Introduction

David Herrin
University of Kentucky

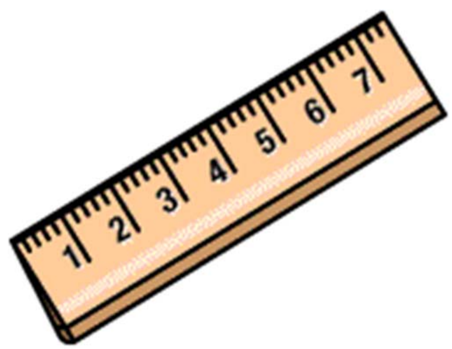
Wave Animation

http://www.acs.psu.edu/drussell/Demos/waves-intro/waves-intro.html

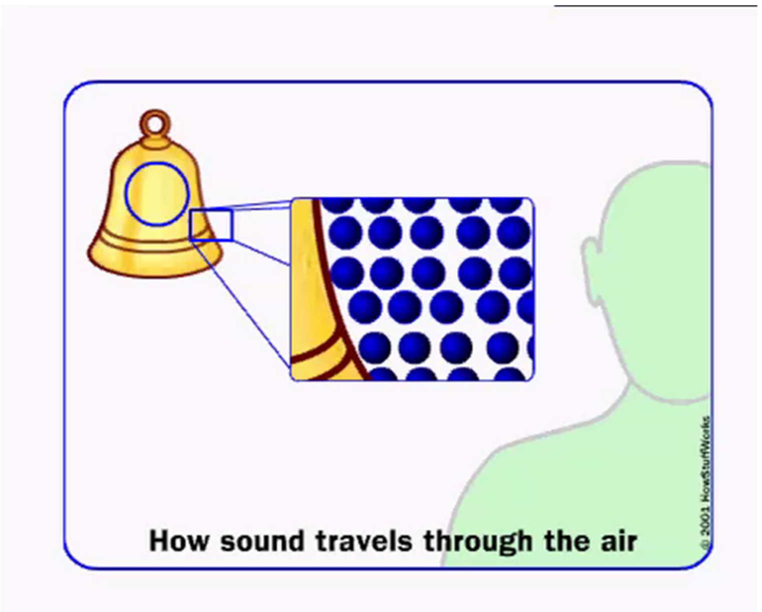
Wave Motion – Some Basics

- Sound waves are pressure disturbances in fluids, such as air or hydraulic fluid as a result of vibration, turbulence, pumping, etc.
- These disturbances propagate at the *speed of sound* c (c = 343 m/s or 1125 ft/s in air at room temperature)
- The wavelength $\lambda = c/f$. For f = 1 kHz, the wavelength is approximately 0.34 m or 1.13 ft.

The wavelength is the acoustic yardstick.



Particle Motion



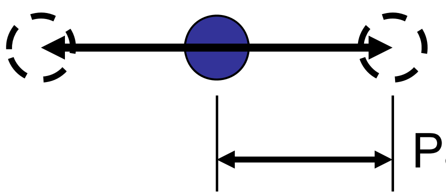
- Particles oscillate (but no net flow)
- Waves move much faster than particles

Particle Displacement

$$d(t) = D\sin(2\pi f t)$$

Particle Velocity

$$u(t) = 2\pi f D\cos(2\pi f t)$$

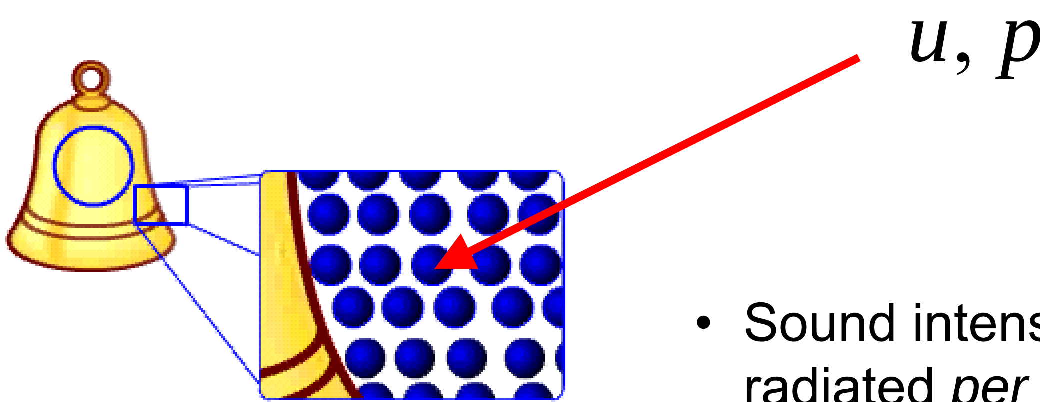


Particle displacement amplitude D

Overview

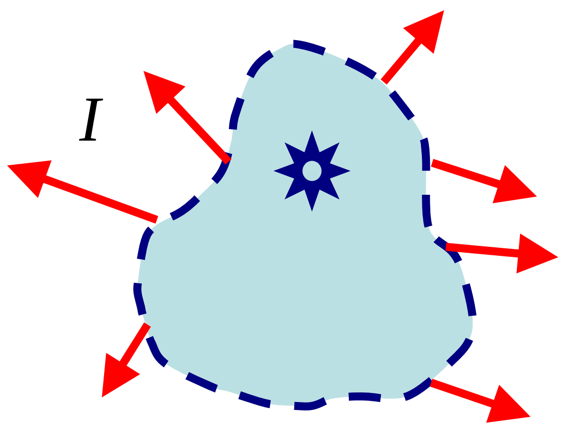
- Sound Power and Decibels
- Measuring Sound Power
- Noise Paths

Sound Intensity and Power



$$I = pu$$

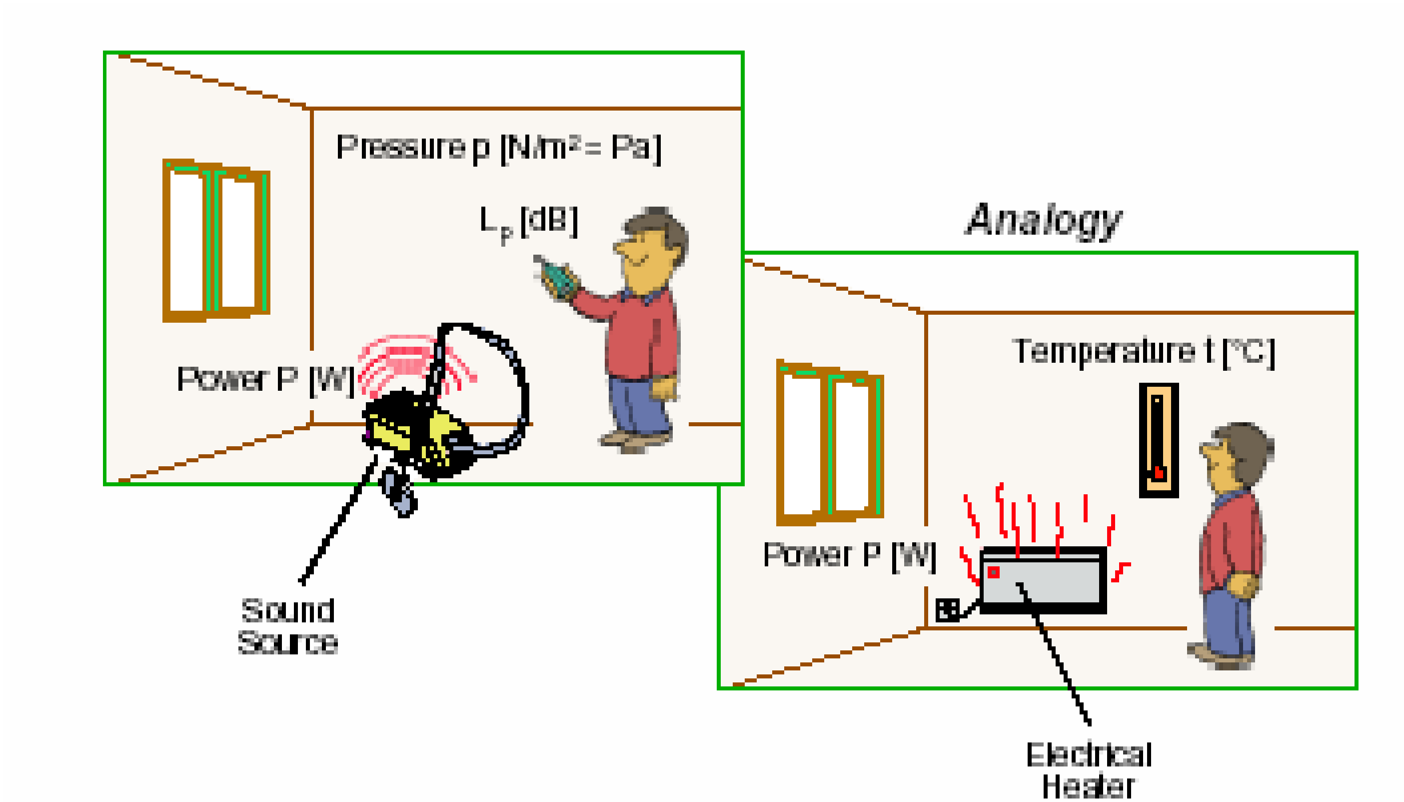
- Sound intensity is the sound power radiated *per unit area*



- To get sound power, we integrate the normal component of the sound intensity over a closed surface

$$W = \int_S I_n dS \qquad \text{(watts)}$$

An Analogy



Like temperature, the sound pressure depends on the source power level AND the environment in which the source is placed.

The Decibel Scale

Sound Pressure Level: $$L_p(\text{dB}) = 10\log_{10}\left(\frac{p_{\text{rms}}}{p_{\text{ref}}}\right)^2 \qquad p_{\text{ref}} = 20\ \mu\text{Pa}$$

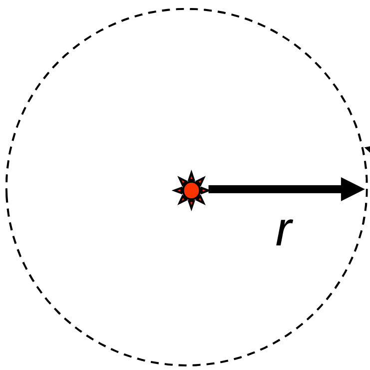
Sound Power Level: $$L_w(\text{dB}) = 10\log_{10}\frac{W}{W_{ref}} \qquad W_{ref} = 1\times 10^{-12}\ \text{watts}$$

The main thing to remember is that 100 dB sound *pressure* level and 100 dB sound *power* level are completely different!

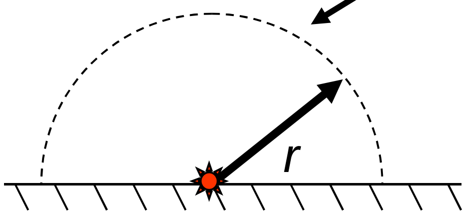
Sound Power to Sound Pressure

$$L_p = L_W - 10\log_{10} S \qquad S \text{ in m}^2$$

(no reflections)

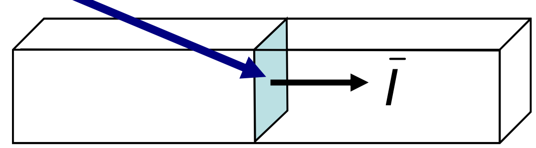


$S = 4\pi r^2$ (Spherical source)



$S = 2\pi r^2$ (Hemi-spherical source)

S = cross-sectional area (duct)



An Example

A source has a sound power level of 90 dB (re 10^{-12} W). What is the sound pressure level at a distance of 10 m in (a) a free field, (b) in a hemispherical free field, and (c) in a duct of cross-sectional area 1 m^2?

a. $L_p = 90 - \log_{10} 4\pi(10)^2 = 59 \text{ dB (re } 20\mu\text{Pa)}$

b. $L_p = 90 - \log_{10} 2\pi(10)^2 = 62 \text{ dB (re } 20\mu\text{Pa)}$

c. $L_p = 90 - \log_{10}(1) = 90 \text{ dB (re } 20\mu\text{Pa)}$

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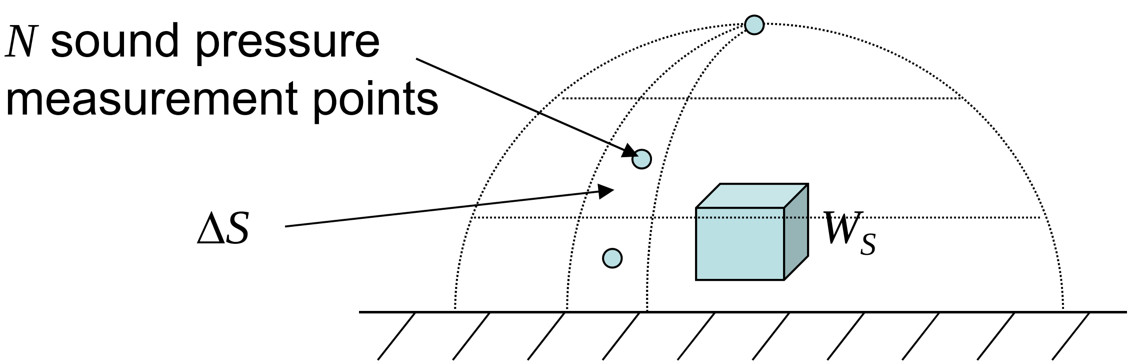
Hemispherical Free Field

- Divide surface S into sub-areas ΔS
- Measure sound pressure at a central point in each area
- Sum up mean-square sound pressures weighted by areas

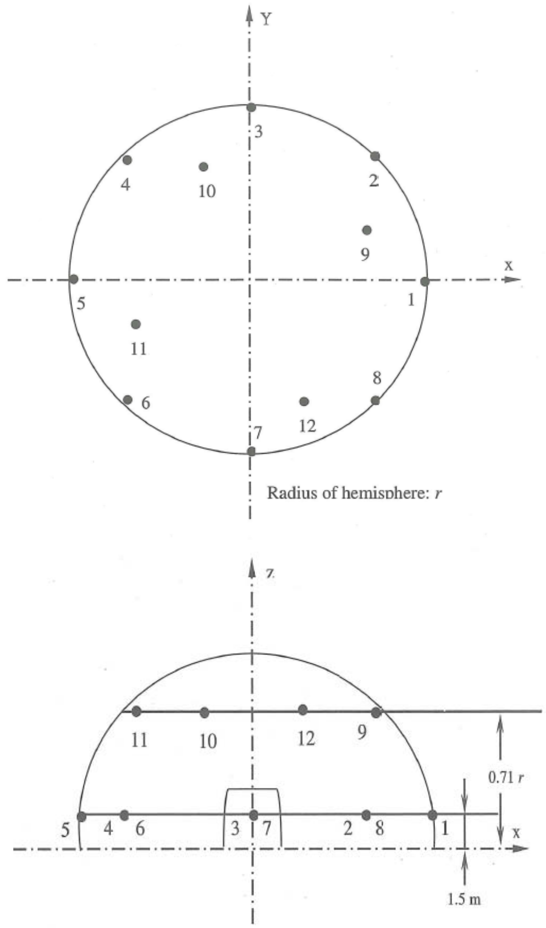


$$W_S \approx \int_S \left(\tilde{p}^2 / \rho_o c\right) dS \approx \left(1/\rho_o c\right) \sum_{i=1}^{N} \tilde{p}_i^2 \Delta S_i$$

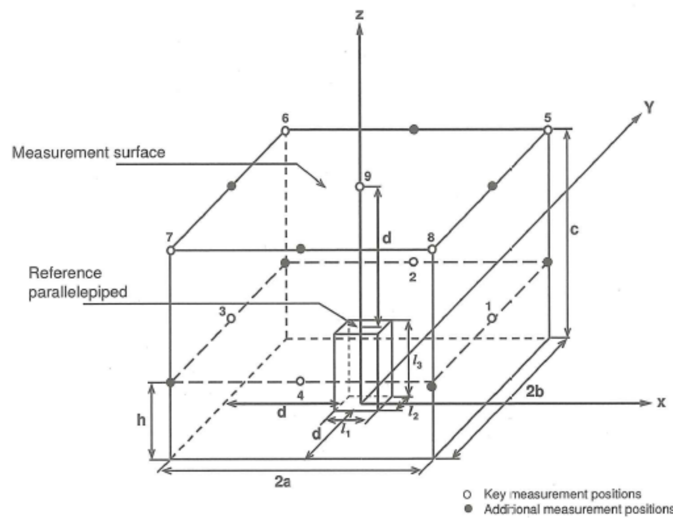
$$\left(L_w\right)_{source} \approx \left(\bar{L}_P\right)_{source} + 10 \log_{10} S$$

Standard Surfaces

Hemispherical Surface



Parallelepiped Surface



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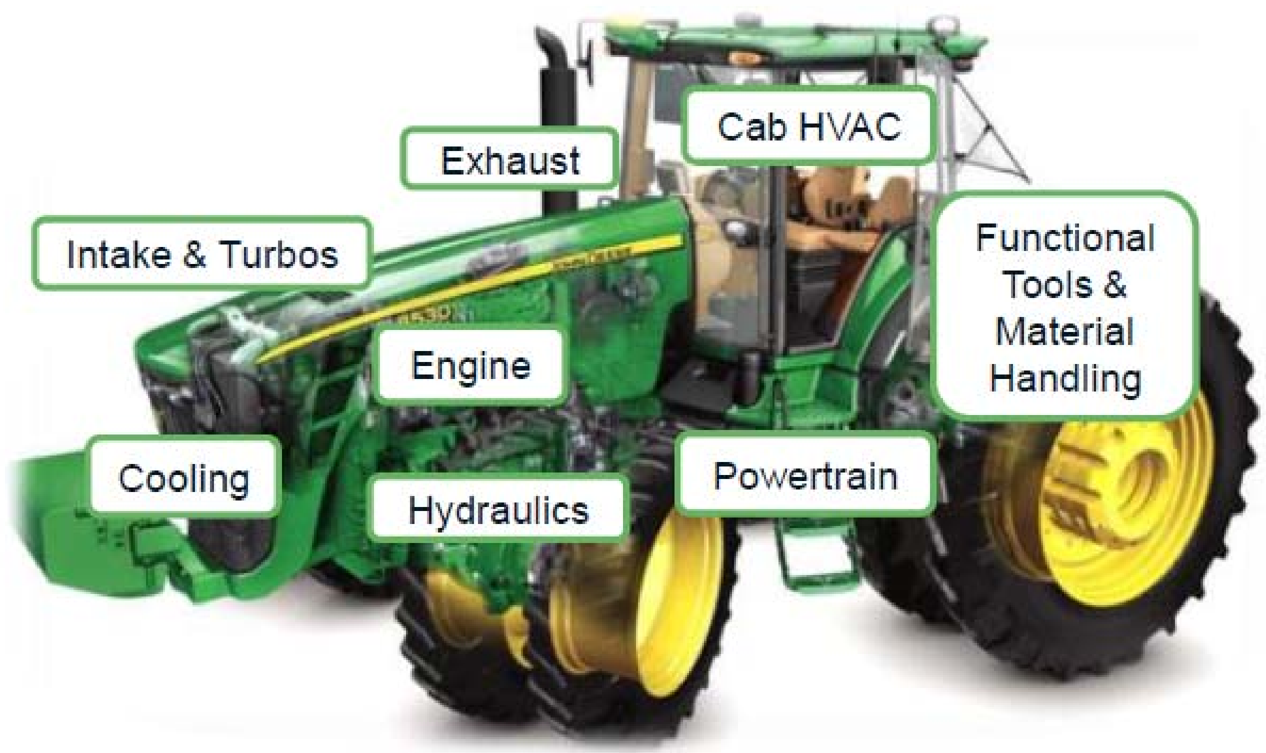
Heavy Equipment Multiple Sources



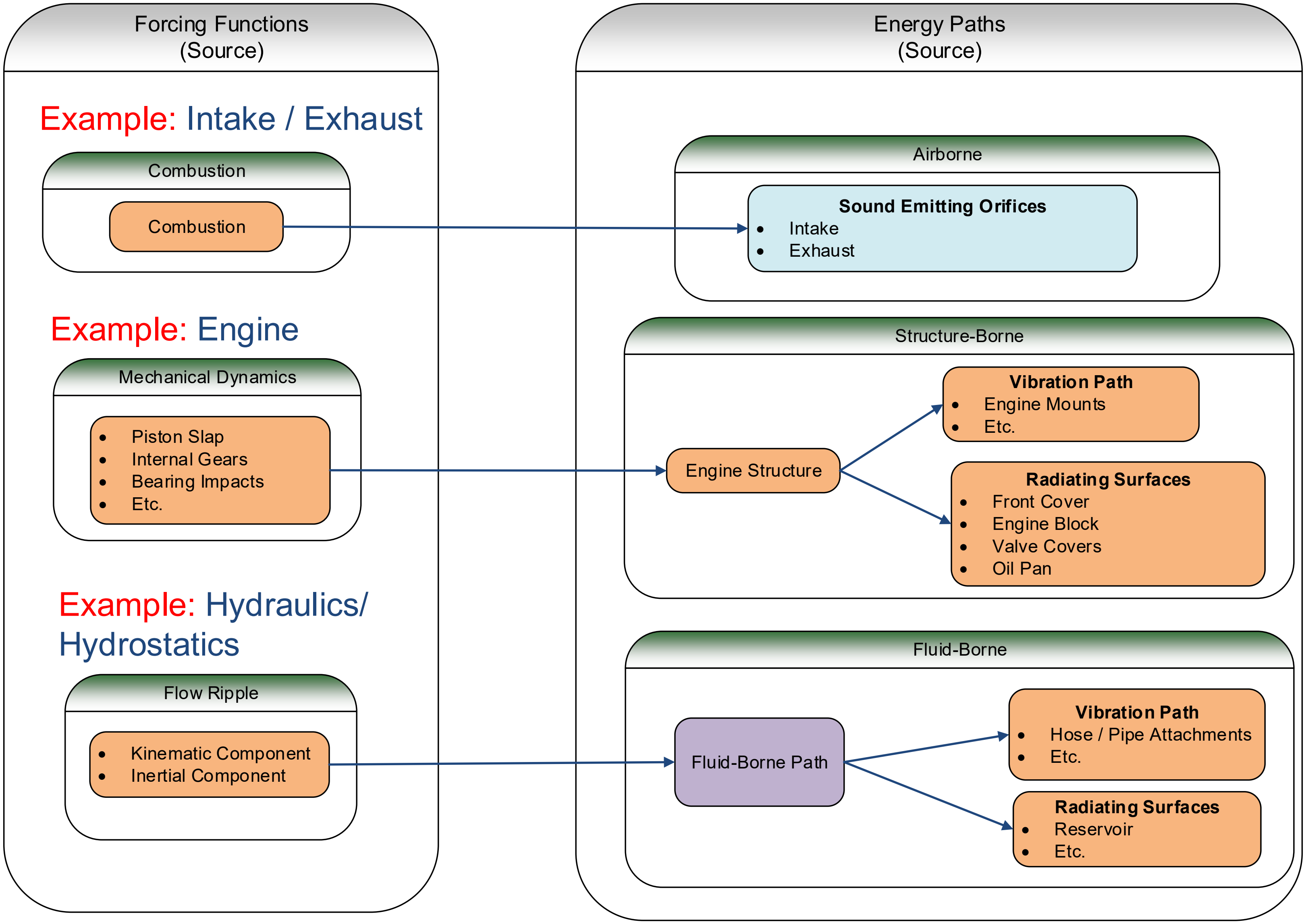
Database of Source Data

Table 1 Average Sound Power Level Spectra of Typical Noise Sources of Off-Road Vehicles

No.	Type of Noise Source	Sound Power Levels (dB) in Octave Frequency Bands (Hz)								A-weighted Sound Power Level (dB)
		63	125	250	500	1000	2000	4000	8000	
1	ICE body	90	100	96	98	100	100	98	95	105
2	ICE exhaust system (with presence of a muffler)	95	105	100	90	90	87	85	80	95
3	ICE intake	82	92	86	80	80	80	75	73	85
4	ICE cooling fan	85	95	100	97	95	92	87	82	100
5	Vibrating roller	100	102	96	104	101	90	83	72	105
6	Track	75	78	85	83	82	85	78	69	90
7	Hydraulic pump	78	80	86	92	92	85	80	76	95

T.O.C.

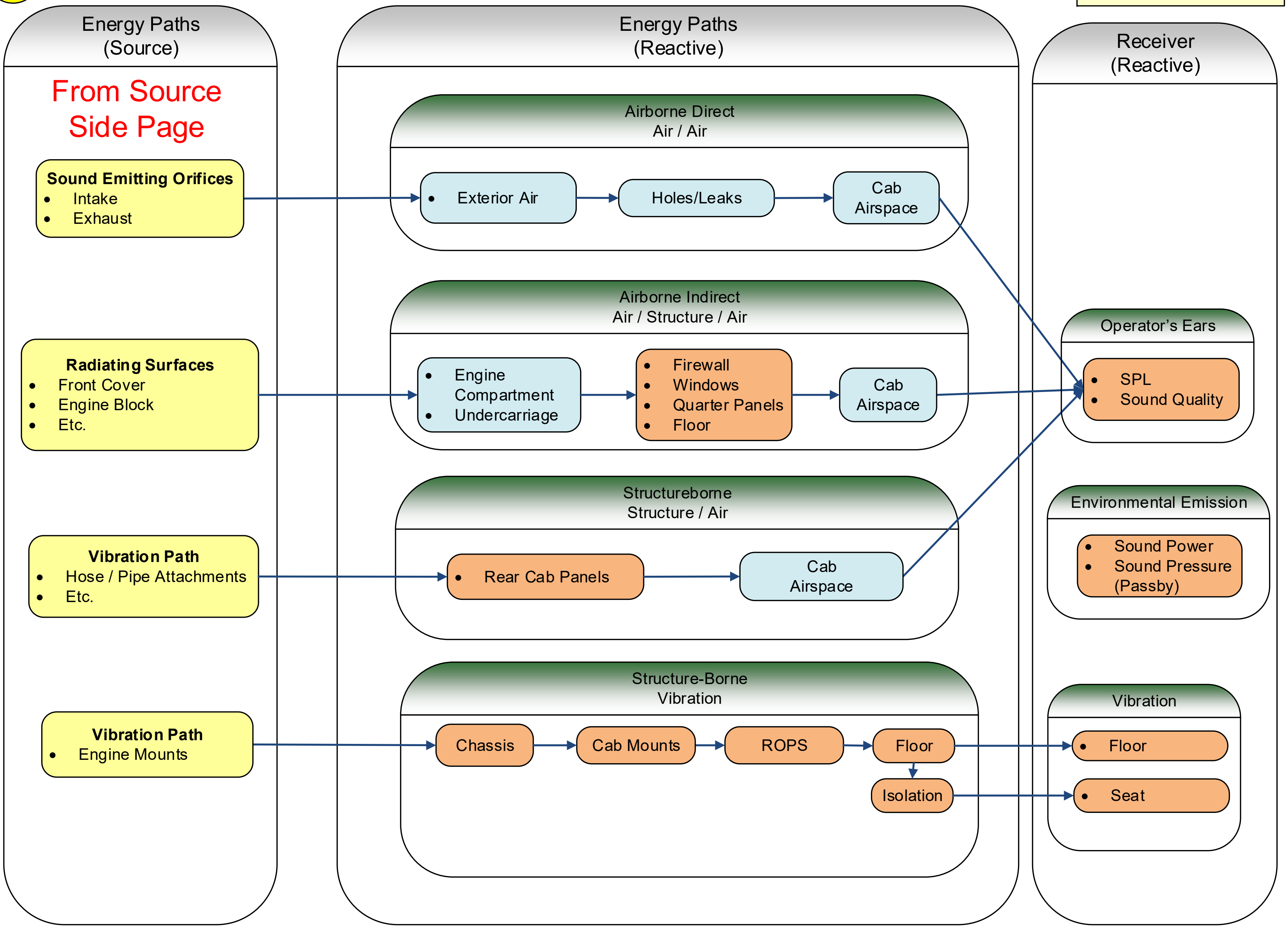
Template
Source Side



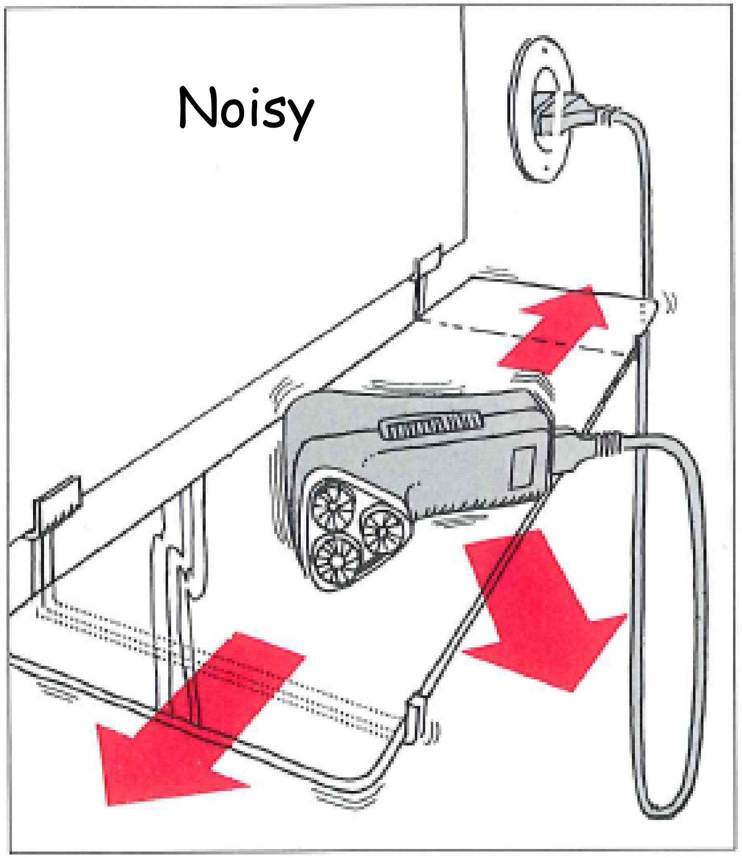
The source energy paths are characterized by the whether the forcing function is airborne, structure-borne, or Fluid-Borne.

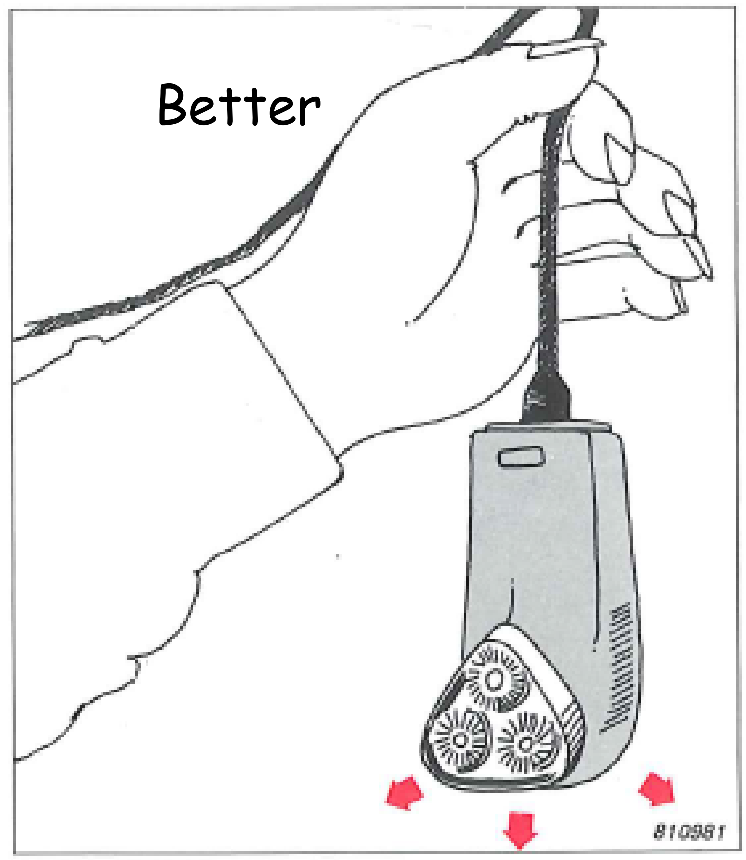
T.O.C.

Receiver or Reactive Side Template



What is the Source Attached to?





Summary

- How are sound pressure and sound power different? What is the importance of each?
- How is sound power measured?
- Why is hydraulic noise difficult to treat?