Measures and sources of sound

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WHAT IS NOISE?

Sound may be defined as a time-varying fluctuation of the density of a fluid from its ambient (mean) state, which is accompanied by a proportional disturbance in the pressure from its mean value which propagates at the speed of sound. Sound may be desired or undesired. Unwanted sound is called noise. Noise may:

- Cause annoyance
- Be stressful
- Degrade speech intelligibility
- Lessen enjoyment of music
- Harmful to hearing

WHAT IS A SOUND SOURCE?

Example: car engine

combustion in cylinders ↓	acts within the structure
engine vibration radiates noise ↓	acts on the air
sound is radiated from car ↓	as seen at the wayside
traffic flow on road	as seen at a distance

DIVERSITY OF NOISE SOURCES PRESENT IN INDUSTRIAL MACHINES

After Walker and White, “Noise and Vibration”, Ellis 1982)

A survey has been undertaken in which the generating mechanisms of 45 different machines are identified. These are:

- jet emission
- fan
- hammer deceleration
- workpiece distortion or vibration
- anvil/case ringing
- supporting structure vibration
- air ejection
- blow-off valves

CLASSIFICATION OF NOISE SOURCES

Sources of sound are extremely diverse in their:

I. Generation mechanism
II. Mechanic-acoustical efficiency (see lecture on ‘sound radiation’)
III. (Free field) directivity
IV. Frequency spectra

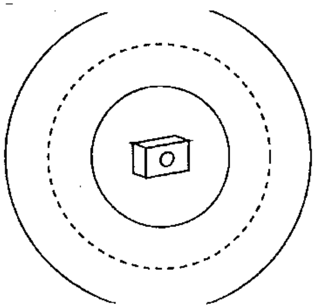
Most mechanical noise sources consist of a mixture of various source types. Consequently, it is difficult to simply categorize them and to devise general formula for predicting their radiated sound.

Nevertheless, sources may be generally categorized in terms of only three fundamental source types: Acoustic monopole, dipoles and quadrupoles.

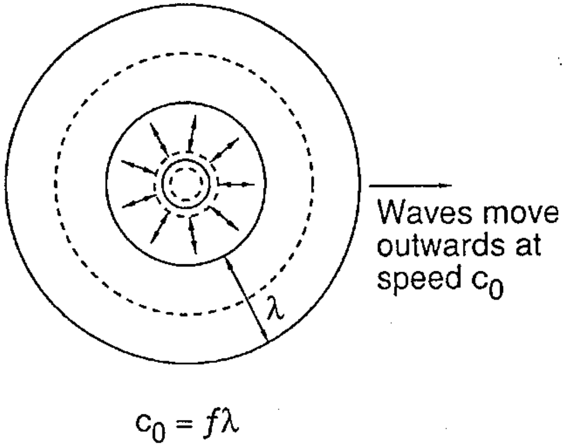
BASIC SOURCE TYPES

Monopole

fluctuating addition / withdrawal of mass

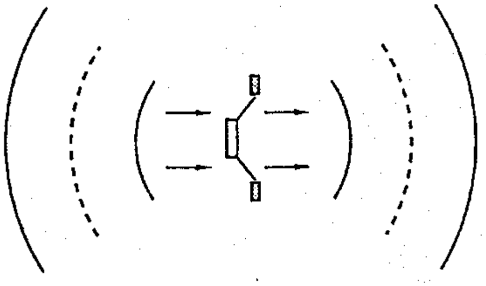


equivalent to a pulsating sphere

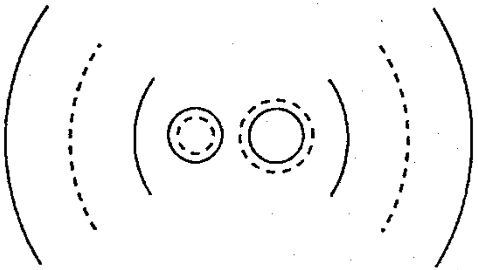


Dipole

fluctuating force

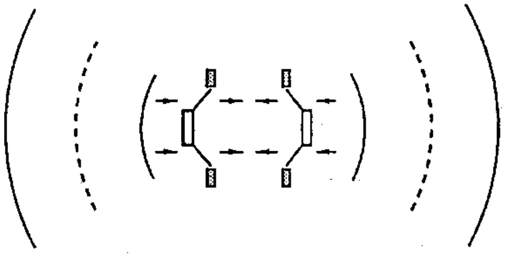


equivalent to two equal and opposite monopoles

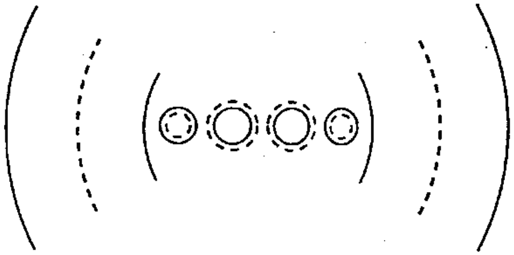


Quadrupole

fluctuating stress



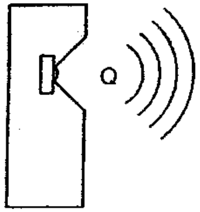
equivalent to four monopoles



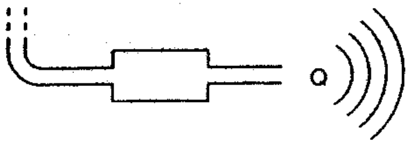
MONOPOLES: FLUCTUATING VOLUME/MASS SOURCES

Examples

Loudspeakers



Exhaust pipe radiation



Air compressors

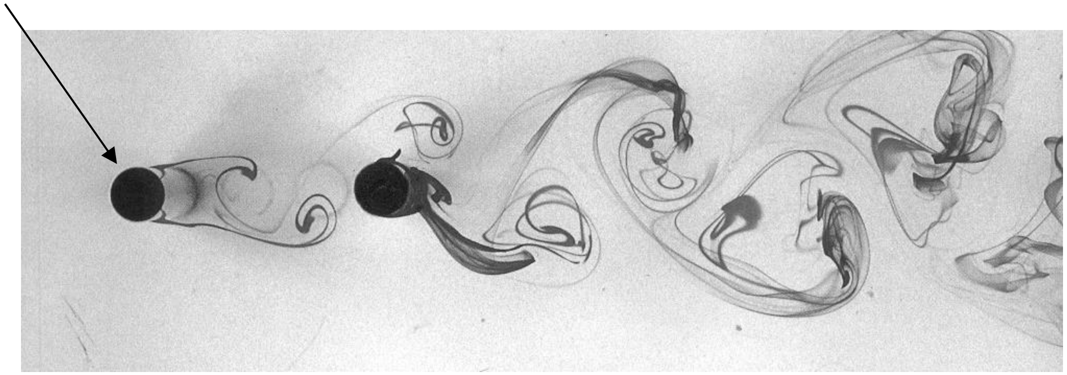
Unsteady combustion

DIPPOLES: APPLICATION OF TIME-VARYING FORCES TO A FLUID WITHOUT VOLUME DISPLACEMENT

Examples

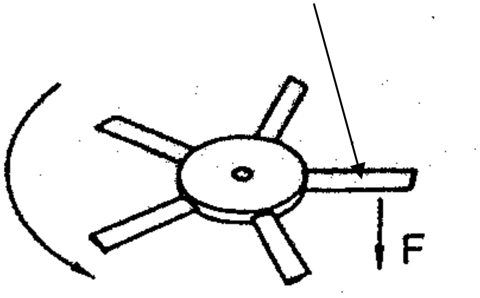
Whistling car antenna

Dipole source on surface



Turbulence (unsteady flow) acting on a rigid surface, such as in fan noise and airframe noise

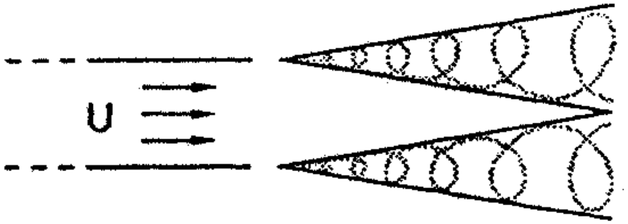
Dipole source on surface



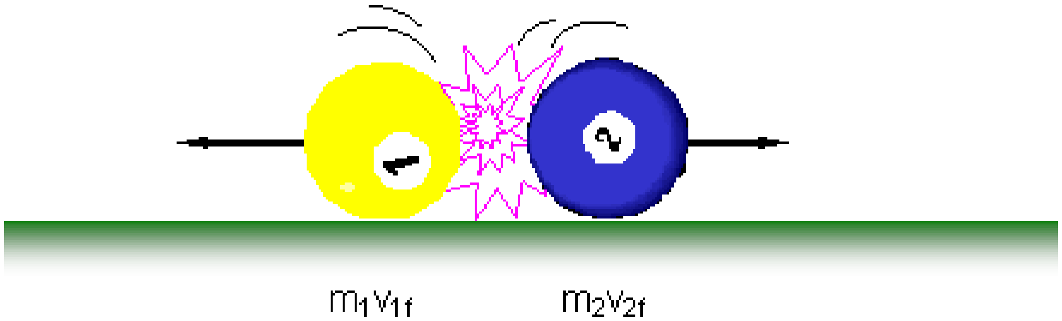
QUADRUPOLES: APPLICATION OF TIME-VARYING FORCES TO A FLUID WITHOUT VOLUME DISPLACEMENT OR NET FORCE ACTING ON FLUID

Examples

Sound radiation by free turbulence



‘Clack’ of colliding billiard balls

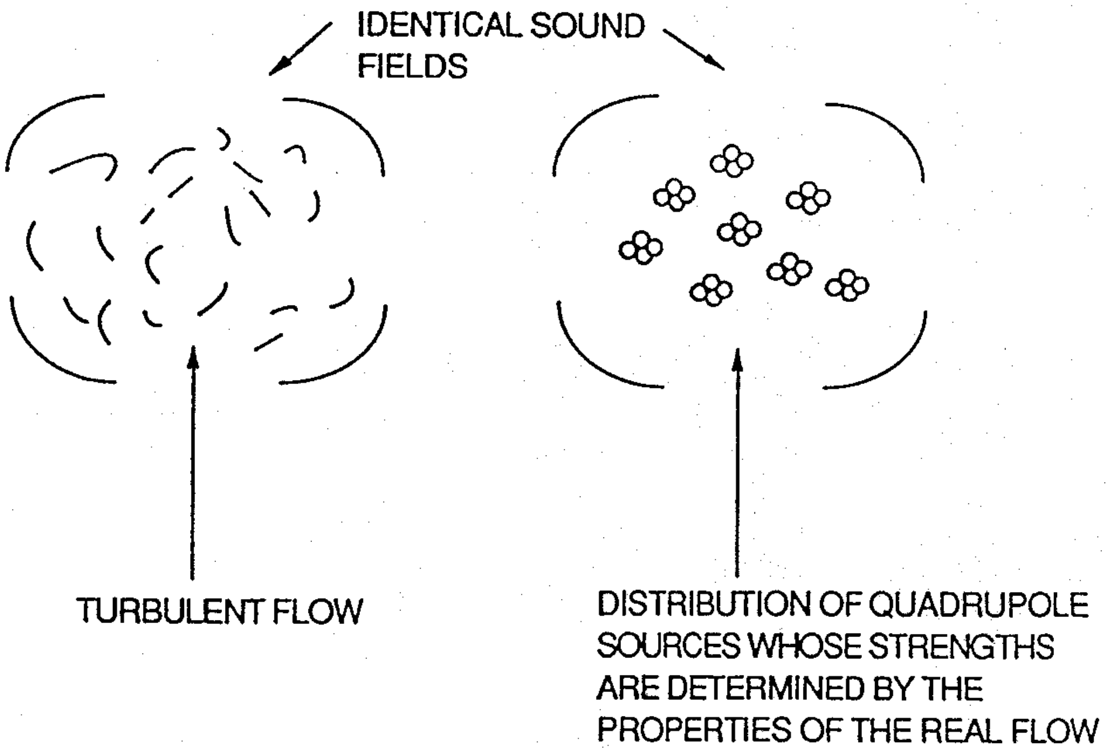


AERODYNAMIC SOURCES

Lighthill's theory

- Lighthill (1952) first showed that sound generated by turbulent flow was *just as if* the field were generated by a distribution of *quadrupole* sources.

  (He did this by rearranging the basic equations of fluid dynamics).



Spectral analysis

SOUND SPECTRA

Fourier's Theorem

Any (pressure) time series, whether random broadband, transient or periodic, can be constructed from an infinite number of appropriately phased single frequency components (tones) of infinite duration!

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega) e^{j\omega t} d\omega$$

Reasons for performing spectra

- The auditory system sensitivity varies with frequency
- Noise control performance varies with frequency
- Mathematical and numerical prediction of sound field is much easier at a single frequency (sound field in cars, for example. The broadband and transient behaviour of the sound field can then be predicted by Fourier synthesis of the single frequency sound fields.

TYPES OF SPECTRA

Repetative time series

p(t)

( )

t

Random b lo [illegible] sient time s

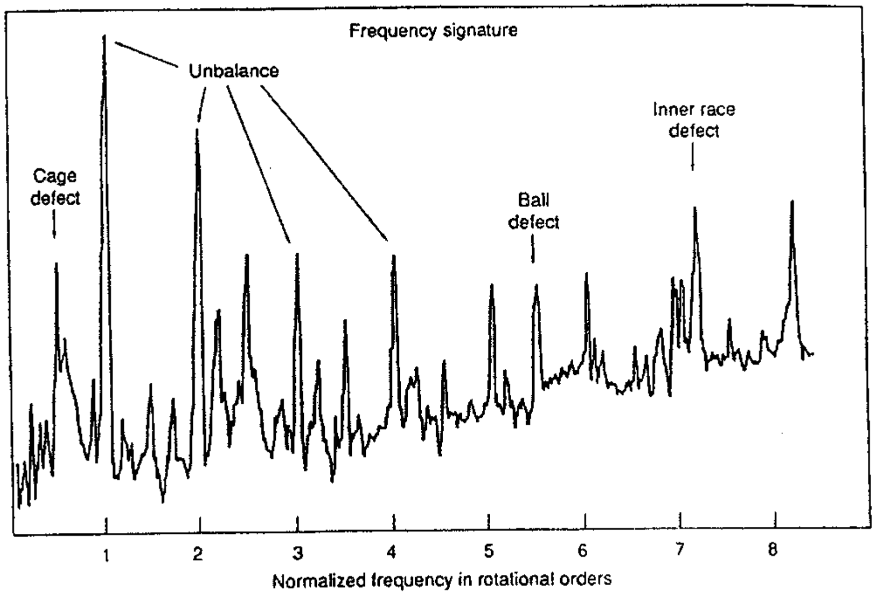
p(t)

t

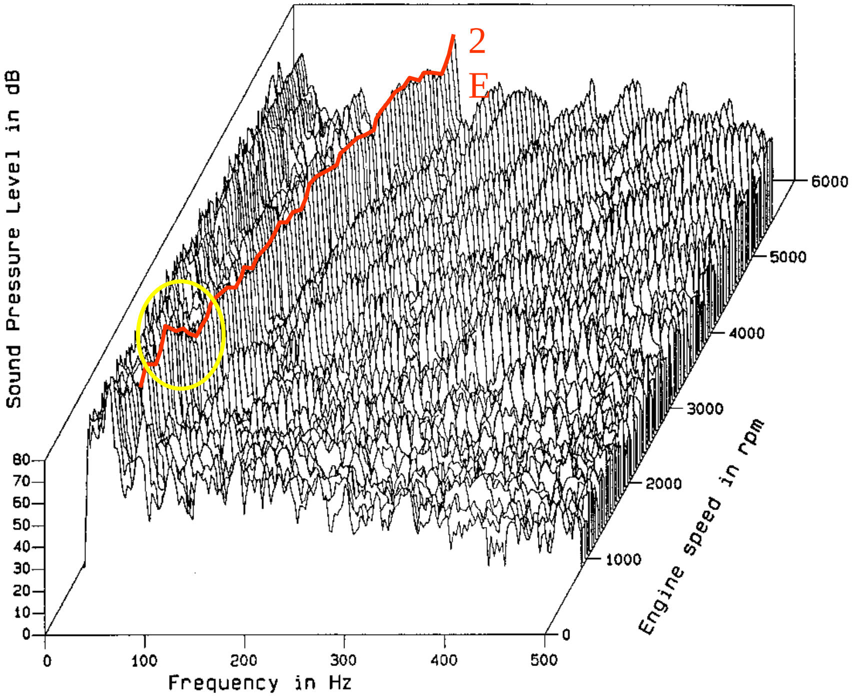
( )

EXAMPLE SPECTRA

mechanical signature of a ball bearing race



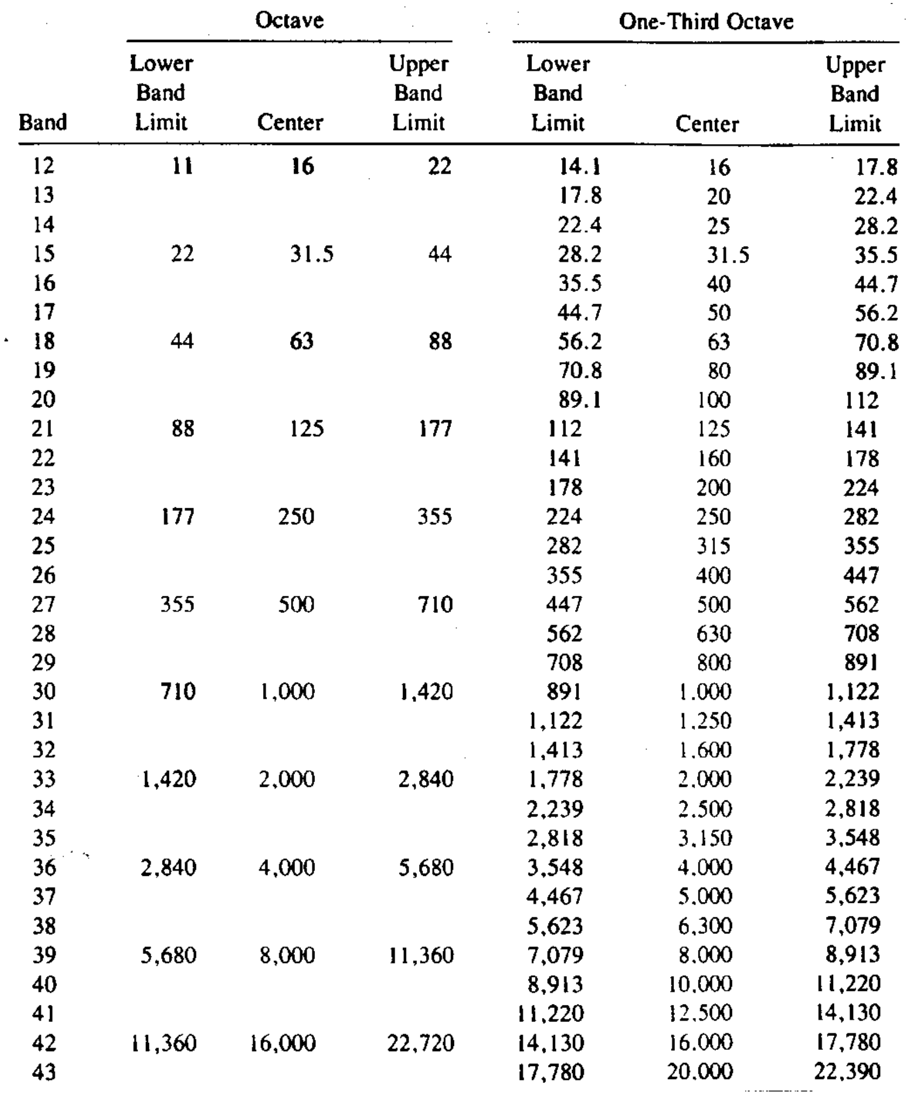
waterfall plot - car A



STANDARD FREQUENCY BANDS

Narrow band frequency analysis is useful for revealing the details in the spectrum, such as the presence of discrete frequency tones in a broadband noise floor. Often, however, a representation of the spectrum in course, fairly large frequency bands is sufficient.

The most usual frequency bands are one-third or whole octave bands. Their lower, centre and upper band limits are given below.



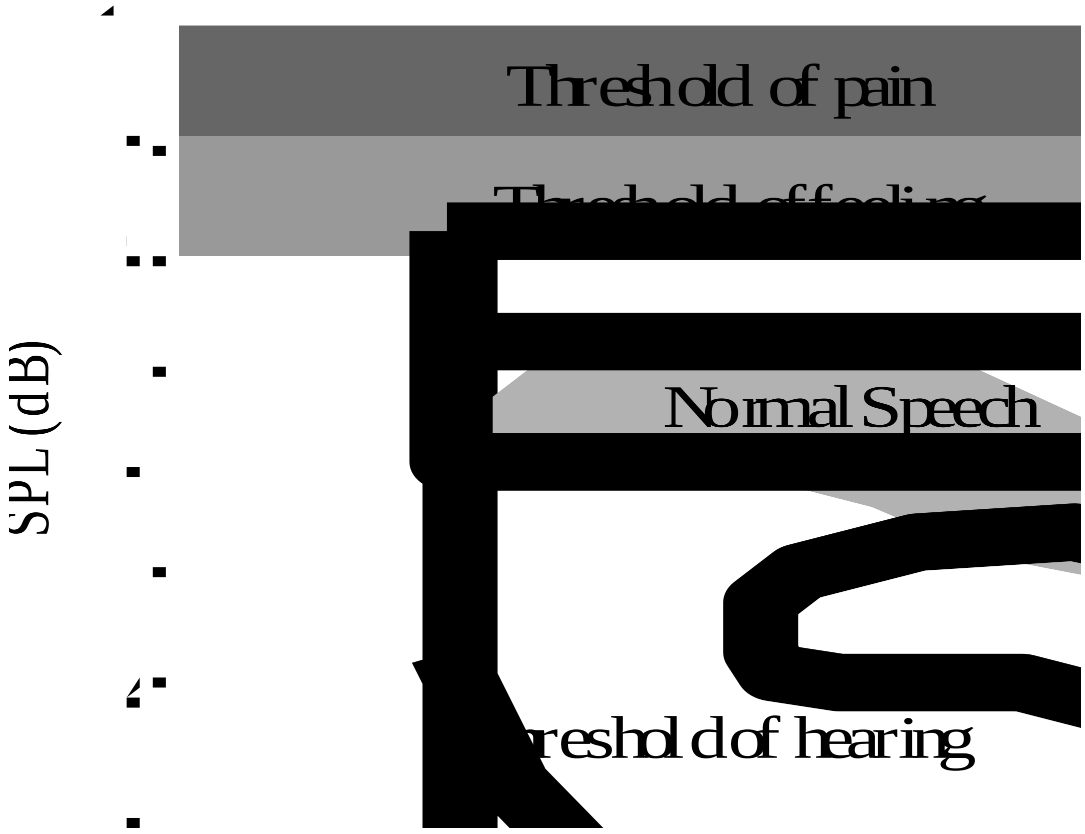
	Octave			One-Third Octave		
Band	Lower Band Limit	Center	Upper Band Limit	Lower Band Limit	Center	Upper Band Limit
12	11	16	22	14.1	16	17.8
13				17.8	20	22.4
14				22.4	25	28.2
15	22	31.5	44	28.2	31.5	35.5
16				35.5	40	44.7
17				44.7	50	56.2
18	44	63	88	56.2	63	70.8
19				70.8	80	89.1
20				89.1	100	112
21	88	125	177	112	125	141
22				141	160	178
23				178	200	224
24	177	250	355	224	250	282
25				282	315	355
26				355	400	447
27	355	500	710	447	500	562
28				562	630	708
29				708	800	891
30	710	1,000	1,420	891	1,000	1,122
31				1,122	1,250	1,413
32				1,413	1,600	1,778
33	1,420	2,000	2,840	1,778	2,000	2,239
34				2,239	2,500	2,818
35				2,818	3,150	3,548
36	2,840	4,000	5,680	3,548	4,000	4,467
37				4,467	5,000	5,623
38				5,623	6,300	7,079
39	5,680	8,000	11,360	7,079	8,000	8,913
40				8,913	10,000	11,220
41				11,220	12,500	14,130
42	11,360	16,000	22,720	14,130	16,000	17,780
43				17,780	20,000	22,390

THE HUMAN AUDITORY RESPONSE

The range of sound pressure level frequency that the human ear can perceive is vast.

This figure is for a healthy normal adult. Hearing worsens with:

- Old-age (Presbycusis)
- long term exposure to loud noise levels
- Illness – conductive deafness, Nerve deafness and cortical (brain) deafness

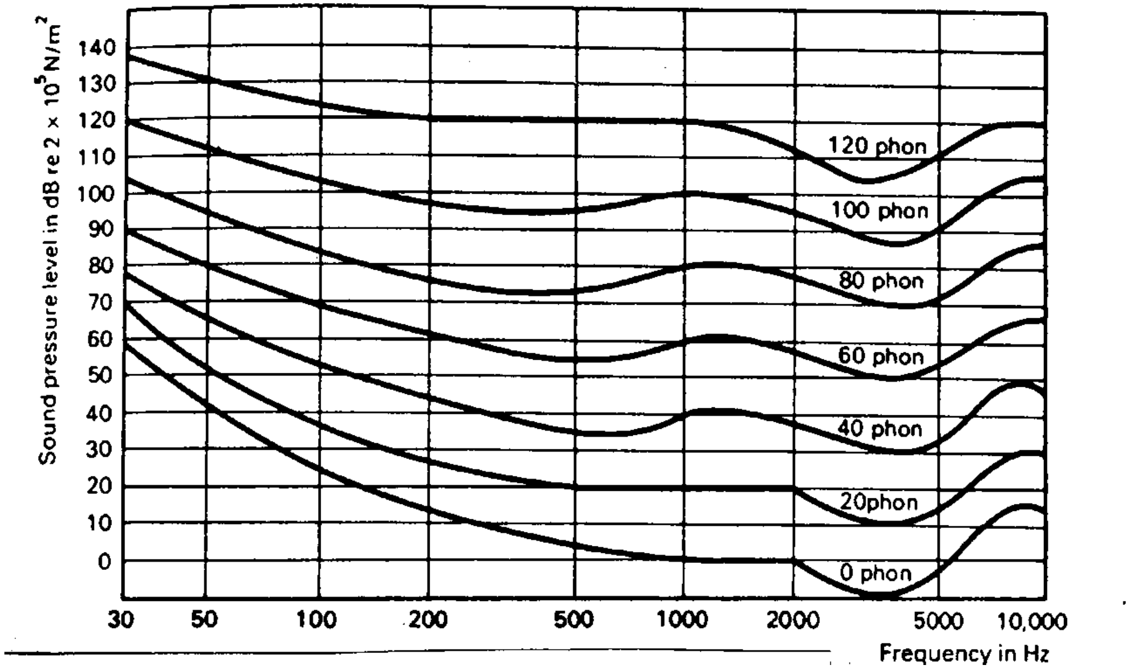


SUBJECTIVE NOISE MEASURES

A - WEIGHTING - (dBA)

The sensitivity of the ear varies with frequency. The commonest ‘weighting’ (or correction) scale for incorporating this subjective sensitivity, which approximates the inverse of the human equal loudness curves, is the A - weighted sound level L_A expressed in dBA (or dB(A)).

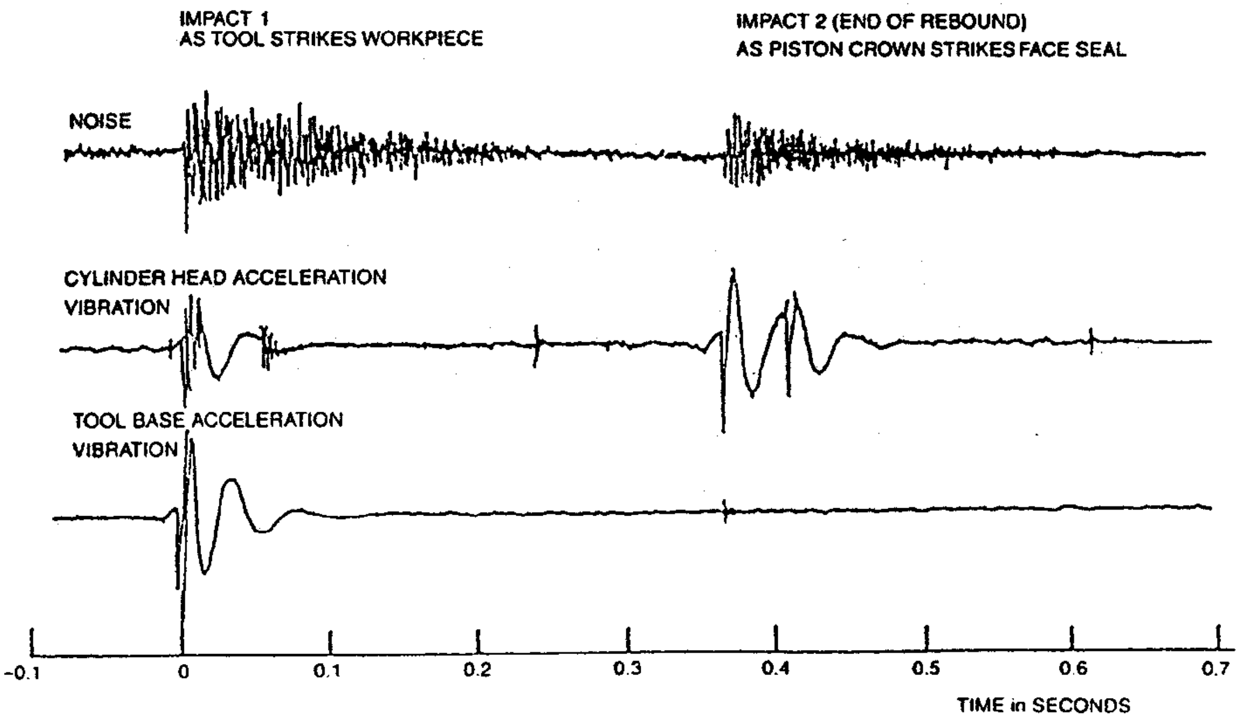
Centre frequency	Correction (dB)
31.5	-39.4
63	-26.2
125	-16.1
250	-8.6
500	-3.2
1000	0
2000	1.2
4000	1.0
8000	-1.1



(the phon is dB measure of perceived loudness)

TIME DEPENDENCE OF SOUND SIGNALS

Frequency analysis is very useful. But it may obscure the nature of the noise-generating mechanisms. As part of diagnostic tests it is often instructive to study the time-histories of radiated sound pressure or intensity. It can also be helpful to slow down a recording of the noise of a source so that the listener can more readily identify individual events.



DIRECTIVITY
GEOMETRIC SPREADING

For a *point* monopole source

$$\overline{p^2} \approx \rho c I = \frac{\rho c W}{S} = \frac{\rho c W}{4\pi r^2}$$

i.e. $L_\mathrm{p} \sim -20 \log_{10} r$ or –6 dB per doubling of distance

For a *line* monopole source

$$\overline{p^2} \approx \rho c I$$

i.e. $L_\mathrm{p} \sim -10 \log_{10} r$ or –3 dB per doubling of distance

DIRECTIVITY
FAR FIELD VARIATION

In the far field the sound field can be approximated as having

- a dependence on distance,
- a separate dependence on direction D_θ.

For a (point) source in free field, at a distance r from the source, write the mean intensity as

$$\langle I \rangle = \frac{W}{4\pi r^2}$$

Then the directivity factor D_θ is defined as the ratio of intensity in the direction (θ, ψ) to the mean intensity:

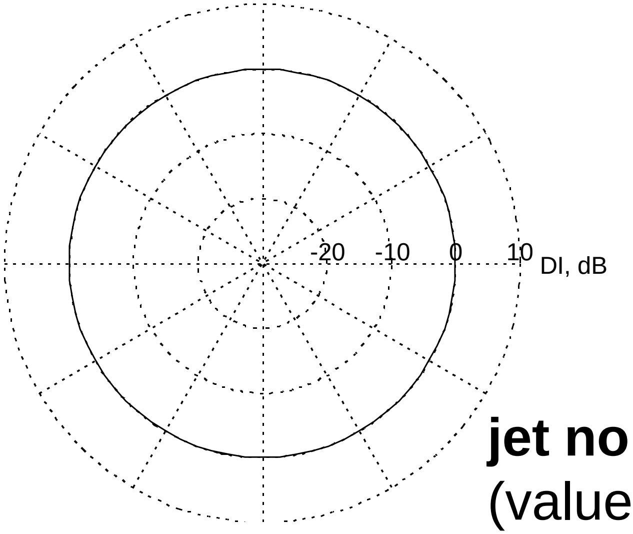
$$D_\theta = I_\theta / \langle I \rangle$$

and the directivity index as $DI = 10 \log_{10} D_\theta$

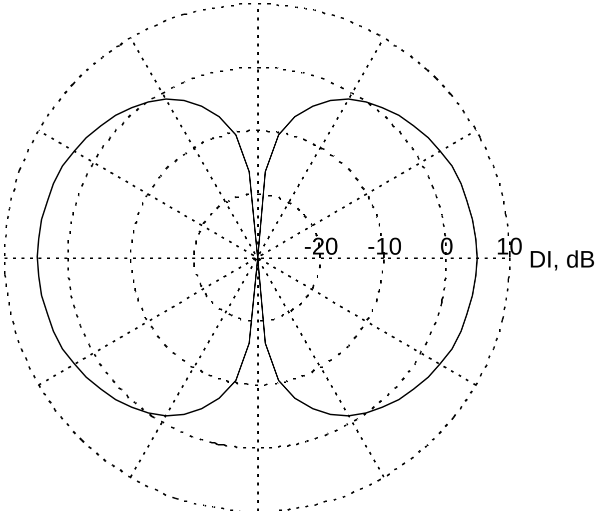
$$I_\theta = \langle I \rangle D_\theta = \frac{W D_\theta}{4\pi r^2} \qquad L_\mathrm{p} \approx L_\mathrm{I} = L_\mathrm{W} - 20 \log_{10} r - 11 + \mathrm{DI}$$

DIRECTIVITY - EXAMPLES

monopole: omnidirectional
(equal sound in all directions)



dipole: $p(\theta) \sim p_0 \cos \theta$



jet noise
(values from Bies and Hansen)