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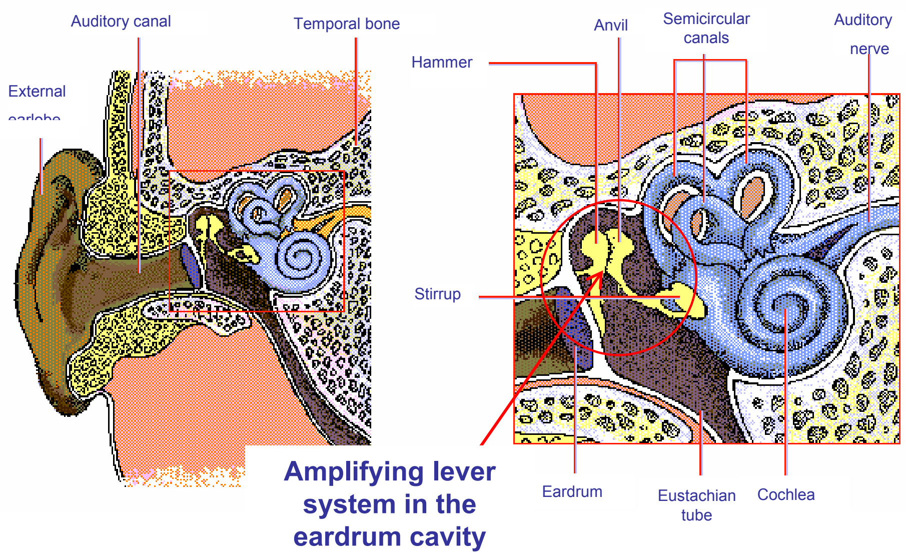
The use of decibels and loudness in the assessment of S&R in vehicles

Evaluation of noise

Introduction

The performance and versatility of human hearing as a sound analyzer has not yet been matched by a technical system.

Is very difficult to define parameters that correctly assess the human hearing sensation.



Sound pressure level

The simplest way to quantify the noise is calculating the root mean square (rms) value of the sound pressure:

$$p_{rms} = \sqrt{\frac{1}{T}\int_0^T p(t)^2\,dt}$$

$$p_{rms}(t) = \sqrt{\frac{1}{T}\int_{\tau-T}^{\tau} p(\tau)^2\,d\tau}$$

p_{rms}	$p_{rms}(t)$	root mean square sound pressure
t	τ	time variables
$p(t)$	$p(\tau)$	sound pressure versus time

Limitations

- Sound pressure range too big $p = 0{,}00002 \div 100$ Pa
- Perception logarithmic

Sound pressure level

In order to overcome the above limitations we define logarithmic scales:

$$L_{eq} = SPL = 20\log\frac{p_{rms}}{p_0} \quad (dB)$$

$$SPL(t) = 20\log\frac{p_{rms}(t)}{p_0} \quad (dB)$$

p_{rms}	root mean square sound pressure
t	time variable
SPL	sound pressure level
$p_0 = 20 \cdot 10^{-6}$	auditory threshold
dB	decibel (unit)

But, this scales does not take into account that

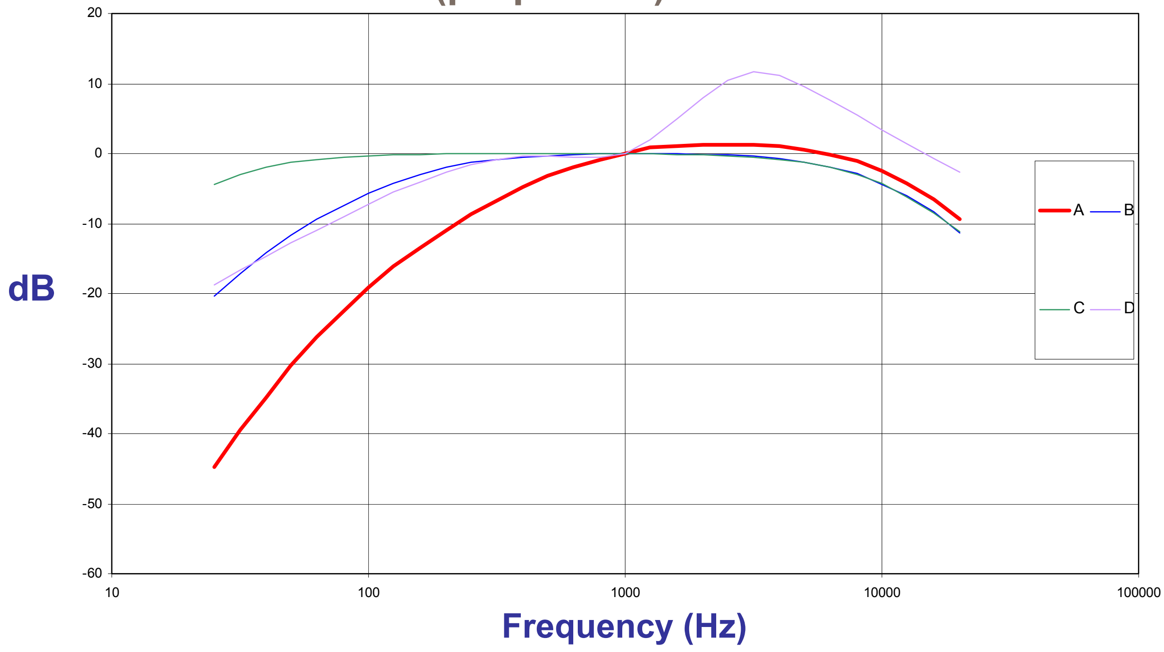
- The sensitivity of the human ear depends on the frequency.

Sound pressure level

Weighting scales

We can define weighting scales according to the sensitivity of human ear to the acoustic frequency:

- Scale A: low noise (40 dB) (red line)
- Scale B: medium noise (70 dB) (blue line)
- Scale C: loud noise (100 dB) (green line)
- Scale D: aircraft noise (purple line)



Sound pressure level

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A-weighted sound pressure level

$$L_{eq} = SPL = 20\log\frac{p_{Arms}}{p_0} \quad (dB(A))$$

$$SPL(t) = 20\log\frac{p_{Arms}(t)}{p_0} \quad (dB(A))$$

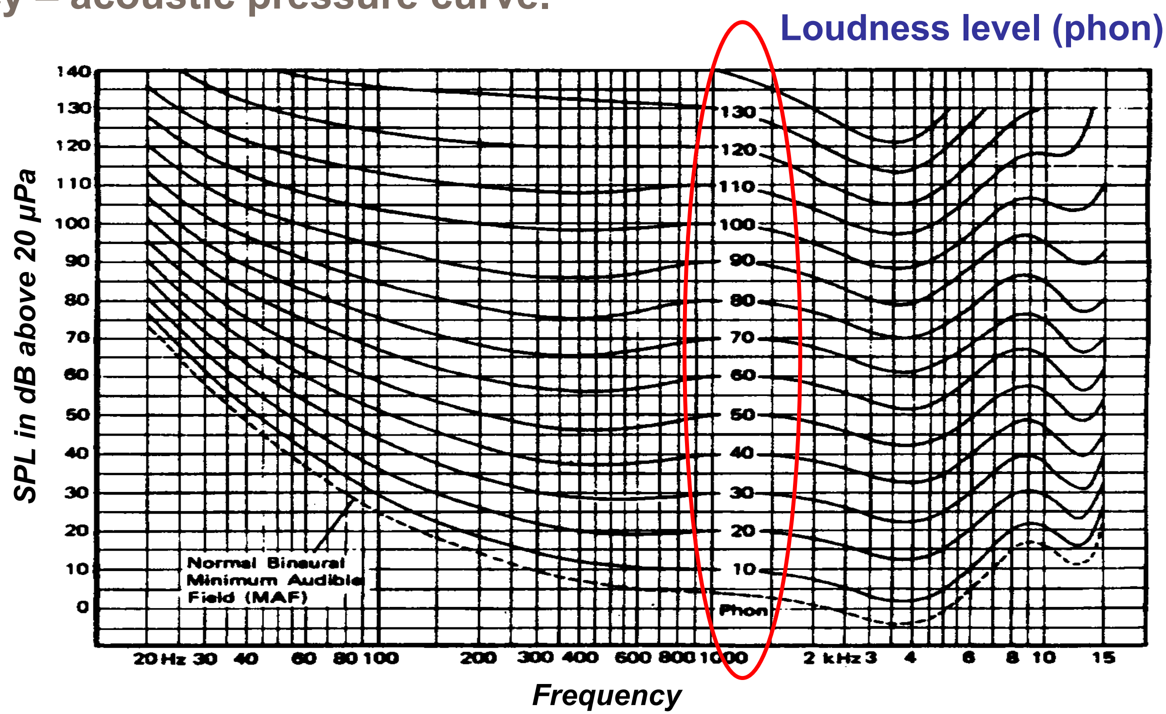
p_{Arms}	A-weighted root mean square sound pressure
t	time variable
SPL	sound pressure level
$p_0 = 20{\cdot}10^{-6}$	auditory threshold
$dB(A)$	A-weighted decibel (unit)

dB(A) is still the most common parameter to quantify a sound.

Loudness level of tones

Curves of equal loudness level

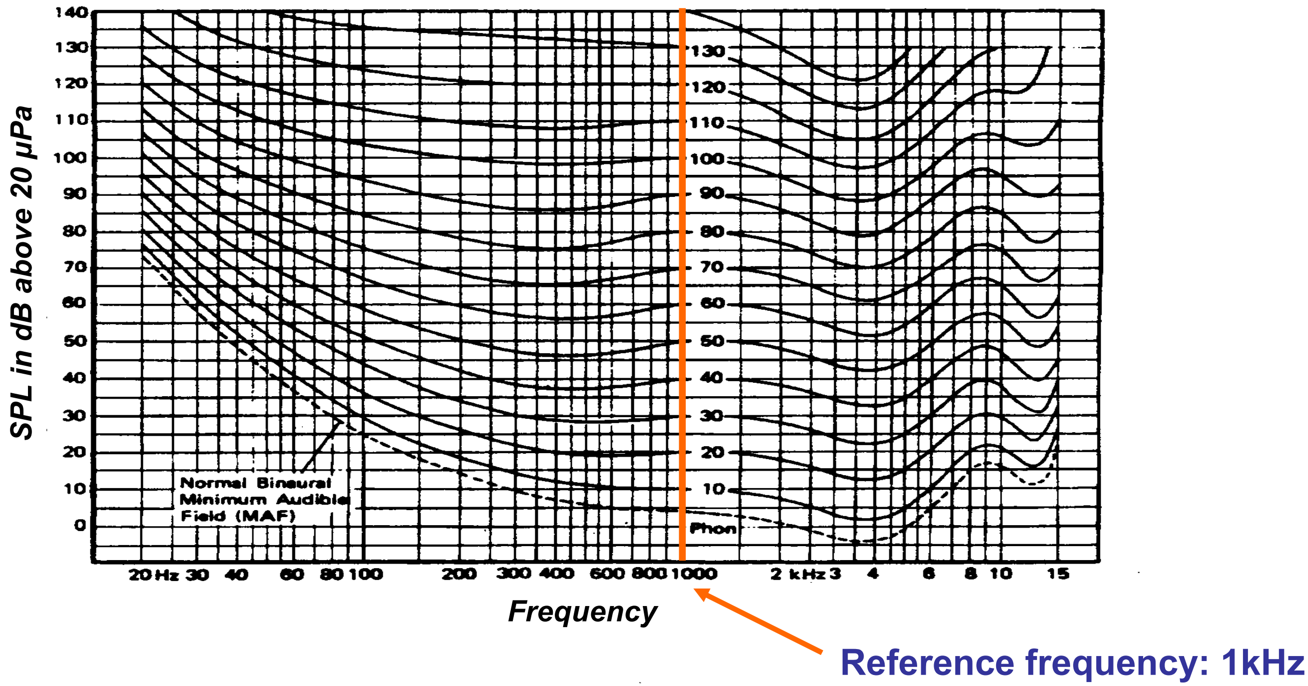
Comparing tones of different frequency in the laboratory, we can define curves of equal sensation (equal loudness level). These curves are depicted in a frequency – acoustic pressure curve.



Loudness level of tones

Curves of equal loudness level

These curves have been standardized by ISO 226.
The unit of loudness level is the ***phon*** that is the number of dB corresponding to 1000 Hz.

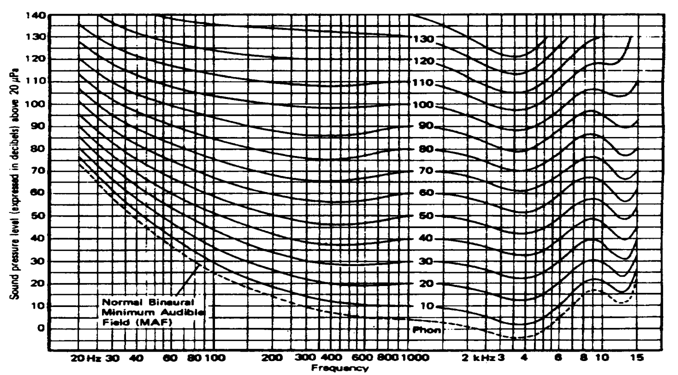


Loudness of tones (Comparative loudness)

Does loudness level completely define the acoustic sensation?

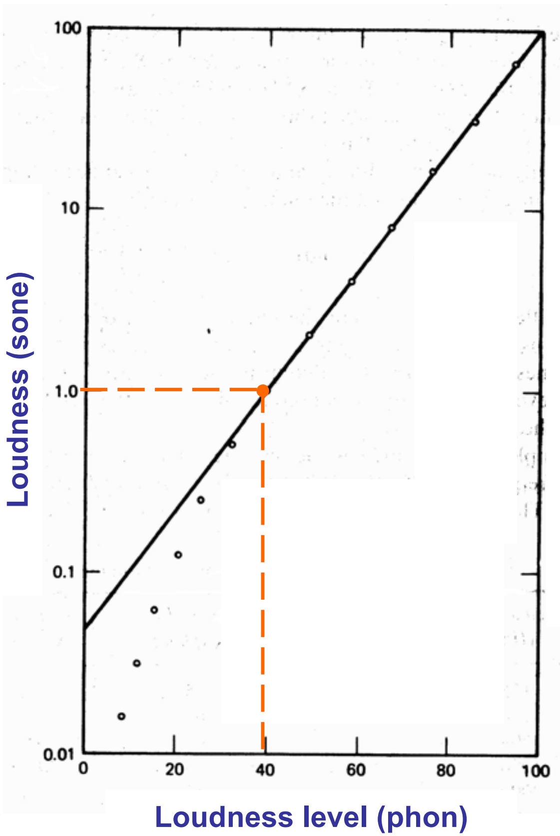
- 2 tones with the same loudness level, consequently corresponding to the same curve produce the same acoustic level feeling.
- However, a relative change in perception is not proportional to loudness level: a tone of 60 phons does not produce 2 times the feeling than a tone of 30 phons.

Consequently, LOUDNESS LEVEL DOES NOT DEFINE COMPLETLY THE RELATIVE CHANGE IN ACOUSTIC SENSATION.
A new parameter called LOUDNESS is defined that corrects this limitation



Loudness of tones

Relationship between loudness level (phons) and loudness (sone)



The relationship between Loudness (sone) and Loudness level (phons) is given by the dotted line. For loudness levels higher than 40 phons, we can fit the following equation (continuous line)

$$S = 2^{\frac{F-40}{10}}$$

S Loudness (sone)

F Loudness level (phons)

Loudness of complex sounds

ISO 532-1975

METHOD A (Stevens)

Octave band spectrum
Acoustic field:
- Diffuse field: sone OD or phones OD

METHOD B (Zwicker)

One – third octave band spectrum
Acoustic field:
- Diffuse field: sone GD or phones GD
- Free field: sone GF or phones GF

Loudness of complex sounds

Stevens method

ISO 532-1975 (E)

- Calculation of octave band spectrum
- Calculation of loudness index for each band using the graph
- Calculation of total loudness in sone:

$$S_t = S_m + F\left[\left(\sum S\right) - S_m\right]$$

S_t Total loudness in sone

S_m Maximum loudness in sone

$F = 0{,}3$

$\sum S$ Sum of loudness of all bands

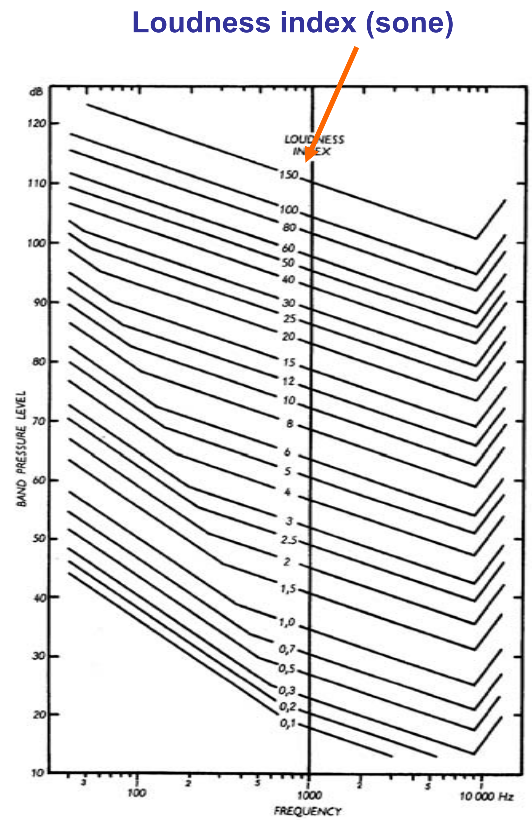


FIGURE 1

Loudness as a tool for Jury Test analysis

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Application in the context of Jury Tests

The most direct way to assess the quality of a sound is by listen to it and expressing an opinion about it.

Statistical procedures are used, involving not only a single listener, but a jury of listeners.

An assessment of a particular quality aspect in a number of different sounds is carried out. The sounds that we compare in order to make the evaluation may be:

- Competitor products
- Various design alternatives
- Different sound manipulations

Tests performed:Determination of S&R detection thresholds

Interior noise

Reference sound:
Interior noise of a vehicle was measured in the IDIADA's facilities.

Interior noise

Test equipment used and measurement conditions:

- HEAD ACOUSTICS Binaural acquisition system
- Front passenger seat
- 100km/h
- 5th gear
- Car without any rattle

Rattle noise

Rattle noise was generated in a trimming part mounted on a shaker and excited in vertical direction by a random signal. An acoustic chamber was built over the shaker in order to get a low background noise. Absorbent material was layered in order to have free field conditions.

Rattle noise

The rattle noise was recorded.

The equipment used in this test was:

- LDS Electro-dynamic shaker 806
- LDS DPA 8 DC Power amplifier
- DATA PHISICS 550 Vibration controller
- B&K Microphone 4190
- B&K Acquisition system PULSE

Characteristics of the jury test

A jury test was carried out using the interior noise and rattle noise signals modified and mixed.

This jury test had the following characteristics:

- About 50 people
- 70 % men, 30 % women
- 4 sessions
- 9 sounds in each session

Signals assessed by the jury test:

\- Interior Noise (IN) (dB) +

	SESSION 1	SESSION 2	SESSION 3	SESSION 4
SOUND A	IN - 9	IN - 6	IN - 3	IN
SOUND B	IN - 9 + R	IN - 6 + R	IN - 3 + R	IN + R
SOUND C	IN - 9 + R + 5	IN - 6 + R + 5	IN - 3 + R + 5	IN + R + 5
SOUND D	IN - 9 + R + 10	IN - 6 + R + 10	IN - 3 + R + 10	IN + R + 10
SOUND E	IN - 9 + R + 15	IN - 6 + R + 15	IN - 3 + R + 15	IN + R + 15
SOUND F	IN - 9 + R + 20	IN - 6 + R + 20	IN - 3 + R + 20	IN + R + 20

\- Rattle Noise (R) (dB) +

Results

Jury test results

Rattle noise perception threshold (green).

Rattle noise annoyance threshold (red).

	SESSION 1	SESSION 2	SESSION 3	SESSION 4
SOUND A	IN - 9	IN - 6	IN - 3	IN
SOUND B	IN - 9 + R	IN - 6 + R	IN - 3 + R	IN + R
SOUND C	IN - 9 + R + 5	IN - 6 + R + 5	IN - 3 + R + 5	IN + R + 5
SOUND D	IN - 9 + R + 10	IN - 6 + R + 10	IN - 3 + R + 10	IN + R + 10
SOUND E	IN - 9 + R + 15	IN - 6 + R + 15	IN - 3 + R + 15	IN + R + 15
SOUND F	IN - 9 + R + 20	IN - 6 + R + 20	IN - 3 + R + 20	IN + R + 20

DETECTION

NOT ACCEPTABLE

Results

Sound pressure level (in dB(A)) of the different signals

dB(A) are independent on the rattle.

	SESSION 1	SESSION 2	SESSION 3	SESSION 4
SOUND A	60,7	63,7	66,7	69,7
SOUND B	60,7	63,7	66,7	69,7
SOUND C	60,7	63,7	66,7	69,7
SOUND D	60,7	63,7	66,7	69,7
SOUND E	60,7	63,7	66,7	69,7
SOUND F	60,7	63,7	66,7	69,7

(dB(A))

Results

Loudness (Sone) of the different signals, calculated by the Zwicker method

Sone values are sensitive to the rattle noise!

	SESSION 1	SESSION 2	SESSION 3	SESSION 4
SOUND A	12,93	15,9	19,54	23,89
SOUND B	12,95	15,92	19,55	23,9
SOUND C	12,99	15,94	19,56	23,91
SOUND D	13,04	15,98	19,59	23,92
SOUND E	13,19	16,09	19,66	23,97
SOUND F	13,53	16,34	19,84	24,09

(Sone)

Results

Relative loudness

Relative loudness = Loudness (IN+R) – Loudness (IN)

	SESSION 1	SESSION 2	SESSION 3	SESSION 4
SOUND A	0	0	0	0
SOUND B	0,02	0,02	0,01	0,01
SOUND C	0,06	0,04	0,02	0,02
SOUND D	0,11	0,08	0,05	0,03
SOUND E	0,26	0,19	0,12	0,08
SOUND F	0,6	0,44	0,3	0,2

Relative loudness corresponding to the detection thresholds

These values have been obtained from the jury test results. In order to have a better accuracy, a linear interpolation has been applied.

	SESSION 1	SESSION 2	SESSION 3	SESSION 4
SOUND A	0	0	0	0
SOUND B	0,02	0,02	0,01	0,01
SOUND C	0,06	0,04	0,02	0,02
SOUND D	0,11	0,08	0,05	0,03
SOUND E	0,26	0,19	0,12	0,08
SOUND F	0,6	0,44	0,3	0,2

Results

Relative loudness

Relative loudness values corresponding to the perception threshold and annoyance threshold.

	SESSION 1	SESSION 2	SESSION 3	SESSION 4	AVERAGE
DETECTION	0,028	0,032	0,026	0,027	**0,03**
NOT ACCEPTABLE	0,23	0,19	0,18	0,17	**0,19**

Summary and conclusions

- Loudness as a measurement of the human ear sensation or feeling to the noise is introduced
- SPL(A) is independent on the rattle level
- Loudness is dependent on the rattle level
- Relative loudness as the difference between loudness with rattle and loudness without rattle is defined as a sensitive parameter
- Relative loudness corresponding to rattle detection threshold is roughly constant and equal to 0,03 sones
- Relative loudness corresponding to rattle annoying threshold is roughly constant and equal to 0,19 sones

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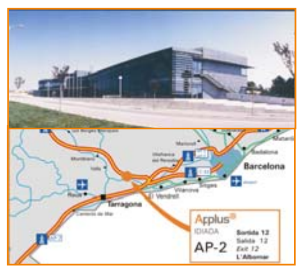

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