Importance of NVH

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Vibro-Acoustics Consortium

HVAC and Refrigeration Industry
- Emerson Climate
- Ingersoll Rand (Trane)
- JCI York
- Transicold Carrier

Heavy Equipment Industry Diesel Engines
- Caterpillar, Inc.
- Cummins Inc.
- Deere and Company

Automotive / Motorcycle
- Active Exhaust Corp.
- Dana Corp.
- DENSO International
- Eaton Corp.
- Ford Motor Company
- Harley-Davidson Motor Co.

Small Engines / Generator Sets
- BASCO
- Kohler Corp.

Absorbing Materials
- 3M Company
- American Acoustical Products
- Blachford Inc.
- Commercial Vehicle Group
- Federal Foam Technologies

Other
- Bechtel Marine Propulsion Corp.
- Ebco Inc.

VAC Mission Statement

- Identify, demonstrate, and assess vibro-acoustics software
- Conduct experiments to verify vibro-acoustics software
- Train, formally and informally, VAC members in the use of vibro-acoustics software and experimental methods
- Develop noise reduction solutions

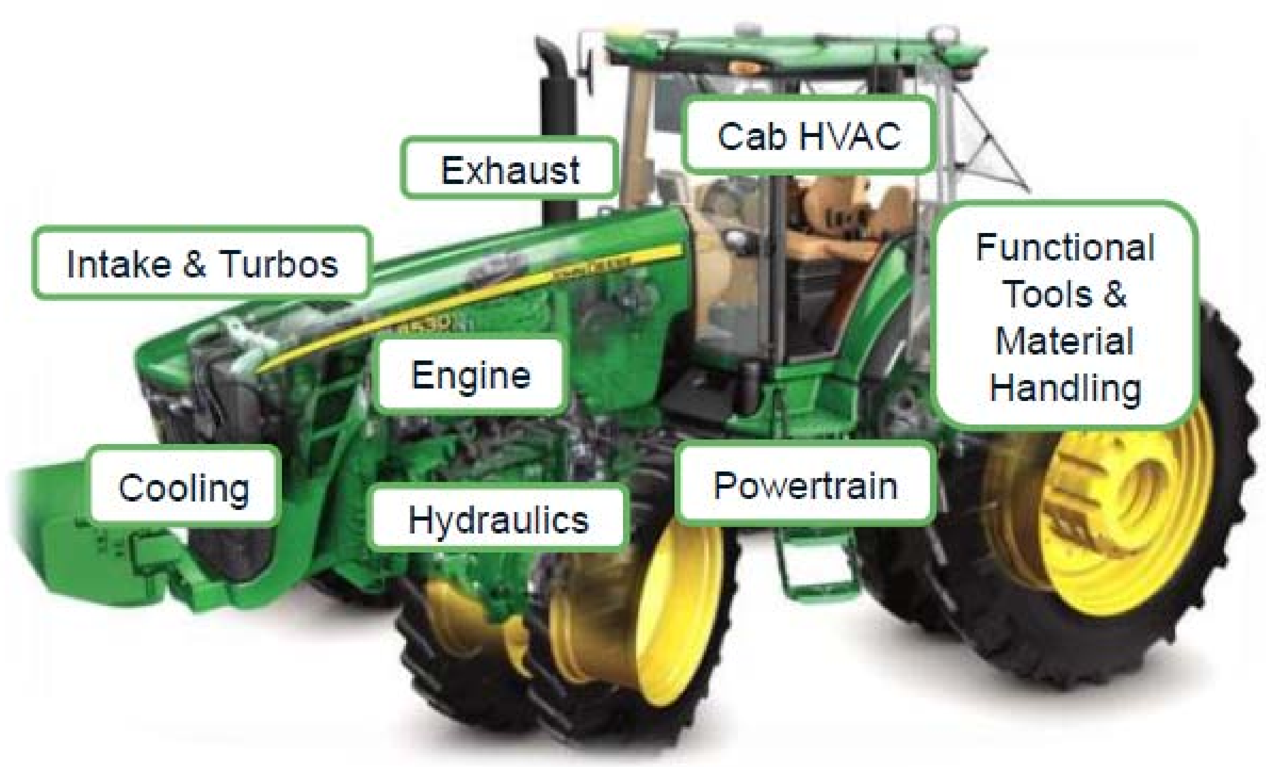
Overview

- Importance of NVH
- Sound Quality
- Fluidborne Sound Propagation

Heavy Equipment Little NVH Concern

Historically, noise and power were equivalent.

Heavy Equipment Multiple Sources



Heavy Equipment Improvements

- Noise has been reduced by 10 dB(A) in some motor graders and four-wheel drive loaders while power has increased by 15%.
- In cab noise levels are under 70 dB(A).
- Improvements have been driven by
  - ✓ EU Outdoor Equipment Noise Directive 2000/14/EC set limits for each type of equipment in 2002 then lowered baseline sound powers an additional 3 dB(A) in 2006.
  - ✓ Advanced technologies like high efficiency fans that reduce fuel consumption and are quieter, and SCR and DPF filters that reduce bark and roar of engines.
- Jurors were willing to pay $600 for a quiet tractor ($23,000 base price).

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The Field of NVH

General terms for the area

- Vibro-Acoustics
- Noise, Vibration and Harshness (NVH)

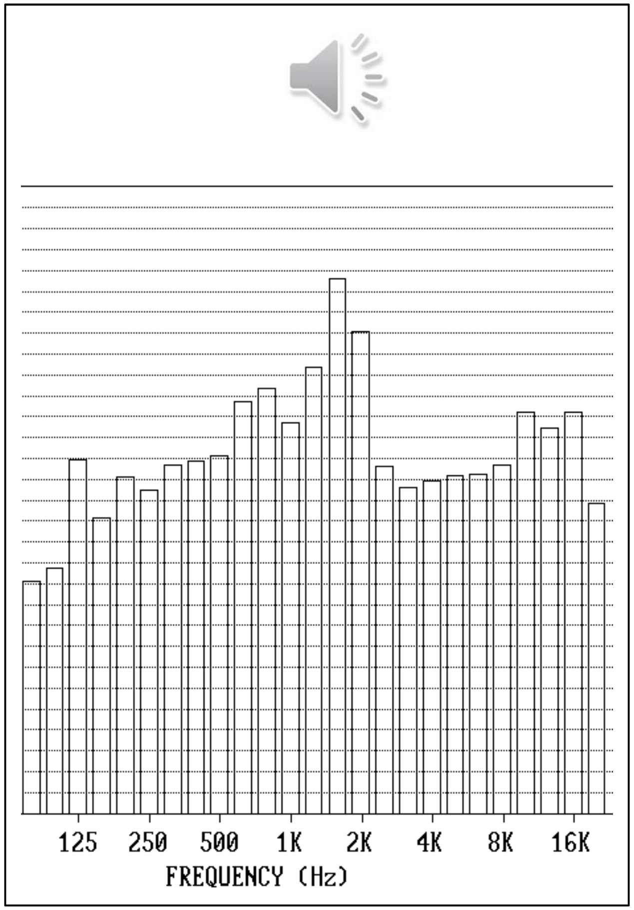
Harshness is a reference to sound quality

- Examples include the Harley-Davidson engine and the Mercedes door closing
- Subjective descriptors like “sharpness”, “rawness”, and “boxiness”

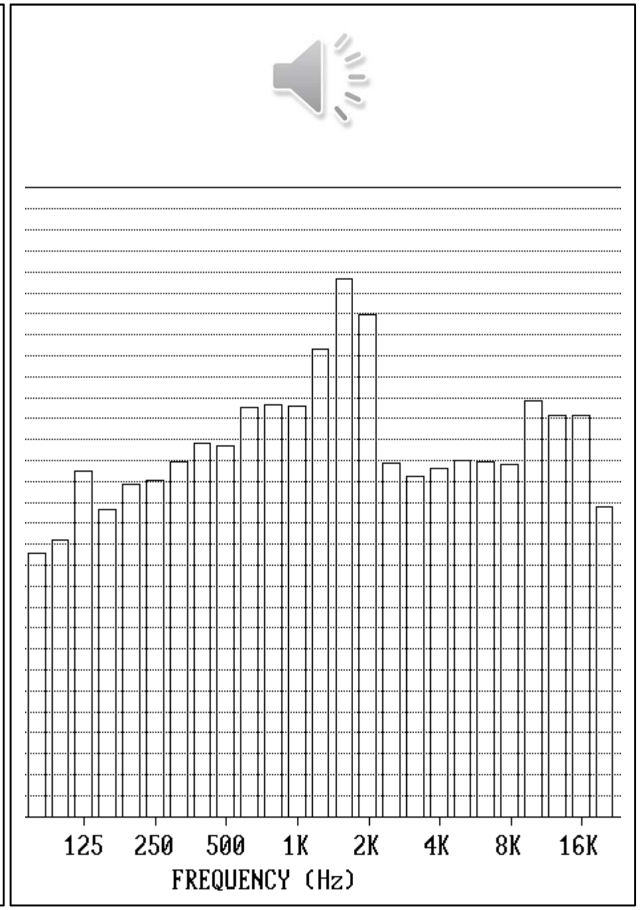
Sources of noise

- Vibration
- Flow
- Combustion

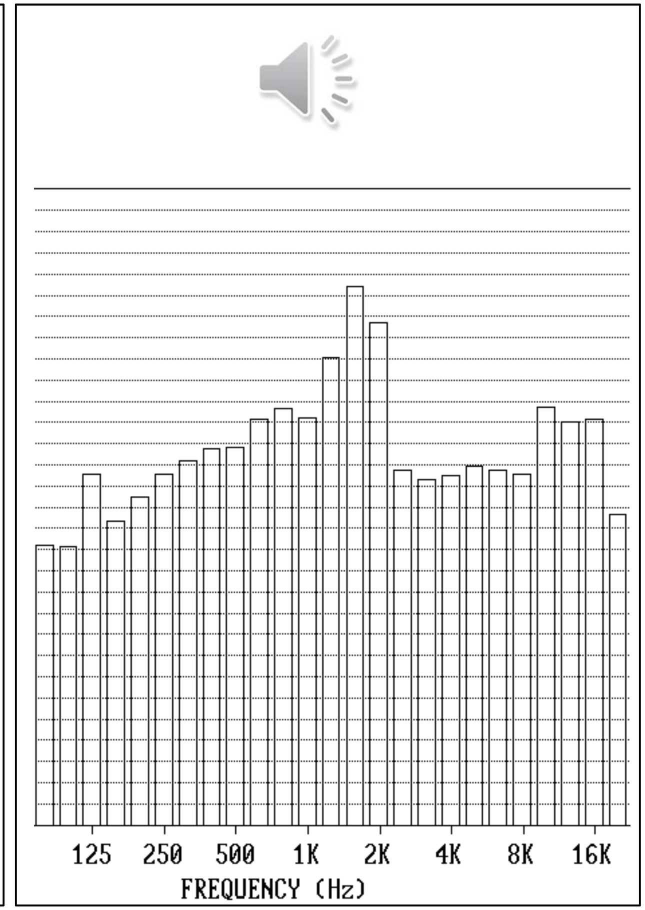
Same Noise Levels



74.5 dB



75.1 dB



74.7dB

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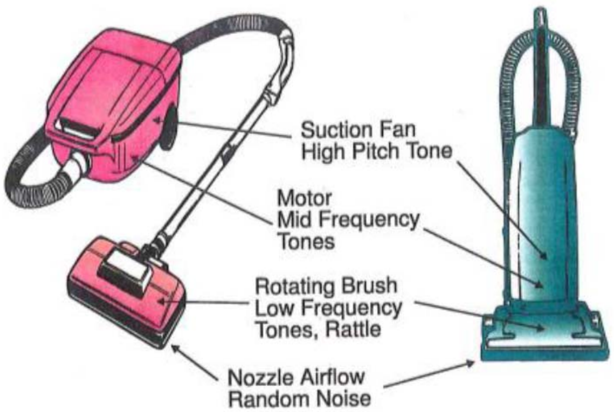
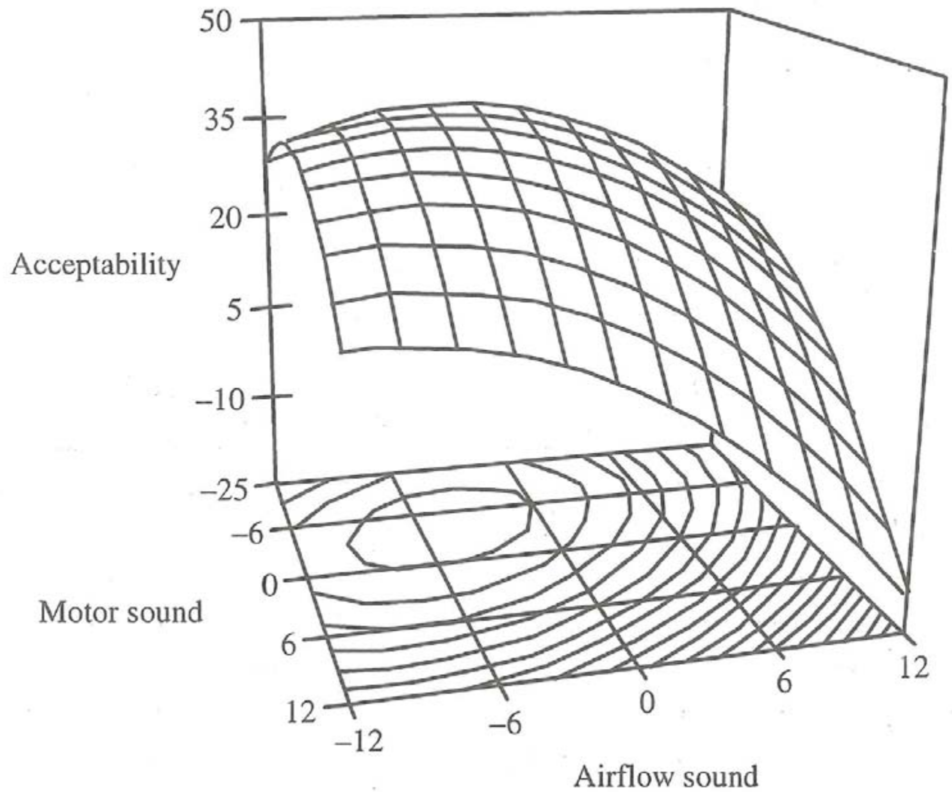
Courtesy of Mike Beyer

Acceptability Vacuum Cleaner



Lyon, 2000



The strongest contributors to the perceptions of acceptability and perceived power were the motor and airflow sound, and a higher level of rotating brush noise could increase perceived power without decreasing acceptability. By this step and further increasing acceptability by essentially redesigning the motor, Acentech achieved a 5 to 10 dBA reduction in broadband motor vibration level and a 6 dBA reduction in noise level. (Bowen, 2016)

Sound Quality Metrics

Some perceptual psychologists, among which psycho-acousticians are a subset, propose additional metrics that can be used to choose among product variations. In the area of sound, such metrics carry names like roughness, sharpness, and fluctuation strength. They are measured using combinations of frequency and temporal filtering, and instrumentation is available for computing these metrics.

These metrics undoubtedly shed some light on the correlation between features of sound and perception. But engineers design gear trains, motors, and structures, not spectra, so a correlation between component sounds and the acceptability of a product (which we have defined as sound quality) is of more direct value to the design engineer. (Lyon, 2000)

Metrics are not always reliable (Lyon, 2003b)

- Bach
- Bach with notes reversed

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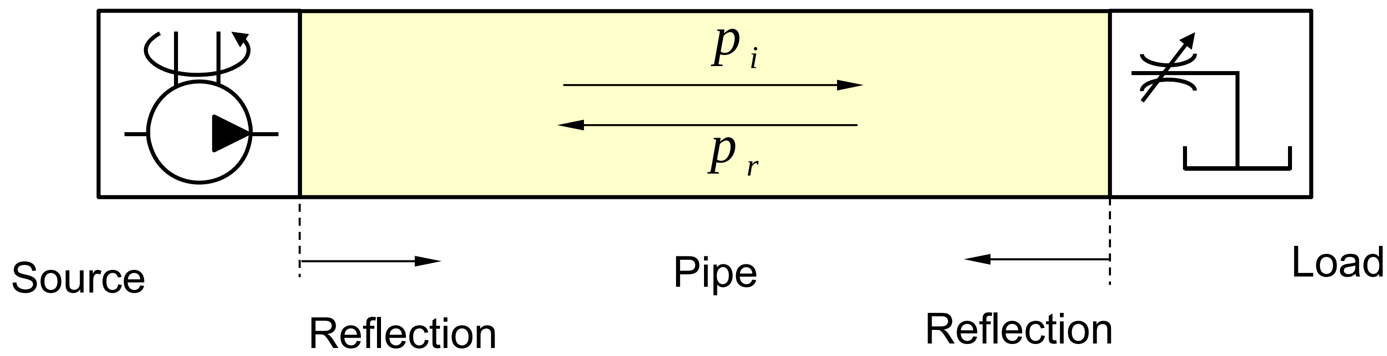
Fluidborne and Airborne

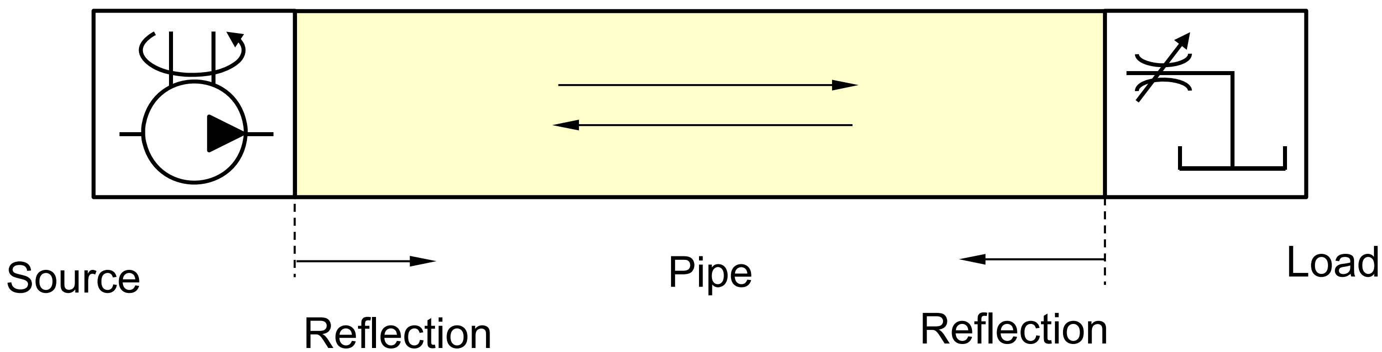


Reflections ⇨ Standing wave inside ducts ⇨ Vibrations (pipes, valves…) ⇨ Airborne noise

Standing Waves

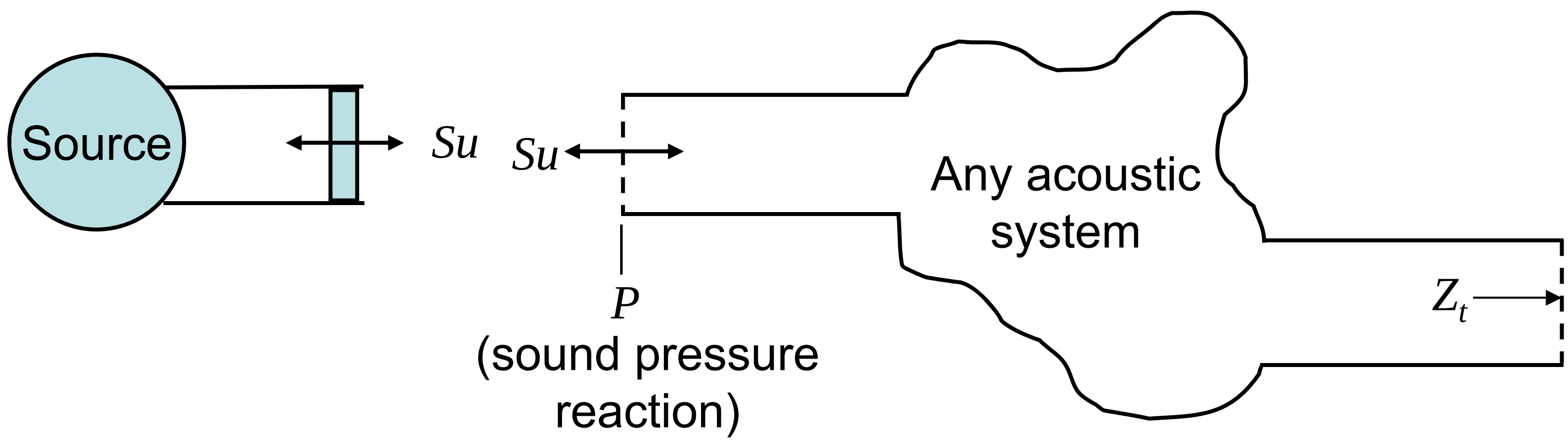
http://www.acs.psu.edu/drussell/Demos/SWR/SWR.html

Variables that Matter



- Speed of Sound (c)
- Other fluid properties (ρ,ν)
- Source Impedance (Z_S)
- Termination Impedance (Z_T)

Acoustic Impedance



Input or load impedance $$z = \frac{P}{Su} = r + jx$$

Termination impedance $$z_t = \frac{P_t}{Su_t} = r_t + jx_t$$

Hydraulic Circuit Standards

ISO 15086 Hydraulic fluid power – Determination of fluid-borne noise characteristics of components and systems

- Part 1 (2001): Plane wave model in hydraulics
- Part 2 (2000): Measurement of speed of sound
- Part 3 (2008): Measurement of hydraulic impedance

ISO 10767 Hydraulic fluid power – Determination of pressure ripple levels generated in systems and components

- Part 1 (2015): Measurement of source flow ripple and source impedance