# Annex 1 – Symbols

The symbol definitions used in this book are alphabetically arranged, by type of letter, and tabulated below.

## Latin Capitals

| | |
|---|---|
| A, B, C | scales for sound level measurement |
| $D_e$ | effective trunk diameter |
| E | Young's modulus [GPa, Pa or $N/m^2$] |
| G | coefficient depending on the geometric characteristics of leaves |
| I | sound intensity [$W/m^2$] |
| L | longitudinal or axial growth direction of a tree |
| $L_a$ | scattering length |
| $L_s$ | scattering length |
| FFT | fast Fourier transform |
| MOE | modulus of elasticity, also E |
| N | number of trees per square meter |
| $P_s$ | ambient pressure [Pa] |
| R | radial direction related to the annual rings |
| $R_e$ | effective refraction factor |
| T | absolute temperature [K] |
| SPL | sound pressure level [dB] |
| U | voltage |
| V | railcar speed [km/h] |
| $V_0$ | the reference speed [60 km/h] |
| W | watt |
| Z | mechanical impedance |

## Script Latin Lower-case Letters

| | |
|---|---|
| $a$ | half diameter of elliptical cross area of a trunk |
| $b$ | half diameter of elliptical cross area of a trunk |
| $r_1$ | length of the direct ray from the source to the receiver |
| $r_2$ | the reflected ray |
| $c$ | sound velocity |

| | |
|---|---|
| $d$ | distance |
| $d_0$ | reference distance |
| $f$ | frequency |
| $f'$ | first maximum frequency |
| $f_{\mathrm{pr}}$ | frequency of the associated pressure minimum |
| $i$ | $\sqrt{-1}$ |
| $k$ | wave number |
| $l$ | length |
| $m$ | mass |
| $n$ | integer |
| $p$ | sound pressure |
| $p_A(t)$ | instantaneous sound pressure |
| $p_{\mathrm{rms}}$ | root-mean-square sound pressure [Pa or $N/m^2$] |
| $p_{\mathrm{reference}}$ | reference pressure of $20\,\mu Pa = 2 \times 10^{-5}\,N/m^2$ |
| $r$ | correlation coefficient |
| $t$ | time [s] |
| $t_D$ | growing time of trees [years] |
| $t_{D_{\mathrm{ref}}}$ | growing reference-time, trees now aged 12 years |
| $x, y, z$ | spatial coordinates |

## Script Latin Capitals

| | |
|---|---|
| $A$ | excess attenuation |
| $\mathbf{A}$ | acoustic strength |
| $(Att)_{\mathrm{absorption}}$ | attenuation produced by leaves absorption |
| $A_{\mathrm{d}}$ | direct field attenuation |
| $A_{\mathrm{s}}$ | total scattering attenuation |
| $E_{\mathrm{d}}$ | energy in the direct field |
| $E_{\mathrm{f}}$ | energy in the free field |
| $E_{\mathrm{r}}$ | energy in the reverberant field |
| $E_{A,T}$ | A-weighted sound exposure [$Pa^2\,s$] |
| $E_0$ | reference A-weighted sound exposure [$1.15 \times 10^{-10}\,Pa^2\,s$] |
| $F$ | total surface of leaves per unit volume |
| $I_{\mathrm{a}}$ | axial inertia momentum |
| $L_{\mathrm{A}}$ | sound level on A scale [dB] |
| $L_{E_{A,T}}$ | A-weighted noise exposure [dB] |
| $L_{\mathrm{A}}$ | A-weighted sound pressure [dB] |
| $L_{\mathrm{d,n}}$ | day–night noise level [dB] |
| $L_{\mathrm{p}}$ | sound pressure level; SPL [dB] |
| $L_{\mathrm{eq}}$ | equivalent continuous sound pressure level [dB] |
| $L_{\mathrm{min}}$ | minimum sound pressure level [dB] |
| $L_{\mathrm{max}}$ | maximum sound pressure level [dB] |

| | |
|---|---|
| $L_{10}$ | sound pressure level exceeded 10% of the time [dB] |
| $L_{50}$ | sound pressure level exceeded 50% of the time [dB] |
| $L_{90}$ | sound pressure ambient level [dB] |
| $Q_{res}$ | quality score |
| $S_d$ | sound level at distance $d$ |
| $S_0$ | sound level at the source |
| $T$ | averaging time |
| $\boldsymbol{T}$ | long time over which averaging takes place (h) |
| $I$ | sound source intensity |
| $I_{ref}$ | sound source reference intensity [$10^{-12}$ W/m$^2$] |
| $IL$ or $L_I$ | sound intensity level |
| $P_t$ | total pressure at the receiver |
| $P_d$ | direct contribution |
| $P_r$ | speculary reflected contribution |
| $R_p$ | pressure reflection coefficient for a plane wave |
| $W$ | sound power level [dB $re W_0$] |
| $W_0$ | the reference sound power [$10^{-12}$ W] |
| $Z$ | ground impedance |

## Greek Capitals

| | |
|---|---|
| $\Phi$ | diameter |
| $\Delta t$ | difference in time |
| $\Delta_L$ | difference in sound pressure level |

## Greek Lower-case Letters

| | |
|---|---|
| $\alpha_{leaves}$ | absorption coefficient of leaves |
| $\alpha_m$ | absorption coefficient of trees |
| $\beta$ | relative admittance |
| $\lambda$ | wavelength [m] |
| $\pi$ | value of pi = 3.14 |
| $\nu$ | frequency [Hz] |
| $\theta$ | ambient temperature [°C] |
| $\varrho$ | density [kg/m$^3$] |
| $\varphi$ | phase angle [°] |
| $\sigma_e$ | effective flow resistivity [N s m$^{-4}$] |

# Annex 2 – Some Theoretical Considerations

The basic equations and theoretical considerations presented in this section can help the reader in a better understanding of sound propagation in air and are based on my discussion with D. Fellot (personal communication).

In an isotropic medium, the equations of propagation of a plane wave are:

$$\frac{\partial^2 p}{\partial t^2} + c^2 \frac{\partial^2 p}{\partial x^2} = 0 \tag{1}$$

and:

$$\frac{\partial^2 v}{\partial t^2} + c^2 \frac{\partial^2 v}{\partial x^2} = 0 \tag{2}$$

where: $c$ is the propagation velocity, $p$ is the sound pressure, $v$ is the particle velocity, $t$ is time and $x$ is the distance of propagation.

In the air, considered as a perfect gas, in which the variations of atmospheric pressure $P$ and volume $V$ are adiabatic, we have $PV^{\gamma}$ = constant and the propagation velocity of an acoustic wave at constant temperature can be calculated with the equation:

$$c^2 = \frac{\gamma P}{\varrho} \quad \text{and} \quad c = \sqrt{\frac{\gamma P}{\varrho}} \tag{3}$$

where $\gamma$ is the ratio between the specific heat at constant pressure and the specific heat at constant volume and $\varrho$ is air density, 1.293 kg/m$^3$.

$$\gamma = \frac{C}{c} = 1.4$$

The atmospheric pressure is $P = 1.034 \times 10^5$ Pascal.

From (3), the air velocity has the value $c = \sqrt{1.4 \frac{1.034}{1.293} 10^5} = 334.53$ m/s at a constant temperature of 0 °C.

The sound velocity at a temperature $T$ can be deduced from Marriotte's law, written as:

$$PV = nRT \tag{4}$$

where $n$ is the number of moles, $R = 8{,}314\,\mathrm{J\,kmol^{-1}\,K^{-1}} = 2\,\mathrm{J}$. $V$, the volume of the air, is:

$$V = \frac{m}{\varrho}\text{, where } m \text{ is the air mass.}$$

Coming back to (4) we have:

$$P\frac{m}{\varrho} = nRT$$

if the temperature is constant, it can be deduced that:

$$\frac{\partial P}{P} - \frac{\partial \varrho}{\varrho} = 0$$

and:

$$2\frac{dc}{c} = \gamma\left(\frac{\partial P}{P} - \frac{\partial \varrho}{\varrho}\right) = 0$$

From previous equations, it can be stated that the sound velocity $c$ is independent of the atmospheric pressure and is strongly dependent on temperature. It can be written as:

$$c^2 = \frac{PV}{m} = \gamma\frac{nRT}{m}$$

the sound velocity $c$ at temperature $t$ [°C] is:

$$c = c_0\sqrt{\left(1 + \frac{t}{273}\right)} \approx c_0\left(1 + \frac{t}{546}\right)$$

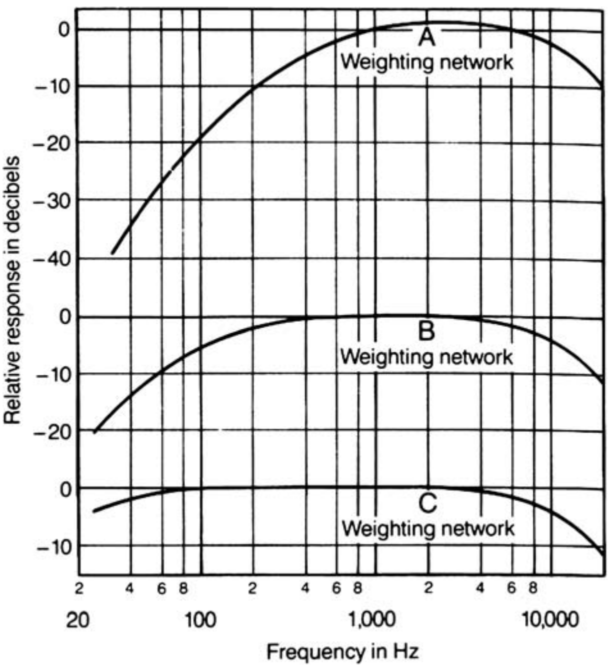
where $c_0$ is the sound velocity at 0 °C.

Because of space limitation, the theoretical aspects treated in this book are limited here.

More theoretical aspects related to the attenuation of sound in air are given by Beranek (1993).

# Annex 3 – Frequency Weighting

Frequency weighting is shown in the figure below, which gives the random incidence relative levels as a function of frequency for weighting networks A, B and C (Beranek 1993, p. 808).



# Annex 4 – Standards

During the past four decades, the introduction of noise control legislation all over the world required the development of appropriate techniques for the measurement of noise produced by outdoor sources.

The reader interest in more details can refer to *Noise Control Engineering Journal* 1987, vol. 29(1), which is entirely devoted to "Measurement Standards", to Harris (1998) and to the International Noise Control Engineering (INCE) collected papers.

The standards listed below are placed in four groups as: (a) acoustics – vocabulary, symbols, units, (b) general noise measurement methods, (c) measurement of specific types of sources, (d) measurement of structures used in noise control.

## (a) Acoustics – Vocabulary, Symbols, Units

- ANSI S1. 1-1960 (R 1976) Acoustical terminology
- SAE J 1184 Definition of acoustical terms
- ISO R31/7 Quantities and units of acoustics, 2nd edn, 1992-09-01
- ISO 31-2-1992 Quantities and units. Part 2: periodic and related phenomena, corrected and reprinted 1993-05-15
- ISO/TC 12 quantities, units, symbols, conversion factors
- ANSI/ASME, Y10.11-1084 Letter symbols for acoustics

## (b) General Noise Measurement Methods

- ANSI S1. 6-1984 Preferred frequencies, frequency levels and band numbers for acoustical measurements
- ANSI S1. 8-1969 (R1974) Preferred reference quantities for acoustical levels

## (c) Measurement of Specific Types of Sources

- ANSI S1. 13-1971 (R1986) Methods for measuring sound pressure levels
- ANSI S1. 34-1980 (R1986) Engineering methods for the determination of sound power levels of noise sources for essentially free-field conditions over a reflecting plane

- ANSI S1. 36-1979 (R1985) Survey methods for the determination of sound power levels of noise sources
- ANSI S12. 37-1988 Determination of sound power levels of sound sources. Methods for in situ measurements using a reference sound source
- ASTM E1014-84 Method for the measurement of outdoor A-weighted sound levels
- SAE J 184-1980 Qualifying a sound data acquisition system
- ISO 2204 Acoustics. Guide to international standards on the measurement of airborne acoustical noise and evaluation of its effect on human beings
- ISO 3740 Acoustics. Determination of sound power levels of noise sources. Guidelines for the use of basic standards and for the preparation of noise test codes
- ISO 3744 Acoustics. Determination of sound power levels of noise sources using sound pressure. Engineering method in an essentially free field over a reflecting plane

## (d) Measurement of Structures used in Noise Control

- ANSI S12. 36-1987 Methods for the measurement of acoustical performance of outdoor noise barriers
- ASTM E1014 6 1984 Method for the measurement of outdoor A-weighted sound levels
- ISO 1996-1: 2003 Description measurement and assessment of environmental noise. Part 1 Basic quantities and assessment procedures. Part 2 Acquisition of data pertinent to the land use. Part 3 Application to noise limitations
- ISO 9613 Acoustics. Attenuation of sound during propagation outdoors. Part 1 Calculation of the absorption of sound by the atmosphere. Part 2 General methods of calculation
- IEC 804:1985 integrating averaging sound level meters, Amendment 1: 1989, Amendment 2: 1993

# Annex 5 – Units

Commonly used units in this book, presented in alphabetic order:

- bel [B]; 1 B is the level of a power quantity when $\log \frac{P}{P_0} = 1$, $P_0$ being the reference power. Also 1 B is the level of field quantity when $2 \log \frac{A}{A_0} = 1$; 1 B = 1.151293 Np
- decibel [dB]; 10 dB = 1 B; 1 dB = 0.1151293 Np
- degree Celsius [°C]; for conversion to K, use temperature [°C] = $T$ [K] −273.15
- hertz [Hz]; 1 Hz = $s^{-1}$
- joule [J]; 1 J = 1 N m = $m^2\,kg\,s^{-2}$
- kilogram [kg]; derived unit $kg/m^3$
- kelvin [K]
- meter [m]; derived unit $m^2$, $m^3$ m/s, $m/s^2$
- neper [Np]; 1 Np is the level of a field quantities when the logarithm of the ratio of two amplitude is 1 as $\ln \frac{A}{A_0} = 1$
- newton [N]; 1 N = $1\,kg\,m\,s^{-2}$
- octave – the frequency interval between $f_1$ and $f_2$, if $\frac{f_1}{f_2} = 2$
- pascal [Pa]; 1 Pa = $1\,N\,m^{-2} = m^{-1}\,kg\,s^{-2}$
- phone [phone]; 1 phone is the loudness level when $2 \log \frac{p_{\mathrm{eff}}}{p_0} = 0.1$. For a pure tone of frequency 1 kHz, 1 phone $\approx$ 1 dB
- radian [rad]; 1 rad = $mm^{-1}$; $1^\circ = \frac{\pi}{180}$ rad, derived unit rad/s
- second [s]
- watt [W]; 1 W = $1\,J\,s^{-1} = m^2\,kg\,s^{-3}$

The reader interested in measures, units and conversions is invited to visit:

http://www.ex.ac.uk/cimt/dictunit/dictunit.htm (a dictionary of units by F. Tapson)

http://physics.nist.gov./cuu/units (the NIST reference on constants, units and uncertainty)

http://convert-me.com/en (online conversion of weights and units, metric conversions)

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