Virtual Noise Synthesis
listening to machines that don’t exist

Goran Pavić
Acoustics & Vibration Laboratory
National Institute of Science
Lyon, France
evolution of noise demands

- time-to-prototype of industrial products forced to reduce
- noise increasingly judged by both its level and its subjective quality

<table>
<thead>
<tr>
<th>Legislation</th>
<th>Competition</th>
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<tbody>
<tr>
<td>level</td>
<td>comfort</td>
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Needs of industry: understand noise / have adapted tools / autonomy.

Usual task of noise control: entire re-design
- modify coupling between components
- apply absorption / shielding.
The majority of assembled products involve components produced by external suppliers.

- Suppliers feel little concerned with noise of the assembled product.
- Assemblers often formulate unjustified demands on suppliers.
- There is a deep shortage of data on noise of components.
- Regulations concern finalised products only, not components.
- Little data exist on vibration and fluid pulsation which cause noise.
- Commercial noise software → poor understanding → low creativity.
- Software does not cover the most important factor → noise sources.
noise prediction entirely by computation?

feasible?

difficulties in modelling:
- primary sources
- material, joints, trim
- contact, connections
- distributed excitation

industry software:
- FEM, BEM
- SEA

other methods:
- ray tracing
- SEA upgrades
- hybrid approaches
- other approaches

answer → no

Engineering software favours detail & graphical presentation but lacks the realism of true manufacturing and operating conditions!
passive and active components

active component = source
(fan, pump, compressor…)

passive component = transmitter
(hood, duct, cavity, open space…)

Excitation

Transfer

Reception

Interaction

Effect of interaction:

- noise level is changed, sometimes increased
- subjective noise perception is modified
how to make reliable predictions?

- entirely by computation
  - not realistic results
- entirely by measurement
  - missing interactions
- combine measurement & computing
  - looks like a good idea
  - but can we do it?

yes, we can!
by hybrid sub-structuring!
sub-structuring: the principle

Steps (building block approach):

- break the whole unit down to components
- characterise each component separately
- compute coupling state at interfaces
- reconstruct global behaviour.

Key advantages:

- characterisation of components → by either measurement or computation!
- breakdown done on functional components → true industrial approach!

Many key components, such as sources, usually exist before finalisation
   → characterise by measurements!
example: lawn-mower

two noise sources: engine + blade

two transmitters: mounts + deck

direct air-borne engine noise

structure-borne excitation due to engine vibration

source I: engine

structure-borne excitation due to blade vibration

source II: blade

deck and air gap noise due to blade-induced pulsations

reflected air-borne engine noise

blade noise via deck outlet

noise at the receiver (ear)
noise sources

- excitation
- transfer
- reception

frequency

highly sensitive to detail

moderately sensitive to detail

air-borne

- fluid-borne
- structure-borne
air-borne source characterisation

1) replace the real source by several elementary sources.

2) develop the surface pressure and normal particle velocity into orthogonal functions.

3) discretise the surface into patches and apply classical point-impedance approach.

4) use a dummy source of simple geometry.
structure-borne noise characterisation

Source characterised by:
- free velocity or blocked force
- coupling mobility or impedance

Transmission characterised by:
- coupling mobility or impedance
- TRF coupling / reception points.

characterisation in coupled state
fluid-borne noise characterisation

- blocked pressure
- coupled pressure

- two-load method: synchronisation!
- four-load method: synchronisation!
..allow engineers simulating the impact of design alternatives on the noise of the final product.
transfer: uncertainty syndrome

excitation  transfer  reception

highly sensitive to detail  moderately sensitive to detail

FRFs of 48 “identical” beer cans
Fahy & al, 1993

FRFs of 57 “identical” vans
Kompella & al, 1994
Example: noise radiated by a steel plate:

- *shape variation*: ± 20%
- *surface variation*: ± 20%
- *average:*

Transmission paths: average out details → use base features of the entire family of similar objects → smoothing!
This corresponds to simplifying the transmission path model!
phantom periodicity

synthesis is done by convolution (*): $p(t) = s(t) * h(t)$

response pressure waveform
source waveform
path impulse response

exact impulse response:

$\tilde{H}$

effect of band averaging:
tests of smoothing

smoothing the transmission:

- Source: original path → target sound
- Smooth path: smooth source → synthesised sound

smoothing the source:

- Original source: path → target sound
- Smooth source: smooth path → synthesised sound

### Smoothing Bandwidth

- **Random**:
  - 10 Hz: 0
  - 20 Hz: 1
  - 50 Hz: 4

- **Periodic**:
  - 10 Hz: 0
  - 20 Hz: 0
  - 50 Hz: 1

### Transient

- 2 Hz:
  - 0
  - 1
- 5 Hz:
  - 0
  - 1

- Smoothing: source → path
examples of synthesis: electrical equipment

early synthesis: 2003

telecommunication station

cooling fan

68.2 dBA 70.2 dBA
examples of synthesis: refrigerator

diffraction by cabinet

reflection by hard walls

SB direct

SB via mounts

0.21 mm/s pulsations

3.7 mm/s oscillations

puls

osc

radiation efficiency
Examples of synthesis: lawn mower

- Engine
- Hood
- Chassis
- Blade
- Deck
- Exhaust

Level change:

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<tr>
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<th>DECK%</th>
<th>EXH%</th>
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<td>100</td>
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- +4 dBA
- +2 dBA
- -2 dBA
- -4 dBA

Equal dBA noise:

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synthesis by sub-structuring: summary

- allows merging computation and measurement data
- sources → fairly detailed characterisation
- transmission paths → smoothing for robustness & accuracy
- full-scale characterisation fairly demanding
- industrial applicability → pragmatic simplifications.

- suitable for a large variety of products
- offers increased independence to designers
- improves understanding of noise physics
- rank order different noise transmission paths
- assist in the analysis of noise reduction
- enable specifying demands on noise of components
- enables noise data exchange suppliers ↔ assembler
- helps clients to shape the desired sound.