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Acoustics — Noise from shooting ranges —

Part 4:
Prediction of projectile sound

Acoustique — Bruit des stands de tir —

Partie 4: Estimation du bruit du projectile

Reference number
ISO 17201-4:2006(E)

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17201-4 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

ISO 17201 consists of the following parts, under the general title *Acoustics — Noise from shooting ranges*:

- *Part 1: Determination of muzzle blast by measurement*
- *Part 2: Estimation of muzzle blast and projectile sound by calculation*
- *Part 4: Prediction of projectile sound*

The following parts are under preparation:

- *Part 3: Guidelines for sound propagation calculation*
- *Part 5: Noise management*

The initiative to prepare a standard on impulse noise from shooting ranges was taken by AFEMS, the Association of European Manufacturers of Sporting Ammunition, in April 1996, by the submission of a formal proposal to CEN. After consultation in CEN in 1998, CEN/TC 211, *Acoustics*, asked ISO/TC 43/SC 1, *Noise*, to prepare the ISO 17201 series.

Introduction

Shooting sound consists in general of three components: muzzle sound, impact sound and projectile sound. This part of ISO 17201 deals solely with projectile sound, which only occurs if the projectile moves with supersonic speed.

It specifies a method for calculating the source sound exposure level of projectile sound. It also gives guidelines for calculating the propagation of projectile sound as far as it deviates from the propagation of sound from other sources.

Projectile sound is described as originating from a certain point on the projectile trajectory, the “source point”. The sound source exposure level is calculated from the geometric properties and the speed of the projectile along the trajectory. As a result of non-linear effects, the frequency content of the projectile sound exposure depends on the distance from the source point. This is taken into account. Guidance is given on how the sound exposure level can be calculated from the sound exposure level at the receiver location, taking into account geometrical attenuation, attenuation due to the non-linear effects, and atmospheric absorption. In addition, the effects on the sound exposure level of the decrease of the projectile speed and of atmospheric turbulence are taken into account.

Projectile sound exposure levels are significant compared to the muzzle sound exposure level in a restricted region, the Mach region (region II — see Clause 4). Outside this region only diffracted or scattered projectile sound is received, with considerably lower levels than in the Mach region. Projectile sound behind the Mach region (region I) is negligible compared to muzzle sound. In this part of ISO 17201, a computational scheme for the levels in regions II and III is provided. In the bibliographical reference [2], measurements and calculations were compared for a set of calibres and distances, i.e. from the source point to the receiver location. For this set, there is a slight tendency of an overestimation of the projectile sound: on average 1,8 dB, A-weighted.

Acoustics — Noise from shooting ranges —

Part 4:
Prediction of projectile sound

1 Scope

This part of ISO 17201 provides a computational model for determining the acoustical source level of projectile sound and its one-third-octave-band spectrum, expressed as the sound exposure level for nominal mid-band frequencies from 12,5 Hz to 10 kHz. It also gives guidance on how to use this source level to calculate the sound exposure level at a receiver position.

This part of ISO 17201 is intended for calibres of less than 20 mm, but can also be applied for large calibres. Additionally, the data can be used to compare sound emission from different types of ammunition used with the same weapon. This part of ISO 17201 is meant for weapons used in civil shooting ranges, but is also applicable to military weapons.

The computational method can be used as a basis for environmental noise assessment studies. The prediction method applies to outdoor conditions, straight projectile trajectories, and streamlined projectile shapes. Because of the latter, it cannot be applied to pellets. Default values of parameters used in this part of ISO 17201 are given for a temperature of 10 °C, 80 % relative humidity, and a pressure of 1 013 hPa. Annex A can be used for calculations in other atmospheric conditions. Particularly for calibres < 20 mm, the spectrum is dominated by high frequency components. As air absorption is rather high for these frequency components, calculations are performed in one-third-octave-bands, in order to allow a more accurate result for air absorption to be obtained.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9613-2, *Acoustics — Attenuation of sound during propagation outdoors — Part 2: General method of calculation*

ISO 17201-1, *Acoustics — Noise from shooting ranges — Part 1: Determination of muzzle blast by measurement*

Guide to the expression of uncertainty in measurement (GUM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, first edition, 1993, corrected and reprinted in 1995.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 17201-1 and the following apply.

3.1

streamlined projectile

body of revolution of which the first derivative of the cross-sectional area $A(x)$ at a distance x behind the nose of the body is continuous for $0 \leqslant x < l_\mathrm{p}$

NOTE For the definition of effective projectile length, l_p, see 3.2.

3.2

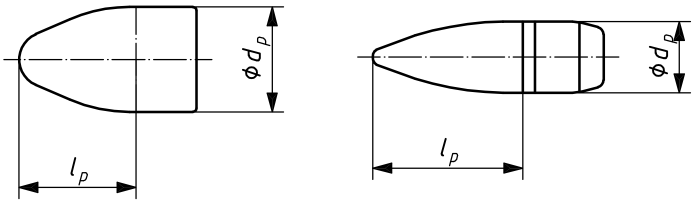
effective projectile length

l_p

distance between the nose and the cross-section with the maximum diameter of the projectile

See Figure 1.

NOTE The effective length of the projectile is measured along the length-axis of the projectile and is expressed in metres (m).



Key

l_p	effective projectile length (m)
d_p	maximum diameter of projectile (m)

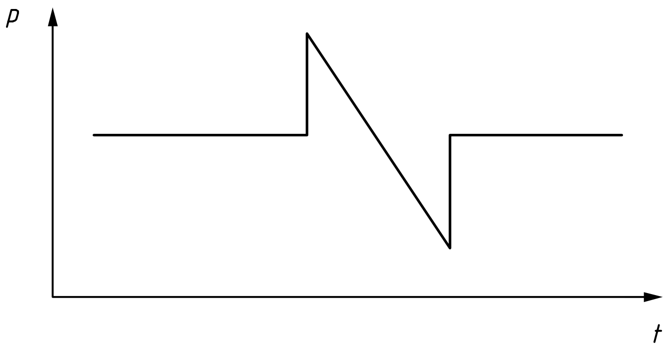
Figure 1 — Effective projectile length

3.3

N-wave

sound pressure having a variation with time described by a sudden initial increase to a maximum followed by a linear decay to a minimum and ending with a sudden increase to the initial sound pressure

See Figure 2.



Key

t	time
p	sound pressure

Figure 2 — Assumed N-shaped waveform for sound of supersonic projectile at 1 m from source point on projectile's trajectory

3.4
duration time

T_{c}

time between two pressure increases of the N-wave

NOTE 1 The duration time is expressed in seconds (s).

NOTE 2 Resulting from the non-linear acoustic effects, T_{c}, for the N-wave along the sound path will change.

3.5
characteristic frequency

f_{c}

inverse of the duration time, T_{c}

$$f_{\text{c}} = \frac{1}{T_{\text{c}}}$$

NOTE The characteristic frequency is expressed in Hertz (Hz).

3.6
coordinate system (x, y)

plane co-ordinate system describing geometry, where the x-axis denotes the line of fire with $x = 0$ at the muzzle, and the y-axis measures the perpendicular distance from the line of fire in any plane around the line of fire

NOTE 1 The sound field of projectile sound is rotational symmetric around the line of fire.

NOTE 2 The co-ordinates are given in metres (m).

3.7
coherence distance

R_{coh}

distance between the source point on the trajectory and a receiver beyond which the contribution of different parts of the trajectory are incoherent due to atmospheric turbulence

NOTE The coherence distance is expressed in metres (m).

3.8
Mach number

M

ratio of projectile speed to local sound speed

3.9
source sound exposure level

$L_{E,\text{s}}$

sound exposure level expected at a distance of 1 m from the source point

NOTE 1 The source sound exposure level is expressed in decibels (dB).

NOTE 2 The reference distance of 1 m is "measured" in the direction of the receiver and not perpendicular to the trajectory.

3.10
source point

point where a line from the receiver perpendicular to the wave front intersects the projectile trajectory

NOTE In this part of ISO 17201, the source point is used to represent the trajectory that in principle is a line source [see Equation (4)].

3.11
projectile launch speed

v_{p0}

speed of the projectile at the muzzle

NOTE The muzzle velocity is expressed in metres per second (m/s).

3.12
projectile speed

v_p

speed of the projectile along the trajectory

NOTE 1 The projectile speed is expressed in metres per second (m/s).

NOTE 2 Published data on the projectile speed as a function of distance refer to air density at sea level. For other elevations above sea level, changes of density could have to be taken into account.

3.13
end speed

v_{pe}

speed of the projectile as it hits the target or at the trajectory point where the Mach number is reduced to 1,01

NOTE The end speed is expressed in metres per second (m/s).

3.14
reference sound speed

adiabatic sound speed averaged over a period of at least 10 min

NOTE The reference sound speed is expressed in metres per second (m/s).

3.15
fluctuating effective sound speed

sum of the instantaneous adiabatic sound speed and the instantaneous horizontal wind velocity component in the direction of the sound propagation

NOTE The fluctuating effective sound speed is expressed in metres per second (m/s).

3.16
standard deviation of the fluctuating acoustical index of refraction

μ_0

standard deviation of the ratio of the reference sound speed to the fluctuating effective sound speed

NOTE In accordance with [5], a value of $\mu_0^2 = 10^{-5}$ is used within the context of this part of ISO 17201 [see Equation (12)].

3.17
projectile speed change

κ

local change of projectile speed along the trajectory per length unit of trajectory

NOTE 1 The speed change is expressed in reciprocal seconds [(m/s · m) = 1/s].

NOTE 2 It is negative for non-self-propelled projectiles.

4 Regions

The wave front originating from the nose of the projectile has the shape of a cone (see Figure 3). The projectile speed decreases along the projectile trajectory. As a consequence, the wave front is curved. Three regions (I, II and III) are distinguished (see Figure 3). In regions I and III considerably lower sound exposure levels occur compared to those in region II. In this part of ISO 17201, a computational scheme for the sound exposure levels in regions II and III is provided. The levels in region I are negligible in comparison to the muzzle blast. The projectile speed is locally approximated by a linear function of the distance x along the projectile trajectory, according to Equation (1):

$$v_{\mathrm{p}}(x) = v_{\mathrm{p0}} + \kappa\, x \tag{1}$$

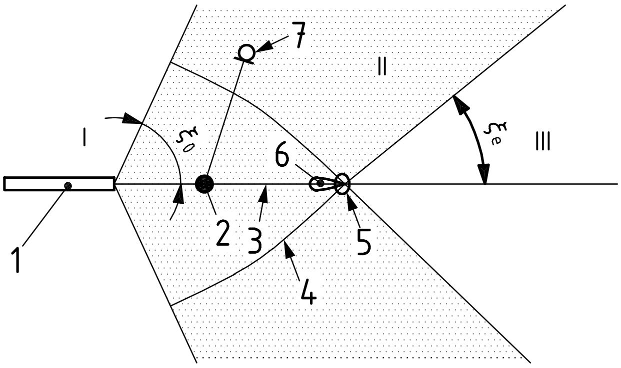
The boundaries of region II are described with the angles ξ_0 and ξ_{e}, shown in Figure 3. These angles are given by Equation (2):

$$\xi_0 = \arccos\left(\frac{c_{\mathrm{am}}}{v_{\mathrm{p0}}}\right) \quad \text{and} \quad \xi_{\mathrm{e}} = \arccos\left(\frac{c_{\mathrm{am}}}{v_{\mathrm{pe}}}\right) \tag{2}$$

where

v_{pe} is the projectile speed at the end of the trajectory, in metres per second (m/s);

c_{am} is the speed of sound in metres per second (m/s).



Key

1 weapon
2 source point
3 projectile trajectory
4 wavefront
5 target
6 projectile
7 receiver

Figure 3 — The three regions for describing the sound of a projectile

The speed of sound is a function of the absolute temperature of the ambient air, T_{am}, in Kelvin and is given by Equation (3):

$$c_{\text{am}} = c_{\text{ref}} \left(T_{\text{am}} / T_{\text{ref}} \right)^{1/2} \tag{3}$$

where

T_{ref} = 283,15 K (10 °C);

c_{ref} = 337,6 m/s (the speed of sound at T_{ref}).

When the projectile speed along the trajectory decreases below the speed of sound, the angle ξ_{e} becomes zero; the region III vanishes in this case. The “target” is then replaced by the trajectory point where the Mach number is reduced to 1,01.

5 Source description

5.1 Source point

The position of the source point (x_{s}, 0) for receivers in region II can be determined by iterative methods. For straight trajectories this can be determined with the use of Equation (4). A co-ordinate system (x, y) is used, with the x axis along the projectile trajectory and the origin at the muzzle, according to Equation (4):

$$\begin{gathered} \left(x - x_{\text{s}} \right)^2 \cdot \left(v_{\text{p0}} + \kappa x_{\text{s}} + c_{\text{am}} \right) \cdot \left(v_{\text{p0}} + \kappa x_{\text{s}} - c_{\text{am}} \right) = c_{\text{am}}^2 y^2 \\ \text{with} \quad 0 < x_{\text{s}} < x \quad \text{and} \quad x_{\text{s}} < \left| \frac{c_{\text{am}} - v_{\text{p0}}}{\kappa} \right| \end{gathered} \tag{4}$$

where (x, y) is the position of the receiver.

In the case that the calculated source point lies beyond the target or for receivers in region III, the source point is set at the target position.

5.2 Source sound exposure level

The (broadband) source sound exposure level, $L_{E,\text{s,bb}}$, expressed in decibels, is given by the geometric properties of the projectile and its speed at the source point [4], according to Equation (5):

$$L_{E,\text{s,bb}} = L_0 + 10 \lg \left(\frac{d_{\text{p}}^3}{l_{\text{p}}^{3/4} r_0^{9/4}} \right) \text{dB} + 10 \lg \left[\frac{M^{9/4}}{\left(M^2 - 1 \right)^{3/4}} \right] \text{dB} \tag{5}$$

where

L_0 [re (20 µPa)^{2}s]	= 161,9 dB (see A.2);
$M = v / c_{\text{am}}$	the local Mach number of the projectile at the source point with the projectile speed determined from Equation (1) and the speed of sound from Equation (3) for the ambient air temperature applicable to the prediction of the sound source exposure level for the projectile;
r_0	= 1 m.

In principle, the total length of the projectile can be used instead of the effective length to calculate the (broadband) sound exposure level, but — to be consistent — then the total length should also be used to calculate the shape factor K and from this the constant L_0 (see Annex A).

When the Mach number approaches unity, the third term in Equation (5) becomes undeterminable. Therefore, a lower limit of M = 1,01 is used in these expressions.

The spectrum of the projectile sound can be calculated as the Fourier transform of the N-wave. The one-third-octave-band spectrum of the sound exposure level at a receiver position is assumed to have a single characteristic frequency, f_c, determined in hertz, according to Equation (6), with spectral roll-offs to lower and higher frequencies:

$$f_\mathrm{c} = f_0 \frac{\left(M^2 - 1\right)^{1/4}}{M^{3/4}} \frac{l_\mathrm{p}^{1/4}}{d_\mathrm{p}} \frac{r_0}{r^{1/4}} \tag{6}$$

where

r is the distance from the source point to the receiver in metres (m);

f_0 is the reference frequency, equal to 175,2 Hz at 10 °C (see A.3).

NOTE Equation (6) shows that the characteristic frequency, f_c, decreases as distance, r, increases. This is a consequence of pulse broadening due to non-linear effects.

Over the range of nominal mid-band frequencies, f_i, from 12,5 Hz to 10 kHz for standard one-third-octave-band filters, and with the characteristic frequency, f_c, calculated according to Equation (6), the one-third-octave-band spectrum of the sound source exposure level is given by Equation (7):

$$L_{E,\mathrm{s}}\left(f_i\right) = L_{E,\mathrm{s,bb}} + C_i - C_\mathrm{tot} \tag{7}$$

where

$$C_i = 2{,}5\ \mathrm{db} + 28\ \lg\left(\frac{f_i}{f_\mathrm{c}}\right)\mathrm{dB} \quad \text{if} \quad f_i < 0{,}65 f_\mathrm{c} \tag{8}$$

$$C_i = -5{,}0\ \mathrm{dB} - 12\ \lg\left(\frac{f_i}{f_\mathrm{c}}\right)\mathrm{dB} \quad \text{if} \quad f_i \geqslant 0{,}65 f_\mathrm{c} \tag{9}$$

$$C_\mathrm{tot} = 10\ \lg \sum_{i=11}^{40} 10^{C_i / 10^{\mathrm{dB}}}\ \mathrm{dB} \tag{10}$$

and where

f_i $= 10^{i/10}$ Hz, is the nominal mid-band frequency of the one-third-octave band (12,5 Hz to 10 kHz, $i = 11$ represents a mid-band frequency of 12,5 Hz, and $i = 40$ represents a mid-band frequency of 10 kHz).

6 Guidelines for calculating sound exposure levels at receiver locations

6.1 Basic equation

The one-third-octave-band-spectrum of the sound exposure level at the receiver location, $L_{E,\mathrm{r}}(f_i)$, needs to account for the attenuation caused by various factors that reduce the amplitude of the sound as it propagates over the path from the 1 m reference distance to the location of the receiver at distance r. The following expression accounts for the principal factors that need to be considered.

$$L_{E,\mathrm{r}}(f_i) = L_{E,\mathrm{s}}(f_i) - A_{\mathrm{div}} - A_{\mathrm{nlin}} - A_{\mathrm{atm}}(f_i) - A_{\mathrm{excess}}(f_i) \qquad (11)$$

where

$L_{E,\mathrm{s}}(f_i)$	is the one-third-octave-band sound source exposure level at nominal mid-band frequency f_i and at the 1 m reference distance from the source point [see Equation (7)], expressed in decibels;
A_{div}	is the attenuation of the level of the sound in a field free of reflections and resulting from the divergence of the geometric area of the wave front as the distance increases from the 1 m reference distance, expressed in decibels;
A_{nlin}	is the attenuation caused by non-linear effects associated with the large initial amplitude of projectile sound near the source point, expressed in decibels;
$A_{\mathrm{atm}}(f_i)$	is the attenuation caused by absorption processes in the atmosphere as the sound propagates over the path from the 1 m reference distance to the location of the receiver, expressed in decibels;
$A_{\mathrm{excess}}(f_i)$	is the excess attenuation including losses due to the interaction with the ground, atmospheric refraction and shielding by a barrier, expressed in decibels.

NOTE As the projectile sound propagates from the 1 m reference distance to a receiver at distance r, the attenuation includes losses resulting from interaction of the sound wave with the surface of the ground, refraction or bending of the sound path caused by gradients in the vertical profile of the sound speed of the air, and shielding by a barrier. ISO 9613-2 provides guidance on appropriate procedures to account for the additional attenuation terms in a prediction of projectile sound. Guidance is given in A.4 for the approximation of the barrier effect.

6.2 Calculation of the attenuation terms

6.2.1 Geometric attenuation

For the computation of the geometric attenuation, A_{div}, receiver positions in regions II and III are distinguished. In region II, the geometric attenuation varies between 10 lg (r/r_0) dB and 25 lg (r/r_0) dB, where r is the distance from the source point to the receiver, as the consequence of two effects:

a) effect of the decrease of the projectile speed along the trajectory;

b) effect of atmospheric turbulence.

At short distances the first effect is dominant. After some coherence distance (R_{coh}), the second effect dominates. At distances greater than 10 km from the source point on the projectile trajectory, the attenuation approaches the spherical limit 20 lg (r/r_0) dB [5].

The coherence distance, R_{coh}, in metres, is given by Equation (12):

$$R_{\text{coh}} = \min\left\{ \frac{(M^2-1)(l_{\text{t}}/2)^2}{M^2 c_{\text{am}}/f_{\text{c}}}, \frac{1}{\sqrt{\pi}}\left[\frac{\frac{3}{2} l_0 l_{\text{t}}^2 \left(M^2-1\right)}{M^2 \mu_0^2}\right]^{1/3} \right\} \tag{12}$$

where

l_{t} is the total length of the trajectory calculated for Equation (12), either to the target or to the point where the local Mach number has decreased to 1,01, expressed in metres (m);

l_0 = 1,1 m, see bibliographical reference [5];

μ_0^2 = 10^{-5};

M is the local Mach number at the location of the source point;

c_{am} is the speed of sound at the temperature of interest for ambient air, see Equation (3), expressed in metres per second (m/s).

The geometric attenuation for region II is given by Equations (13) and (14):

$$A_{\text{div,II}} = 10 \lg \left[\frac{r^2 k + r\left(M^2-1\right)}{r_0^2 k + r_0\left(M^2-1\right)}\right] \text{dB} \qquad \text{for } r < R_{\text{coh}} \tag{13}$$

$$A_{\text{div,II}} = 10 \lg \left[\frac{R_{\text{coh}}^2 k + R_{\text{coh}}\left(M^2-1\right)}{r_0^2 k + r_0\left(M^2-1\right)}\right] \text{dB} + 25 \lg\left(\frac{r}{R_{\text{coh}}}\right) \text{dB} \qquad \text{for } r \geqslant R_{\text{coh}} \tag{14}$$

where

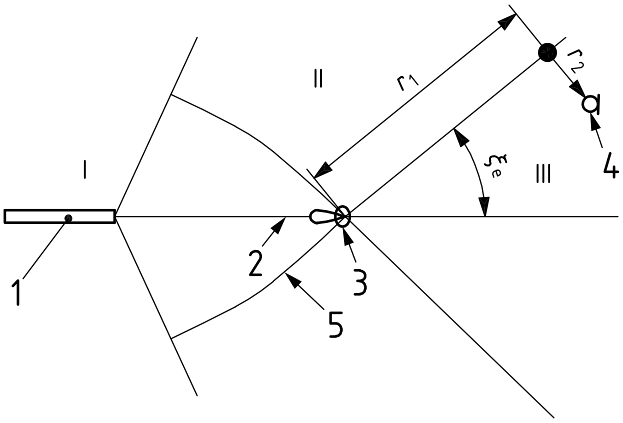
k $= -\kappa / c_{\text{am}}$;

r_0 = 1 m.

In region III, in front of the weapon, the geometric attenuation of projectile sound is approximated by a sum of two terms, according to Equation (15), with distances r_1 and r_2 as shown in Figure 4:

$$A_{\text{div,III}} = A_{\text{div,II}}(r{=}r_1) + 20 \lg \left[\frac{\max\left(r_2, R_0\right)}{R_0}\right] \text{dB} \quad \text{with} \quad R_0 = 2 + \frac{r_1}{100} \tag{15}$$

The first term on the right hand side of Equation (15) is the geometric attenuation calculated according to Equation (13) or Equation (14), as appropriate for a location on the boundary between region II and region III and at the distance r_1 that is closest to the location of the receiver in region III. The additional contribution of the second term depends on the distance r_2 (see Figure 4).



Key

1 weapon

2 projectile trajectory

3 target

4 receiver

5 wave front

Figure 4 — Distances to consider for receiver in region III

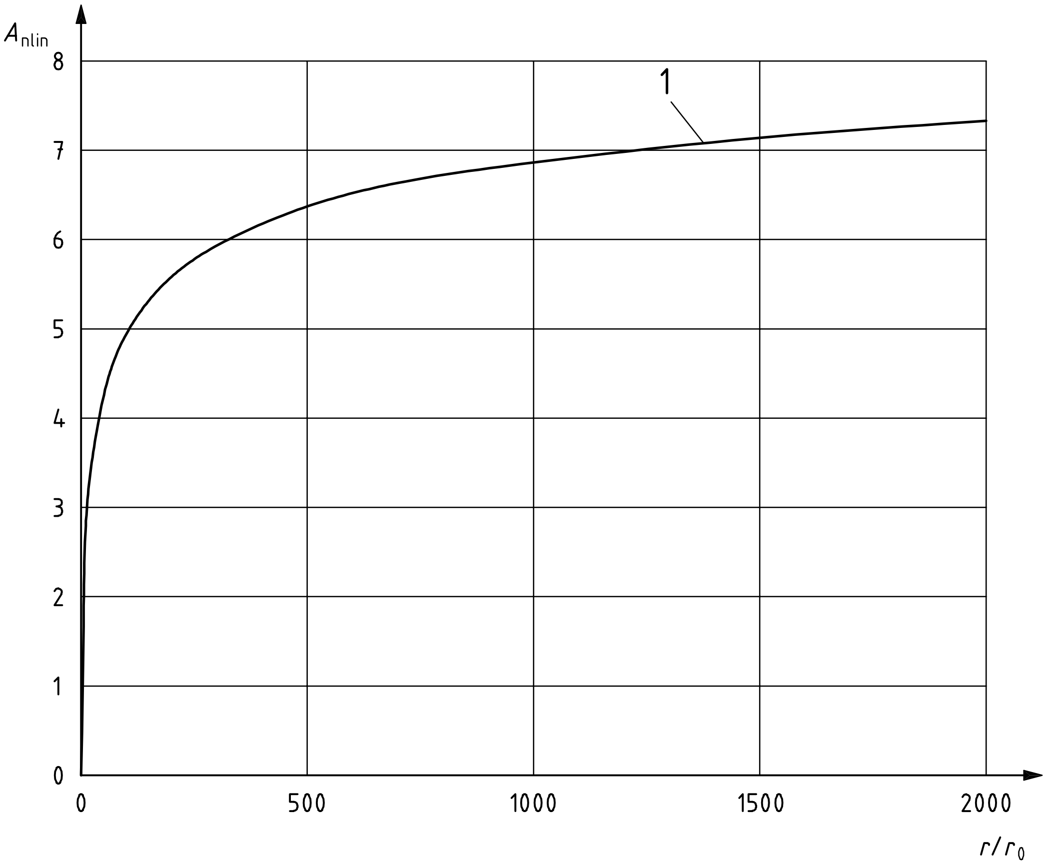
6.2.2 Non-linear attenuation

For receivers in region II, the attenuation in decibels due to non-linear wave propagation is given by Equation (16):

$$A_{\text{nlin}} = 5\ \lg \left\{ 1 + \frac{1}{2}\sqrt{1 + \frac{(M^2 - 1)}{r_0 k}} \quad \ln \left[\frac{r + \frac{M^2-1}{2k} + \sqrt{r^2 + r\left(\frac{M^2-1}{k}\right)}}{r_0 + \frac{M^2-1}{2k} + \sqrt{r_0{}^2 + r_0\left(\frac{M^2-1}{k}\right)}} \right] \right\} \text{dB} \tag{16}$$

The typical non-linear behaviour is illustrated in Figure 5.

For receiver locations in region III, non-linear attenuation is determined from Equation (16), but with r_1 instead of r for the distance.



Key

A_{nlin}	non-linear attenuation (dB)
r	distance from source point to receiver (m)
r_0	= 1 m
1	M = 1,3; k = 0,8/340 m^{-1}

Figure 5 — Non-linear attenuation as function of distance

6.2.3 Atmospheric absorption, excess attenuation and barrier effects

The attenuation $A_{\text{abs}}(f_i)$, in decibels, caused by absorption mechanisms during propagation from the source point at the 1 m reference distance shall be calculated from Equation (17) for the nominal mid-band frequency of the one-third-octave-band sound exposure levels:

$$A_{\text{abs}}(f_i) = \alpha(f_i) \times r \tag{17}$$

where

$\alpha(f_i)$ is the pure-tone atmospheric-absorption attenuation coefficient at the nominal mid-band frequency, in decibels per metre, for the applicable static air pressure, air temperature, and relative humidity (see ISO 9613-1);

r is the propagation path length, in metres, from the 1 m reference distance to the location of the receiver.

NOTE The method given above is not trivial due to the non-linear effect in which the energy shifts to lower frequencies due to pulse broadening. From Equation (6) one can see that the characteristic frequency will decrease with increasing distance from source to receiver due to the 1/r dependency. As a consequence the source spectrum will shift to lower frequencies with increasing distance from source to receiver. Because of the higher frequency content close to the source, air absorption will be relatively higher close to the source. In the method above this non-linear effect is not taken into account in the calculation of air absorption. It is, however, a good approximation, because this frequency shift is only significant close to the source.

The ground attenuation effect, which is a part of A_{excess}, can be calculated by means of any relevant method for prediction of outdoor sound propagation (for example, ISO 9613-2). For different ground surface types and meteorological situations, the parabolic equation method [3] can be used.

For the approximation of the barrier effect, guidance is given in A.4.

7 Uncertainty in source description and propagation

The prediction uncertainties associated with the one-third-octave-band spectrum of the sound exposure level determined in accordance with this part of ISO 17201 shall be evaluated, preferably in compliance with the *Guide to the Expression of Uncertainties in Measurement (GUM)*.

The uncertainties arise from the uncertainty concerning the one-third-octave-band sound source exposure level and from those concerning the attenuation terms.

The expanded measurement uncertainty, together with the corresponding coverage factor, shall be stated for a coverage probability of 95 %, as specified in the *GUM*.

Guidance on how to express the uncertainty is given in Annex B.

Annex A
(informative)

Derivation of constants and consideration of barrier and other effects

A.1 General

Clauses A.2 and A.3 of this annex give the user background on from where the different constants are derived. In A.4, consideration on barrier effects and additional effects are given.

A.2 Calculation of L_0

In the estimation of the source sound exposure level, the constant L_0 is used. It is expressed in decibels as is a function of the following parameters, according to Equation (A.1):

$$L_0 = 10\ \lg \frac{2^{5/4} r_0 \rho^2 c^3 K^3 (\pi/4)^{3/2}}{3 p_0^2 \beta^{1/2} t_0}\ \text{dB} \tag{A.1}$$

where

ρ is the density of the air ($\rho = 1{,}24$ kg/m^3 at 10 °C);

c is the sound speed [$c = 337{,}6$ m/s at 10 °C, see also Equation (3)];

K is a constant depending on the projectile shape ($K = 0{,}59$ for streamlined projectiles — see [4], [6], [7], and also below);

p_0 is the reference sound pressure ($p_0 = 20$ µPa);

β is the coefficient of non-linearity ($\beta = 1{,}2$ — see [4]);

t_0 is the standard reference duration for the reference sound exposure ($t_0 = 1$ s);

r_0 = 1 m.

NOTE The density, ρ, depends on the temperature, T, in degrees Celsius, with $\rho = 1{,}29/(1+T/273{,}15)$.

$L_0 = 161{,}9$ dB at 10 °C, based on the values given between the brackets.

The constant K is a shape factor based on the Whitham function [7]. It is defined by Equation (A.2):

$$K^2 = \frac{\sqrt{l_\text{p}}}{\pi (d_\text{p}/2)^2} \max \left[\int_{-\infty}^{y} F_\text{W}(y')\text{d}y' \right] \tag{A.2}$$

The Whitham function $F_\mathrm{w}(y)$ is defined by

$$F_\mathrm{w}(y) = \frac{1}{2\pi} \int_{-\infty}^{y} \frac{S''(x)}{\sqrt{y-t}} \mathrm{d}t \tag{A.3}$$

where

$S''(x)$ is the second derivative of the function $S(x) = 1/4\ \pi d^2(x)$, where $d(x)$ is the cross-section diameter of the projectile.

A typical approximation for the shape of a projectile is given by Equation (A.4):

$$d(x) = d_\mathrm{p}\left[1-(1-x/l_\mathrm{p})^3\right] \quad \text{for} \quad 0 < x < l_\mathrm{p} \tag{A.4}$$

$$d(x) = d_\mathrm{p} \quad \text{for} \quad x > l_\mathrm{p} \tag{A.5}$$

where

$d(x)$ is the cross-section diameter of the projectile;

x is the distance from the projectile point along the line of symmetry.

Using the given formulas, this estimate leads to $K = 0{,}59$.

A.3 Calculation of f_0

In the estimation of the source spectrum, a frequency f_0 is used which is defined by Equation (A.6):

$$f_0 = \frac{c}{2^{7/4} r_0 \beta^{1/2} K \sqrt{\pi/4}} \tag{A.6}$$

where

r_0 = 1 m;

β is the coefficient of non-linearity ($\beta = 1{,}2$);

K is a constant depending on the projectile shape ($K = 0{,}59$ for streamlined projectiles — see [4], [6] and [7], and also A.2).

A.4 Consideration of barrier effects and additional effects

A.4.1 General

The presented model is described as if projectile sound is stemming from a single point on the trajectory. This description can be used in most cases. But there are situations where it must be taken into account that the whole trajectory, travelled with a projectile speed exceeding the speed of sound, is radiating energy. Most contributions cancel each other out. Only a distinct section of the trajectory contributes energy to the resulting signal at the receiver. This section is situated approximately symmetrically around the source point. Its length is dependant on the distance to the receiver point, the signal length and the velocity of the projectile.

A.4.2 Border region of region II

When the source point is either close to the muzzle or to the target such that the contributing section is not fully on the trajectory anymore, a prediction by the model will overestimate the resulting sound exposure levels by up to 3 dB. Using a Fresnel zone model, the necessary length on the trajectory around the source point can be calculated. Levels begin to decrease significantly when less than half a Fresnel zone is still free. The necessary source length for half a Fresnel zone can be approximated using Equation (A.7):

$$FZ_{0,5} \approx \frac{M\sqrt{2cT_c}}{\sqrt{M^2-1}}\sqrt{r} \qquad \text{(A.7)}$$

where

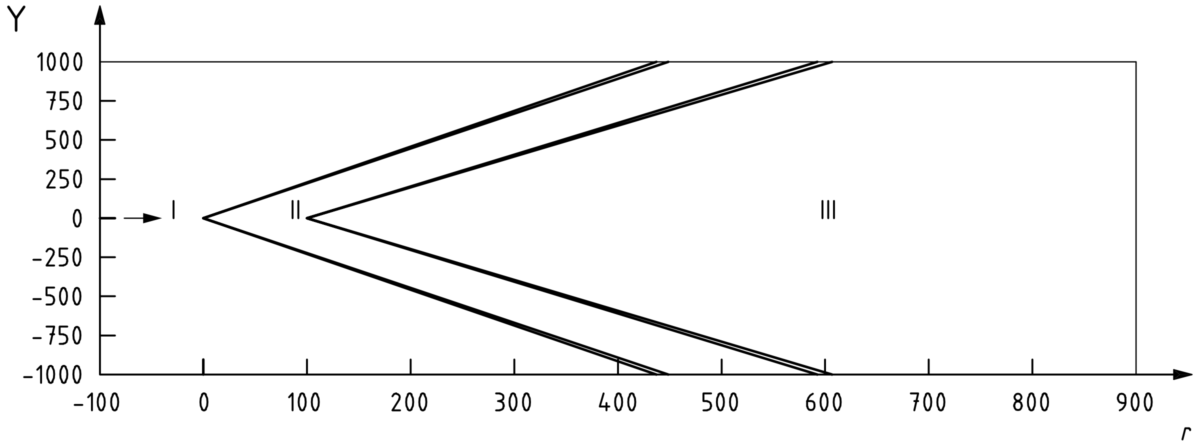
c is the speed of sound, in metres per second (m/s);

M is the Mach number of the projectile at the source point;

T_c is the signal length of the impulse $T_\mathrm{c} = 1/f_\mathrm{c}$, in seconds (s);

r is the distance from receiver to the source point, in metres (m).

Figure A.1 shows the border region of region II for a typical situation (trajectory length: 100 m; $v_{\mathrm{p}0} = 750$ m/s; $\kappa = 1$ s^{-1}, $T_\mathrm{c} = 5 \cdot 10^{-4}$ s).



Key

r distance from the receiver to the source point (m)

Y horizontal distance (m)

Figure A.1 — Border region of region II

With very short trajectories and receiver points in great distances, a receiver can be in the border region of the muzzle as well as in that of the target. In these rare cases, the sound exposures are expected to decrease significantly in relation to the calculated values and the model is no longer applicable.

A.4.3 Barrier effect

When the direct path from the source to the receiver point is blocked by a barrier, the resulting sound exposure level is composed of contributions coming from over the barrier and around the sides of the barrier (see Figure A.2). The shielding effect may be approximated using ISO 9613-2, provided that the contribution from the sound coming over the barrier dominates that coming round the sides. To check whether this condition is valid, Equation (A.8) can be used:

$$D_\mathrm{H} < 20 \lg \left(\frac{1}{\sqrt{n+1} - \sqrt{n}} \right) \tag{A.8}$$

where

D_H is the barrier effect over the barrier, according to ISO 9613-2;

n is the number of shielded Fresnel-zones

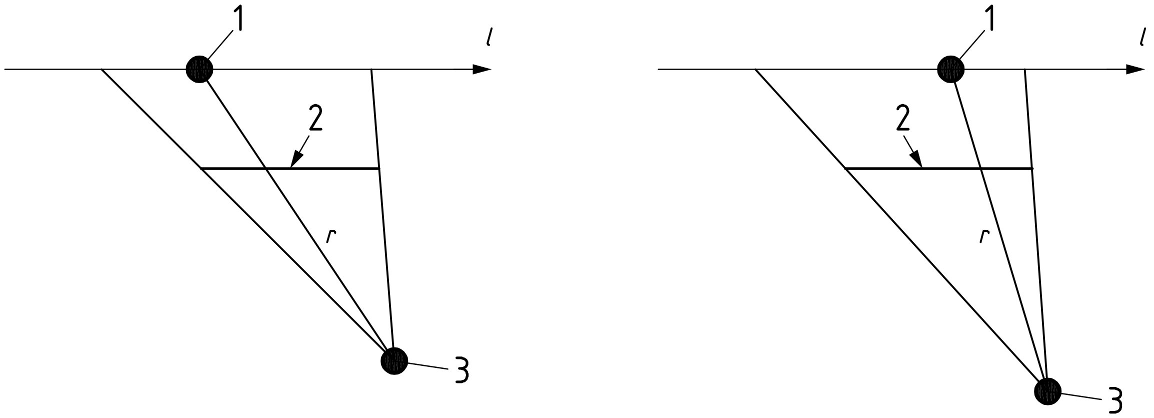
$$\approx \frac{l^2 (M^2 - 1)}{M^2 c \, T_c \, r}$$

l is the shortest distance from the source point to the first unshielded point on the trajectory, either in the shooting or opposite direction, expressed in metres (m);

c is the speed of sound, in metres per second (m/s);

M is the Mach number of the projectile at the source point;

r is the distance from the receiver to the source point, in metres (m).



Key

1 source point

2 barrier

3 receiver point

Figure A.2 — Shielding effects caused by a barrier

An alternative method, which is also defined for cases where the foregoing condition does not hold, can be found in [8].

Annex B
(informative)

Guidance on prediction uncertainty

B.1 General

The accepted format for expression of uncertainties is given in the *GUM*. Its principles can be applied to the prediction method as specified in this part of ISO 17201, as well. The format for expression of uncertainties incorporates an uncertainty budget, in which the various sources of uncertainty are identified and quantified, from which the combined uncertainty can be obtained. The general approach to calculation of uncertainties appropriate to this part of ISO 17201 is illustrated for information.

B.2 Uncertainty of one-third-octave-band spectrum of sound exposure level

B.2.1 Functional relationship

The general expression for the one-third-octave-band spectrum of the sound exposure level at the receiver location, $L_{E,\mathrm{r}}(f_i)$, is given by Equation (B.1):

$$L_{E,\mathrm{r}}(f_i) = L_{E,\mathrm{s}}(f_i) - A_{\mathrm{div}} - A_{\mathrm{nlin}} - A_{\mathrm{atm}}(f_i) - A_{\mathrm{excess}}(f_i) \tag{B.1}$$

where

$L_{E,\mathrm{s}}(f_i)$	is the one-third-octave-band sound source exposure level at nominal mid-band frequency f_i and at the 1 m reference distance from the source point [see Equation (7)], expressed in decibels;
A_{div}	is the attenuation of the level of the sound in a field free of reflections and resulting from the divergence of the geometric area of the wave front as the distance increases from the 1 m reference distance, expressed in decibels;
A_{nlin}	is the attenuation caused by non-linear effects associated with the large initial amplitude of projectile sound near the source point, expressed in decibels;
$A_{\mathrm{atm}}(f_i)$	is the attenuation caused by absorption processes in the atmosphere as the sound propagates over the path from the 1 m reference distance to the location of the receiver, expressed in decibels;
$A_{\mathrm{excess}}(f_i)$	is the excess attenuation which includes losses due to the interaction with the ground, atmospheric refraction and shielding by a barrier, expressed in decibels.

A probability distribution (normal, rectangular, student-t, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of its variance, termed standard uncertainty. These uncertainties contribute to the combined uncertainty associated with values of the sound exposure level.

B.2.2 Contributions to prediction uncertainty

The contributions to the combined uncertainty associated with the value of the one-third-octave-band spectrum of the sound exposure level depend on the uncertainties and the related sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how the values of the one-third-octave-band spectrum of the sound exposure level are affected by changes in the values of the respective input quantities. Mathematically, they are equal to the partial derivative of the physical relationship with respect to the relevant input quantity. The contributions of the respective input quantities are then given by the products of the standard uncertainties and their associated sensitivity coefficients. Thus, the information needed from which to derive the overall uncertainty is that given in Table B.1.

Table B.1 — Uncertainty budget for determinations of one-third-octave-band spectrum of sound exposure level

Quantity	Estimate [a] dB	Standard uncertainty [a] u_i dB	Probability distribution [a]	Sensitivity coefficient c_i	Uncertainty contribution $c_i\,u_i$ dB
$L_{E,\mathrm{s}}(f_i)$	$L_{E,\mathrm{s,\ est}}(f_i)$	u_1 [b]		1	u_1
A_{div}	$A_{\mathrm{div,est}}$	u_2 [c]		1	u_2
A_{nlin}	$A_{\mathrm{nlin,est}}$	u_3 [c]		1	u_3
$A_{\mathrm{atm}}(f_i)$	$A_{\mathrm{atm,est}}(f_i)$	u_4 [c]		1	u_4
$A_{\mathrm{excess}}(f_i)$	$A_{\mathrm{excess,est}}(f_i)$	u_5 [d]		1	u_5

[a] The estimate, the standard uncertainty and the probability distribution have to be estimated for each quantity based on information available or expert judgement.

[b] The standard uncertainty in $L_{E,\mathrm{s,est}}(f_i)$ is less than 1 dB.

[c] Compared with the standard uncertainty in the attenuation term A_{excess}, the uncertainties in the other attenuation terms are negligible (small).

[d] The standard uncertainty in $A_{\mathrm{excess}}(f_i)$ can be found in ISO 9613-2.

B.2.3 Combined and expanded prediction uncertainty

The combined uncertainty of the determination of the one-third-octave-band spectrum of the sound exposure level, $u\left[L_{E,\mathrm{r}}(f_i)\right]$ is given by the following equation:

$$u\left[L_{E,r}\ (f_i)\right]=\sqrt{\sum_{\mathrm{i}=1}^{5} u_i^2} \tag{B.2}$$

The *GUM* requires an expanded uncertainty, U, to be specified, such that the interval $\left[L_{E,\mathrm{r}}(f_i)-U, L_{E,\mathrm{r}}(f_i)+U\right]$ covers, for example, 95 % of the values of $L_{E,\mathrm{r}}(f_i)$ that might reasonably be attributed to $L_{E,\mathrm{r}}(f_i)$. To that purpose, a coverage factor, k, is used, such that $U = k\,u$.

Table B.2 — Coverage factors associated with different coverage probabilities

Coverage probability %	Coverage factor
67	1,0
80	1,3
90	1,6
95	2,0
99,9	2,6

Bibliography

[1] ISO 9613-1, *Acoustics — Attenuation of sound during propagation outdoors — Part 1: Calculation of the absorption of sound by the atmosphere*

[2] Berg, F.H.A., van den. *Validation of a computational model for projectile sound*, TNO report DGT-RPT-030078, 2004

[3] Gilbert, K.E., and White, M.J., Application of the parabolic equation to sound propagation in a refracting atmosphere, *Journal of the Acoustical Society of America*, 85, pp. 630-637, 1989

[4] Pierce, A.D., *Acoustics. An Introduction to its Physical Principles and Applications*, American Institute of Physics, College Park Maryland, USA, 1991

[5] Salomons, E.M., A coherent line source in a turbulent atmosphere, J*ournal of the Acoustical Society of America*, 105 (2), pp. 652-657, 1999

[6] Whitham, G.B., The Flow Pattern of a Supersonic Projectile, *Communications on Pure and Applied Mathematics*, 5, pp. 301-348, 1952

[7] Whitham, G.B., On the propagation of Weak Shock Waves, *J. Fluid Mech*., 1, pp. 290-318, 1956

[8] Wunderli, J.M., Shielding effect for sonic boom of projectiles, *acta acustica/ACUSTICA*, Vol. 87, pp. 91-100, 2001

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