SOUND IN PRODUCT DESIGN

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RH Lyon Division

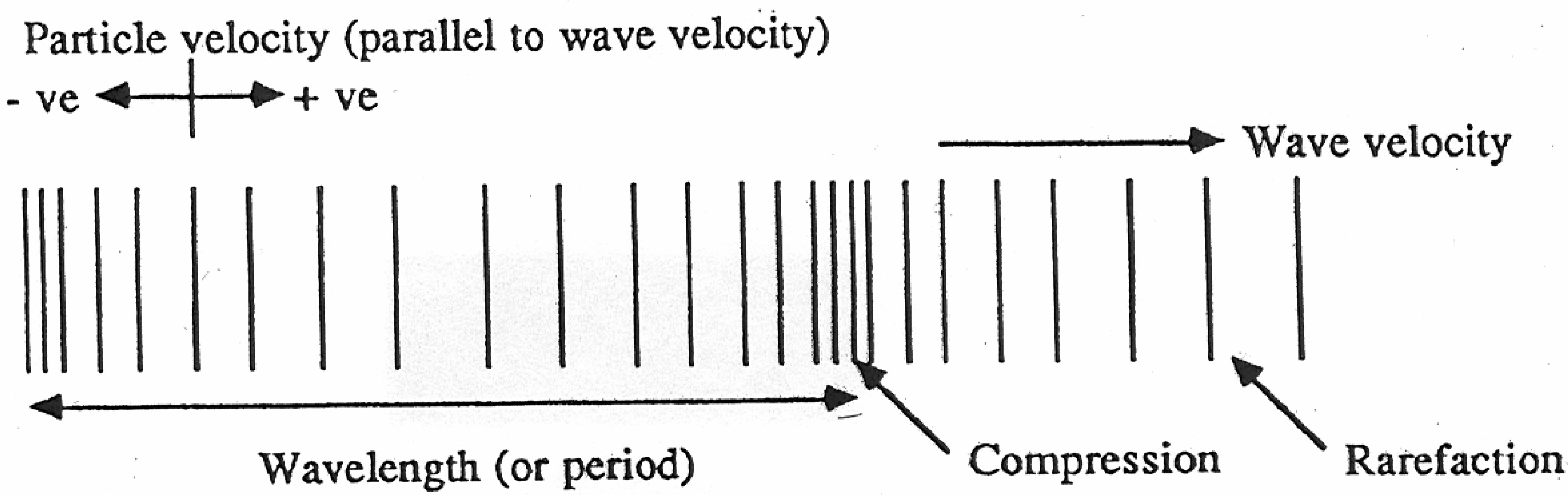
Topics

- Some Background on Acoustics
- Quiet Product Design
- Sound Quality

Some Background on Acoustics

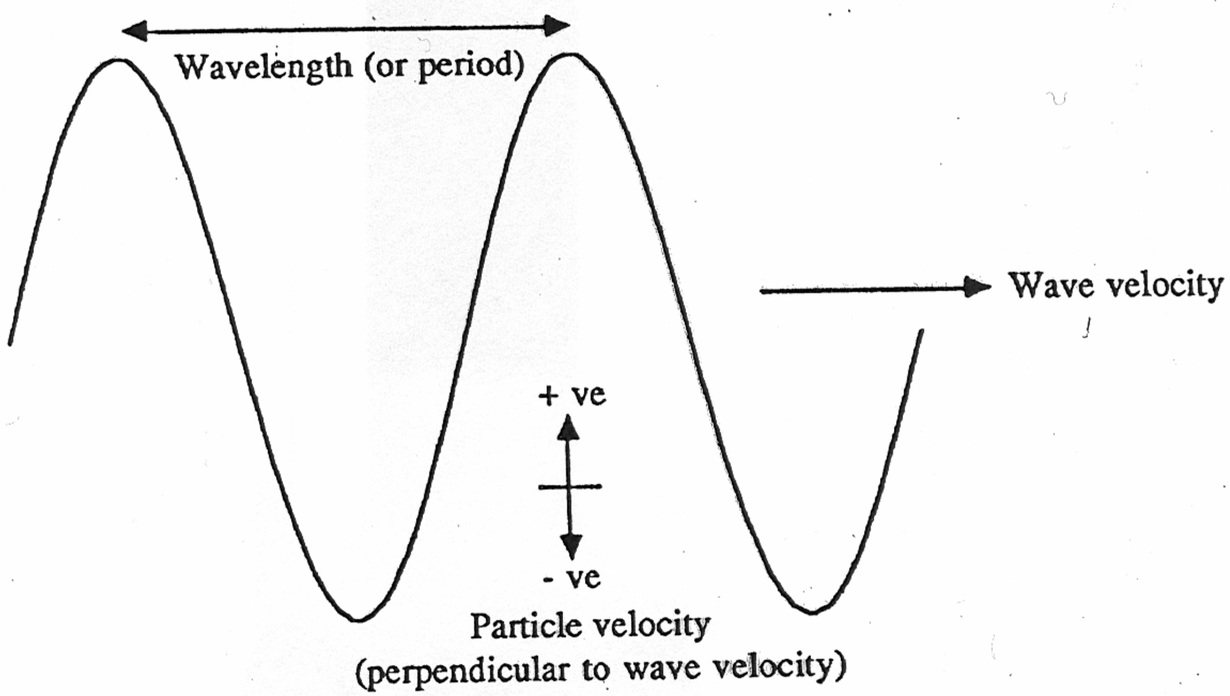
- A quick review of some basic concepts

Compressional Waves



(a) Compressional (longitudinal) wave

Bending Waves in structures



(b) Flexural (transverse or bending) wave

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Acoustical Units

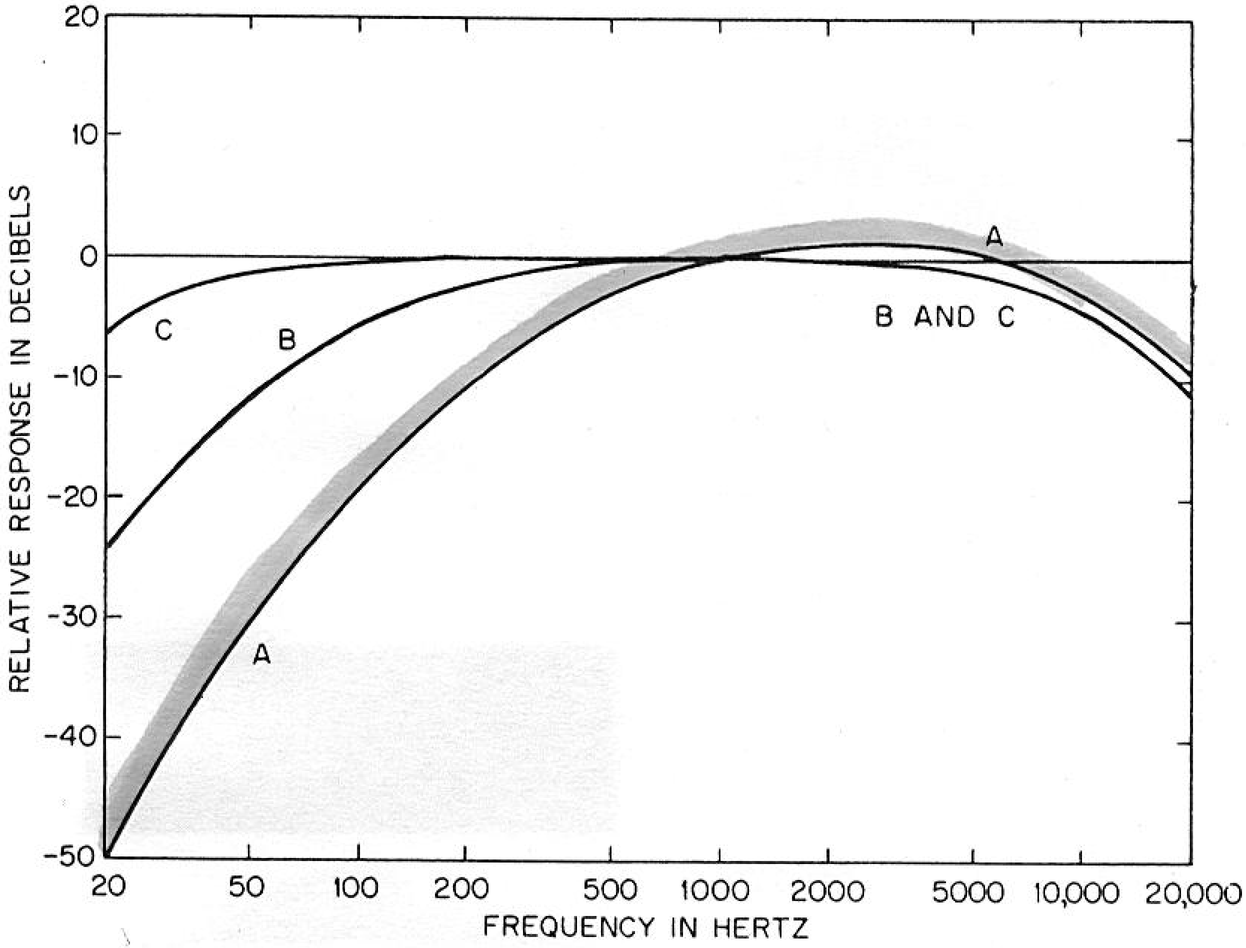
- **Sound Pressure:** A measure of the environment's "reaction" to a sound source. This is what a microphone measures - units are *Pascals*.
- Sound Pressure Level, in dB:

$$\mathbf{20*log_{10}(Prms/Pref)}$$

where Pref = reference pressure of 20 μPa.

- **Sound *Power*:** A measure of the source's property only. A derived quantity - units of *watts*.

A-weighting



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Quiet Product Design

- Incorporate noise/vibration considerations into the design phase
- Most cost effective means of noise control
- May also improve performance/functionality

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- Often synonymous with sound level, but not the only criteria involving noise (*sound quality*)

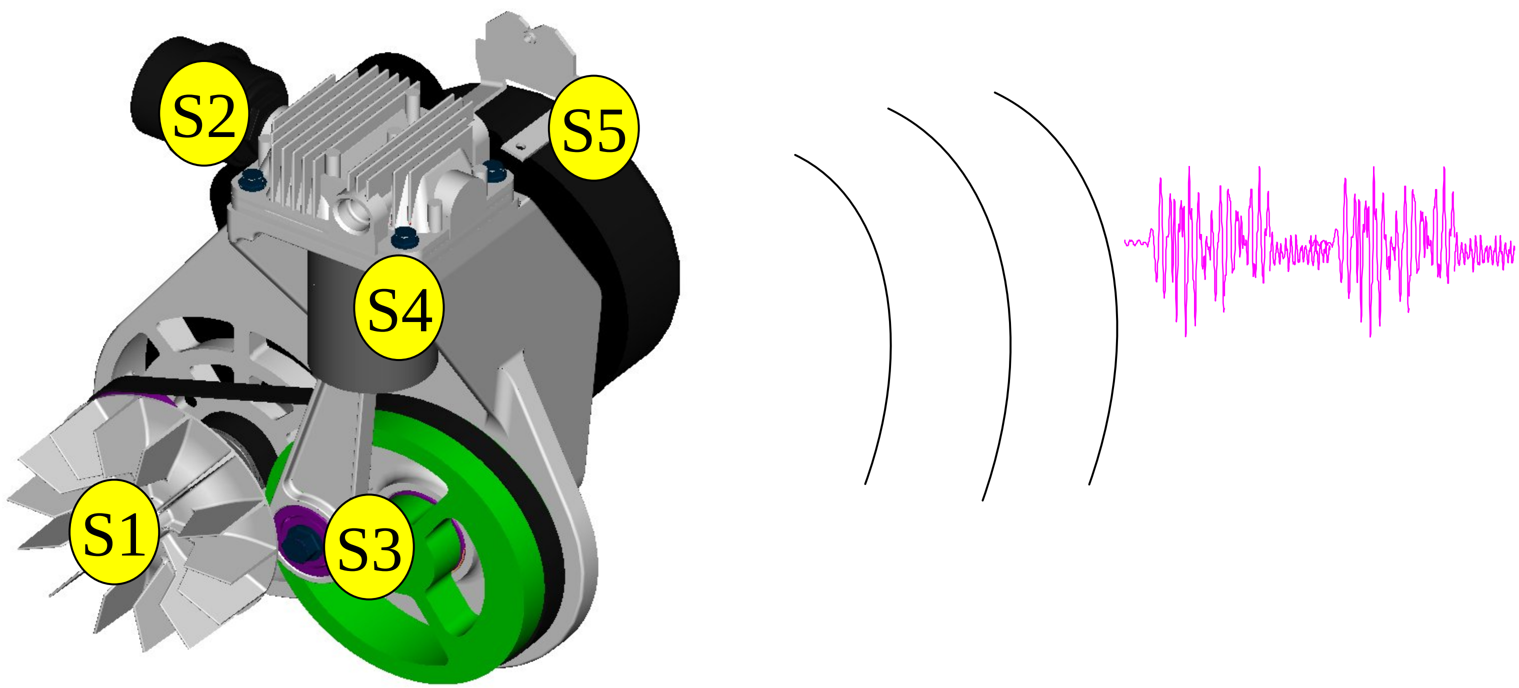
Listener Reactions to Changes in Sound Level

- 1 dB $\Rightarrow$ Smallest perceivable change
- 3 dB $\Rightarrow$ Noticeable change
- 6 dB $\Rightarrow$ Significant change
- 10 dB $\Rightarrow$ Judged to be one half as loud.
  This is a very significant noise reduction.

Example of Addition of Sound Levels

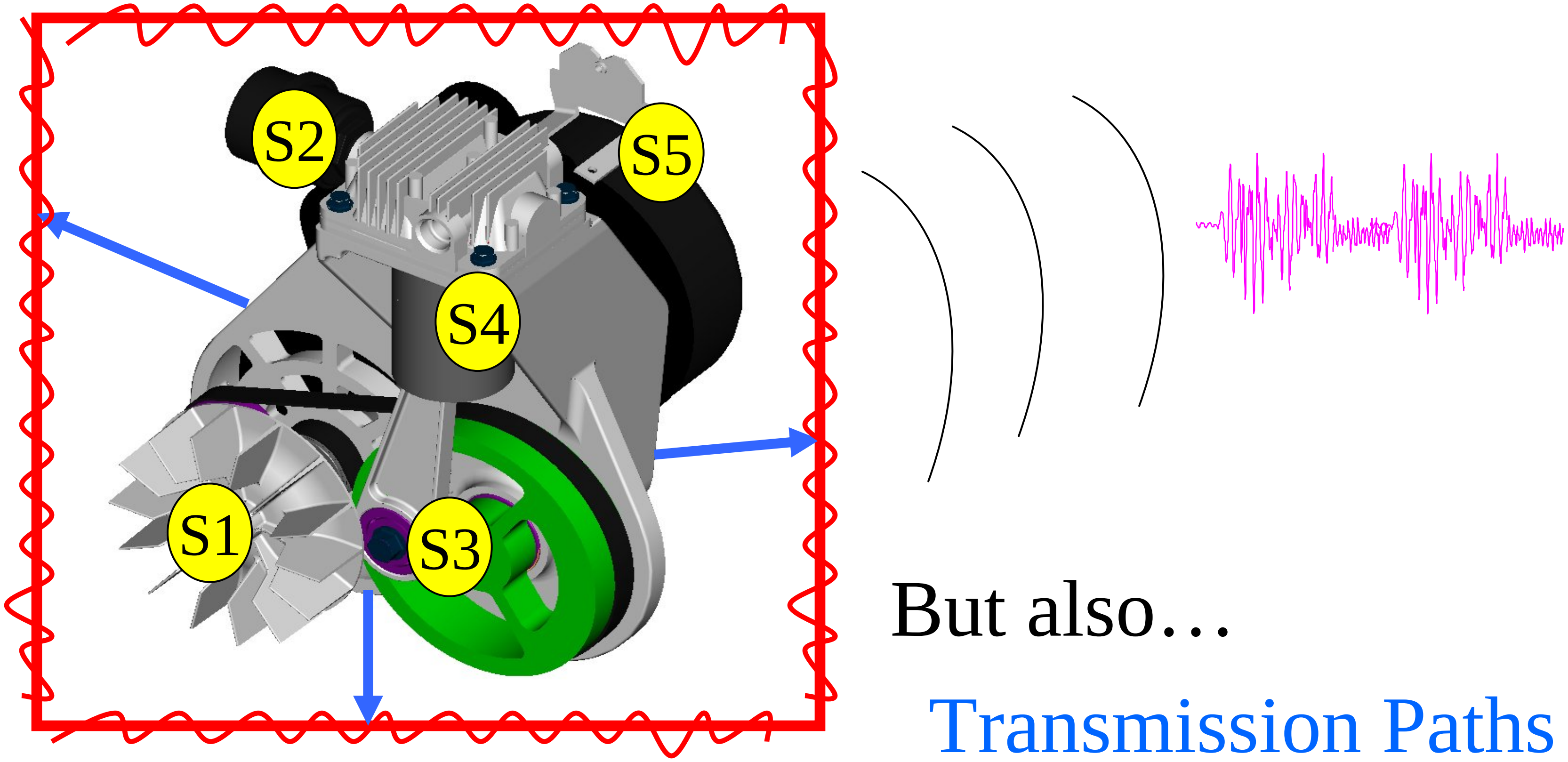
- Two fans each Lw = 37 dBA. Resulting overall level is 40 dBA.
- If we want an overall level of 37 dBA we could either:
  - Reduce both fans to 34 dBA, or
  - Leave one fan alone and reduce the other by ~12 dB. or
  - Reduce one fan to 35 dBA and the other to 33 dBA.

Where Does Product Sound Come From?



Primary Sources

Where Does Sound Come From?



But also…

Transmission Paths

Radiating Surfaces

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Sources and Mechanisms of Sound

<u>Characteristics</u>:
-Broadband or Tonal

<u>Transmission</u>:
-Airborne
-Structureborne (from vibration)

<u>Typical Sources</u>:
- Fans
- Impacts
- Fluid flow
- Stick-slip
- Gears
- Electrodynamic
- Imbalance
- Combustion

☞ e.g., rapidly changing forces, mass/heat injection, or shearing

Quiet Products Result from

- Identifying the potential sources of excitation, path, and radiation
- Minimizing unwanted noise by:
  - ***Choosing a quiet*** source, or modifying the source
  - ***Blocking*** potential paths (mass / stiffness)
  - ***Absorbing*** the sound (foam, etc.)
  - ***Reducing*** radiation coupling & vibration
  - ***Canceling*** the sound at observation point by creating a source (active noise/vibration control)

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Means of Noise Control

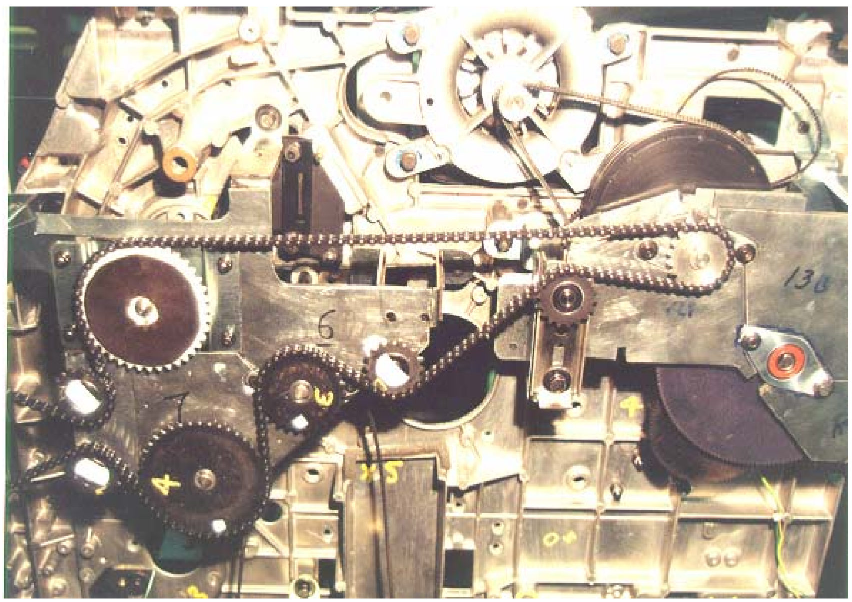
Airborne:

- Absorb the sound (absorption coefficient)
- Block / enclose the sound (transmission loss)
- Alternative design!

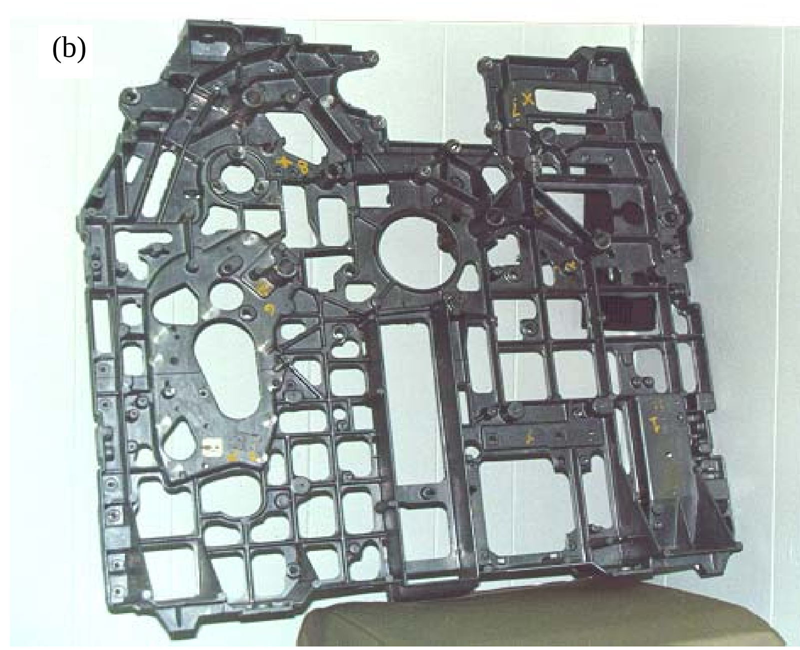
Structureborne:

- Isolate the source
- Damp the radiating surfaces
- Reduce radiation efficiency of radiating surfaces (perforation)
- Alternative design!

Example of Reducing Radiation Efficiency



Original structure inside color copier



Modified structure

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Measuring Product Sound

- To qualify individual components
- To determine contribution of various sources (noise audit)
- To measure improvements as product evolves
- To determine overall level
- To investigate statistical spread in Lw

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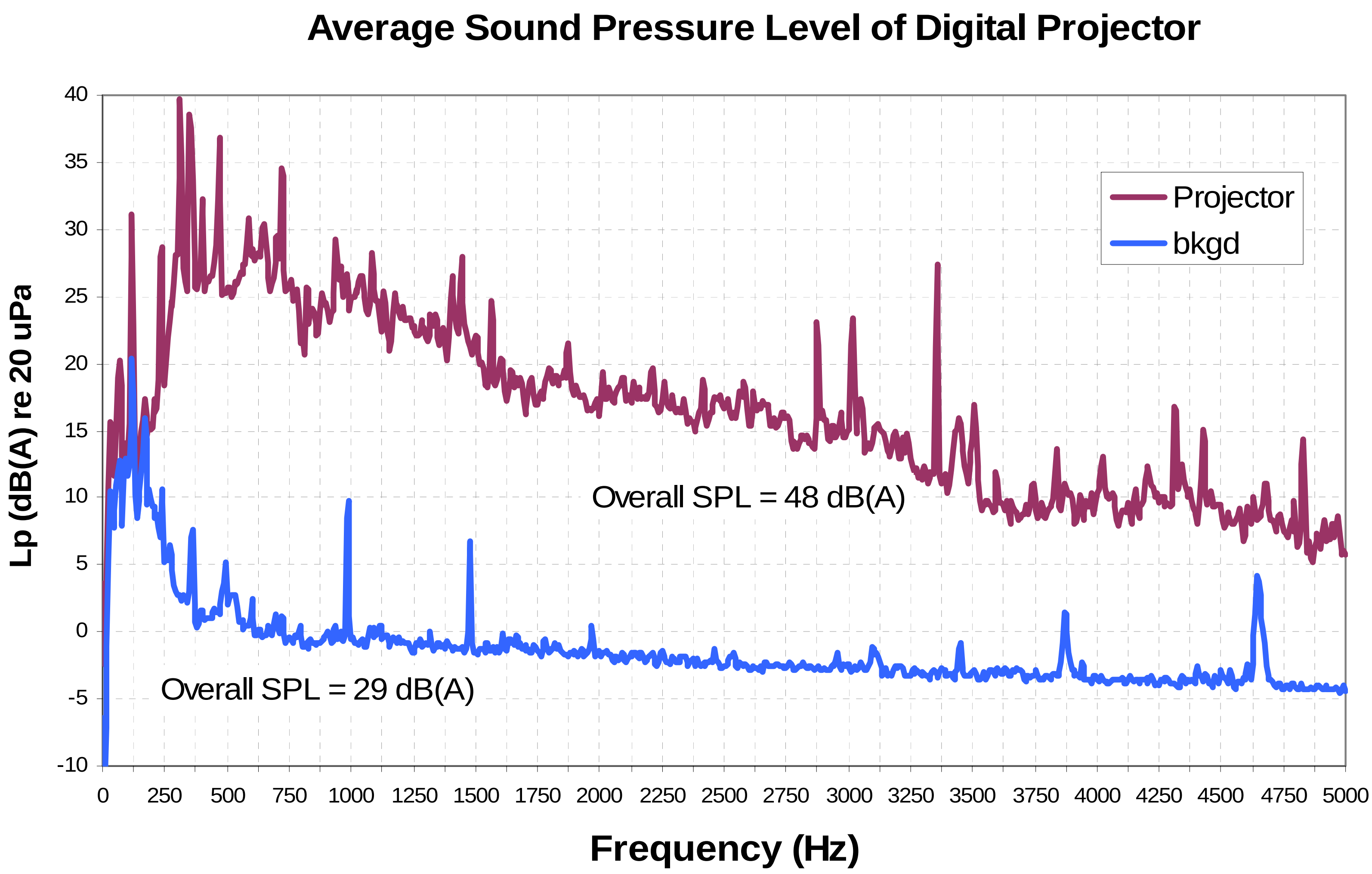
Meaningful measurements require:

- Accurate instrumentation
- A designated measurement location meeting certain criteria
- A repeatable procedure

Narrowband Spectra



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Measurement Facility

- Two possible configurations:
    - Reverberation Room - develops uniform sound field
    - Anechoic Chamber - free field conditions

Repeatable Procedure

- In Reverberation Room
  - Sweep through space in repeatable way
  - Maintain low background
  - Maintain integrity of room (stable configuration)

- In Anechoic Chamber
  - Microphones must be positioned accurately

Standards & Labeling

- Increasingly noise emission is being included in voluntary eco-labeling programs.
- For some products the EU is setting “not to exceed” sound power limits.
- ISO 7779 - Specifies measurement of Sound Power in both reverberation and anechoic rooms.
- The US is lagging behind in noise emission standards and labeling.

Sound Quality

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What is Sound Quality?

Definition:

"Sound Quality (SQ) is the perceptual reaction to the sound of a product that reflects the listener's reaction to the *acceptability of that sound for that product* - the more acceptable, the greater SQ."

Sound Quality Challenges

- Often overlooked or ignored by designers
- Can create havoc when specifying components
- Difficult to convince your client of its importance
- Competes with overall sound level in evaluating the success of product design

Why is Sound Quality Important?

- Perceived SQ as a product differentiator
  - Low Perception => Lower margin/market share
- Need to predict during design phase
  - Redesign => Delayed TTM
- Hard to predict based on physical attributes alone
  - Trial & error => Delayed TTM, Cost
- Bottom line loss:
  - Revenue loss, margin loss, expensive multiple redesign

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Degradation of Sound Quality in Products

- Device whose sound and function are at odds
- Device with unexpected, “unpleasant” or otherwise “unsuitable” sounds
- Often tonal noise reduces sound quality

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- Designers need to be diligent and avoid!

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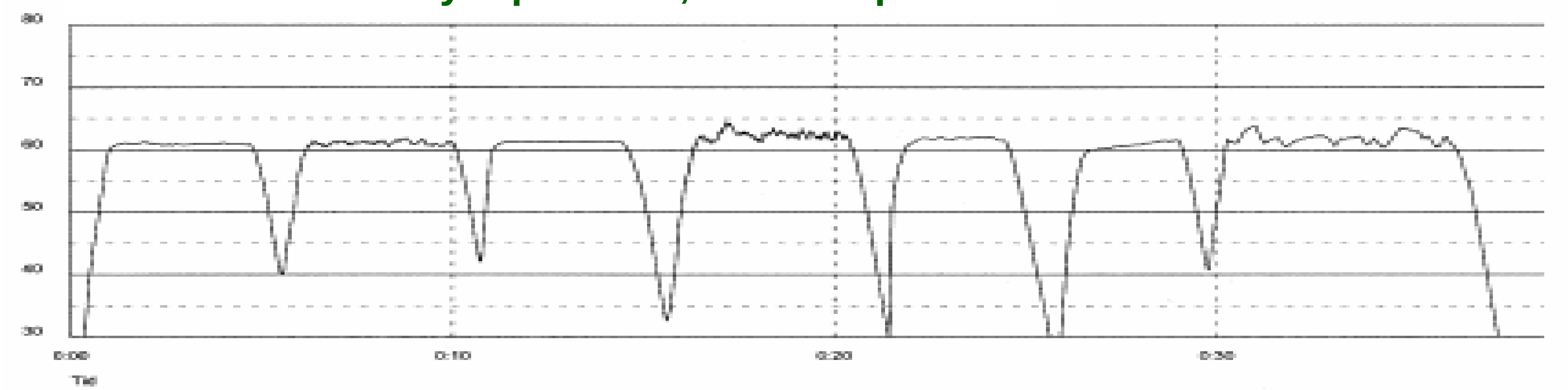
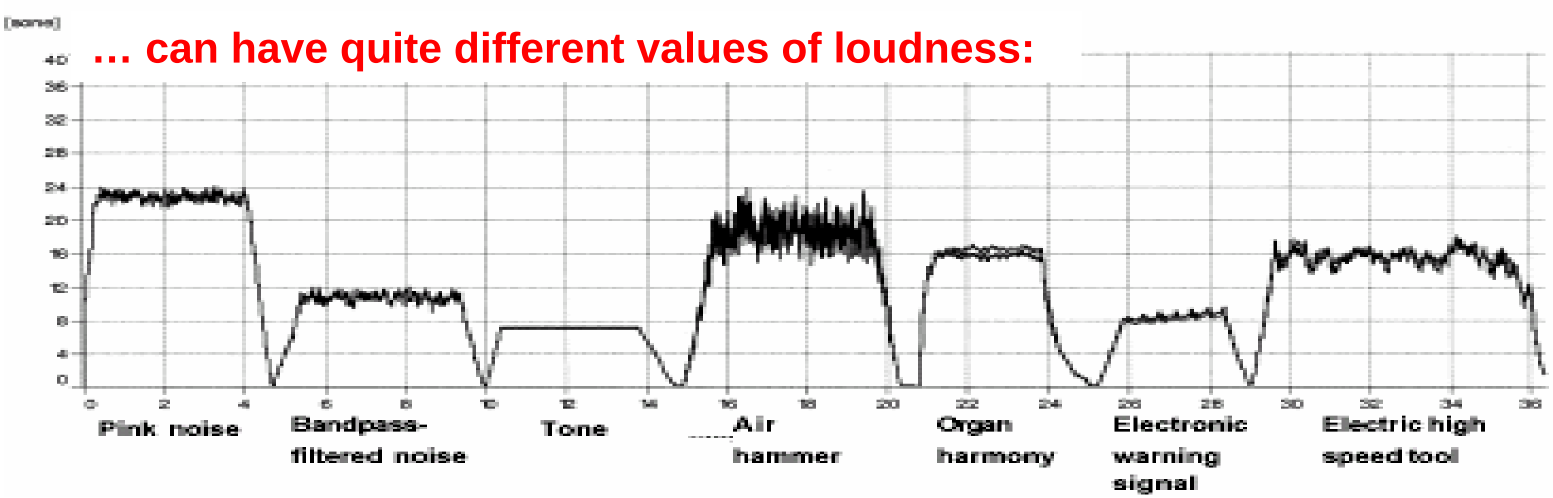
Overall A-weighted sound level doesn't always tell the full story!

Sounds with nearly equal dBA, for example …



… can have quite different values of loudness:



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SQ metrics can help …

- Loudness
- Sharpness
  - high-frequency components
  - acum, 1 kHz, narrow band (<150 Hz), (Lp=60 dB)
  - almost level independent (Aures), Zwicker disagree
- Fluctuation strength
  - Amplitude modulation (< 15 Hz), maximum at 4 Hz
  - vacil, 1 kHz, Lp=60 dB, AM of 4 Hz
- Roughness
  - AM or FM (15…300 Hz)
  - asper, 1 kHz, Lp=60 dB, 100 % AM of 70 Hz
- *Others…*

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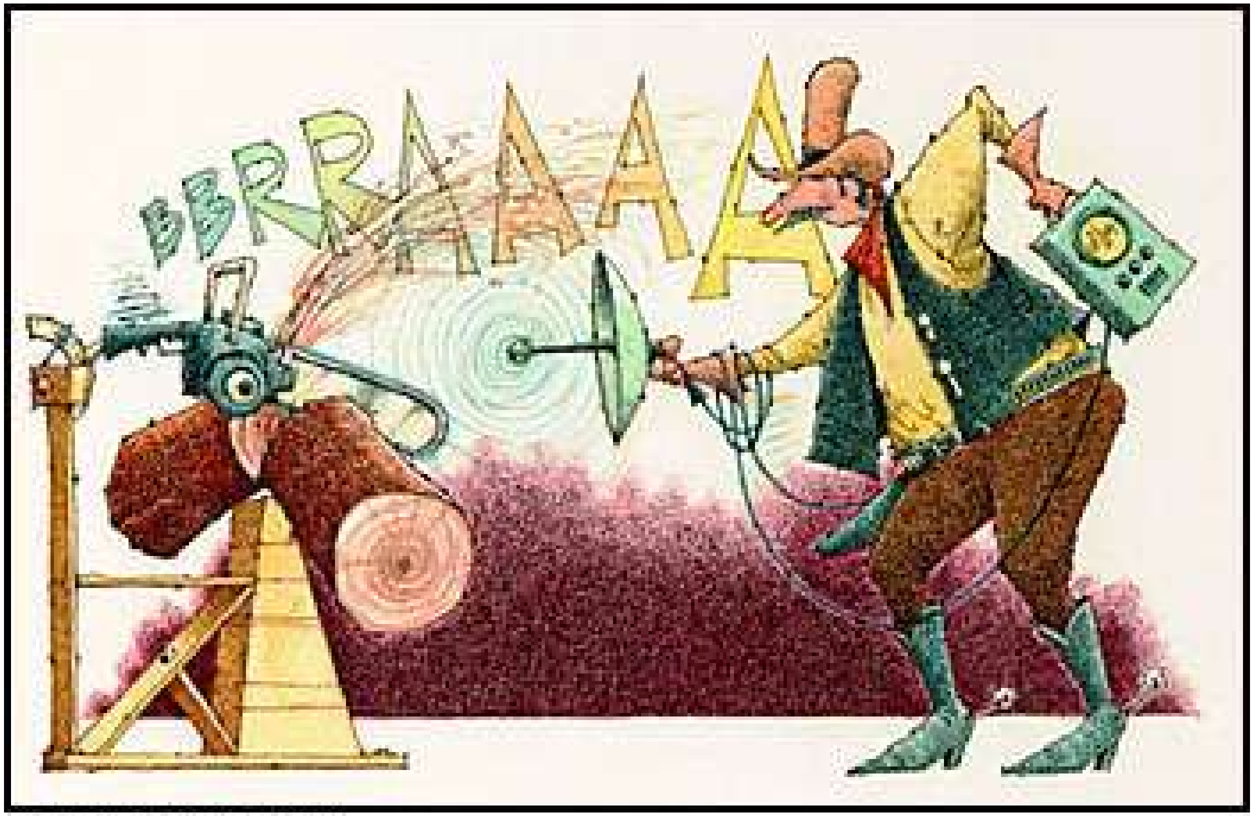
But, even SQ metrics often don't capture full range of ***product-specific*** user perceptions …



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Examples of SQ metrics not correlating well with user perceptions

- Originally was thought that Loudness would predict when product sounds were objectionable –
  - *1950's: Jet aircraft that measured equally loud as prop. planes were much more annoying…*
  - This led to development of "perceived noisiness" metric.
  - PNdB worked well for predicting annoyance of aircraft noise *but not for, example, highway noise or public acceptance of sonic booms*.
- A piano recording played backwards –
  - Sounds more like an organ than a piano, but values from standard metrics would all turn out to be the same.

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Acceptability of Product Sound

- Dimensions of product sound affecting acceptability:
  - Strength or magnitude (dBA, Loudness, speech interference)
  - Annoyance value (noisiness, roughness, sharpness, PNdB, tonal prominence – bothersome aspects of the sound)
  - Amenity value (regularity, harmonicity, pleasing aspects)
  - Information content (identification, performance, condition of the product, appropriateness)
- *Sound Quality is a response of people, not a meter*
- Generally product-specific

  "*A good lawnmower does not sound like a good refrigerator*"

SQ Jury Testing

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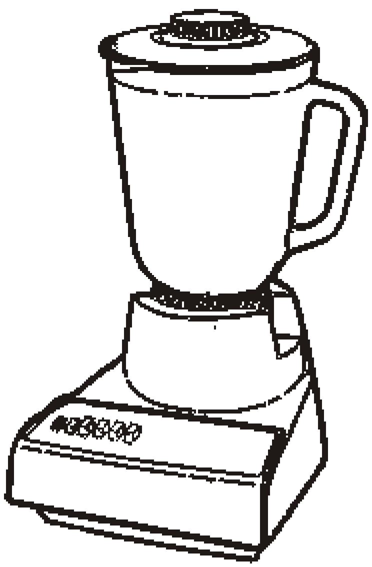
Listening Panels Determine:



- Sound quality preferences
- Product design goals
- Critical component sounds
- Directions for new designs
- Product preferences

Elements of SQ Jury Testing

- * **Statistical design of the experiment**
- * **Preparation of stimulus signals**
- **Measurement of a "metrics profile" for each stimulus (optional)**
- **Presentation to jurors, recording of jury responses**
- **Data analysis:**

  (1) "Qualitor diagrams" (tells how SQ would be enhanced or decreased by changes in individual component sounds)

  (2) Metrics profile to SQ transformation (allows physical measurements to predict effect of product changes on SQ)

Elements of SQ Jury Testing

- **Statistical design of the experiment:**
  - Type of study (magnitude estimation, semantic differentials, paired comparisons, etc.)
  - Parameters (no. of: component sources, operating modes, SQ attributes, participants and repeats; presentation order, 1st or 2nd order regression, interaction terms:

    ⇒ DOE type, for adequately “spanning the range” (simplex, central composite, Box-Behnken, etc.)

    ⇒ Confidence level of results

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Elements of SQ Jury Testing

- **Preparation of stimulus signals:**
  - Appropriate recording of individual component sounds (or just entire unit(s) if limited to a "product preference" type of study)
  - Signal processing to separate out component sounds if not physically possible to record separately
  - Vary levels of components and mix together according to DOE, to create a collection of "virtual" products.

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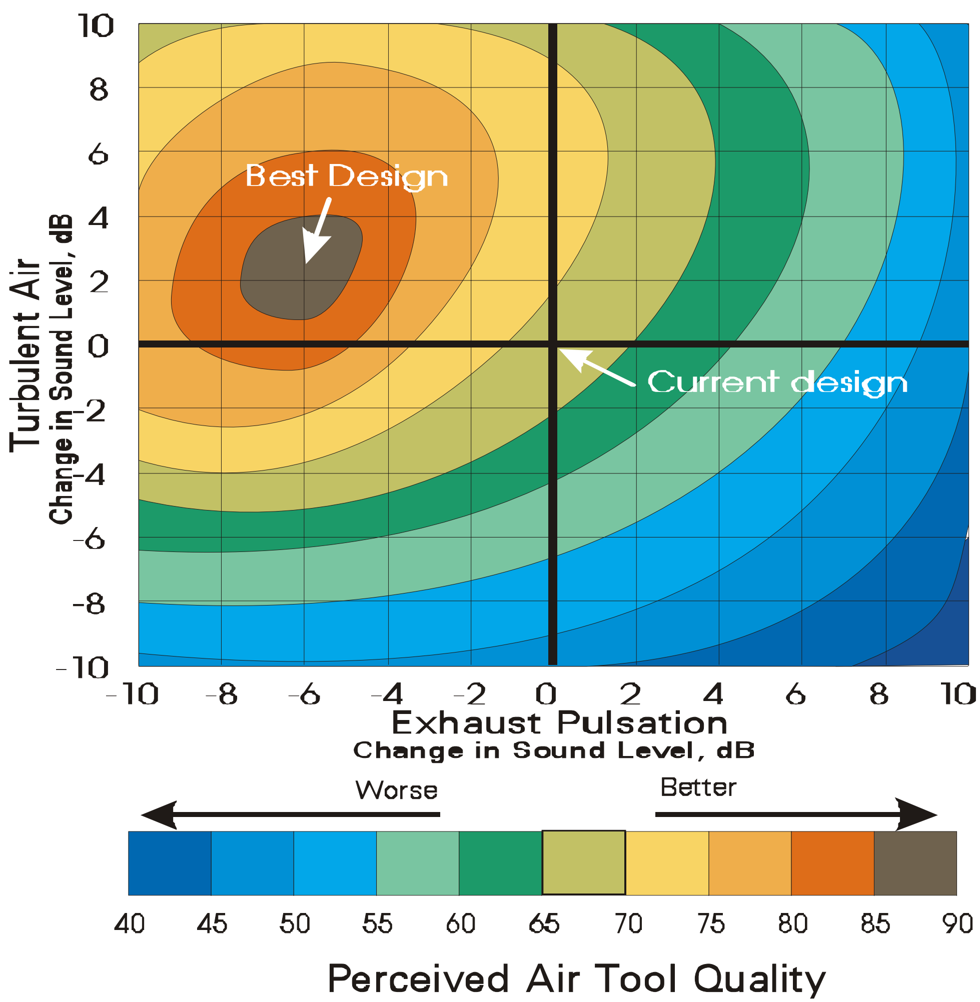
Example of Component Sounds for a Vacuum Cleaner

1. Complete Vacuum Cleaner
2. Motor (w/. cooling fan) Sound (**M**)
3. Airflow Sound (**A**)
4. Agitator (Beater) Sound (**B**)
5. Suction Fan Sound (**S**)

SAMPLE SEQUENCE OF SOUNDS FOR JURY TEST, in "steps" (1 step = 4 dB):

	M	A	B	S
a.	+1	-1	+1	+1
b.	-1	+1	-1	+1
c.	-2	0	0	0
d.	0	0	0	0
e.	0	+2	0	0
f.	+1	-1	-1	-1

Contour Plots from Regression Functions ("Qualitor Diagrams") Show Route to Better Design



- Quantifies tradeoff between perceived SQ and changes in sound levels of various components.
- Contours show designs of equal user acceptability.

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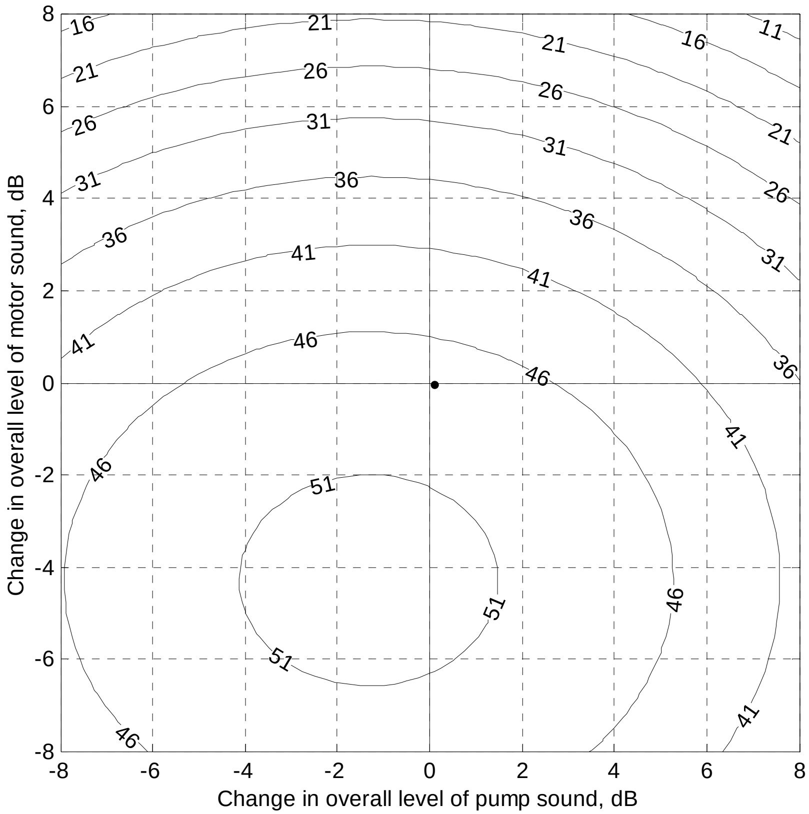
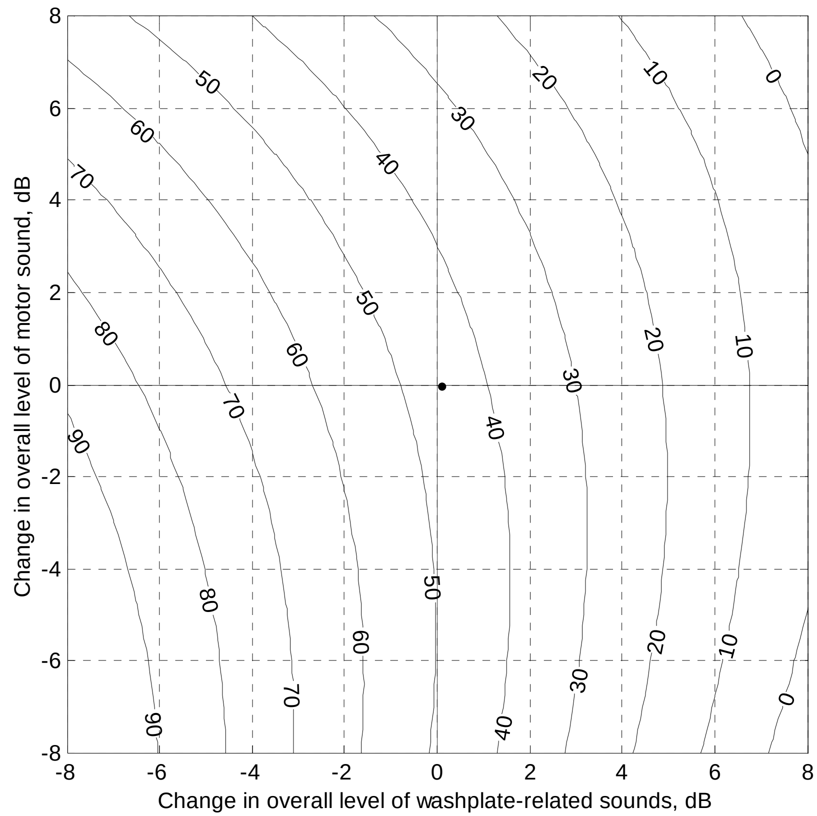
Qualitor Diagrams from a Washing Machine SQ study (wash cycle sounds)



Perceived quality rating versus sound levels for *pump* and *motor* sounds



"**Gentleness**" rating versus sound levels for *washplate* and *motor* sounds

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