

CE/AE/EnSci 524

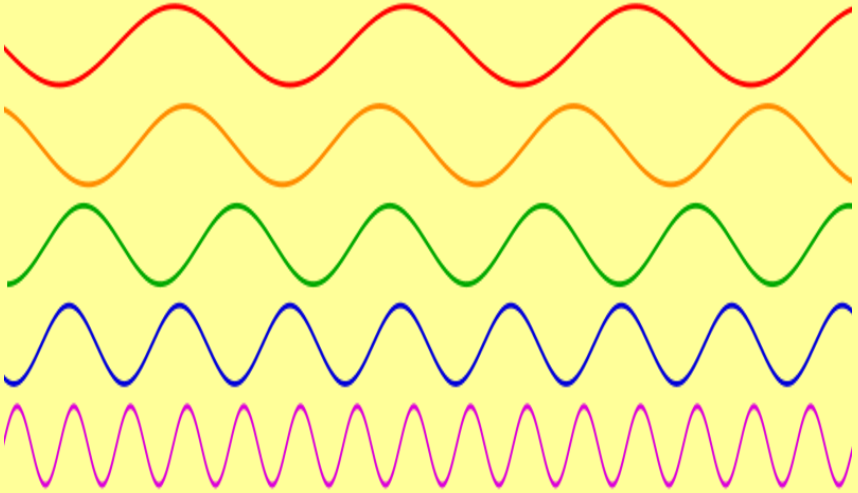
NOISE MEASUREMENT & ABATEMENT

J (Hans) van Leeuwen

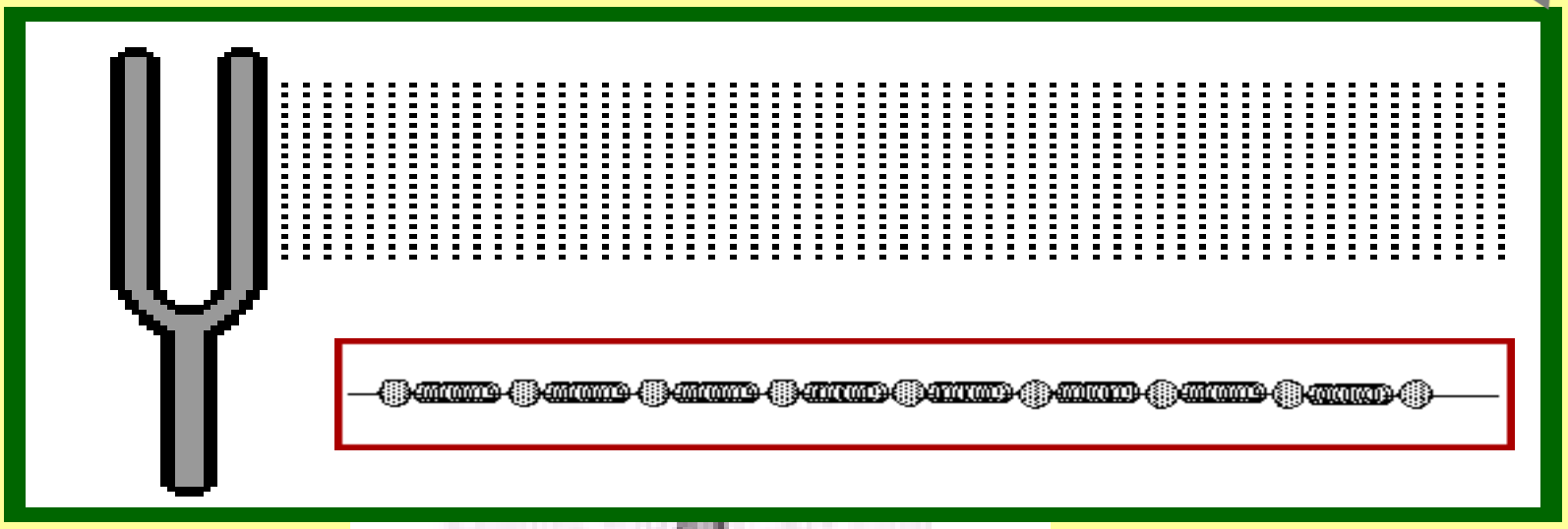
The nature of sound

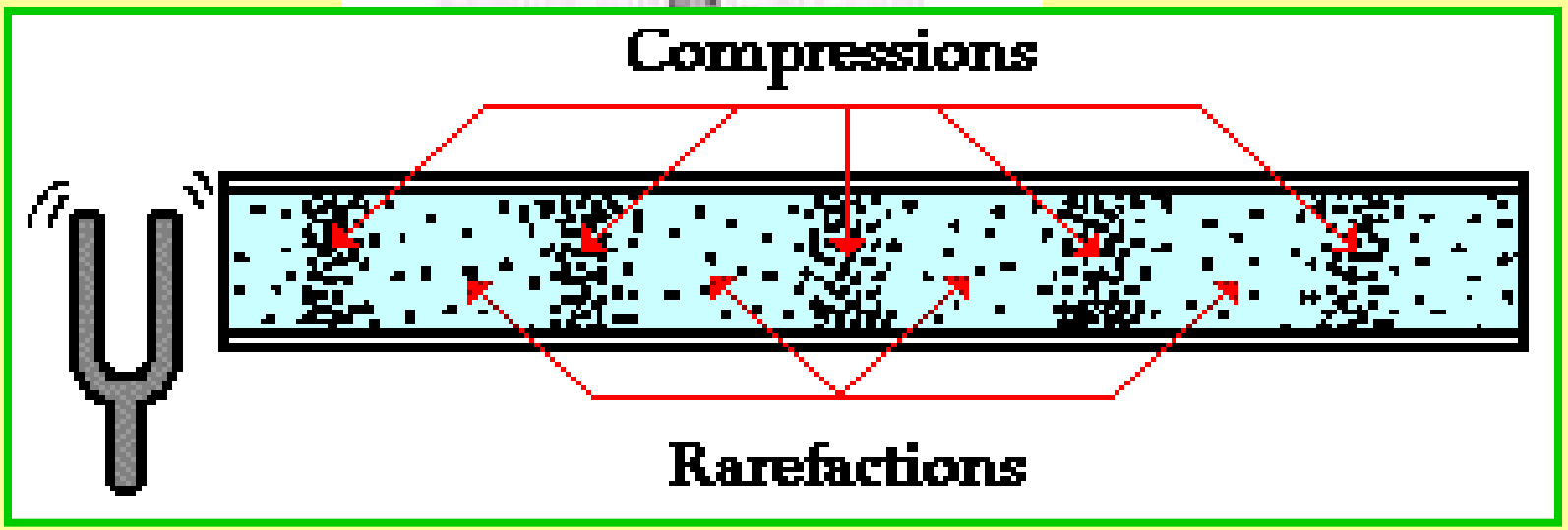
Sound, a manifestation of vibration, travels in wave patterns through solids, liquids and gases.
The waves, caused by vibration of the molecules, follow sine functions, typified by the amplitude and wavelength (or frequency)

Sound waves of equal amplitude with increasing frequency from top to bottom

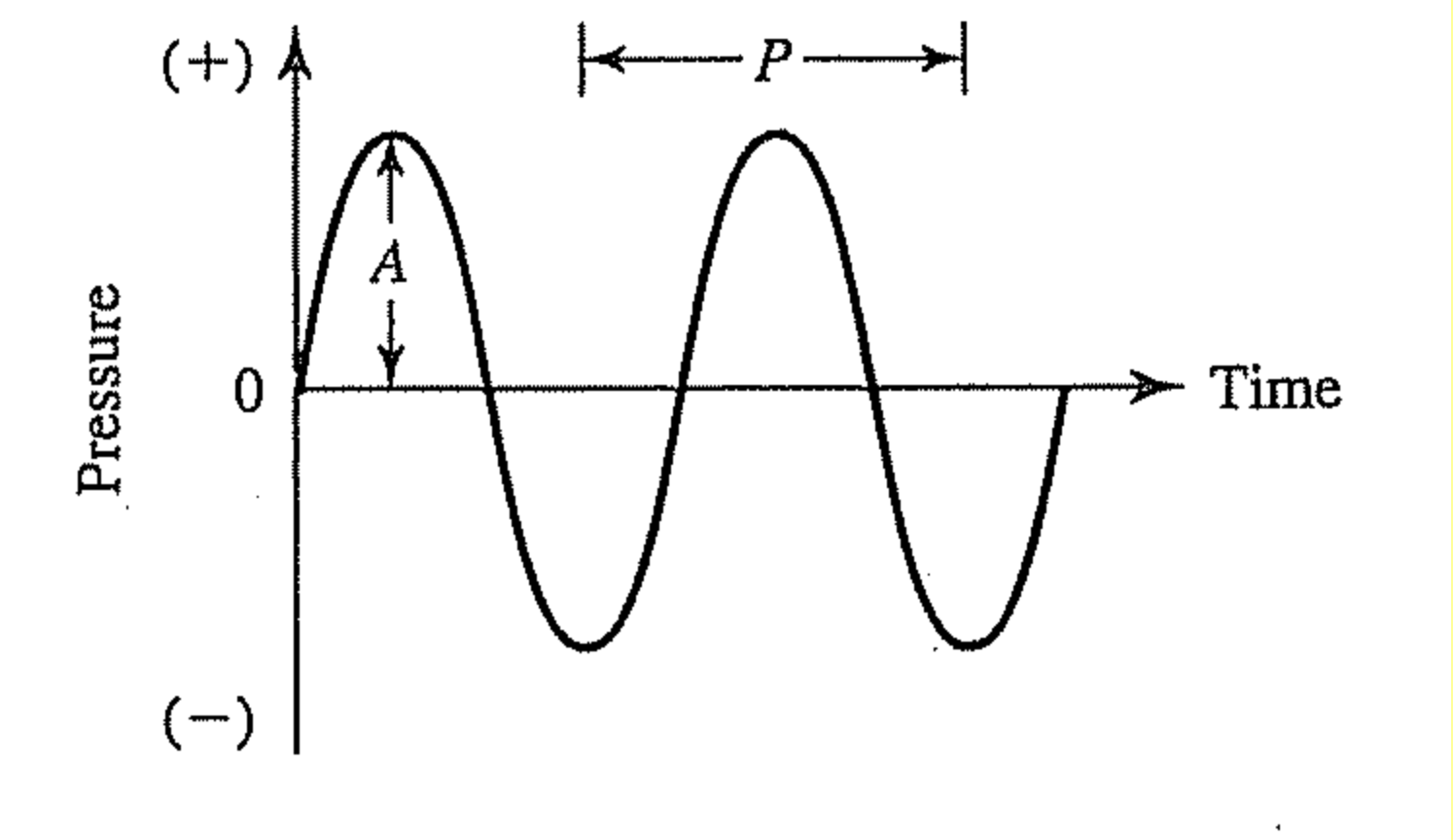


Sound propagation





Amplitude and wavelength (period)



Bels and decibels

Levels and the Decibel

The sound pressure of the faintest sound that a normal healthy individual can hear is about 0.00002 Pa. The sound pressure produced by a Saturn rocket at liftoff is greater than 200 Pa. Even in scientific notation this is an "astronomical" range of numbers.

To cope with this problem, a scale based on the logarithm of the ratios of the measured quantities is used. Measurements on this scale are called levels. The unit for these types of measurement scales is the **bel,** which was named after Alexander Graham Bell:

$$L' = \log \frac{Q}{Q_0} \qquad (15\text{–}7)$$

where L' = level, bels
Q = measured quantity
Q_0 = reference quantity
log = logarithm in base 10

A bel turns out to be a rather large unit, so for convenience it is divided into 10 subunits called **decibels** (dB). Levels in decibels are computed as follows:

$$L = 10 \log \frac{Q}{Q_0} \qquad (15\text{–}8)$$

The decibel does not represent any physical unit. It merely indicates that a logarithmic transformation has been performed.

Sound power and intensity

Sound Power Level. If the reference quantity (Q_0) is specified, then the decibel takes on physical significance. For noise measurements, the reference power level has been established as 10^{-12} W. Thus, sound power level may be expressed as

$$L_w = 10 \log \frac{W}{10^{-12}} \qquad (15\text{–}9)$$

Sound power levels computed with Equation 15–9 are reported as decibels re: 10^{-12} W.

Sound Intensity Level. For noise measurements, the reference sound intensity (Equation 15–4) is 10^{-12} W · m^{-2}. Thus the sound intensity level is given as

$$L_I = 10 \log \frac{I}{10^{-12}} \qquad (15\text{–}10)$$

Sound pressure level

Sound Pressure Level. Because sound-measuring instruments measure the p_{rms}, the sound pressure level is computed as follows:

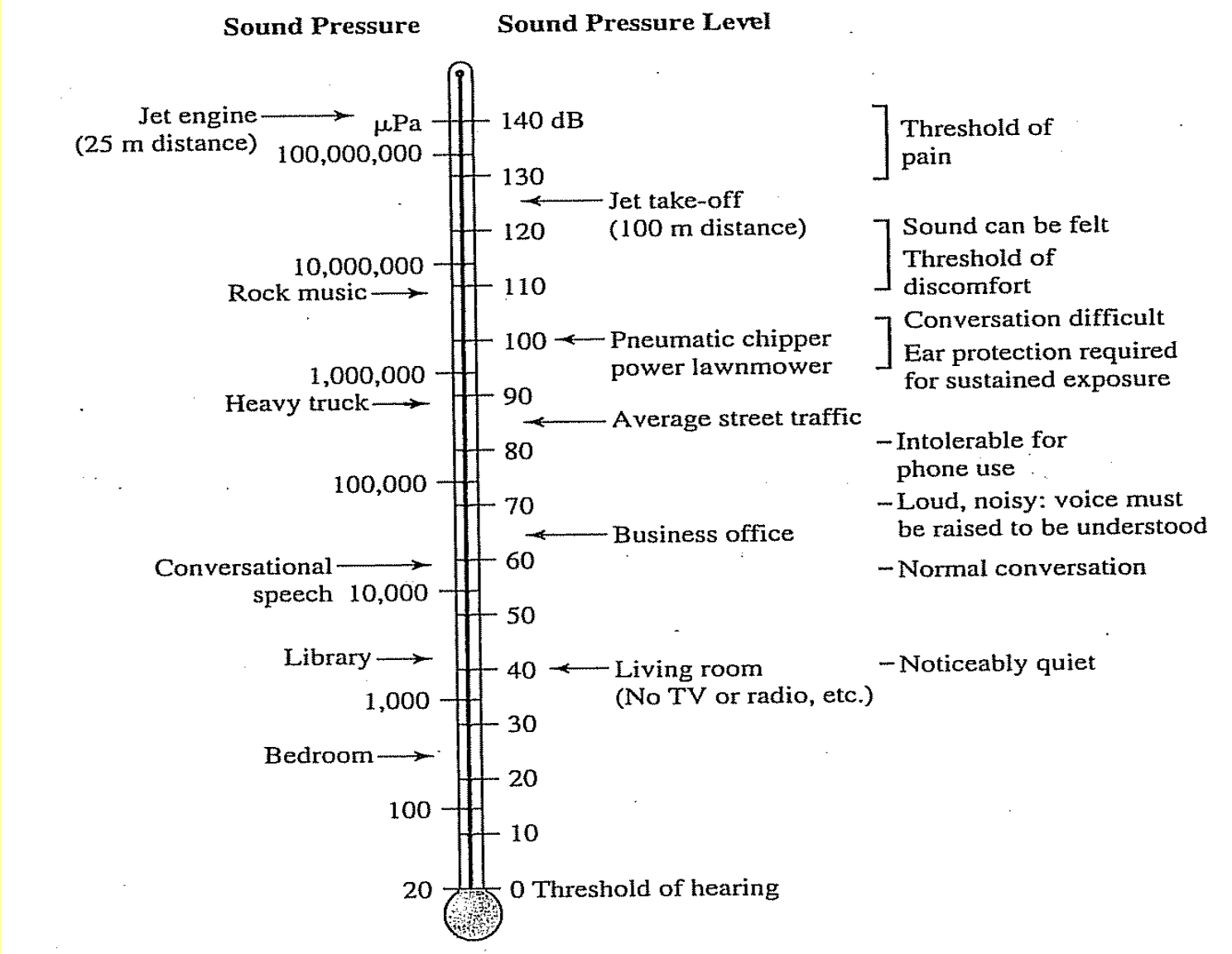
$$L_p = 10 \log \frac{(p_{rms})^2}{(p_{rms})_0^2} \qquad (15\text{–}11)$$

which, after extracting the squaring term, is given as

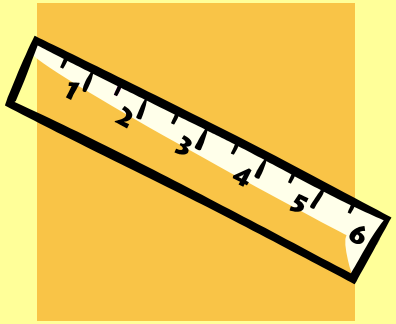
$$L_p = 20 \log \frac{(p_{rms})}{(p_{rms})_0} \qquad (15\text{–}12)$$

The reference pressure has been established as 20 μPa (micropascals). A scale showing some common sound pressure levels is shown in Figure 15–3.

Sound pressure for known sounds



How sound is measured



- **Pressure, P, usually Pascals**
- **Frequency, f, usually Hertz**
- **Intensity, I, usually W/m²**
- **Bels, L', derived from logarithmic ratio**
- **Decibels, L, derived from bels**

$P = 1/f$

$I = W/A$

$L' = \log (Q/Qo)$

$L = 10*\log (Q/Qo)$

E.g. Implications of the decibel scale: doubling sound level would mean that the sound will increase by 10*log2 = +3dB
Ten times the sound level = 10*log10 = +10dB

Exposure to high sound levels



Reflecting on noise

- ❑ “Noise" derived from "nausea," meaning seasickness
- ❑ Noise is among the most pervasive pollutants today
- ❑ Noise is unavoidable for many machines
- ❑ We experience noise in a number of ways
  - ✓environmental
  - ✓cause and victim
  - ✓generated by others “second-hand”
- ❑ Noise negatively affects human health and well-being
- ❑ The air into which second-hand noise is emitted and on which it travels is a "commons“, a public good

Noise regulation

Noise regulation includes statutes or guidelines relating to sound transmission established by national, state or provincial and municipal levels of government. After a watershed passage of the U.S. Noise Control Act of 1972[1], the program was abandoned at the federal level, under President Ronald Reagan, in 1981 and the issue was left to local and state governments. Although the UK and Japan enacted national laws in 1960 and 1967 respectively, these laws were not at all comprehensive or fully enforceable as to address (a) generally rising ambient noise (b) enforceable numerical source limits on aircraft and motor vehicles or (c) comprehensive directives to local government.

Local noise regulation

- Dr. Paul Herman wrote the first comprehensive noise codes in 1975 for Portland, Oregon with funding from the EPA (Environmental Protection Agency) and HUD (Housing and Urban Development). The Portland Noise Code became the basis for most other ordinances for major U.S. and Canadian metropolitan regions.[18]
- Most city ordinances prohibit sound above a threshold intensity from trespassing over property line at night, typically between 10 p.m. and 6 a.m., and during the day restricts it to a higher sound level; however, enforcement is uneven. Many municipalities do not follow up on complaints. Even where a municipality has an enforcement office, it may only be willing to issue warnings, since taking offenders to court is expensive.
- The notable exception to this rule is the City of Portland Oregon which has instituted an aggressive protection for its citizens with fines reaching as high at $5000 per infraction, with the ability to cite a responsible noise violator multiple times in a single day.
- Many conflicts over noise pollution are handled by negotiation between the emitter and the receiver. Escalation procedures vary by country, and may include action in conjunction with local authorities, in particular the police. Noise pollution often persists because only five to ten percent of people affected by noise will lodge a formal complaint. Many people are not aware of their legal right to quiet and do not know how to register a complaint

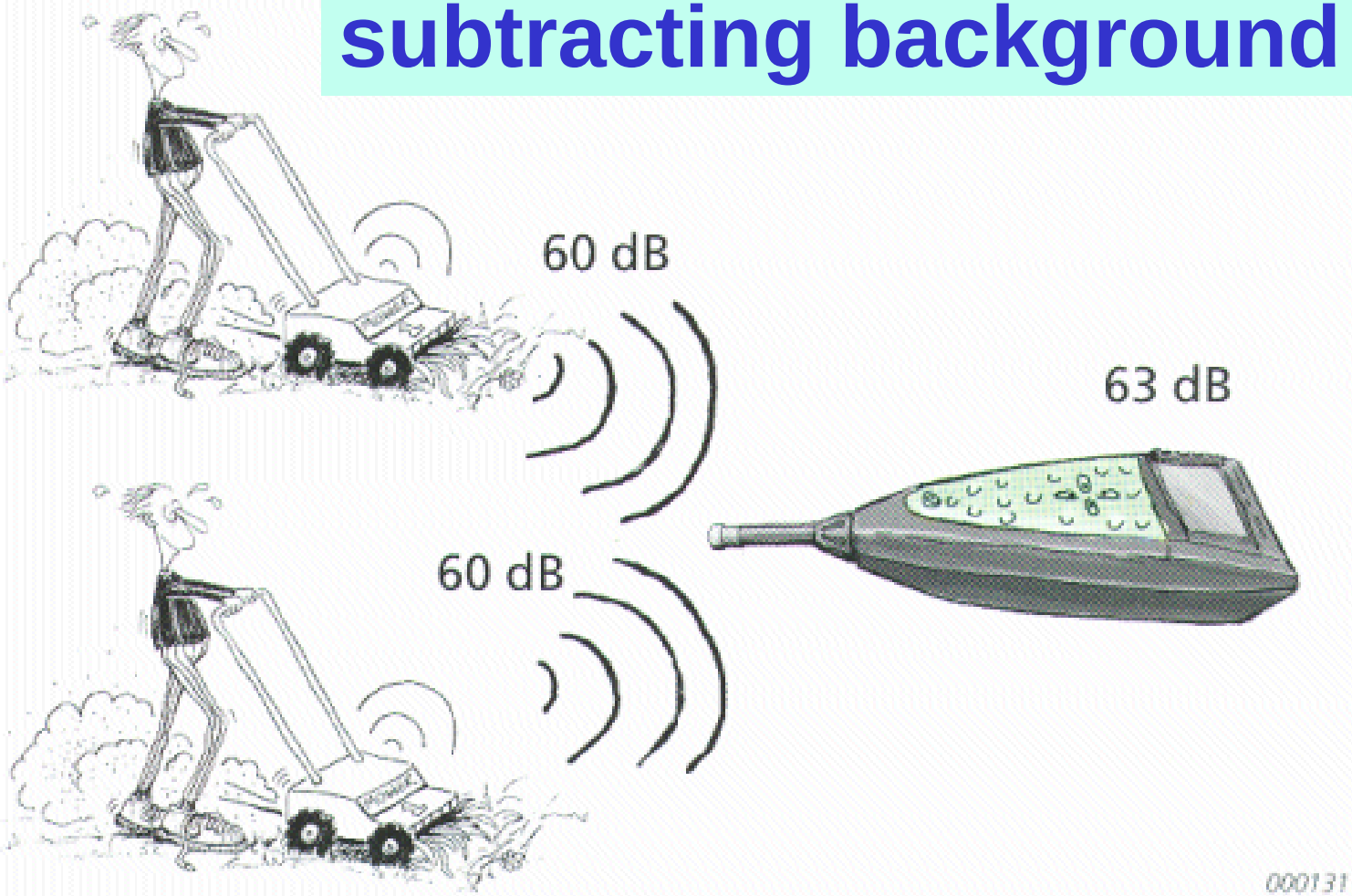
Aircraft noise



FA-18 Hornet breaking sound barrier

$$L_{presult} = 10 \cdot \log\left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + 10^{\frac{L_{p3}}{10}} + \ldots + 10^{\frac{L_{pn}}{10}}\right) \rightarrow L_{presult} = 10 \cdot \log\left(10^{\frac{L_{ptot}}{10}} - 10^{\frac{L_{pbackground}}{10}}\right)$$

Adding noise sources and subtracting background noise



10 log 2
= 3 dB

Chart method – adding decibels

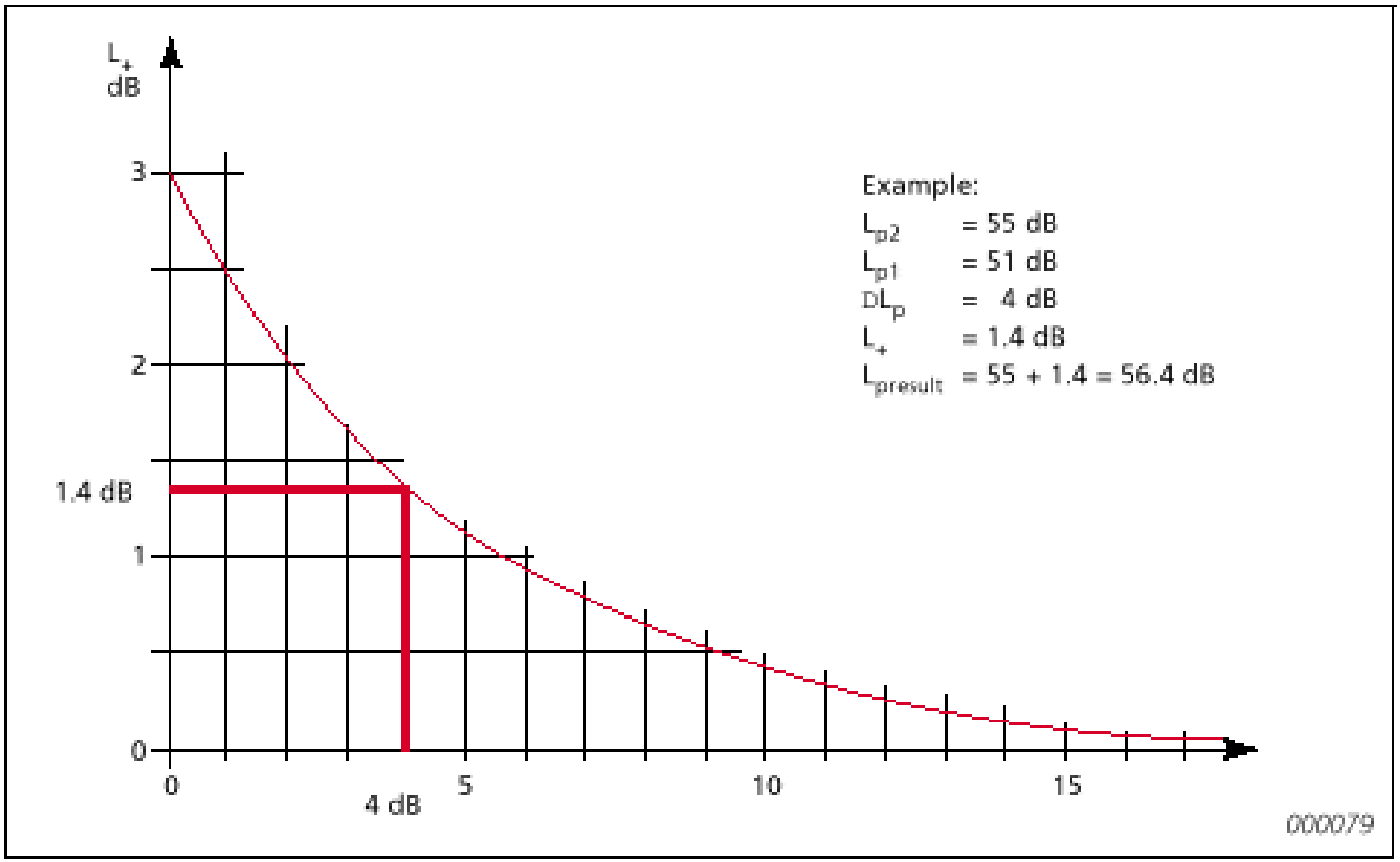
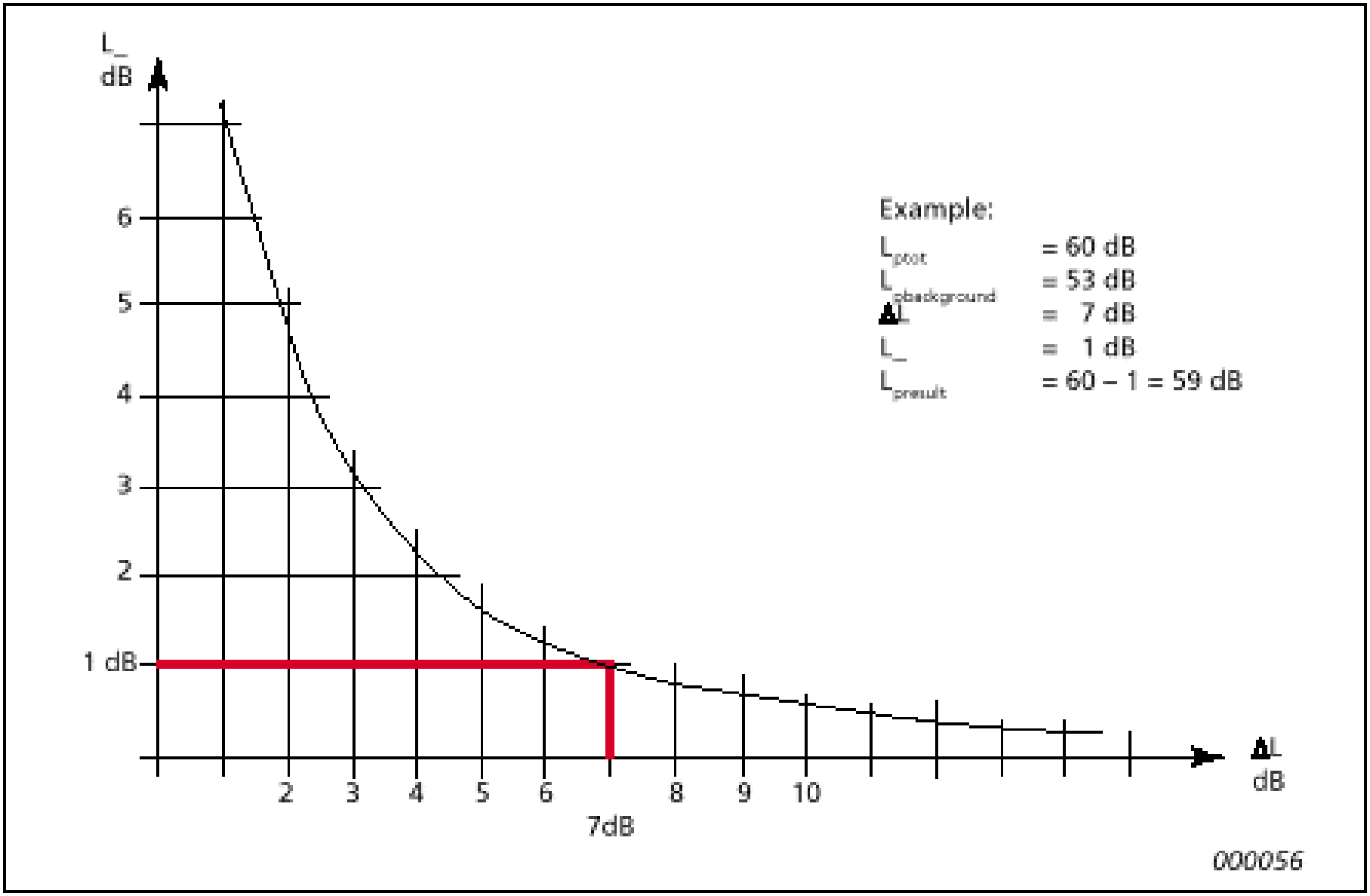
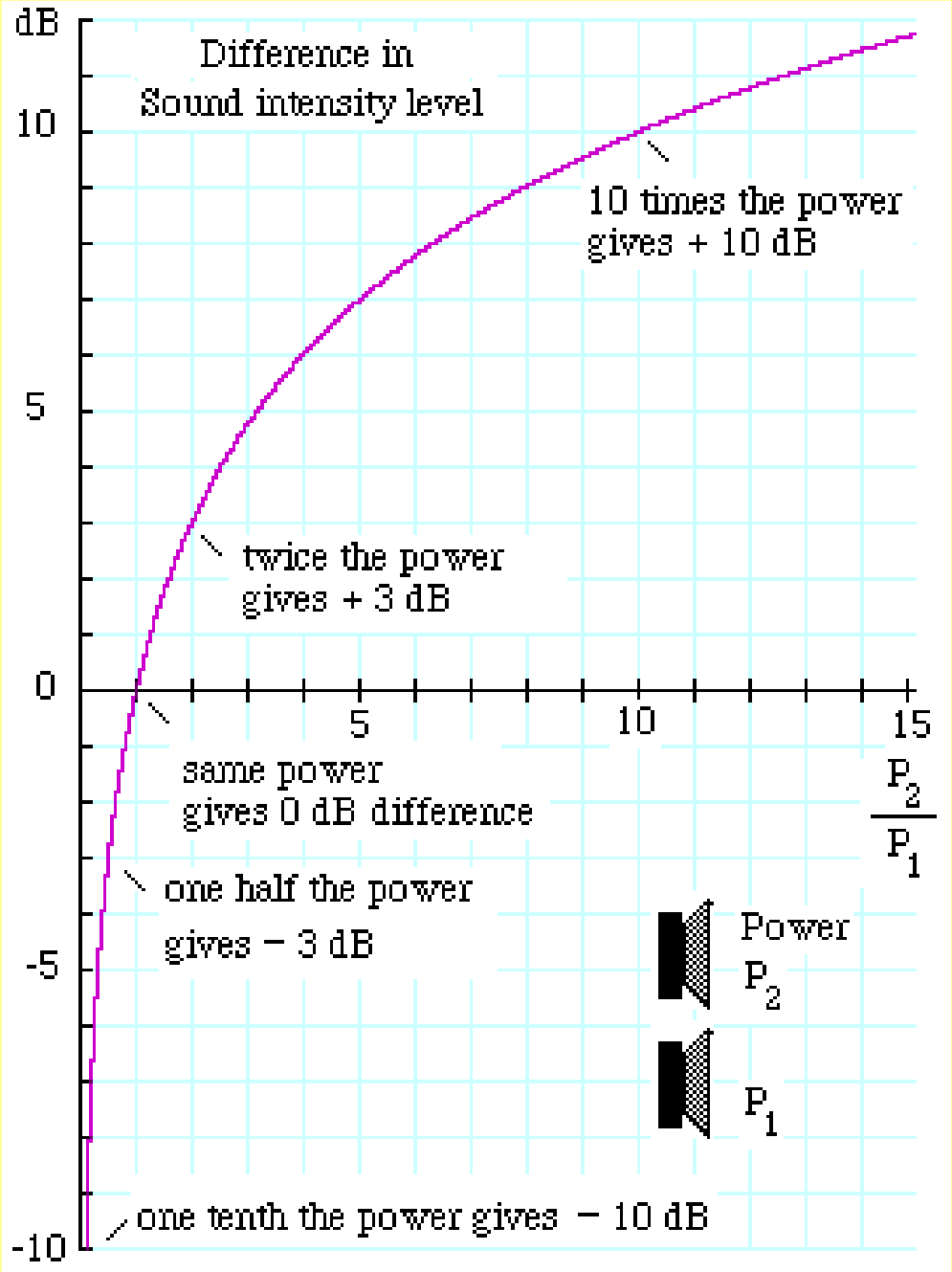


Chart method – subtracting background noise



Power ratio and dB

http://www.phys.unsw.edu.au/jw/dB.html



Sound and human hearing

People generally hear sounds between the “threshold of hearing” and the “threshold of pain”

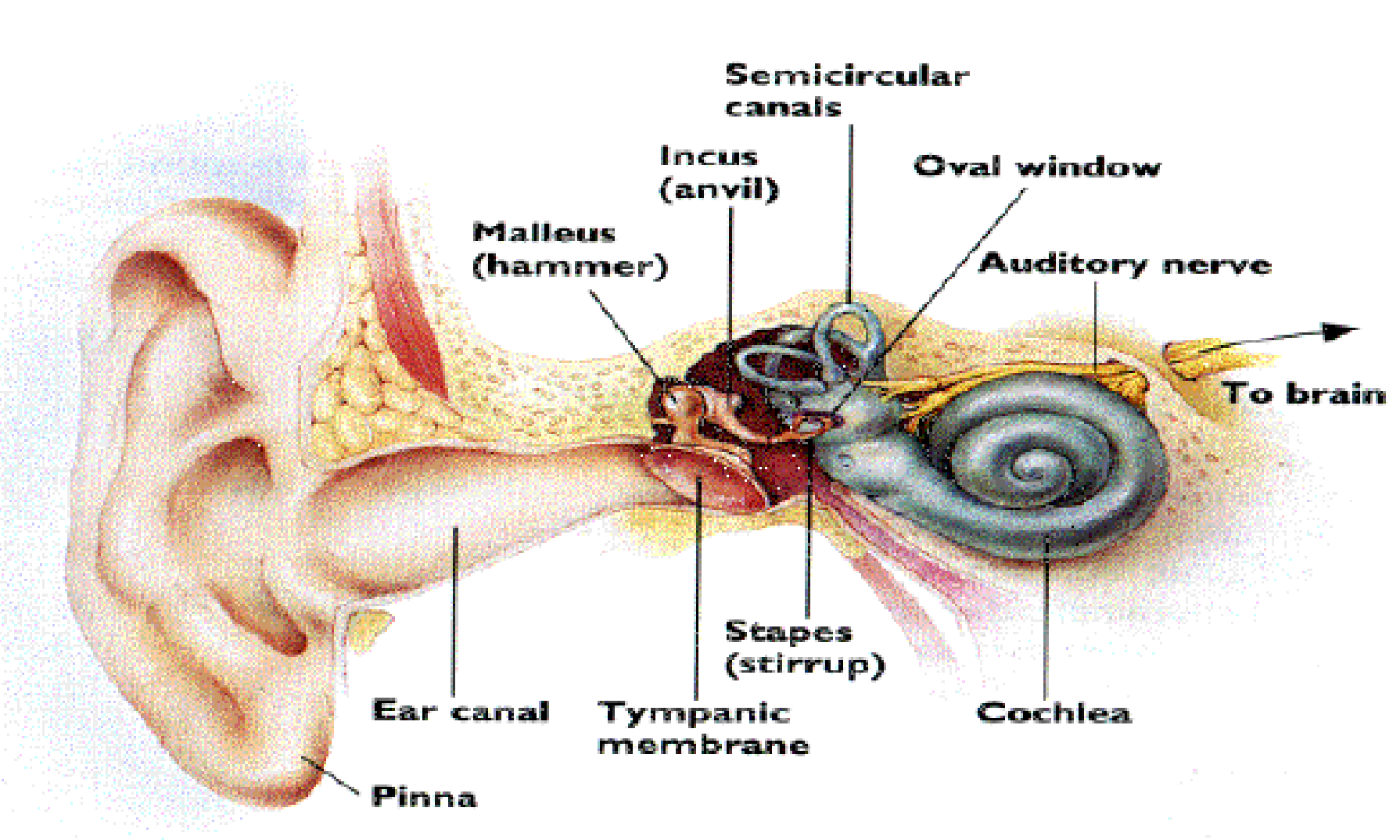


In terms of pressure, this is 20 µPa – 100 Pa

The decibel scale was developed from this fact and makes numbers more manageable

The decibel scale generally ranges from approximately 0 to 130

How Sound is Heard



Human hearing and Frequency

Inaudible



Subsonic

Range

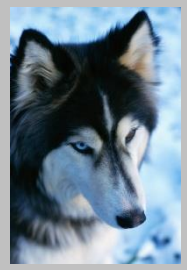
Audible



Sonic

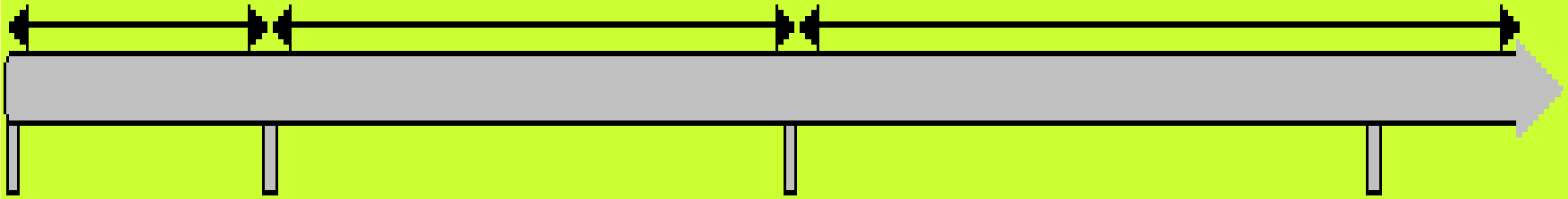
Range

Inaudible



Ultrasonic

Range



0 16 Hz 20 kHz 5 MHz

Sound and human hearing – Frequency

Humans are less sensitive to low frequency sound and more sensitive to high frequency sound. Therefore, sometimes the dB scale is adjusted to take this into account:

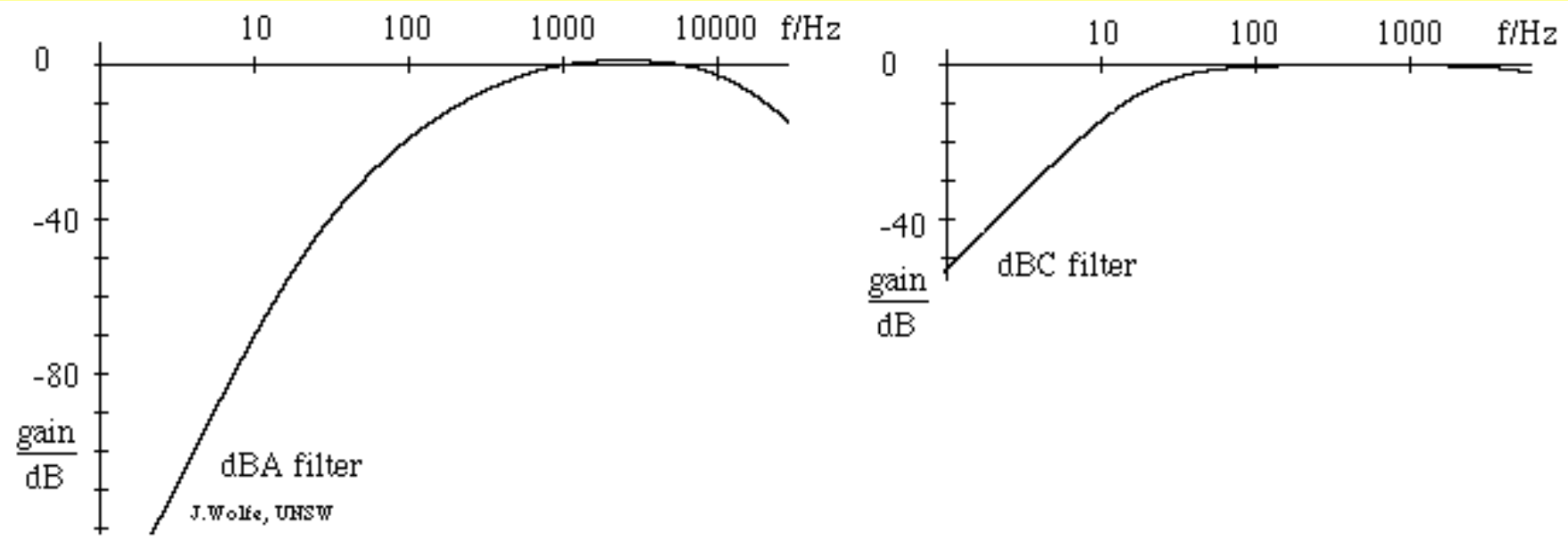
A-weighting (db(A)): adjusts overall scale so it better matches what the human ear would hear

C-weighting (dB(C)): adjusts scale for loud or low frequency sounds

B-weighting (dB(B)): adjusts by factors that are "in between" the A-weighted factors and C-weighted factors (rarely used)

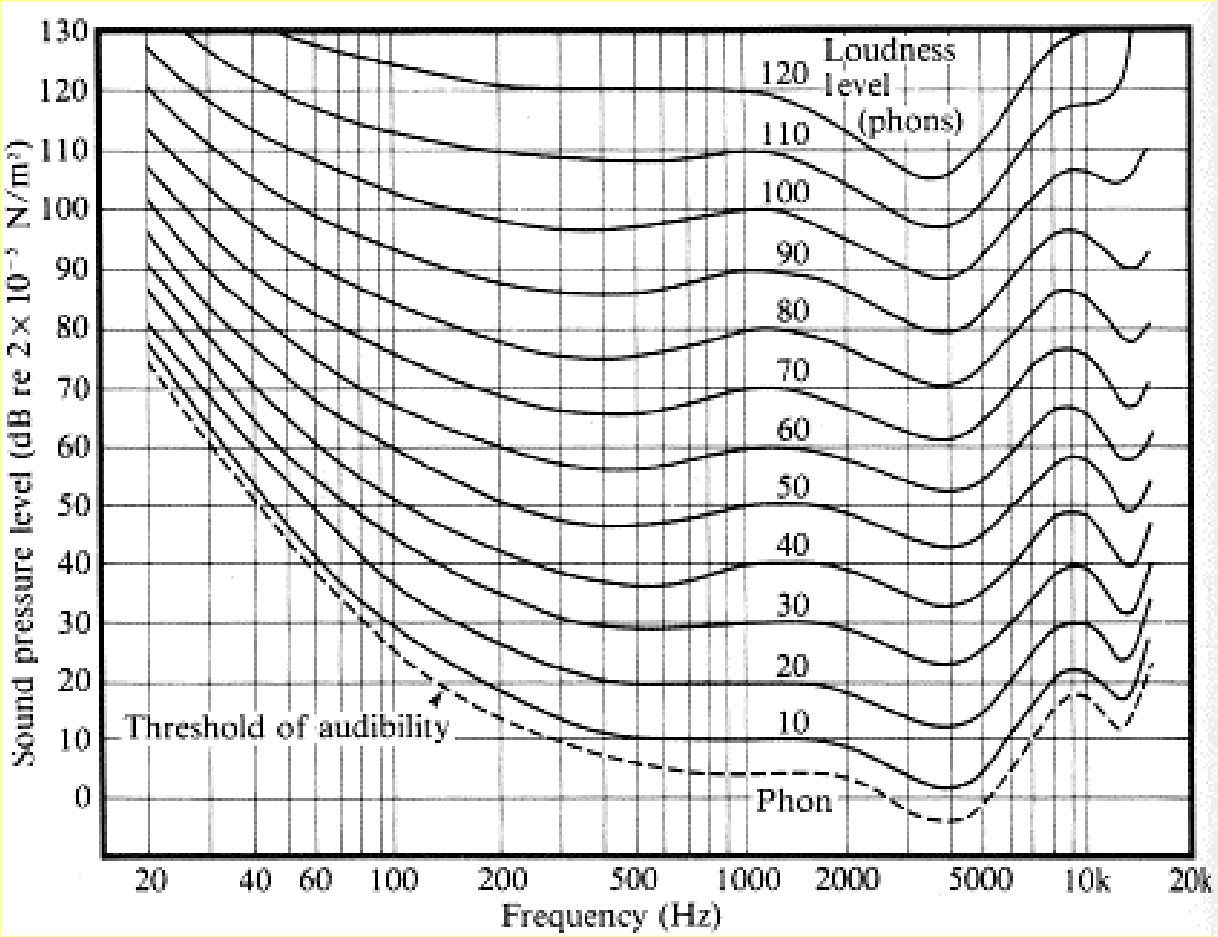
The filters used for dBA and dBC

The most widely used sound level filter is the A scale, which roughly corresponds to the inverse of the 40 dB (at 1 kHz) equal-loudness curve. The sound level meter is thus less sensitive to very high and very low frequencies. Measurements made on this scale are expressed as dBA. The C scale (in dBC) is practically linear over several octaves and is thus suitable for subjective measurements only for very high sound levels.



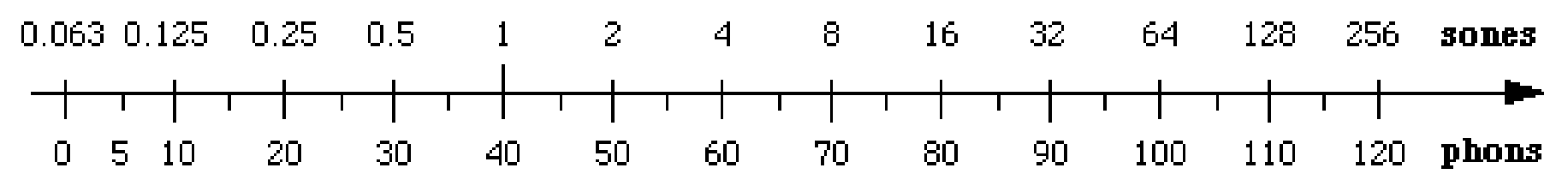
Loudness in phons

The phon is related to dB by the *psychophysically measured* frequency response. Phons = dB at 1 kHz. For other frequencies, the phon scale is determined by loudness experience by humans.



Loudness in sones

The **sone** is derived from psychophysical tests where humans judge sounds to be twice as loud. This relates perceived loudness to phons. A sone is 40 phons. A 10 dB increase in sound level corresponds to a perceived doubling of loudness. So that approximation is used in the definition of the phon: 0.5 sone = 30 phon, 1 sone = 40 phon, 2 sone = 50 phon, 4 sone = 60 phon, etc.



Other descriptors of sound

Equivalent sound level – the level of sound that has the same acoustical energy as does a time-varying sound over a stated time period.

Percentile sound level – the sound level exceeded “n” percent of the observation time interval.

Day-night average sound level – the equivalent sound level for a 24-h period that incorporates a decibel penalty during night hours.

FIGURE I

Loudness Ratio and A-Weighted Decibel Scale for Common Sounds

A – Loudness Level Ratio
B – A-Weighted Sound Pressure Level (dBA)

A	B	
128	130	Threshold of pain
64	120	Jet aircraft takeoff at 100 feet
32	110	Riveting machine at operator's position
16	100	Cutoff saw at operator's position
		Automobile horn at 10 feet
8	90	Industrial boiler room
		Bulldozer at 50 feet
4	80	Sports car interior at 60 m.p.h.
		Diesel locomotive at 600 feet
2	70	Quiet air compressor at 50 feet
1	60	Normal conversational speech at 5-10 feet
1/2	50	Open office area background level
1/4	40	Residential with soft radio music
		Residential background level
1/8	30	Soft whisper at 2 feet
		Recording studio
1/16	20	Concert hall

Typical suburban sound and their levels

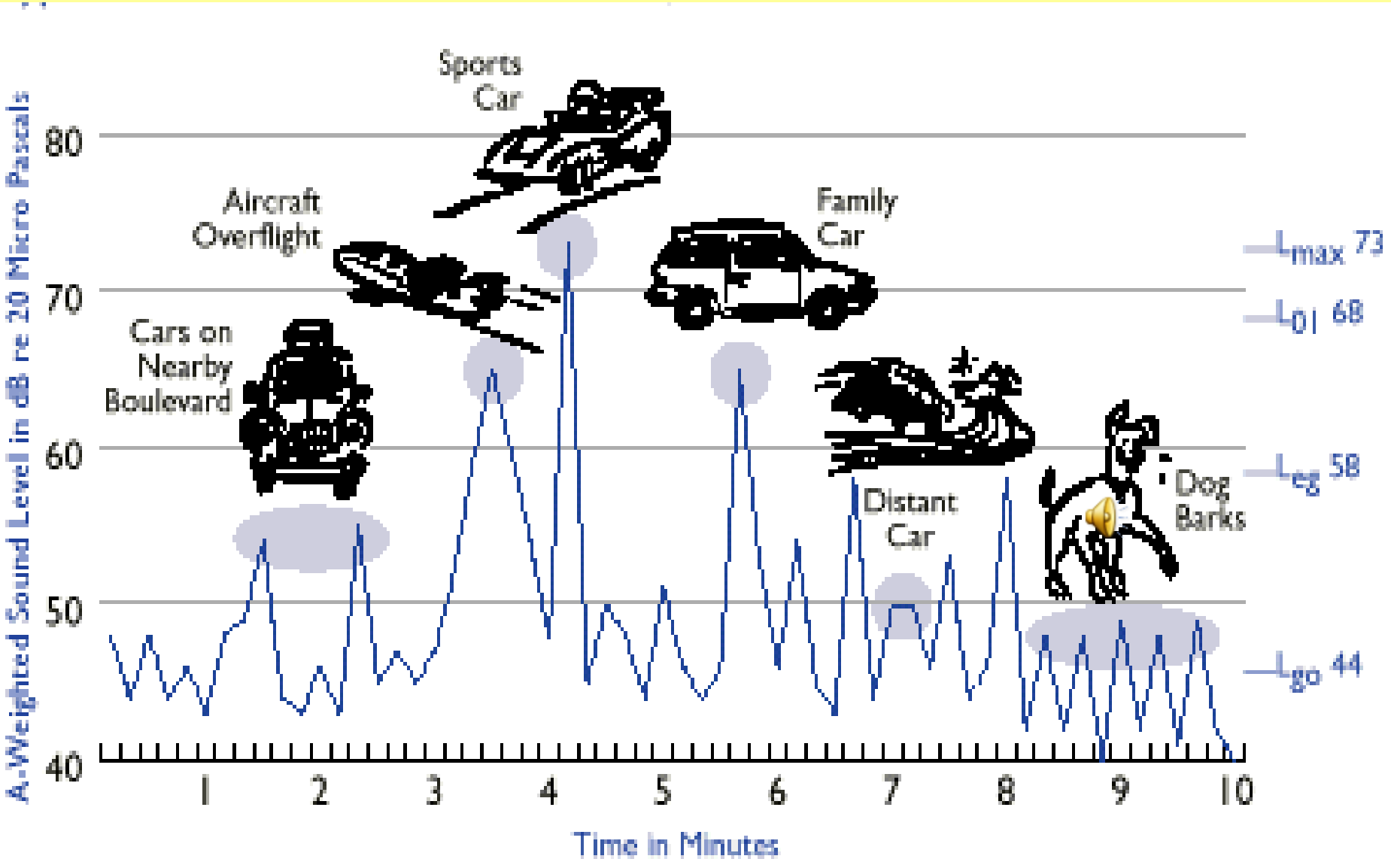
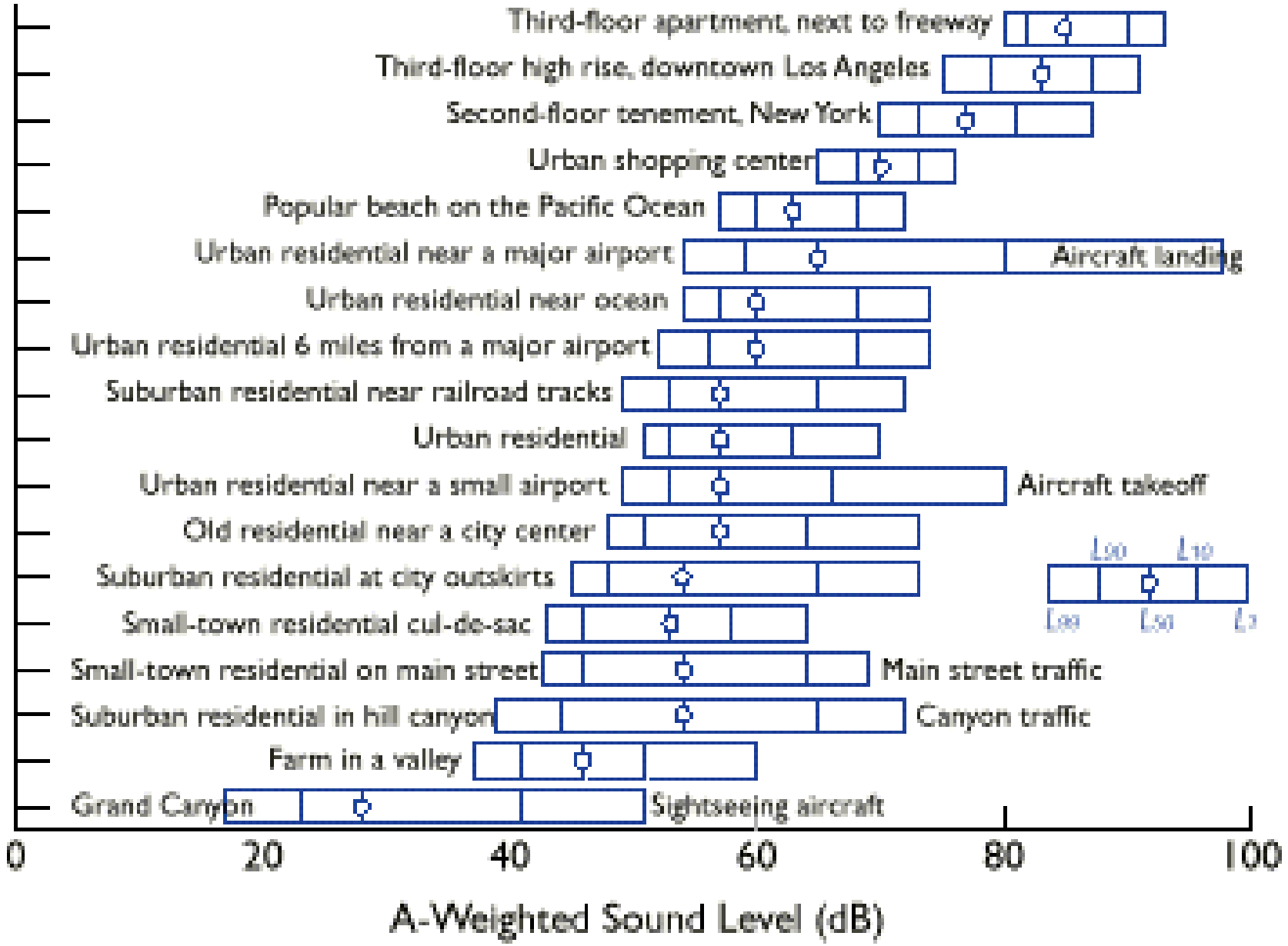
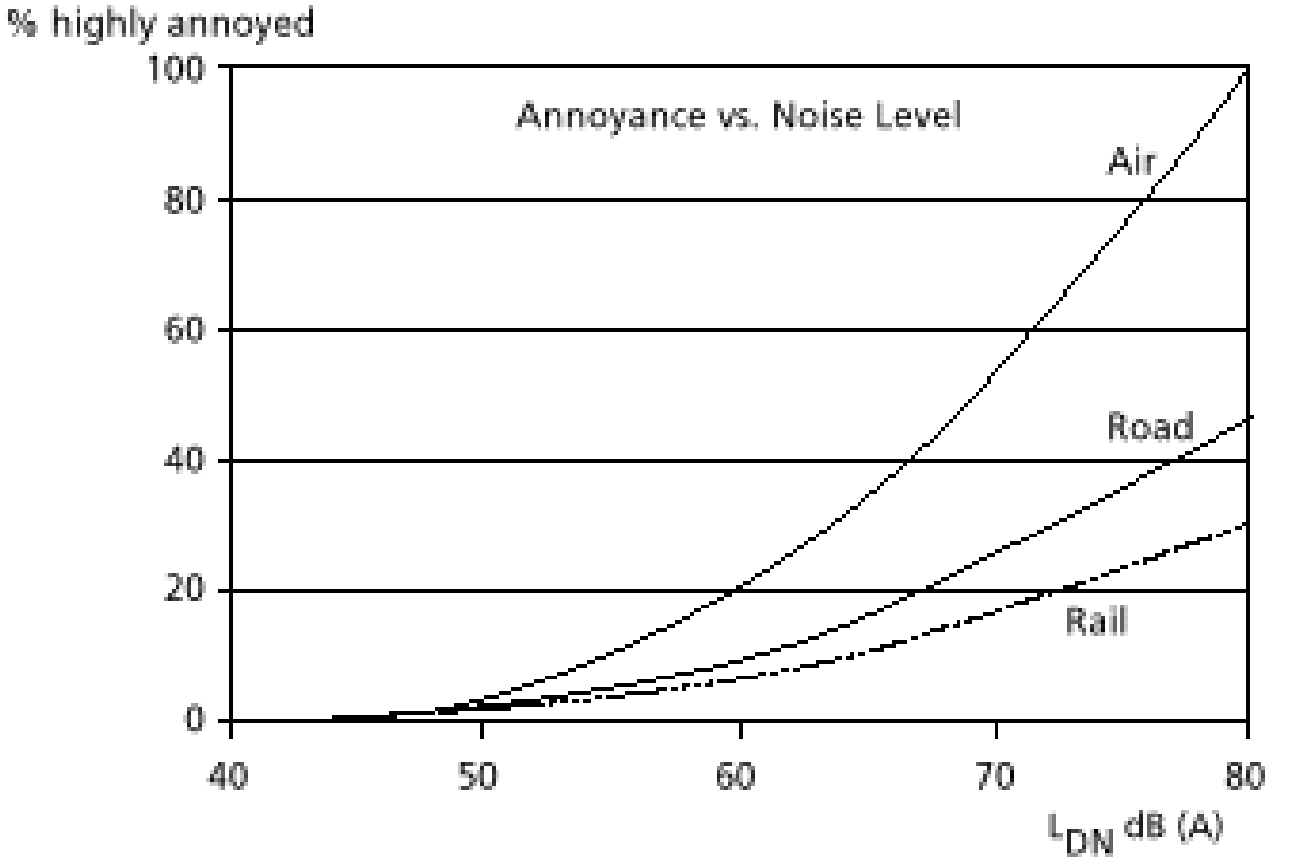


FIGURE 3

A-Weighted Sound Levels Measured at 18 Locations in the United States



Major transportation sources of noise pollution: rail, road, and air





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Rail Noise: A Case Study

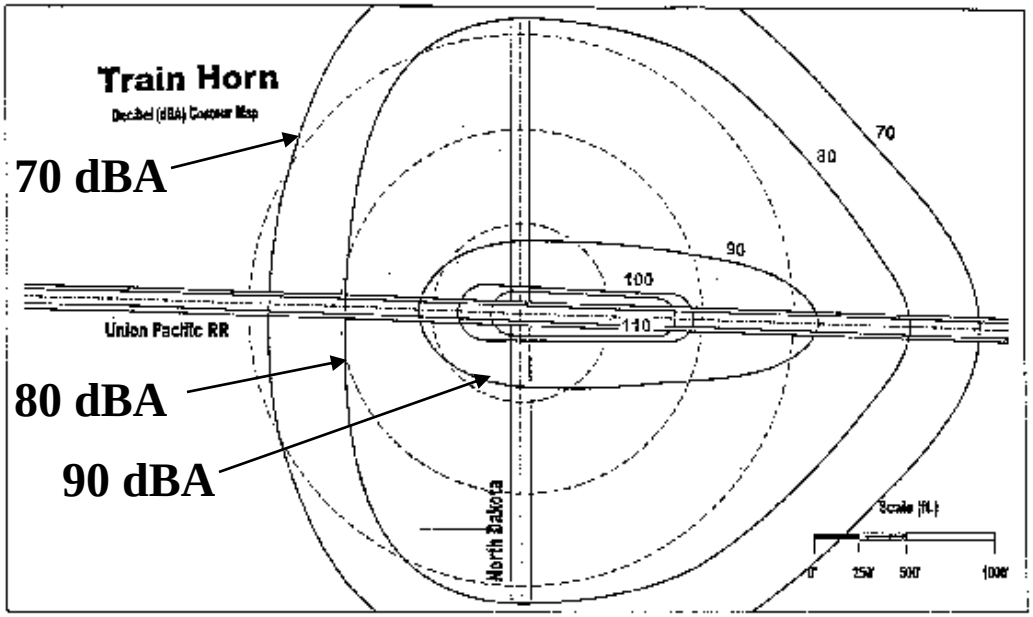
The city of Ames, Iowa, began operation of three automated horn warning systems (AHS) in September of 1998. These systems were installed after nearby residents repeatedly expressed concerns over the disturbance created by the loud train horns.

The automated horn system provides a similar audible warning to motorists and pedestrians by using two stationary horns mounted at the crossing. Each horn directs its sound toward the approaching roadway. The horn system is activated using the same track signal circuitry as the gate arms and bells located at the crossing.

Train Horn Noise Reduction

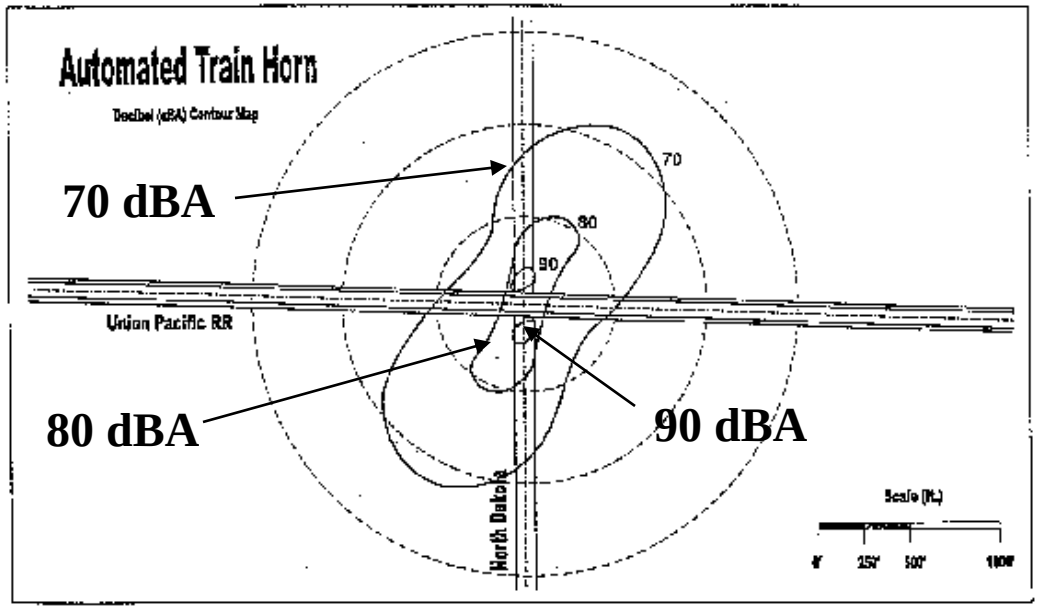
Sound Level	Train Horn	AHS Horn	Reduction
(dBA)	Area (acres)	Area (acres)	
> 70	265	37	86%
> 80	171	5	97%
> 90	31	< 1	98%

Intersection of railroad with North Dakota Avenue: A graphical depiction of the reduction



Before

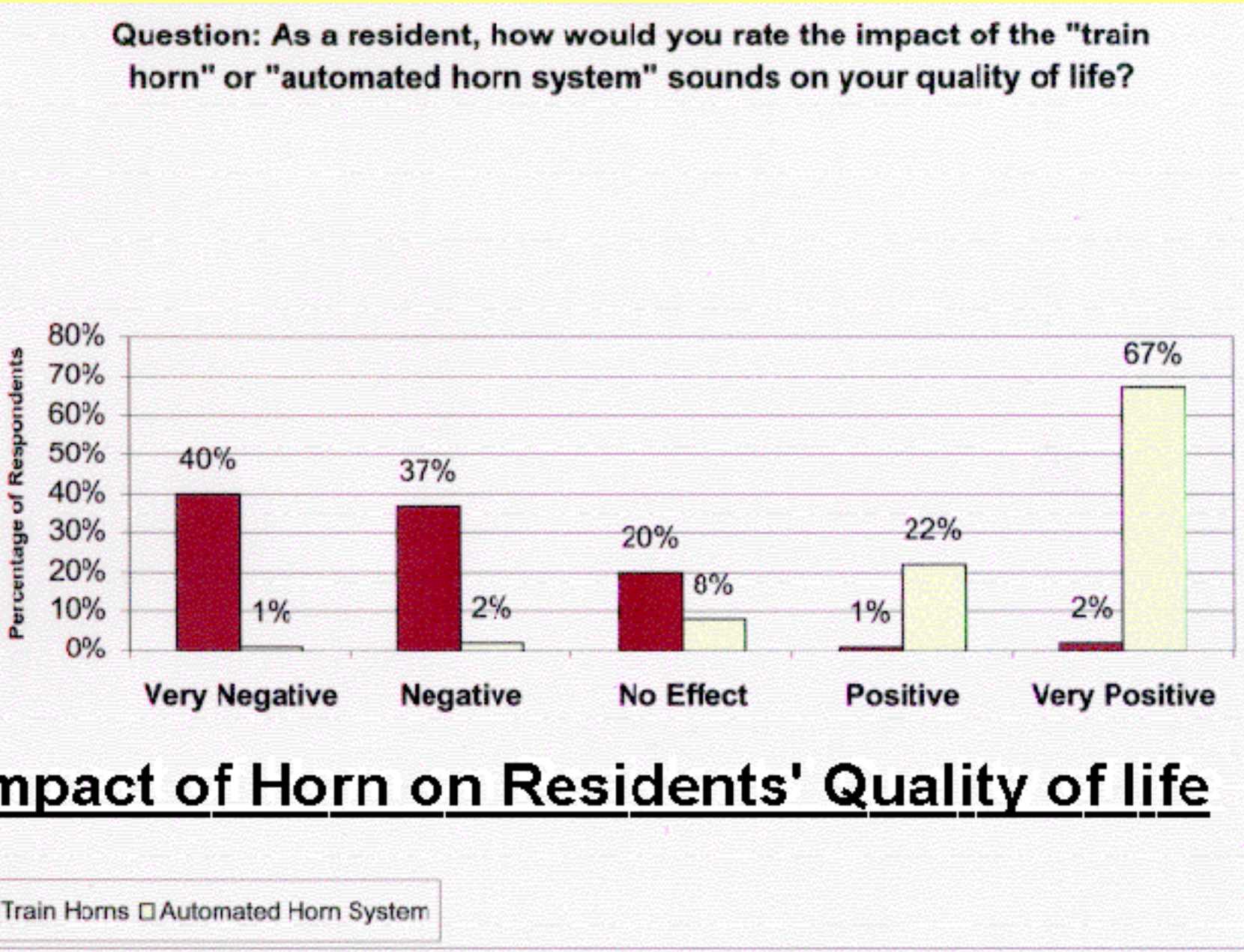
Figure 1



After

Figure 2

Ames Train Horn Noise Survey



Roadway Noise

- **An example of a “line source” of noise pollution (as opposed to a “point source”)**

- **Level of noise is a function of volume, type of vehicle, and speed**

Roadway Noise - Solutions

- **Regulations limit the amount of noise some vehicles can produce**

- **Some regulations require vehicles to be properly operated and maintained**

- **Despite regulations, the noise levels are usually only reduced by 5 to 10 dBA**

Roadway Noise - Solutions

Barriers

- Buffer zones
- Earth berms/wooden fences/concrete walls
- Vegetation (if dense enough)

Aesthetic noise barrier: Highway in Melbourne, Australia



Roadway Noise - Solutions

Pavement type

Certain asphalts, such as those containing rubber or stone, can be less noisy than other pavements.

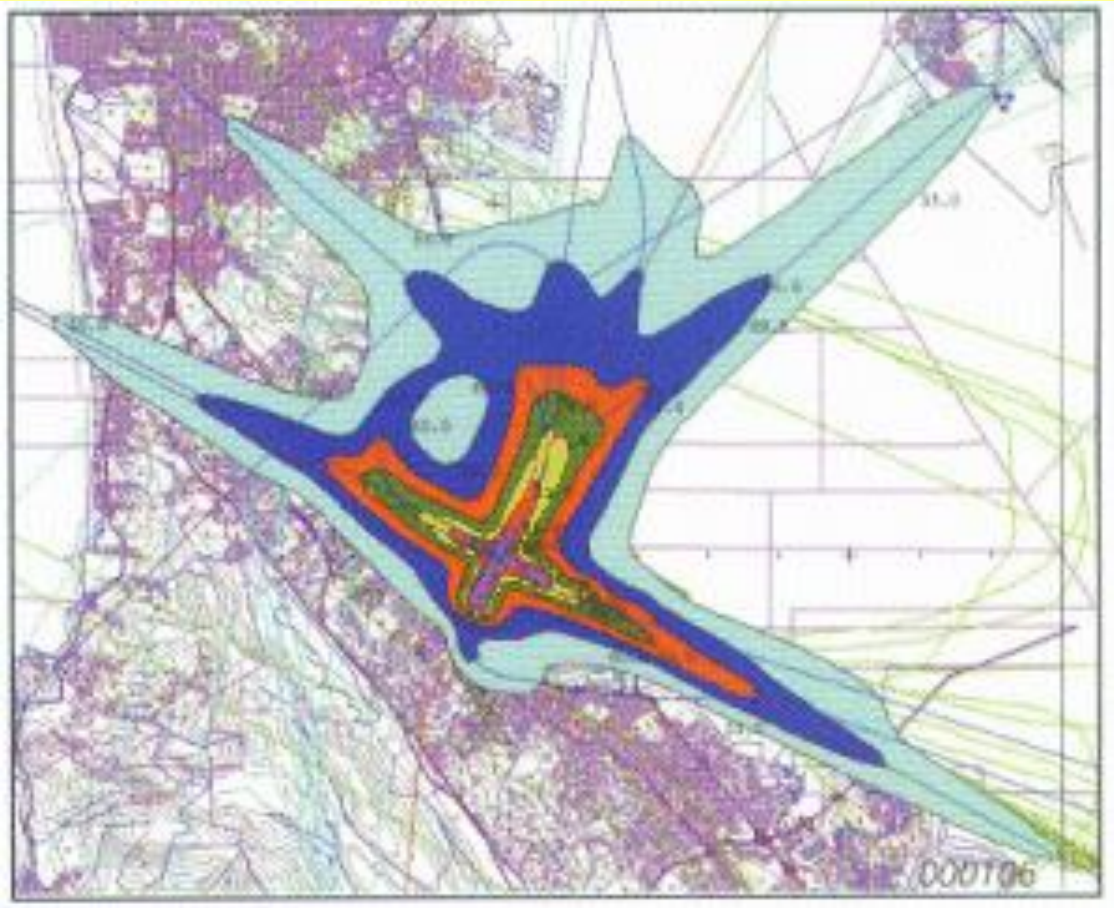
However, some studies have shown the reduction in noise is only a few decibels, not enough to be significant.

More research is needed before pavement type can be an effective noise-reducing technique

Airport Noise

Noise contours around an airport calculated using INM (Integrated Noise Modeling) based on previous noise measurements

55 - 60 dB = Light blue
60 - 70 dB = Dark blue
70 - 75 dB = Red
75 - 80 dB = Green
80 - 85 dB = Yellow
> 85 dB = Pink



Airport Noise

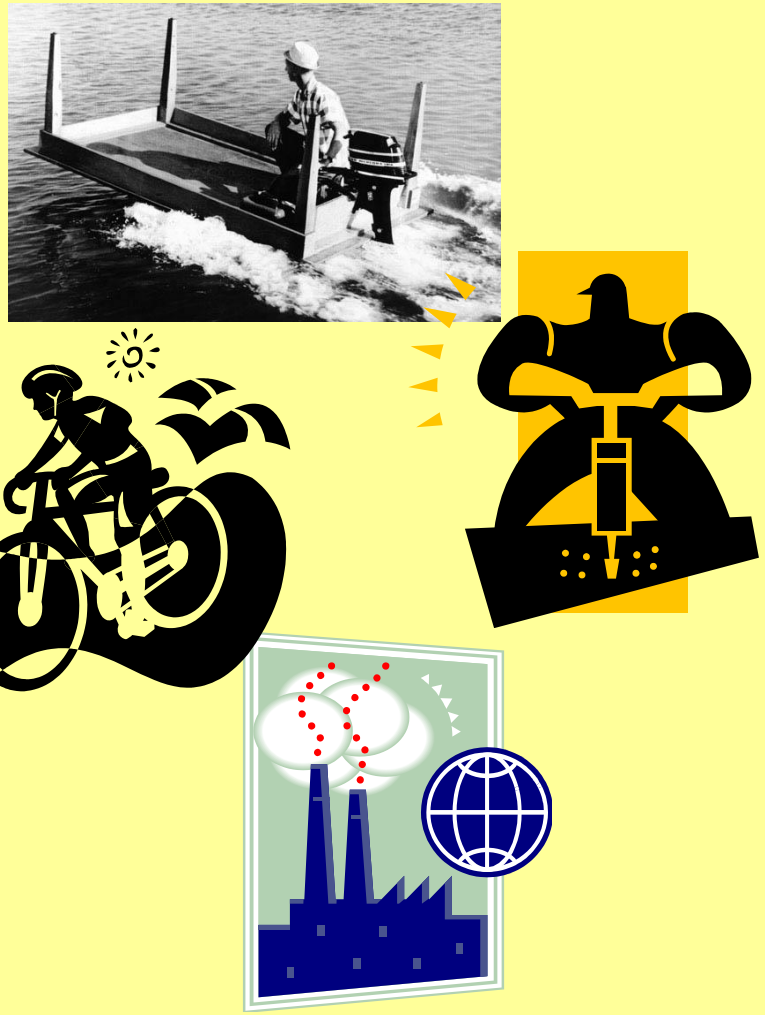
TABLE 3

Possible Airport Noise Abatement Actions

Airport Feature and Activity	Possible Noise Abatement Actions
Flight tracks	Direct aircraft away from populated areas
Preferential runways	Foster use of runways with least impact
Restrict noisy aircraft	Minimize operations during day or night
Noise abatement flight procedures	Require use of noise abatement throttle and flap management procedures for takeoff and/or approach
Airport layout	Extend or build new runways and taxiways to make best use of compatible land and water
Shielding barriers	Shield people from noise of ground operations.
Building soundproofing	Soundproof schools, homes, and churches
Land use control	Ensure compatible land use through acquisition of property or other rights
Monitor and model	Monitor airport noise and flight tracks to provide data to the public and for evaluating proposed alternatives
Communications	Listen to complaints and suggestions; develop and institutionalize continuing effective dialogue and information transfer among all concerned parties

Other sources of noise pollution that need to be addressed

- **Boat noise, especially jet skis**
- **Construction noise**
- **Snow mobiles**
- **Industry**



References



Davis and Masten, Chapter 15

Brüel & Kjær Sound & Vibration Measurement A/S

Steve J. Gent, P.E., Research Coordinator, Iowa Department of Transportation

FHWA

Assignment A2

Please do Problems 15-2, 15-4, 15-8, 15-15 and 15-17

In Davis and Masten, Principles of Environmental Engineering and Science, Chapter 15.