400Hz)

- 15.5 ~ 18 bark
- 5000 rpm

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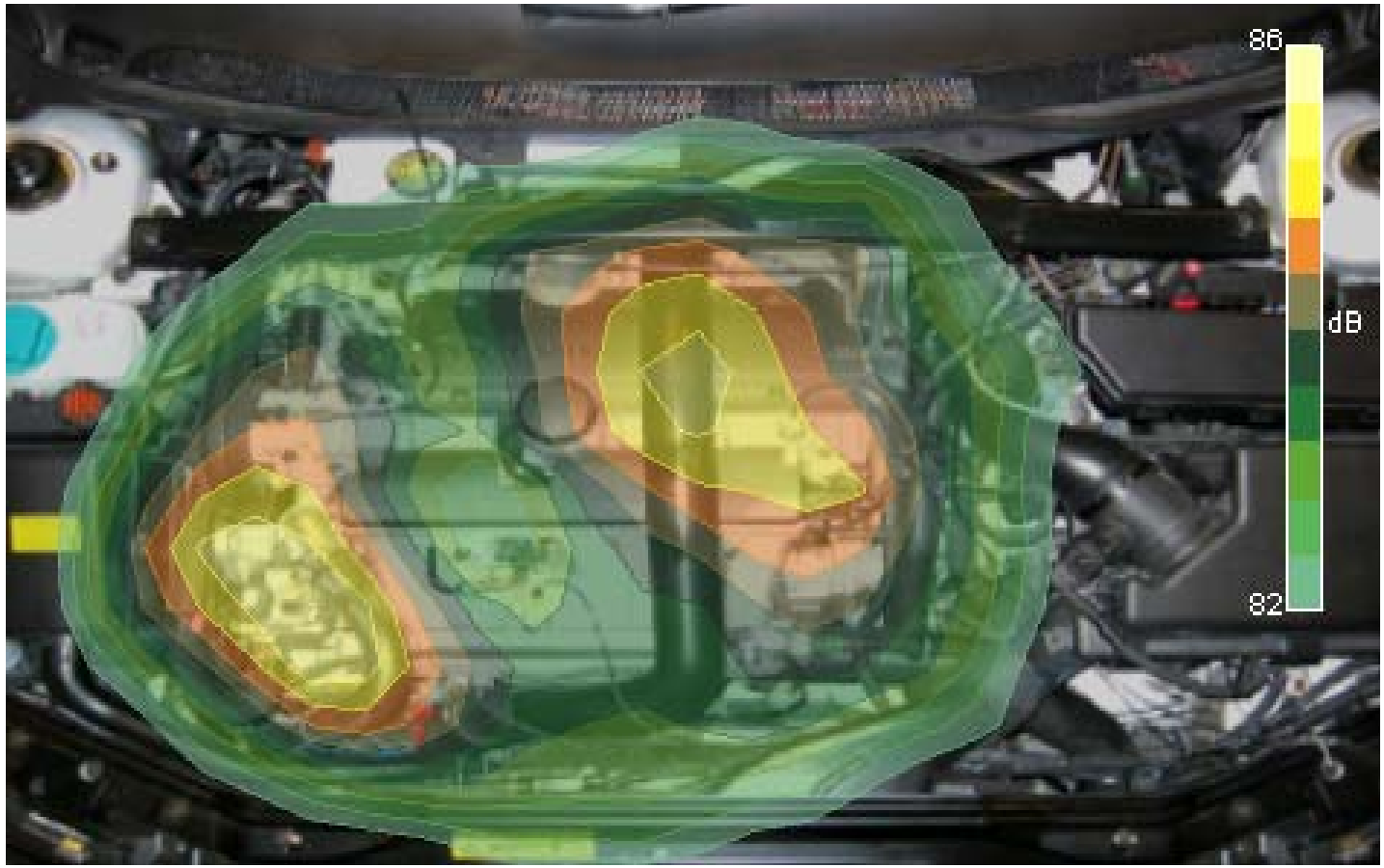
Sound pressure mapping

- 1k ~ 5k Hz
- 5000 rpm



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Sharpness mapping

- 1k ~ 5k Hz
- 5000 rpm

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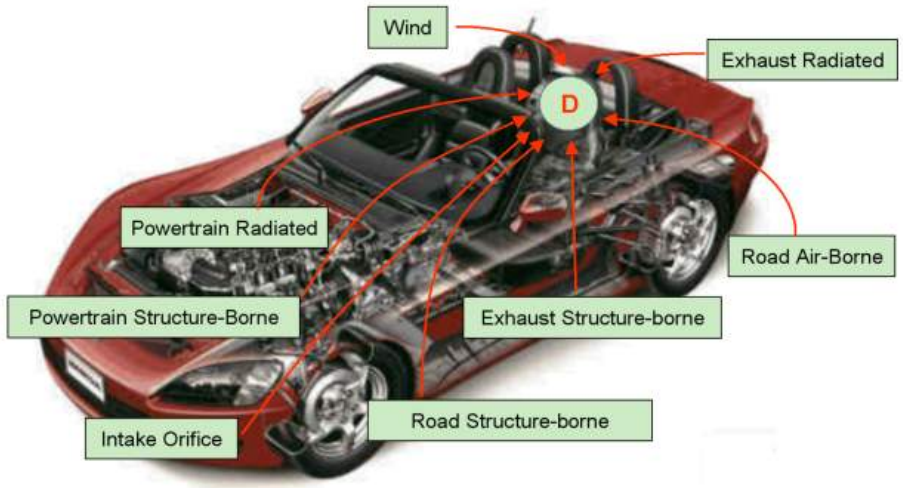

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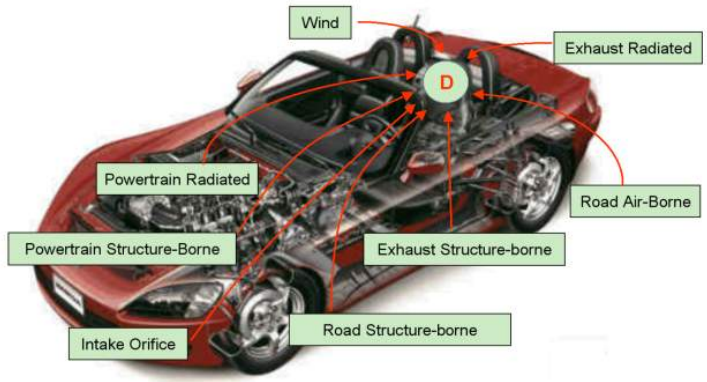
Source Path Contribution (SPC)- Introduction

- SPC method estimates and ranks:
  - noise & vibration contributions between vibration source systems and receiving passive vibro-acoustic systems
- SPC answers:
  - Which inputs are important?
  - Which noise paths are most critical?
  - How do noise paths interact?
  - Is it a system (path) or source problem?
  - How is response affected if this source or path is changed?
- SPC enables at a system and a component level:
  - Target Setting
  - Benchmarking
  - Troubleshooting
  - Response Simulation



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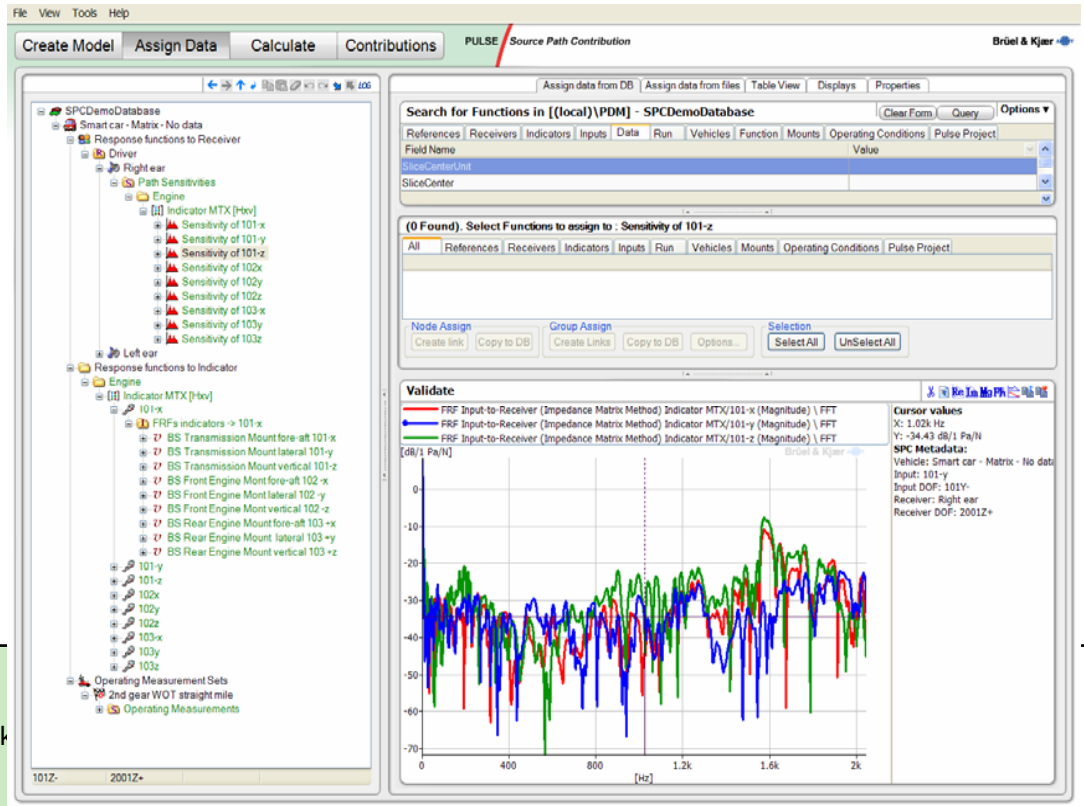
What is Brüel & Kjær SPC?

- Easy, efficient approach to analyzing noise and vibration sources and path contributions:
  - **Create Model, Assign Data, Calculate, Contribution**
- SPC software provides:
  - organization for all data required to perform SPC analysis, (tree model)
  - calculation tools necessary for this process



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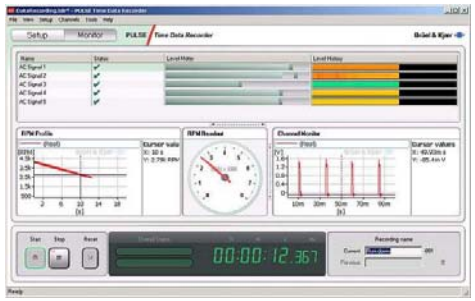
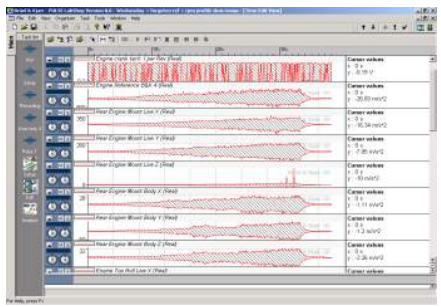
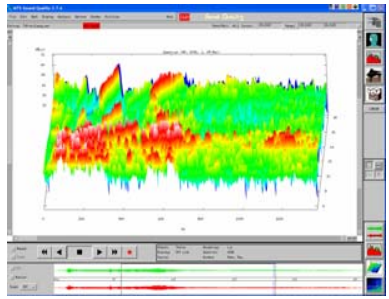
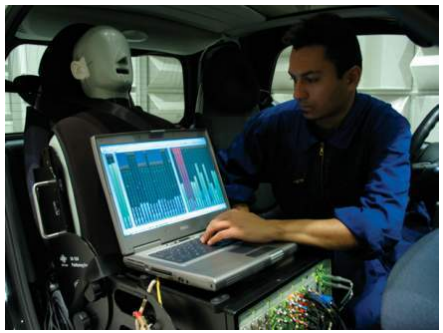
Brüel & Kjær Source Path Contribution

- Most complete solution for source-path-contribution
  - State-of-the-art instrumentation
  - PULSE Dyn-X 160dB Dynamic Range Hardware
  - PULSE data acquisition and analysis software
  - SPC Software
  - NVH Vehicle Simulator
  - Engineering Services





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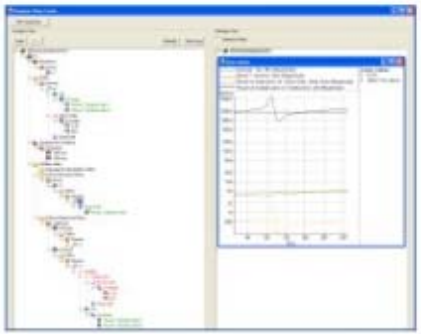
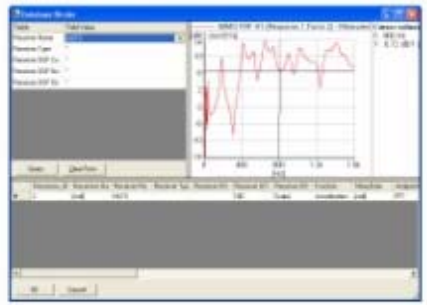
Source Path Contribution framework





Tree Views

(organizes data)

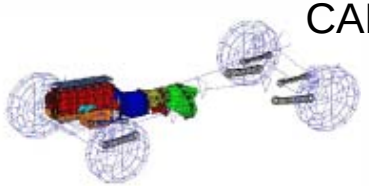
Starts Pulse

Retrieves data for analysis

Files

(optional data storage)

CAE



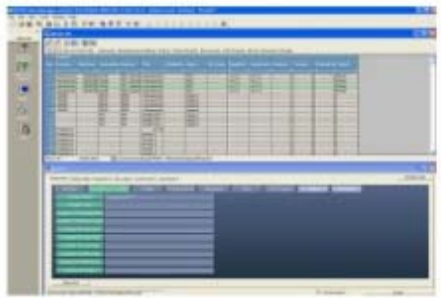
Database

(data storage)

Saves data

Pulse

(Measuring System)



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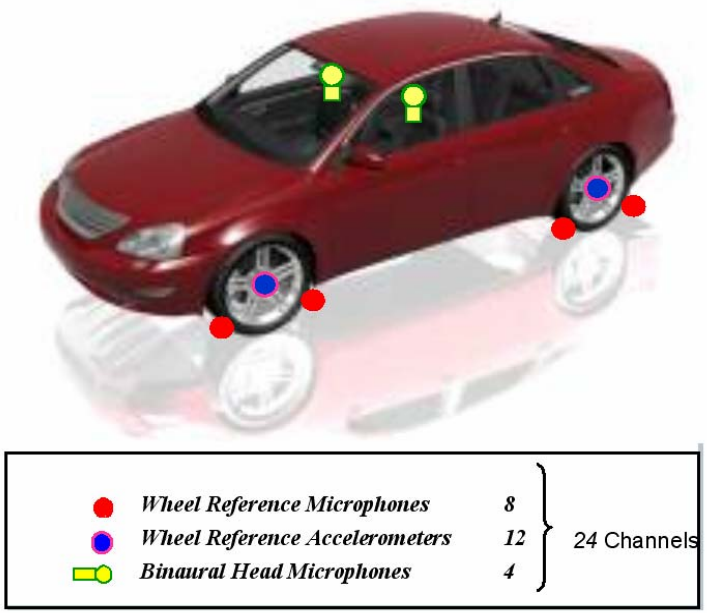
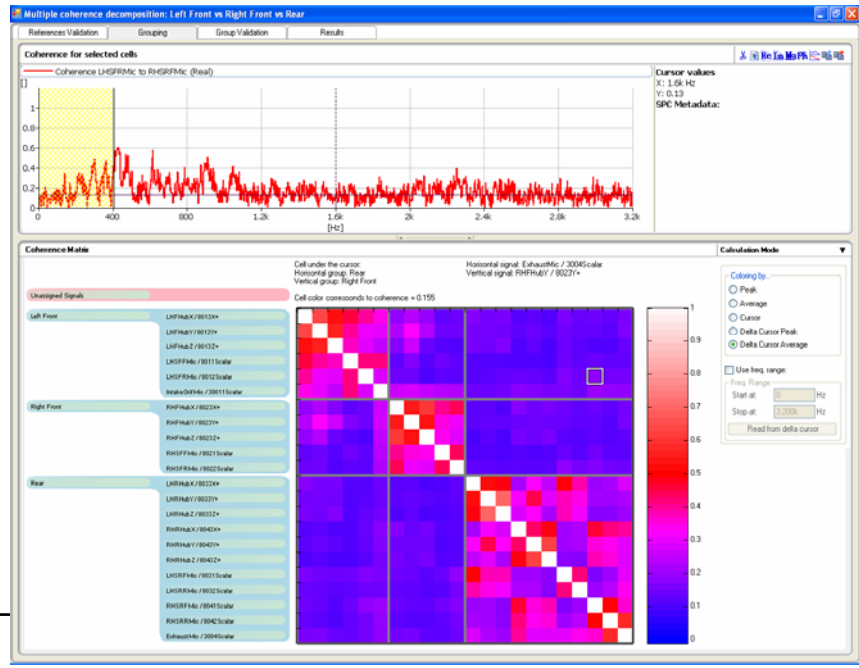
SPC Multiple Input Coherence Analysis (MICA):

- Multiple Input Coherence Analysis (MICA) typically applied to Road Noise Analysis
- Assessment of road noise contributions with only operating measurements: no need for transfer functions measurements
- Easy investigation of contributions from ”front vs rear” wheels or ”structure borne vs airborne”.
- MICA technique is used for source level NVH Vehicle Simulator





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NVH Applications of Source Path Contribution

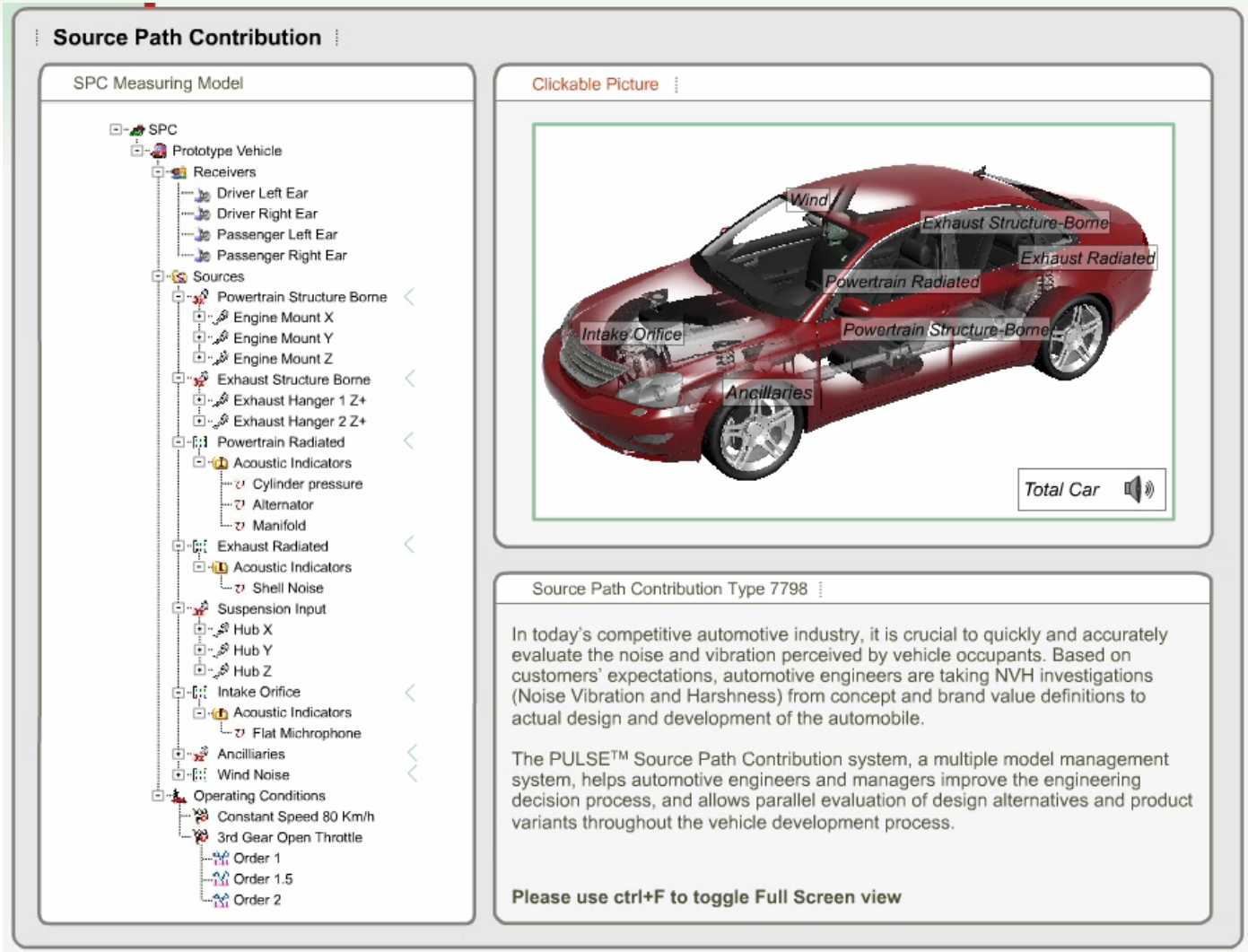
- **Troubleshooting**
  - Engine Noise: overall Level of particular characteristic (boom, growl, clatter)
  - Find dominant noise sources and/or noise paths for objectionable sound
  - Engine mounts (which one), Intake, Exhaust, Exhaust mounts, suspensions, etc.
- **Benchmarking and Target Setting**
  - Engine Noise (including intake/exhaust) and vibration
    - » Measure levels and path characteristics of competitive vehicles and current production vehicles
  - Set targets based on benchmark data and desired vehicle characteristics
  - Transmission, axle, driveline noise and vibration
  - Power steering pump noise
  - Tyre / Road noise / vibration
  - Brake noise (moan, groan and squeal)

Key benefits – Source Path Contribution

- **Create Model:**
  - Tree model to organize the model and data
- **Assign**
  - Open data structure: Import from any common analyzer or CAE program
  - Automatic mapping of data to the SPC model (”assignment of DOFs”)
- **Calculate:**
  - Matrix inversion tool
    - » view and edit FRF matrix before matrix inversion (e.g.remove & nullify cells)
    - » visual inspection
    - » singular value threshold
- **Contribution:**
  - Contribution contour plot to identify major paths across entire frequency or RPM range
  - Quick to change model and to simulate changes to noise and vibration paths and sources
- **4 SPC methods supported:**
  - Mount Stiffness for structure borne contribution
  - Matrix Impedance for structure borne contribution
  - Source Substitution (multi-refence technique) for un- or partially correlated sources such as airborne sources
  - Multiple Input Coherence Analysis (MICA) for road noise investigations, no need for transfer functions

Brüel & Kjær SPC – Interactive Tour
http://www.bksv.com/flash/spc/index.htm

Click Here
to Take Interactive Tour



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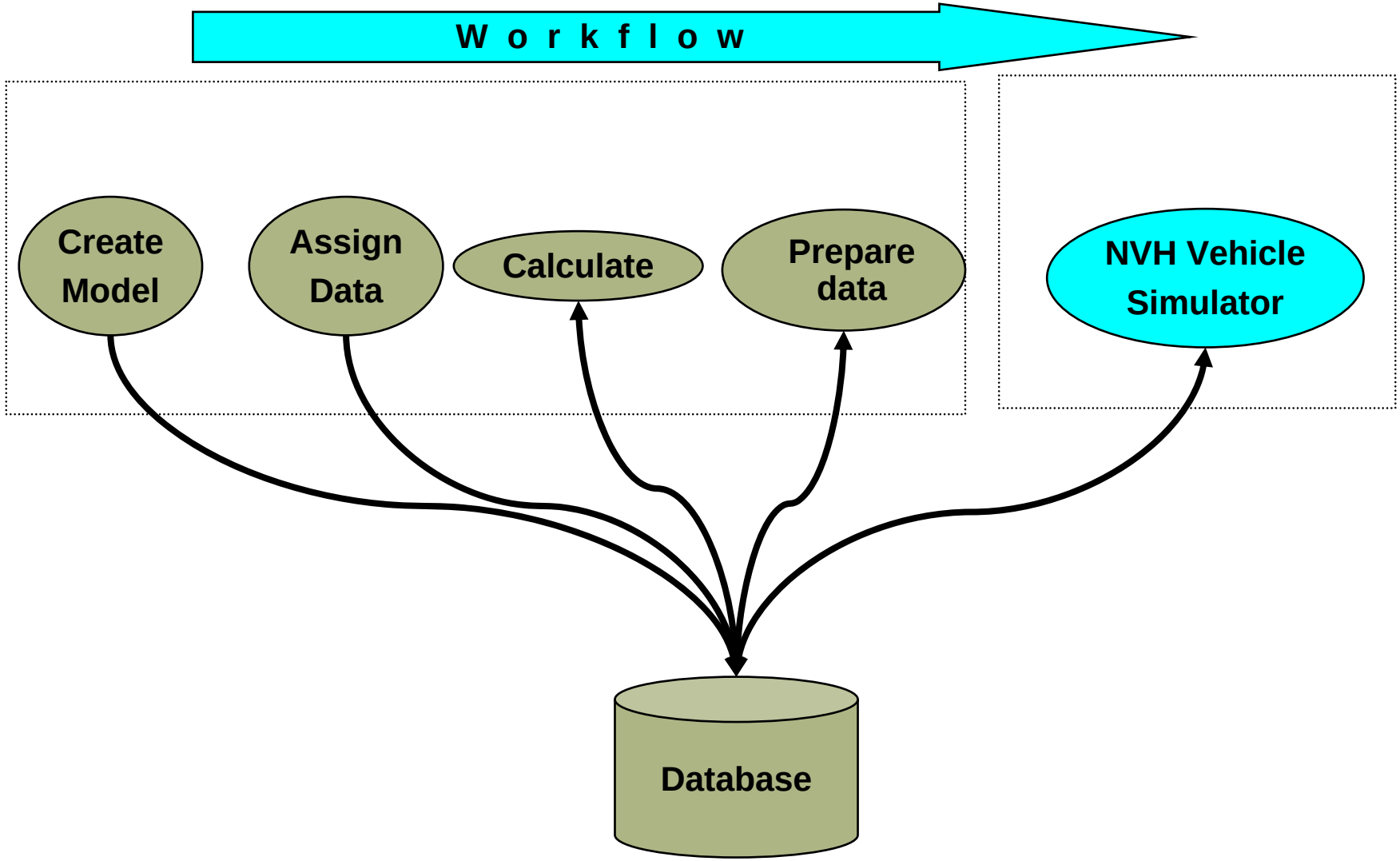
SPC and NVH simulator



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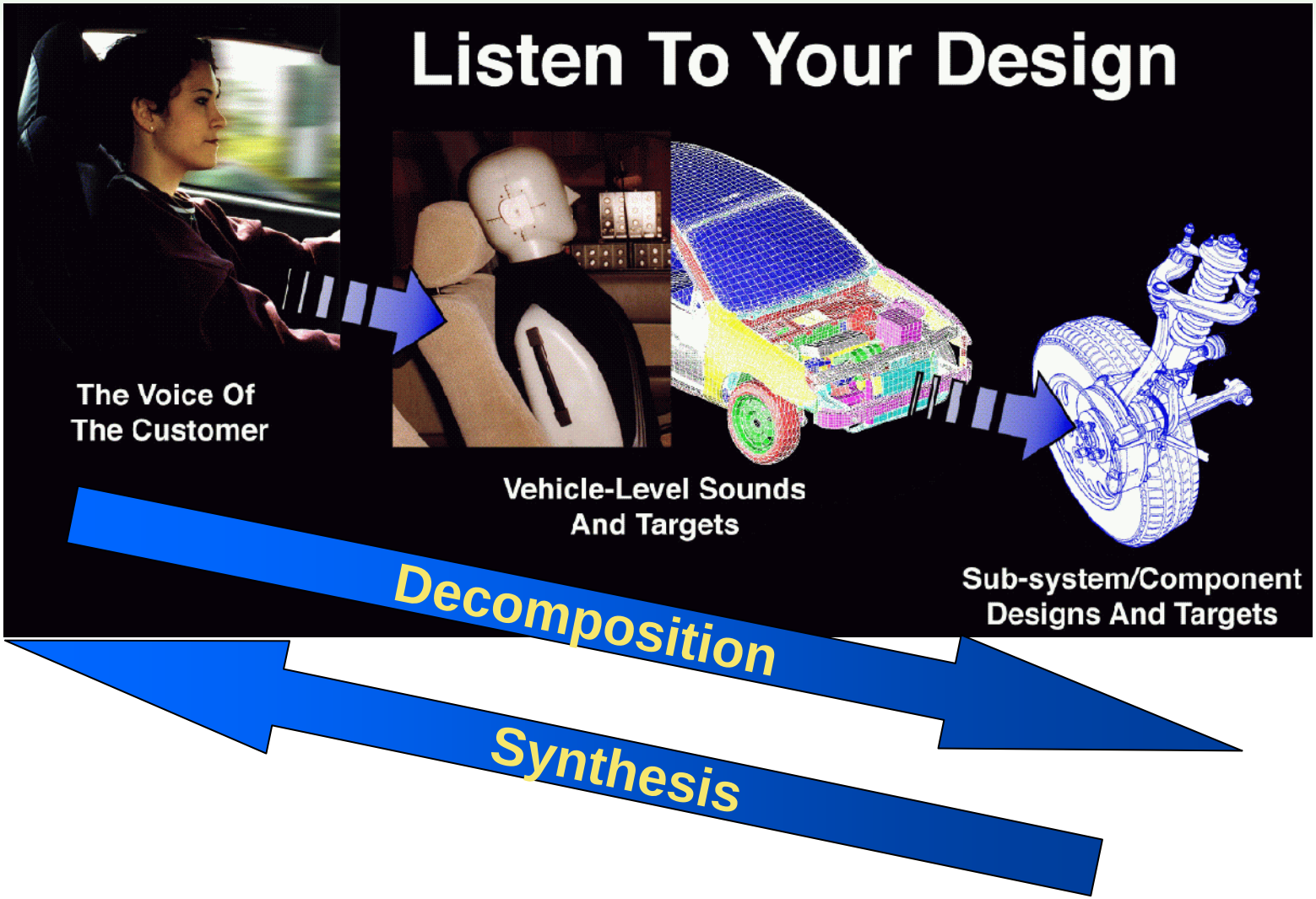
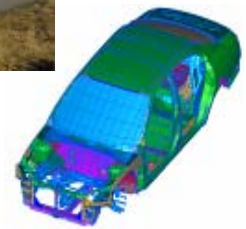
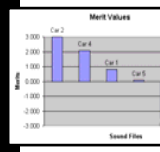
Sound Simulation

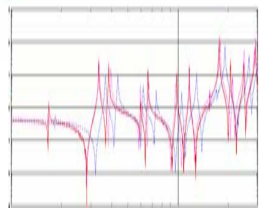


Evaluate vehicle NVH efficiently





Rig Testing

Competitor Benchmarking

Development Testing

Customer Satisfaction

CAE Predictions

Customer Preference

Supplier Data

Evaluate

Understand

Communicate

Make the Correct Decision

Marketing
Chief Engineers
Program Managers
NVH Specialists
Suppliers

Interactive NVH Evaluation >>>>> NVH Vehicle Simulator

- Drive a virtual vehicle on a virtual road, track or test bench
  - ***Interactivity*** and ***Context***
  - Switch back-to back
  - Experience vehicles that don't exist
    - » Targets / What If's / New Designs / …

- *Simple for the non-expert*
- *Very effective use of standard NVH data (Test & CAE)*
- *Better decision making in less time*

Greatly improves the effectiveness of the NVH process

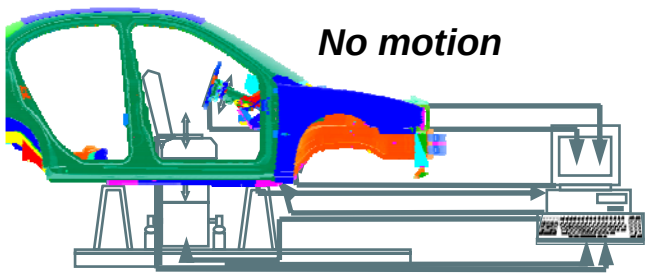
What is the Full NVH Simulator?

Car & Controls

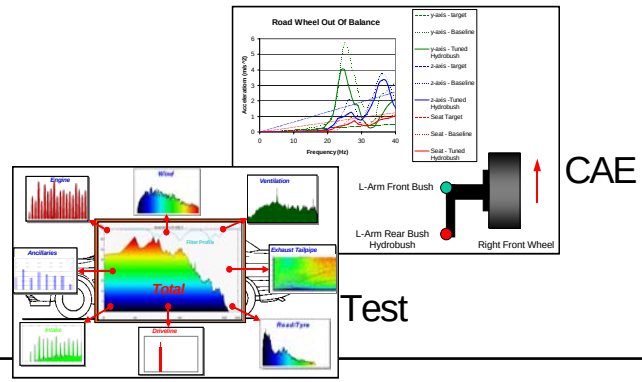
Visuals & Scenarios

NVH stimuli, visuals and vehicle behaviour are created in real-time, responding to driver input

Sound, Vibration & Steering



NVH Data



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What is the Desktop NVH Simulator?

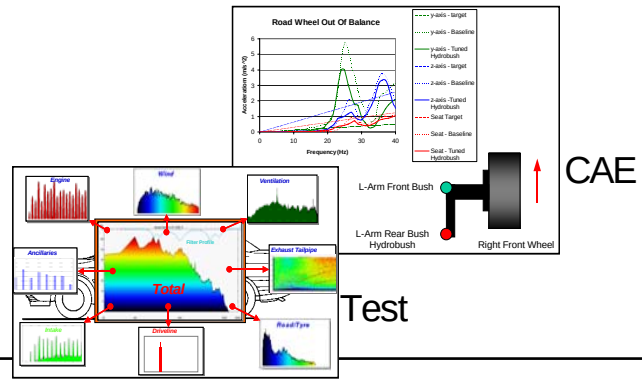
Controls & Interfaces

Visuals & Scenarios

NVH stimuli, visuals and vehicle behaviour are created in real-time, responding to driver input

Full ***interactivity*** but reduced ***context***

NVH Data



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Benefits of the Interactive NVH Approach

- Summary
  - Adds Interactivity and Context to NVH Evaluations
  - Combines Test and CAE data
  - Engineering and Evaluation usage
  - Scalable

You can do things you cannot do in a real car

- Benefits
  - Engages the whole programme team
  - Improved involvement and confidence (Managers, Real Customers…)
  - Simplifying the task of data interpretation
  - Lead the design
  - Training
  - Vehicle library

A more effective NVH process

Evaluation (Jury) Interface

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Engineering Interface

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Key Benefits – NVH Simulator

- Assessment of a virtual vehicle by free driving allows decisions to be made which cannot be achieved by traditional on-road or in-room methods
- New vehicles can be ‘driven’ and assessed well in advance of first physical prototypes
- Drastically reduces the time taken to assess multiple driving conditions
- Simulator database ensures that a vehicle is always available to be driven, unaffected by effect of modifications, weather, age, etc.
- Vehicle level model can be expanded to a full model by adding in source or path contribution data
- NVH simulator model of a new vehicle becomes more complete and accurate as the programme moves from high-level target setting through target cascading and concept evaluation into the detailed design phase
- Increases confidence in the NVH decision-making process
- Highlights the importance of part-load conditions on the overall perception of powertrain sound quality
- Change modelling makes CAE data much more useable, making it easy to create a new variant of a vehicle in the simulator
- Allows CAE analysts to appreciate the relative benefits of different designs

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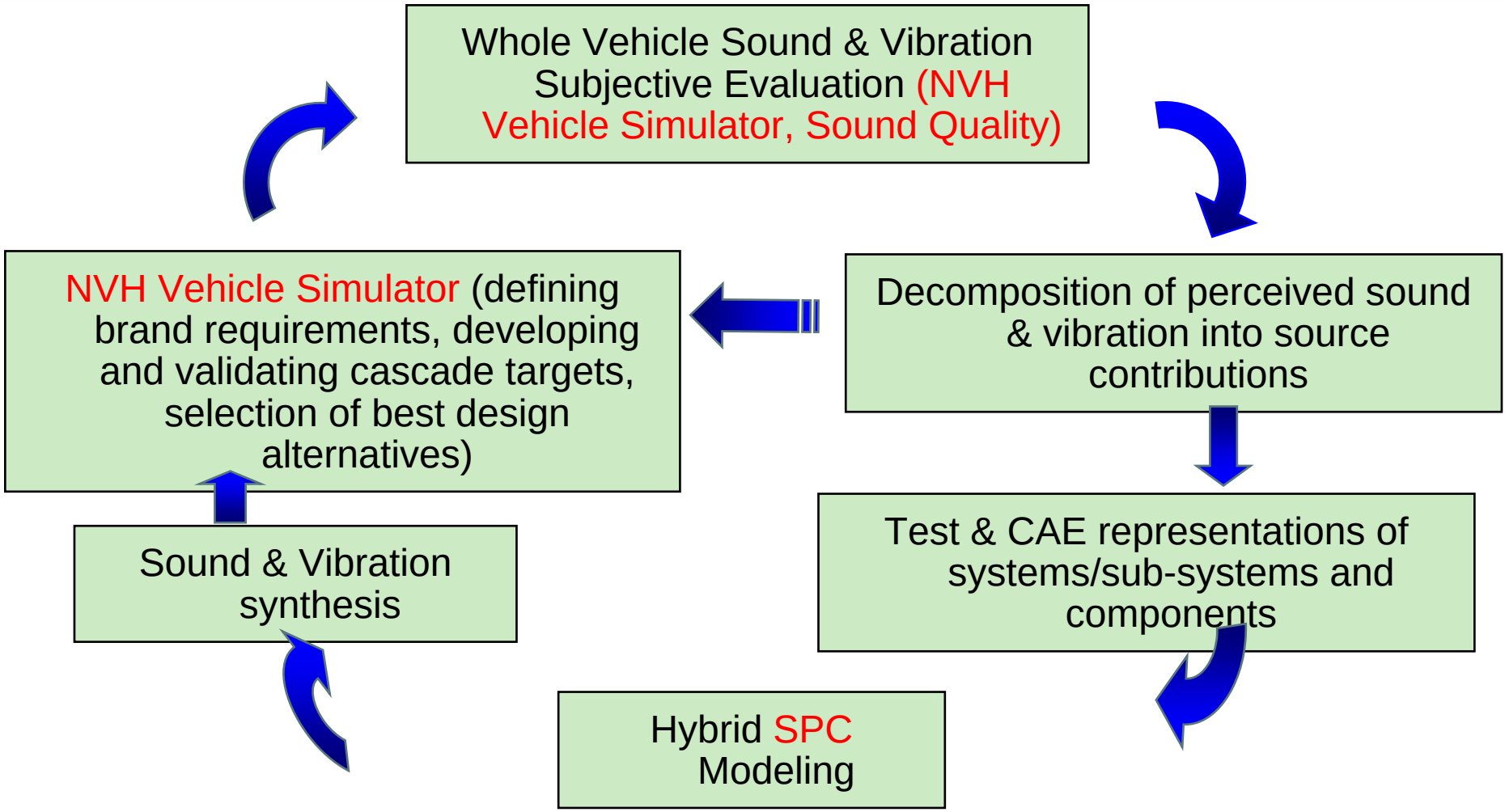
Sound Engineering Process



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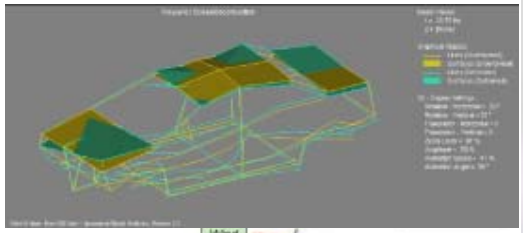
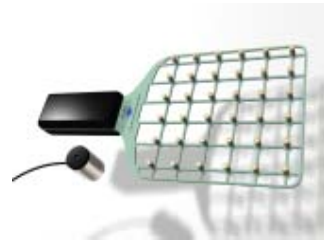
Sound Engineering

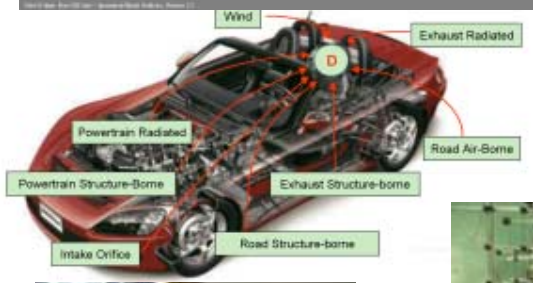
- Sound Engineering enables troubleshooting, target setting, benchmarking and simulation using the source-path-receiver model
- Brüel & Kjær sound engineering measurement and software solutions bring a new level of efficiency in the process evaluating vehicle sound and vibration

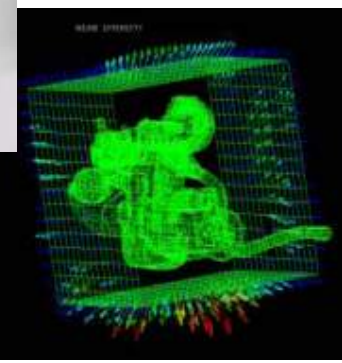
Engineering Consulting Services

- Brüel & Kjær now offers a wide range of NVH consulting services
  - SPC
  - Vehicle Simulator
  - Array Acoustics
  - Sound Quality
  - Sound Quality Jury
  - Target Setting
  - Benchmarking
  - Modal Analysis
  - Structural
  - Electromechanical
  - Methods Development
  - NVH Program Management









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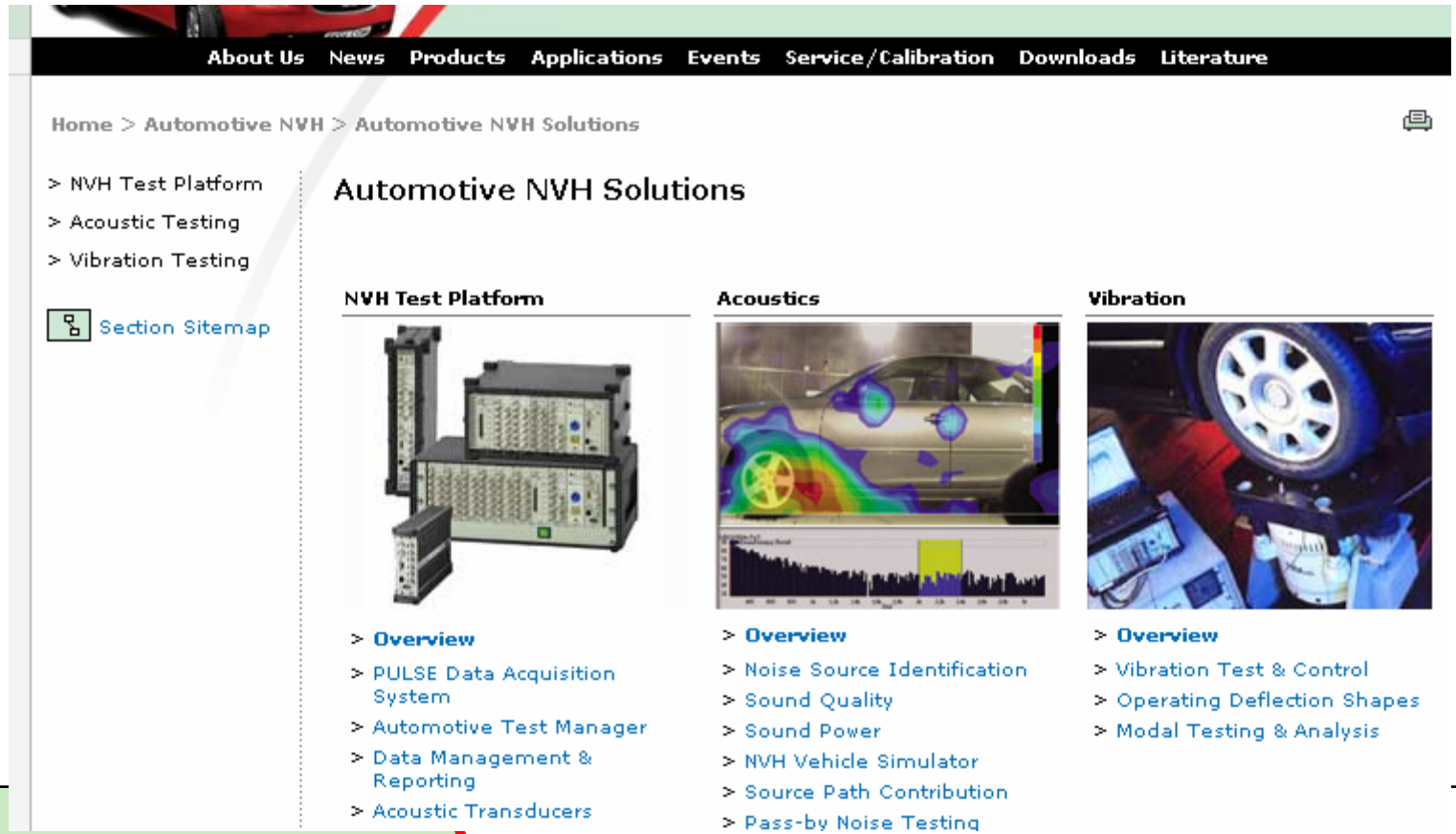
Conclusions

- Too much information to swallow in 1 hr?
- Sign up for future webcourses
- Visit bksv.com Automotive NVH Solutions Page



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