Vehicle Acoustics: Chances for Application of Research Results

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- **Principles and Methods expected to contribute to Vehicle Acoustics Engineering**
- **Recent engineering application and importance of some examples in practical automotive development**
- **Factors to enhance chances for the application of research results**
- **Cross-cultural communication between research and industry**

Topic of this presentation is only the operational noise of vehicles, not any acoustic system (audio etc.)
This presentation quotes selected examples, however does not claim to be complete or absolute in any sense

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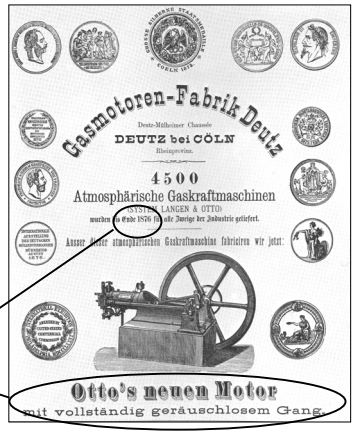
Principles and Methods expected to contribute to Vehicle Acoustics Engineering

Examples :

- Signal Analysis
- Modal Analysis
- Transfer Path Analysis
- Source identification by microphone arrays
- Sound Intensity
- Statistical Energy Analysis
- Psychoacoustics: Customer-related assessment
- Psychoacoustics: Metrics
- Active Noise Control



All problems solved by the end of 1876 :
Otto's new engine - featuring completely noiseless engine operation

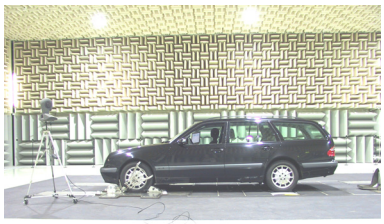
Signal Analysis (Fourier, Order, Time Domain Analysis)

Quantification and analysis of sound including identification hints to sources

Recent Status:
- Broad-range basic method for all automotive NVH engineering including suppliers

Influence factors:
- Easy-go measurement equipment available (risk of misleading evaluation of „dull pushbutton results“)
- Grown application experience, basic principles familiar to almost all engineering graduates, no engineering support necessary
- Supplies hints for the identification of sound sources (e.g. engine orders, timing chain frequency, gearbox meshing frequencies, charger rotation)
- Basic preparation for the application and understanding of advanced methods

Future trend:
- Continuous bread&butter-method for all NVH development
- Improving of method for enhanced time (or operation cycle) - related analyses



Signal analysis equipment is basic equipment of all automotive NVH test facilities

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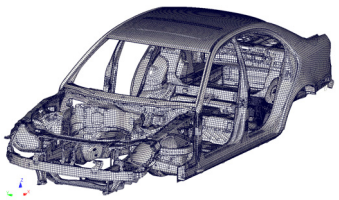
Modal Analysis (including Operational Deflection Shapes)

Analysis and optimization of components shape (natural and under operation)

Recent Status:
- Broad-range basic method for car body and components (engine case, suspension, ...) NVH-optimized design

Influence factors:
- Measurement equipment and engineering support available, grown experience of application, basic principles familiar to majority of automotive engineering graduates
- Instructive vivid presentation of results (management-proof)
- Direct design optimization of cases, panels etc.
- Application of identical techniques (and similar systems) in CAE simulation, experimental testing and hybrid methods

Future trend:
- Increasing effectivity by improved matching / validation between CAE and experiment
- Transfer to complex (damped) structures



CAE body model (approx. 500.000 Elements) allows study and optimization of vibration and structure borne noise properties

Source: DCX Gartmeier

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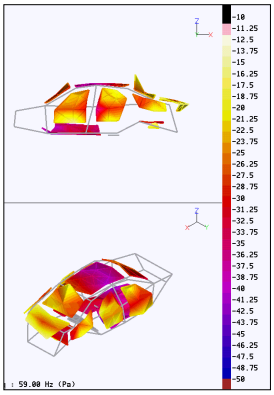
Transfer Path Analysis

Source, transfer path and panel contribution identification including design hints for panels

Recent Status:
- Broad application in automotive engineering

Influence factors:
- Measurement equipment and engineering support available
- Time-consuming and demanding specialized staff
- Supplies complete information on all components accessible for design improvement
- Supplies design hints e.g. for panel shape
- Interfacing to CAE/FEM techniques allows integration of simulated component behaviour and prediction of design modification effect and optimization studies under realistic operational load

Future trend:
- Improved integration of structure borne and airborne pathes analysis
- Application as an evaluation and assessment tool for simulation results



Panel Contribution Analysis:
TPA results combined with measured operational forces in wind tunnel identify panel shape design options

Source: DCX Koners

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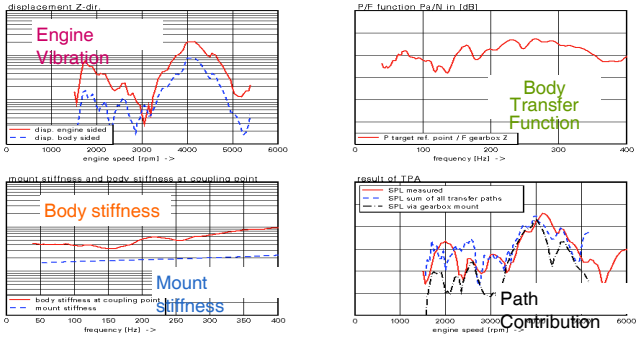
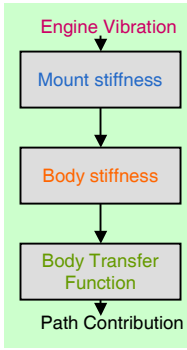
Transfer Path Analysis

Source, transfer path and panel contribution identification including design hints for panels





Powertrain noise analysis example: TPA is a tool to
- identify dominating path contribution to overall noise (here: gearbox mount)
- evaluate design options (here: problem caused by engine vibration, while mount stiffness, body stiffness and body transfer function are good-natured)

Source: DCX Koners

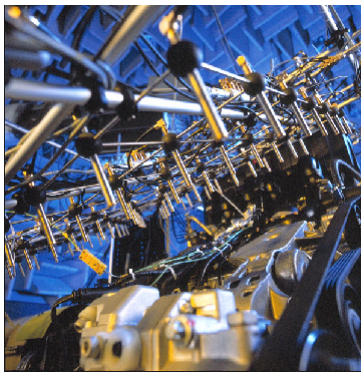
Source Identification by Microphone Arrays

Source localisation and contribution analysis including propagation analysis

Recent Status:
- Localisation of prominent sources in complex or large structures (engines, tyres, passing-by vehicles)

Influence factors:
- Stand-alone systems available with different performance profiles, e.g. propagation analysis by spatial transformation or quick-look management information
- Time-consuming, clumsy measurement hardware, serious evaluation of enormous data sets difficult
- Application/evaluation specialists necessary
- Source location useful, but relatively expensive

Future trend:
- Dedicated special applications continued
- Improvement of performance under physical restrictions (ratio: wavelength - spatial resolution)



Microphone array for sound field and sound propagation analysis in a combustion engine test cell
Source: DCX Helber

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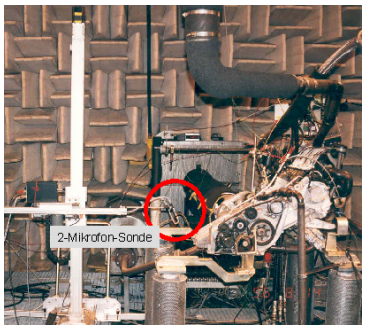
Sound Intensity

Source localisation and panel contribution analysis

Recent Status:
- Localisation of weak points e.g. in isolated panels (firewall, floor, engine case)

Influence factors:
- Systems available
- Time-consuming, stationary operation of object necessary, measurement environment necessary (including robots for probe handling)
- Little add-on benefit compared to „hand-held“ low-budget techniques, enhanced features of intensity method not necessary in automotive engineering

Future trend:
- Continued small-range application



Robotic sample system for measurement of 3D-intensity of combustion engines under typical operation conditions
Source: DCX Helber

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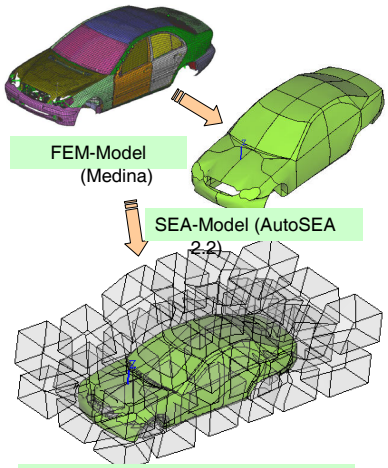
Statistical Energy Analysis

Analysis and optimization of noise transfer elements in upper frequency range

Recent Status:
- Layout of shell and sound isolation package design (upper frequency range airborne noise)

Influence factors:
- Systems available (limited performance, emerging), engineering support in a general sense
- Direct design and material selection of isolation package
- Prediction of design modification effect in early „virtual“ development phase

Future trend:
- Interfacing to CAE/FEM models and use of „templates“ makes access easier
- Increase of analysis systems performance, growth of experience „on the job“
- Development of tools for structure borne noise (correct representation of physical reality)



Source: DCX Liefooghe/Zäh

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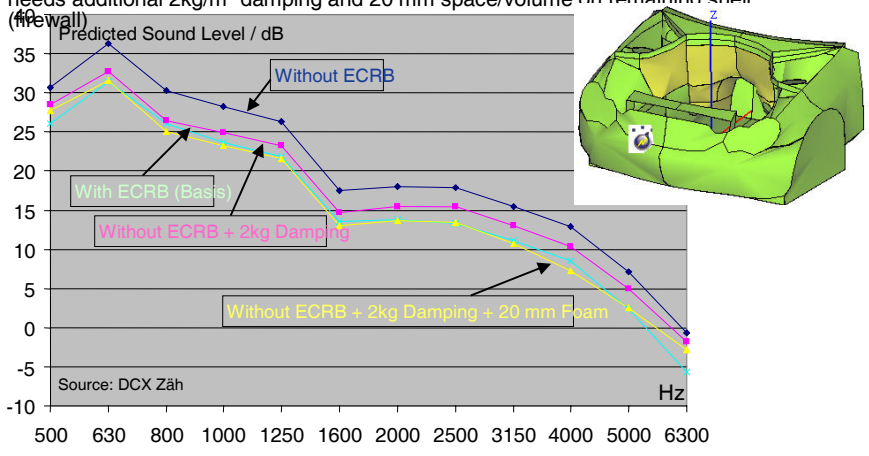
Statistical Energy Analysis

Analysis and optimization of noise transfer elements in upper frequency range

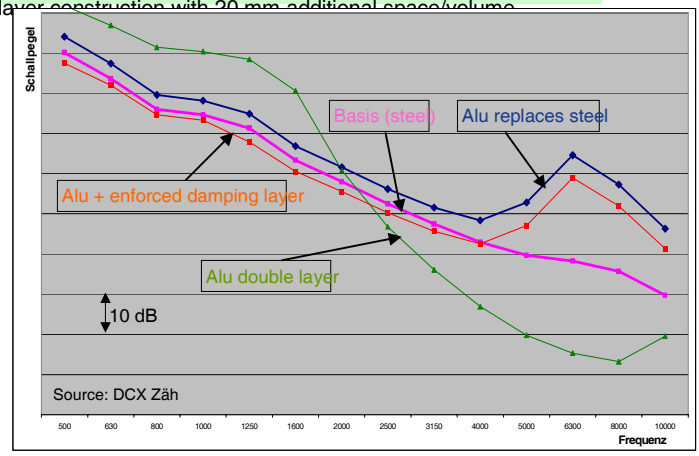
SEA prediction for body front end packaging optimization:
compensation of leave out of a second firewall shell (Engine Compartment Rear Bulk)
needs additional 2kg/m² damping and 20 mm space/volume on remaining shell (firewall)



Statistical Energy Analysis

Analysis and optimization of noise transfer elements in upper frequency range

SEA prediction for firewall optimization under target conflict "weight vs. space/volume":
replacing steel by aluminium needs enforced damping layer in isolation (+2.5 kg/m²) or double-layer construction with 20 mm additional space/volume



Psychoacoustics: Customer-related Assessment

Recording, modification and jury testing for noise evaluation and target setting

Recent Status:

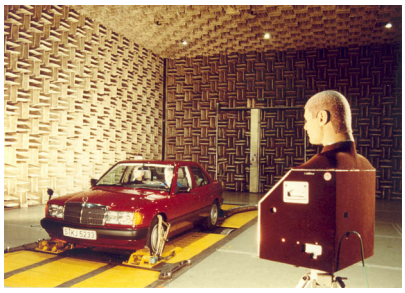
- Broad application of artificial head equipment and jury testing at automotive industry including suppliers

Influence factors:

- The only tool to give access to subjective impression and assessment during development process (no simple metrics for subjective assessment)
- Easy-go equipment and engineering support available from different suppliers
- Good acceptance even by untrained staff (upper management, decision-makers)

Future trend:

- Interfacing for the presentation of simulated results during virtual development phase
- Integration in full range simulation techniques (NVH simulators, interactive „driveable" cars)



Early representative of artificial head family (named „Gottlieb") in action at automotive test bench

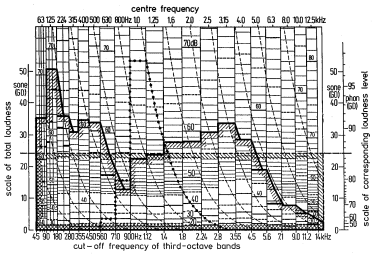
Psychoacoustics: Metrics

Metric description of subjectively perceived noise impression

Recent Status:
- No convincing/accepted single-number-metric for automotive acoustic impression existing: sone is not a major progress vs. dB(A)
- Local use for the analysis of special problems: Sharpness for flow noise, Roughness for engine rumbling, Prominence for gear box whining

Influence factors:
- Difficult application, variety of metrics („zoo“)
- No standards (except stationary loudness), metric definition varies with system supplier („which of all the sharpnesses of the world ?“)
- Little add-on-benefit: only description, no contribution to source identification or design

Future trend:
- Standardization for engineering applications



Scheme for the „graphic“ calculation of Zwicker Loudness based on 3rd-octave-spectra
(Source: Zwicker/Fastl, „Psychoacoustics“, 1990)

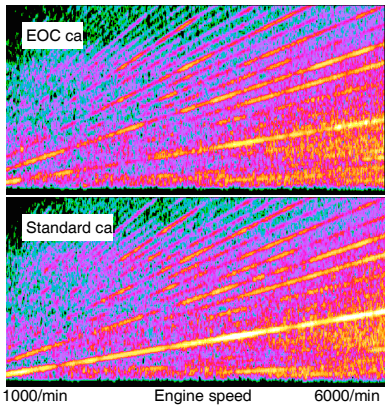
Active Noise Control

Elimination of annoying noise components using compensation signals in destructive interference

Recent Status:
- Technical solutions / systems developed at a physical prototype level for components and complete cars
- No application in any produced car

Influence factors:
- Broad basic knowledge given by numerous research and development activities, glut of patents
- Engineering experts to support practical application available
- Cost, lack of compensatory savings and limited technical effect prevent application
- Engineering workload for car integration not appreciated

Future trend:
- Isolated solutions for troubleshooting that need no car system integration may be possible
- Airborne noise cancellation based on emerging passenger compartment equalization audio systems



Effect of an Engine Order Cancellation System (EOC) in a 4-cyl-engine car
(Driver's seat, 3rd gear WOT; Source: DCX Letens)

Active Noise Control

Elimination of annoying noise components using compensation signals in destructive interference

Evaluation of active technologies in the Maturity vs. Benefit-Cost-Ratio Portfolio

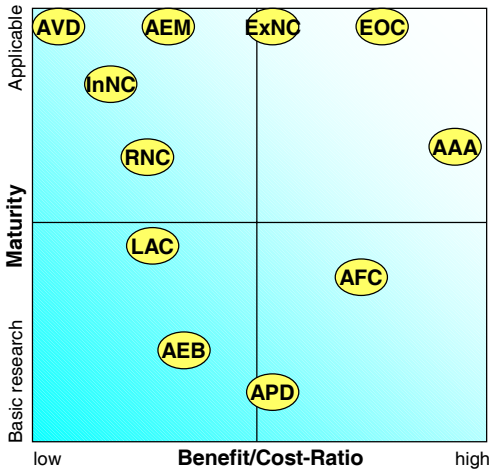
Source: DCX TechColl „ANC/AVC Technologies“

Actuator effects air borne noise:

- ExNC Exhaust Noise Cancellation
- InNC Intake Noise Cancellation
- AAA Active Acoustic Absorbers
- LAC Local Active Cancellation
- EOC Engine Order Cancellation
- RNC Road Noise Cancellation
- AFC Active Flow Control

Actuator effects structure borne noise

- AEM Active Engine Mounts
- AVD Active Vibration Dampers
- APD Active Panel Damping
- AEB Active Engine Brackets



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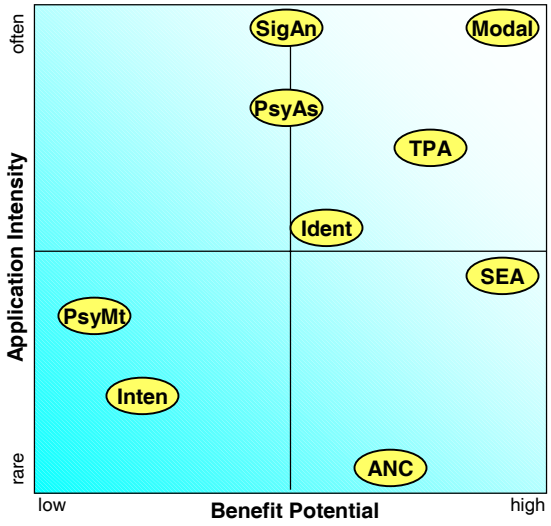
Acoustic Principles and Methods (Summary) Recent Application in Automotive Engineering

Evaluation of Acoustic Principles and Methods in the Application Intensity vs. Benefit Potential Portfolio

- Signal Analysis
- Modal Analysis
- Transfer Path Analysis
- Source identification
- Sound Intensity
- Statistical Energy Analysis
- Psychoacoustics: Assess
- Psychoacoustics: Metrics
- Active Noise Control



Acoustic Principles and Methods (Summary)
Factors to Enhance Chances for the Application of Research Results

- The research output should give a clear support for the solution of problems in terms of automotive engineering: at least identification of crucial components, in best case design information to improve crucial components, in very best case supply of improved components
- The transfer of a research result from laboratory conditions to practical application typically can be done neither by the researcher nor by the automotive engineer: a transfer specialist is needed, e.g. an engineering experts company, a university spin-off, a system supplier etc.
- Critical resource for the car development process is human workload capacity: a method must be „served ready to use“ and must need only short start up time
- Critical resource for technical product content is cost efficiency: to the customer acoustics means a „hygienic factor“, not a „motivation factor“
- Early stage information on target conflicts and vehicle/development context integration conditions is inevitable for successful application
- Demand for predictive devices is increasing strongly to shorten development process time: early availability of design hints beats late perfection, coarse estimation of design change effects beats a-posteriori precision validation

Cross-cultural Communication between Research and Industry
Recommendations for Researchers

- Use most sophisticated wording to describe your invention according to the literary standard of unreadable scientific journals
- Lavish use of (if available multiple) integrals will dramatically improve the persuasive power of your presentation; leave always a portion of at least 30 % of the content incomprehensible to anybody except you to show your intellectual potential
- Give clear evidence that exclusively your invention will solve all the remaining problems of the acoustic community worldwide, even if a precise definition of the time frame seems to be still somewhat difficult at the moment
- Hint confidentially at a vivid Japanese (or BMW) interest in your project
- For project duration calculation use the well-known 80%-rule (80% of project time for the first 80% of the project workload, remaining 80% of the project time for the remaining 20% of the project workload)
- Never forget that you hold a superior moral standard: you represent human culture while the automotive engineer represents ordinary economy, and only poor need for funding urges you to concern yourself with him

Cross-cultural Communication between Research and Industry Recommendations for Automotive Engineers

- Let your first question be „Where is the driveable car to experience your invention practically ?“
- Ask for the basic results not later than after the first 3 minutes of the presentation
- Give clear evidence that you estimate public funding for research projects to be a complete waste of money; however, if that‘s the way it‘s got to be, then at least it should be dedicated to your problem
- Hint confidentially that the Japanese (or BMW) would never fund such a project, while you will find easily somebody else to deal with these trivia
- For project duration calculation use the well-known 20%-rule (20% of the estimated project runtime leads to an 80% problem solution, and this is absolutely sufficient)
- Never forget that you hold a superior responsibility standard: you represent human needs satisfaction while the researcher represents individual playground activities, and only poor need for fresh ideas urges you to concern yourself with him

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Cross-cultural Communication between Research and Industry (Graphic Summary)

The young composer:

They will still perform my music after Mozart has been forgotten for a long time !

The old impresario:

But not before this.

Who needs to learn ?

May be, both.