



Supplement

Audible Sounds based on Cylinder Pressure Signals

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Presentation Slides



Audible Sounds based on Cylinder Pressure Signals

FVV Research Project No.1040
Chairman: Dr.-Ing. Klaus Pfeleiderer, Adam Opel AG

**Institute for Combustion Engines
RWTH Aachen University**

Prof. Dr.-Ing. Stefan Pischinger



Aachen, 26. November 2013
Dipl.-Ing. Michael Kauth → now 



Presentation Content

- **Introduction and Motivation**
- **Methodology**
- **Results**
- **Outlook**
- **Summary**

Presentation Content

- **Introduction and Motivation**
 - Initial Situation
 - Objective
- **Methodology**
- **Results**
- **Outlook**
- **Summary**



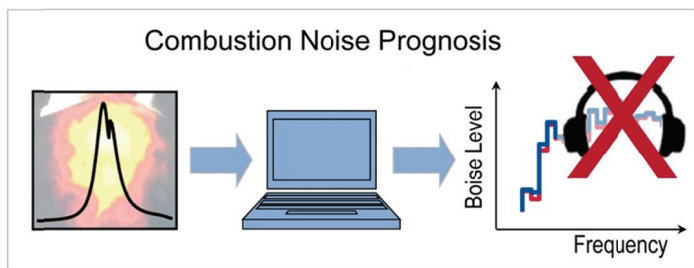
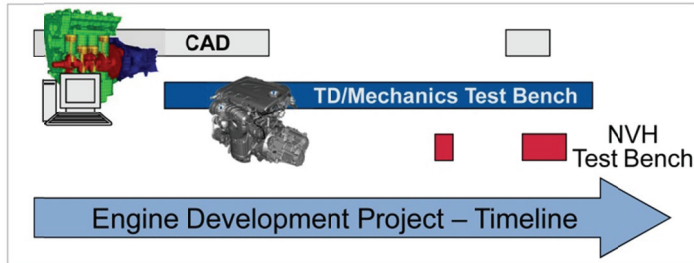
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Introduction and Motivation

Initial Situation

Objective



- NVH measurements only late and discontinuous in the development process
- Early, comprehensive evaluation of engine NVH is desired
- Combustion noise prognosis to date not audible

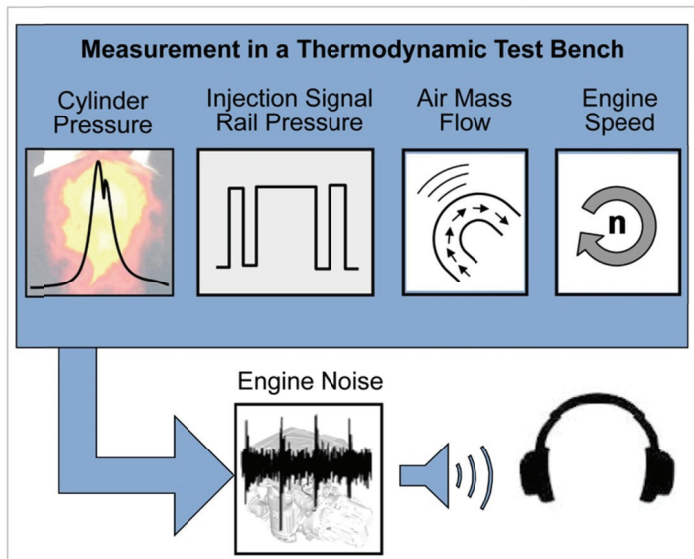
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Introduction and Motivation

Initial Situation

Objective

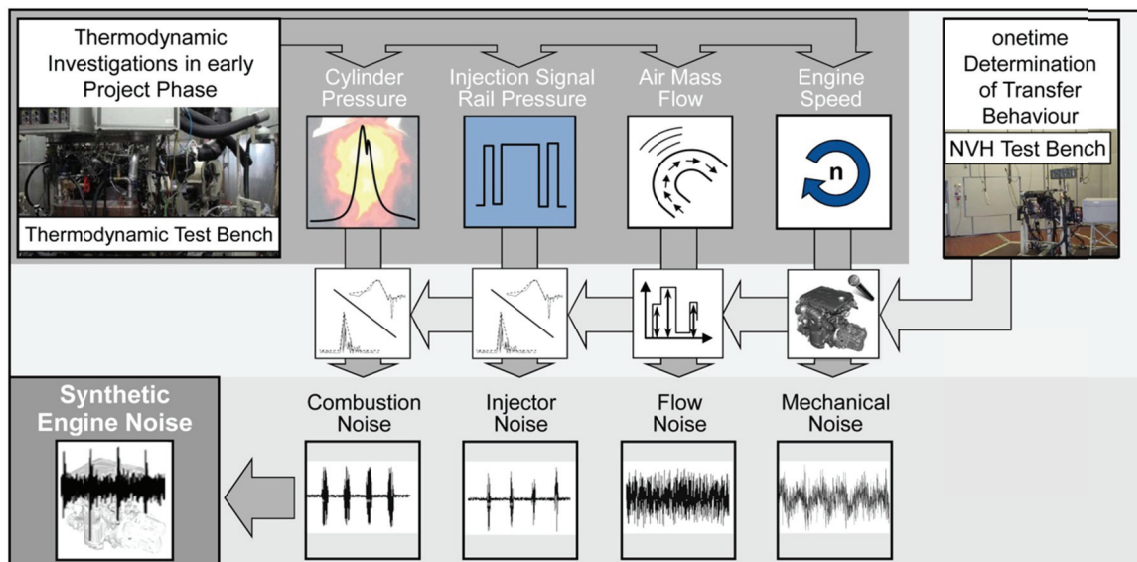


- Cylinder pressure and other values available early
- ➔ Generation of a synthetic engine noise on basis of these values

Presentation Content

- Introduction and Motivation
- Methodology
 - Model Concept
 - Determination of Excitation/Noise-Relations
 - Synthesis of Noise Components
- Results
- Outlook
- Summary

Methodology

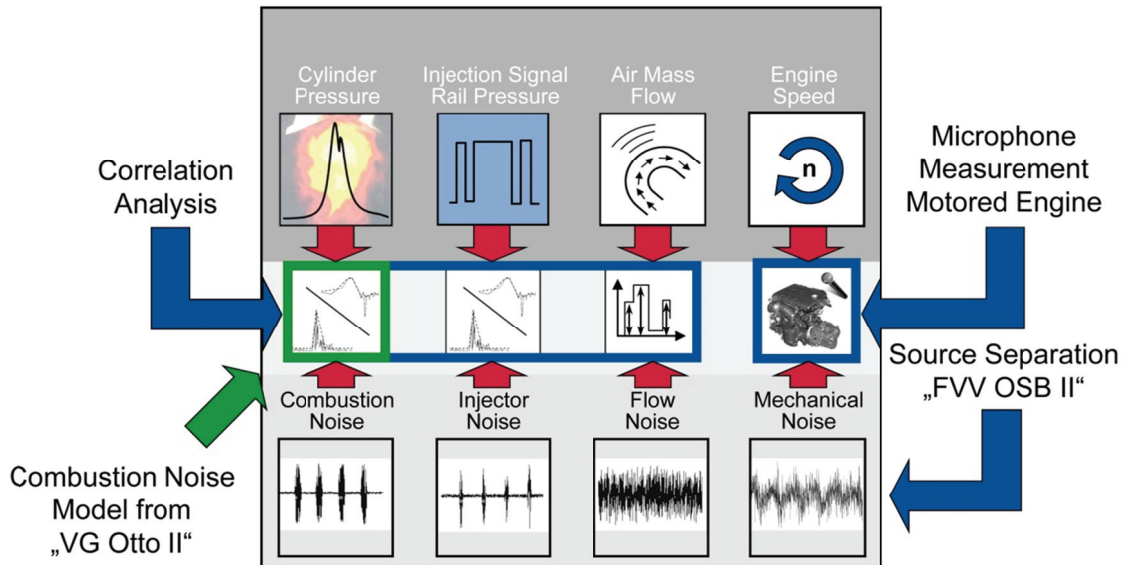




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Determination of Excitation/Noise-Relations



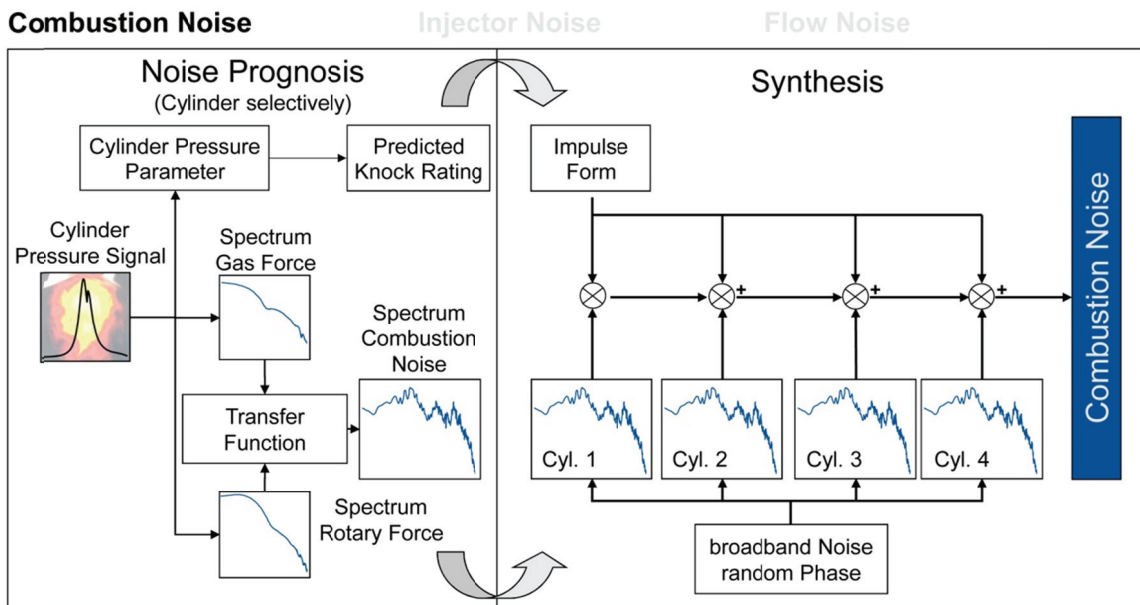
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Synthesis of Noise Components



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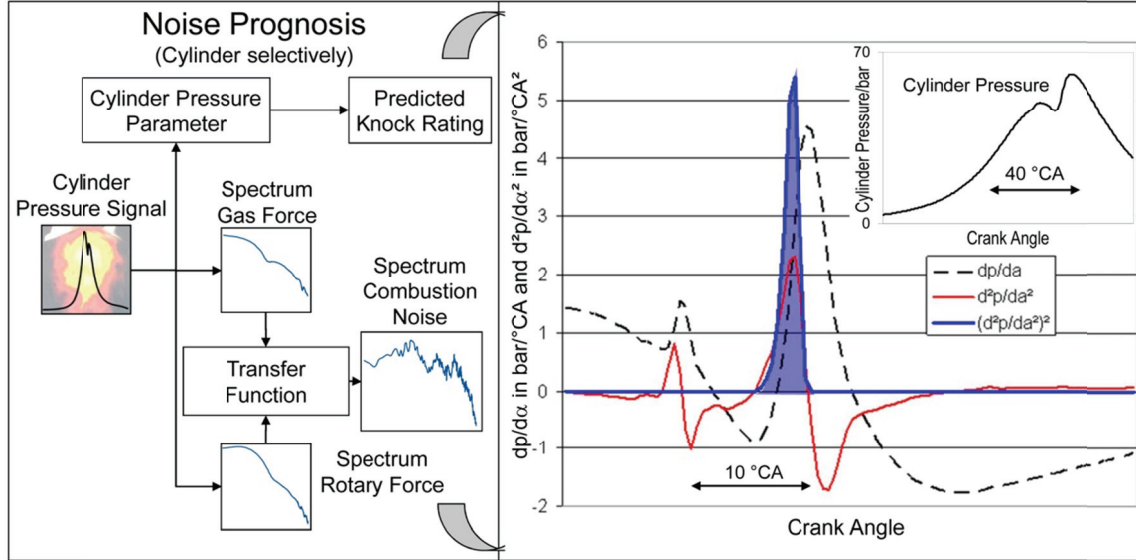
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Synthesis of Noise Components

Combustion Noise

Injector Noise

Flow Noise



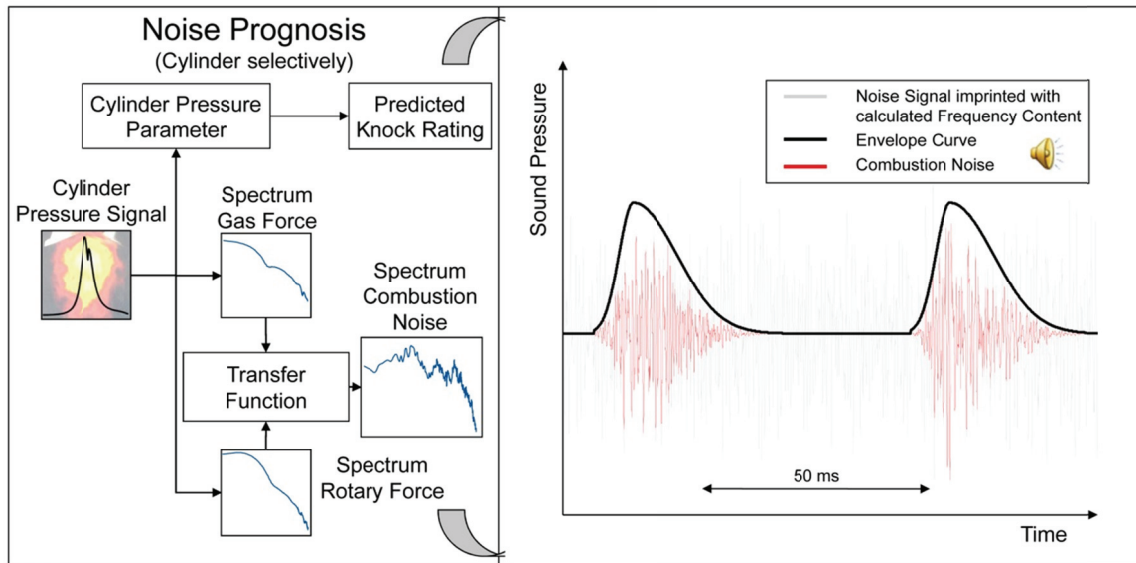
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Synthesis of Noise Components

Combustion Noise

Injector Noise

Flow Noise





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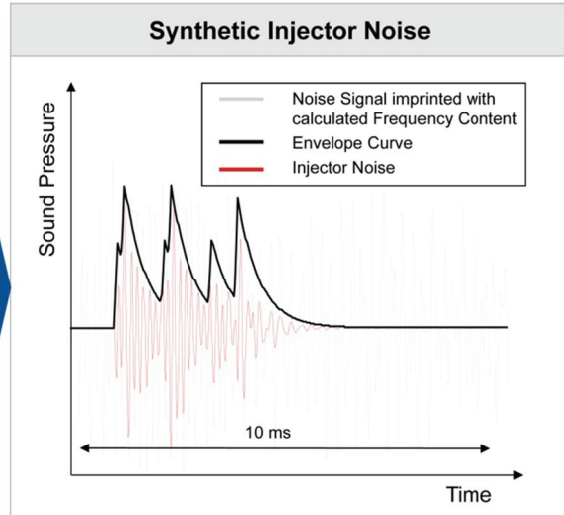
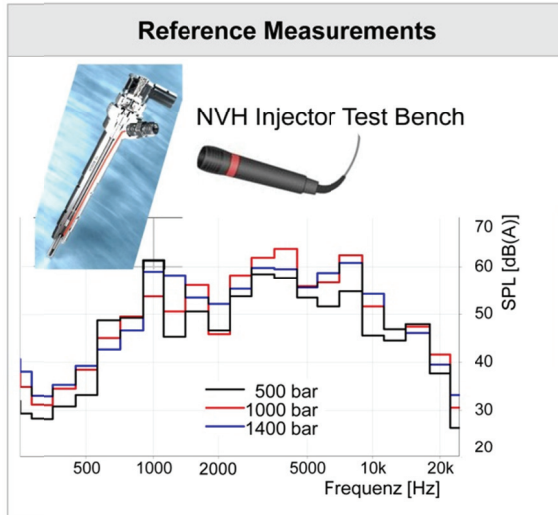


Synthesis of Noise Components

Combustion Noise

Injector Noise

Flow Noise



Injector Photograph: Bosch

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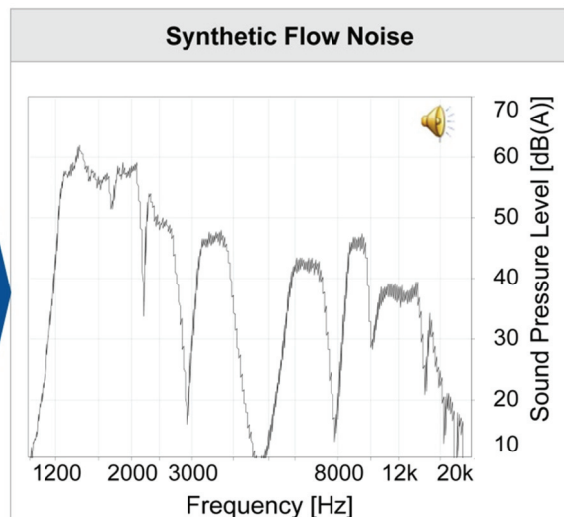
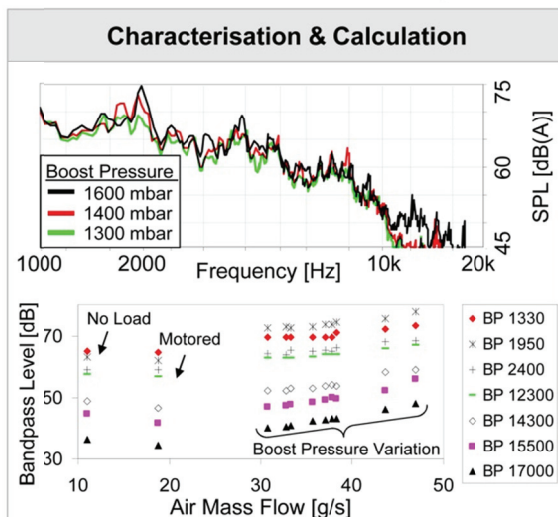


Synthesis of Noise Components

Combustion Noise

Injector Noise

Flow Noise



Boost Pressure Variation at 1500 rpm, 12 bar bmep, Intake Side, Bandpass Level for Measurements at 1500 rpm Full Load, dB-Reference: $2 \cdot 10^{-5}$ Pa, Frequency Resolution: 5.4 Hz

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Presentation Content

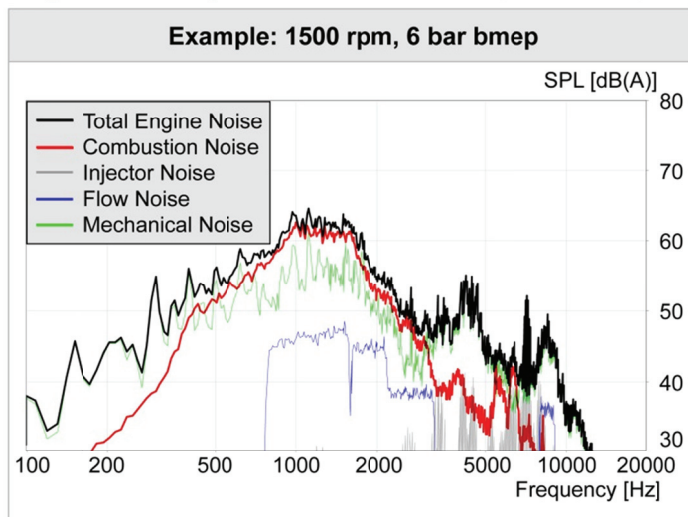
- Introduction and Motivation
- Methodology
- Results
 - Engine Noise Synthesis
 - Microphone/Synthesis Comparison
 - Diesel Knock Prediction
 - Robustness
 - Software Tool
- Outlook
- Summary

Results

Engine Noise Synthesis

Mic./Synth. Comparison

Diesel Knock Prediction



- ### Boundary Conditions
- Pre-series engine calibration
 - Calculation and synthesis conducted with delivered version of the software tool
 - Average rating for total engine noise conformance synthesis/microphone: 7.5



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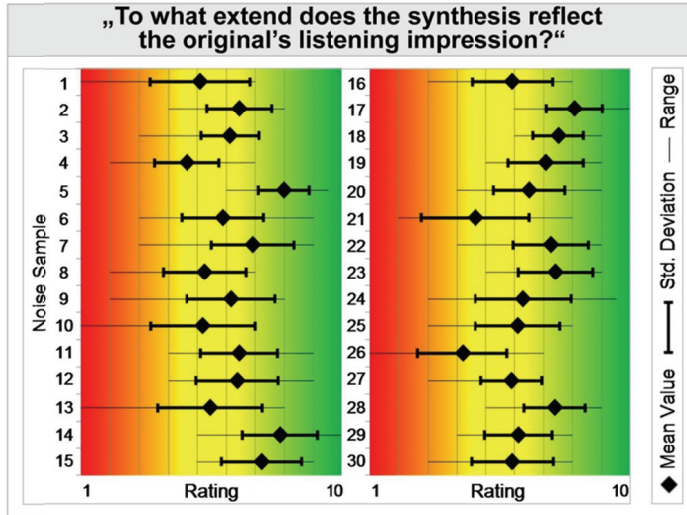


Results

Engine Noise Synthesis

Mic./Synth. Comparison

Diesel Knock Prediction



- ### Subjective Evaluation
- Direct comparison of synthetic noise and corresponding microphone measurement
 - Fairly good conformance (\varnothing 6.3)
 - Evaluation of
 - Total engine noise
 - Combustion Noise
 - Flow Noise
 - “Realistic” noise impression

Audible Sounds based on Cylinder Pressure Signals

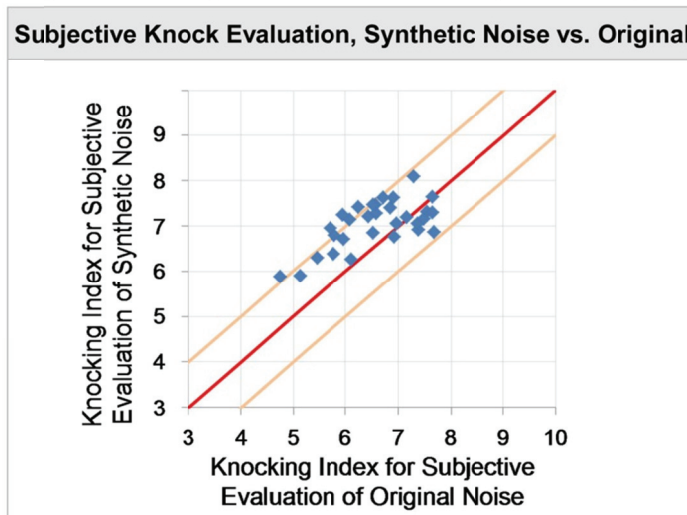


Results

Engine Noise Synthesis

Mic./Synth. Comparison

Diesel Knock Prediction



- Offset of ~1 grade on average
- 0.5-1.5 grades offset for strong combustion noise
- Less deviation if mechanical noise is dominant

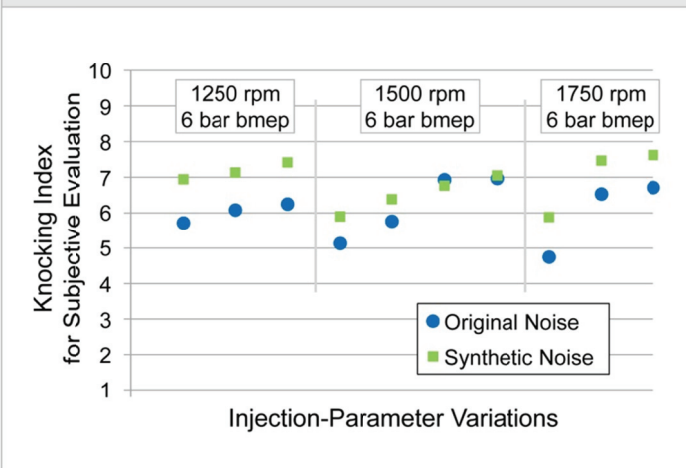
Results

Engine Noise Synthesis

Mic./Synth. Comparison

Diesel Knock Prediction

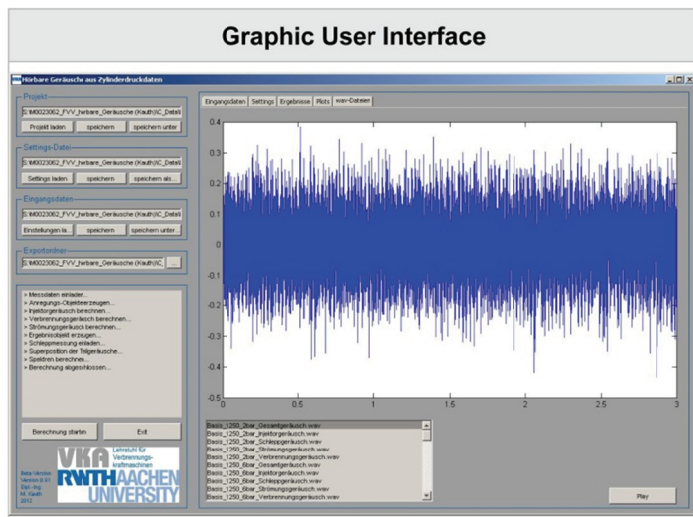
Subjective Knock Evaluation, Synthetic Noise vs. Original



- Variation of injection timing, pilot timing or quantity, rail pressure
- Constant speed and load
- Offset toward better knock rating
- Almost identical relative evaluation!
- Same resulting classification

Results

Software Tool



Features

- Modular structure (interchangeable elements) easy-to-adapt
- Data import
- Calculations
- Results representation, playback and export

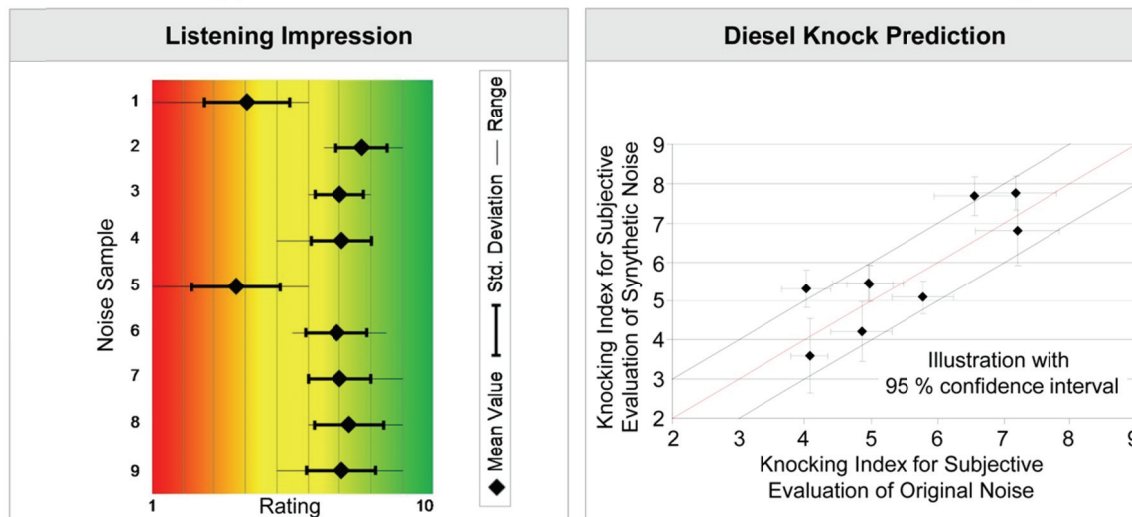


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Results

Robustness – Application to a Dataset from FVV: Noise-Controlled Diesel Engine



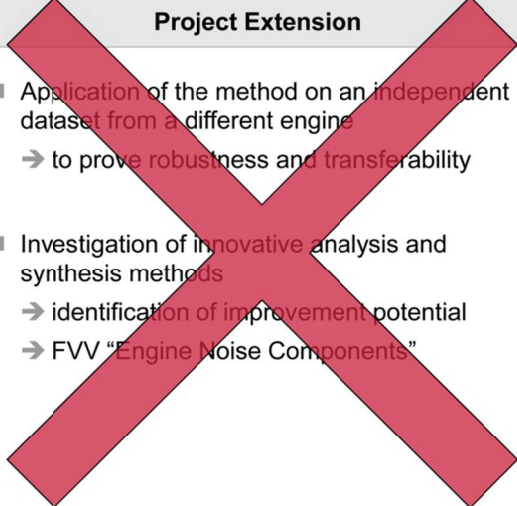
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Outlook

Project Extension	Requested Follow-up Project
 <ul style="list-style-type: none">■ Application of the method on an independent dataset from a different engine<ul style="list-style-type: none">→ to prove robustness and transferability■ Investigation of innovative analysis and synthesis methods<ul style="list-style-type: none">→ identification of improvement potential→ FVV "Engine Noise Components"	<ul style="list-style-type: none">■ Advanced techniques for noise component identification and quantification■ Comprehensive assessment of injector noise■ Improved synthesis algorithms with phase consideration■ Generation of standard transfer functions based of comparative datasets

Project Extension already conducted

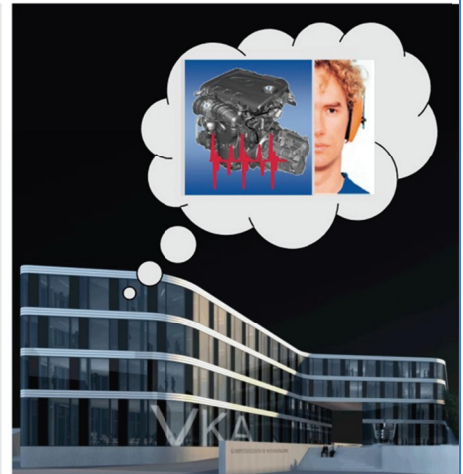
Summary

- A method has been developed that allows for the calculation and synthesis of engine noise based on data from a thermodynamic test bench.
- One engine was thoroughly assessed to determine the relations between excitation and noise.
- The methodology was developed and implemented in a software tool.
- A subjective evaluation study was conducted.
- The results show:
 - Good conformance for comparisons of synthetic noise to microphone measurements.
 - Relative rating for different calibration variant well possible.
 - Robustness has been confirmed by application to a independent dataset.
- A software tool was delivered that enables the evaluation of noise quality on the basis of thermodynamic test bench data.



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for the funding and to the
accompanying work group under
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for the great support!**



Aachen, 26. November 2013
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