UDC 534.88

SHOOTING RANGES:
PREDICTION OF NOISE

Key words: Shooting ranges, prediction of noise, test method

CONTENTS

0 INTRODUCTION

A joint Nordic prediction method for noise from shooting ranges was published in 1984, /1/. It was a simplified method for the A-weighted level of shooting noise, intended for use with nomograms, but based on the Nordic general prediction method for industrial noise, /2/. A proposed revision of /1/ was drawn up by a Nordtest project group in 1994–1995, /7/. In the revision the contribution of noise from supersonic bullets is considered, the calculation of screening is harmonised with /2/ thus allowing correction for multiple screens, correction for shooting halls and firing sheds is treated in more detail, and calculation of reflected noise is refined. The revision includes a full set of equations for the calculations in 1/1-octave bands.

1 THE PREDICTION METHOD

1.1 Scope

This Nordtest prediction method specifies calculation of noise in the vicinity of shooting ranges, etc. from single shots fired with small arms. Formulas are given for calculations in 1/1-octave bands. It is based on the Nordic general prediction method for industrial noise, /2/, and on the reference noise level, which describes the noise emission from the weapon. A measurement method for determination of the reference noise level of muzzle noise is included as Appendix C.

1.2 Field of application

The prediction method is applicable to small arms of less than 20 mm calibre. It is based on sound propagation during downwind conditions and in summer. The calculations are carried out in the 1/1-octave bands 31.5–8 kHz, assuming that the noise is characterised by the maximum level with time weighting constant I. The octave bands are added to form the total A-weighted sound pressure level, L_{pAI}. The contributions from the muzzle noise and the noise from supersonic bullets are calculated independently. Reflected noise is regarded separately. These contributions are not added, usually the highest level is considered.

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It is excepted that the results from the prediction method will not deviate by more than 3 dB from the average of a large number of independent measurement results each obtained under favourable sound propagation conditions in cases where the noise from the shooting range propagates freely. Where significant screening occurs, or where the noise propagates through extended vegetation, the deviation is expected to be less than 5–6 dB. When the calculation method is used to determine the noise reflected from forest, mountains, etc. (as described in Appendix A), larger deviations may occur.

Note: The prediction method is adapted to give the maximum A-weighted sound pressure level with time weighting I, L_{pAI}. The time weighting constant is inherent in the reference noise level and in the corrections that describe increased duration of the signal (corrections for vegetation, reflection, and shooting hall). If in the future the prediction method were to be adjusted to other descriptors, such as e.g. noise dose of single shots, L_{AE}, these corrections, the measurement method for reference noise level of muzzle noise (in Appendix C) and the expressions for reference noise level of bullet noise (Section 2.2) will have to be revised.

1.3 Structure of the prediction method

The type of weapon and the direction between shooting direction and the direction towards the calculation point (immission direction) are parameters of the reference noise level which characterises the noise emission. Separate reference noise levels exist for muzzle noise and for bullet noise, the latter is calculated.

Corrections for shooting halls and firing sheds, distance, screens, ground effect, vegetation, and reflection are added. The calculations are made separately in each 1/1-octave band; the lowest octave band should be included for larger weapons (machine guns 12.7 mm, etc.), but is not important for small hand weapons. The corrections are described in the following sections where the main effort has been to explain what is special to shooting noise compared with industrial noise, /2/. All corrections are described generally, but the text does not cover every situation. For a complete set of calculation rules and explanations reference is made to /2/ and /6/.

The octave band levels are A-weighted and added on energy basis to give the maximum A-weighted sound pressure level time weighting I for single shots, L_{pAI}.

The formulas for the 1/1-octave sound pressure level in the immission point are given by Eq. (1) and (2)–(3) for muzzle noise and bullet noise, respectively. They are of the type $L = L_{ref} + \Delta L$.

L	Octave band sound pressure level in an immission point
L_{ref}	Reference noise level (emission level)
ΔL	Corrections. A negative correction indicates an attenuation while a positive correction indicates amplification. Each type of correction has a subscript. The subscript is the same for muzzle noise and for bullet noise, but the corrections are generally not equal.

Muzzle noise:

$$L_{pI} = L_{pI}(\Phi,10\text{m}) + \Delta L_h + \Delta L_d + \Delta L_a + \Delta L_g + \Delta L_s + \Delta L_v \ (+ \Delta L_r) \qquad (1)$$

Bullet noise: (supersonic projectiles only)

I Immission point <u>within</u> the bullet noise region:

$$L_{pI} = L_{pI}(S_B,10\text{m}) + \Delta L_d + \Delta L_a + \Delta L_g + \Delta L_s + \Delta L_v \ (+ \Delta L_r) \qquad (2)$$

II Immission point <u>outside</u> the bullet noise region:

$$L_{pI} = 0 \text{ (ie the bullet noise does not exist)} \qquad (3)$$

Symbols in Chapter 1:

L_{pAI}	Immission A-weighted sound pressure level. Time weighting constant I.	(dB re 20 μPa)
L_{pI}	Immission 1/1 octave band sound pressure level. Time weighting constant I.	(dB re 20 μPa)
$L_{pI}(\Phi,10\text{m})$	Emission 1/1 octave band sound pressure level in direction Φ, at 10 m distance from the muzzle. Time weighting constant I.	(dB re 20 μPa)
$L_{pI}(S_B,10\text{m})$	Emission 1/1 octave band sound pressure level at 10 m distance from the bullet noise source point S_B. Time weighting constant I.	(dB re 20 μPa)
ΔL_a	Correction for air absorption	(dB)
ΔL_d	Correction for divergence	(dB)
ΔL_g	Correction for ground effect	(dB)
ΔL_h	Correction for shooting hall	(dB)
ΔL_r	Correction for reflection. (Only when calculating reflections. Cf Appendix A)	(dB)
ΔL_s	Correction for screening	(dB)
ΔL_v	Correction for vegetation	(dB)

2 THE REFERENCE LEVEL

The reference level is frequency dependent and different for the muzzle noise (Chapter 2.1) and the bullet noise (Chapter 2.2). Some definitions are given at the end of this chapter together with explanations of the symbols used.

2.1 Muzzle noise, $L_{pI}(\Phi,10\text{m})$

The reference level for muzzle noise shall be based on measurements at 10 m distance from the muzzle. The measured sound pressure levels shall be corrected to free field conditions. The measurement and data analysis method shall be according to the procedure described in Appendix C. Measuring data should (at least) be obtained at 5 equally spaced directions Φ_n (n=1...5) relative to the shooting direction: 0° (n=1), 45°, 90°, 135°, 180°. Symmetry about the 0° axis (ie the shooting direction) may be assumed.

For the general immission direction Φ, the reference level $L_{pI}(\Phi,10\text{m})$ is found by *quadratic interpolation* between the two reference levels (at Φ_n, and Φ_{n+1}) nearest to Φ. ($\Phi_n < \Phi < \Phi_{n+1}$). (Quadratic interpolation is an approximation by the quadratic parabola which passes through Φ_n, Φ_{n+1} and Φ_{n+2}. If $\Phi > 180°$ then Φ is set equal to $360° - \Phi$. If $\Phi_{n+1} = 180°$ then Φ_{n+2} is set equal to Φ_{n-1}).

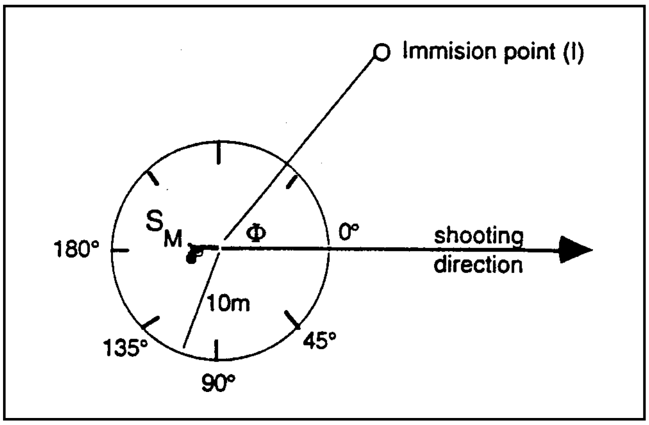

Figure 1. Muzzle noise emission points (10 m) and immission direction (Φ).

2.2 Bullet noise, $L_{pl}(S_B,10m)$

The bullet noise is limited to certain regions, depending on the bullet (supersonic) travelling distance (D) and the Mach angle (Ψ), see the shaded area in Figure 2.

At a certain immission point (I) (within the bullet noise region) the bullet noise can be considered as originating from a certain point (S_B) along the bullet trajectory, cf Figure 3. The source height is the height of the bullet trajectory above ground at S_B.

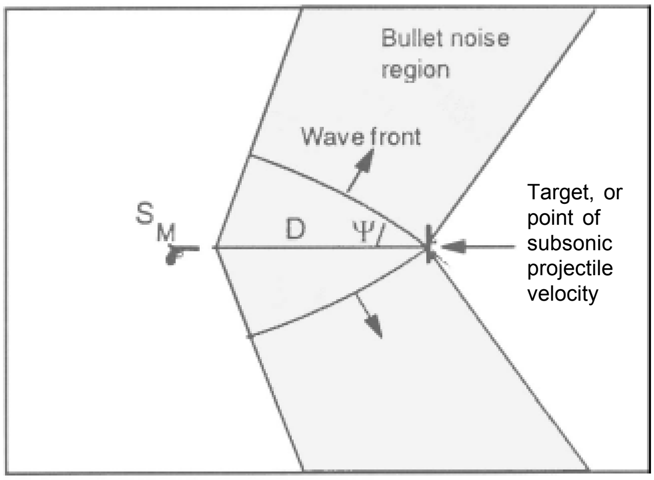

Figure 2. Bullet noise region. (Shaded)

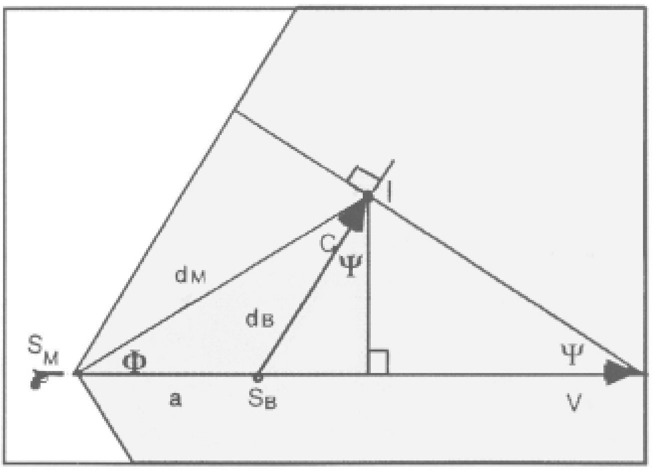

Figure 3. Bullet noise source point (S_B) for immission point (I).

Calculation procedure of distance (a) between the muzzle source (S_M) and the bullet noise source (S_B); (C = sound velocity and V = bullet velocity in source point S_B), cf Figure 3:

$\Psi = \arcsin (C/V)$ ("Mach angle") (4)

$\tan \Psi = ((d_M^2 - d_M^2 \sin^2\Phi)^{1/2} - a)/(d_M \sin\Phi)$
$= C/(V^2 - C^2)^{1/2}$ (5)

$a = d_M (\cos\Phi - \sin\Phi\ C/(V^2 - C^2)^{1/2})$ (6)
(calculate a by numerical iteration)

$V = V_0 - \Delta V \cdot a$ (7)

(V_0 = bullet velocity at muzzle, ΔV = vel. reduction pr. metre).

In Eq. (6) d_M and Φ are known from calculation of the muzzle noise. V_0 and ΔV are weapon dependent. (Typical values for a rifle are: V_0 = 800 m/s, ΔV = 0.5 m/s pr. metre).

The time (T) that elapses from the time the shot is fired until the bullet noise arrives in the immission point I:

$T = a/(V_0 - \Delta V \cdot a/2) + d_B/C$ (cf Figure 3) (8)

The 1/1 octave bullet sound pressure level in a free field at distance d_B = 10m from the source point, $L_{pl}(S_B,10m)$, is generally calculated in 1/1 octave bands according to (9), (/5/):

$L_{pl}(S_B,10m) = L_{pk}(10m)$
$+ 10 \lg([2/(\pi F)^2][(\sin\pi FT(10m))/(\pi FT(10m)) -$
$- \cos\pi FT(10m)]^2[0.707F]) + 14.6$ (9)

$P_{pk}(10m) = ((M^2 - 1)^{1/8} \cdot R/L^{1/4}) \cdot 10{,}3 \cdot 10^3$ (10)
(from /4/)

$T(10m) = M \cdot 10^{1/4} \cdot R/((M^2 - 1)^{3/8} \cdot L^{1/4}) \cdot 10^{-2}$ (11)
(from /4/)

Use of Eq. (9) shall be limited to octave bands $F \geq F^*$. Below F^* (ie $F < F^*$) the 1/1 octave band levels are constant (i.e equal to the level in F^*). F^* is the 1/1 octave band that includes a «shift frequency» f^*. This general course of the spectrum is in agreement with measurement results, /7/.

$f^* = 1/(16 \cdot T(10m))$ (12)

Symbols in Chapter 2:

A	Maximum bullet area	(m^2)
C	Sound velocity (340 m/s)	(m/s)
D	Projectile travelling distance until it hits the target or the velocity becomes subsonic	(m)
F	Centre frequency in 1/1 octave bands 63 - 8000 Hz	(Hz)
F^*	The 1/1 octave band that includes the «shift frequency» f^*	(Hz)
I	Immission point	
K^*	Body shape constant (Usually ≈ 0.6 for projectiles)	
L	Bullet length	(m)
$L_{pl}(\Phi,10m)$	Emission 1/1 octave band sound pressure level in direction Φ, at 10 m distance from the muzzle. Free field. Time weighting constant I.	(dB re 20 μPa)

$L_{pI}(S_B,10m)$	Emission 1/1 octave band sound pressure level at 10 m distance from the bullet source point S_B. Free field. Time weighting constant I.	(dB re 20 μPa)
$L_{pk}(10m)$	$10\ lg(P_{pk}(10m)/P_0)^2$ (P_0 = 2E – 5 Pa)	(dB)
M	Mach number (= V/C)	
$P_{pk}(10m)$	Peak pressure in the sonic boom waveform («N-curve») at 10m from source point. Free field	(Pa)
	General equation /4/: $P_{pk}(d_B) = \gamma\ p_0\ (M^2 - 1)^{1/8} \cdot A^{1/2}\ K^*/(2^{1/4}\ \beta^{1/2}\ d_B^{3/4}\ L^{1/4})$	
R	Maximum bullet diameter	(m)
S_B	Source point position (along the trajectory) for the bullet noise	
S_M	Source point position for the muzzle noise	
T	The time that elapses from the time the shot is fired until the bullet noise arrives in the immission point I	(s)
T(10m)	Total duration of the sonic boom («N-curve») at 10m from source point	(s)
	General equation /4/: $T(d_B) = 2 \cdot 2^{3/4}\ \beta^{1/2}\ M\ d_B^{1/4} \cdot A^{1/2}\ K^*/(C\ (M^2 - 1)^{3/8}\ L^{1/4})$	
V	Bullet velocity	(m/s)
V_0	Bullet velocity when leaving the muzzle	(m/s)
ΔV	Bullet velocity reduction pr. metre	(m/s pr. m)
a	Bullet noise source distance from muzzle along the bullet trajectory	(m)
d_B	Bullet noise source – Immission point distance	(m)
d_M	Muzzle – Immission point distance	(m)
f^*	A «shift frequency» below which the bullet noise 1/1 oct. level is const. $1/f^* = 16 \cdot T(10m)$	(Hz)
n	Emission direction number: n=1...N. (N ≥ 5). n=1 means 0°	
p_0	Ambient pressure (= 1.01E+5)	(Pa)
β	$= (\gamma+1)/2$	kg/m^3
γ	Specific heat constant (= 1.402 in air)	kg/m^3
Φ	Immission direction rel. shooting direction (=0°)	(°)
Ψ	Mach angle	(°)

3 SHOOTING HALLS AND FIRING SHEDS, ΔL_h

The screening and attenuation from firing sheds and interlane screens (ie screens between (groups of) shooting stands) may be considered as a part of the emission level for muzzle noise. The correction for firing sheds is frequency dependent and only valid for the muzzle noise.

ΔL_h for bullet noise = 0.

Appendix B describes the dimensions of 7 different firing sheds and gives measured insertion losses: The insertion losses equal ΔL_h; a negative value of ΔL_h implies an attenuation. These data may be used in the prediction method:

- *Råvatn* is equivalent to the standard shooting hall «Type Z» in /1/.
- *Jægerpris (small), Jægerpris (long), Setnesmoen, Gansrød, Lv6* are all firing sheds with different kinds of ducts in front of the stand.
- Dalgas Shooting Centre /13/.

Insertion loss from other measurements may be applied as well, but the accuracy of the data shall be at least as good as described in Appendix B. Measurement distances shall not be less than 50m. (100m is preferred).

With immission direction Φ, the correction ΔL_h is found by quadratic interpolation between the two measured insertion losses nearest to Φ, cf Figure 4 (and Chapter 2.1).

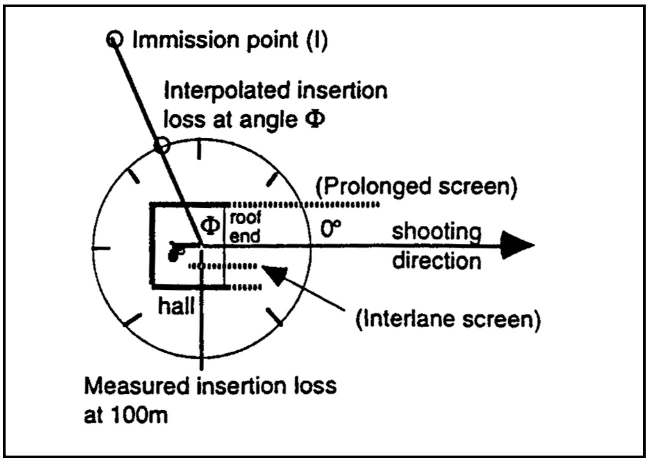

Figure 4. Correction loss ΔL_h in immission direction (Φ).

The correction due to small interlane screens (ie inside the shooting hall, cf Figure 4) of small height (less than 1 m above the source) may be rather limited /7/. If no other data are available then an extra correction to ΔL_h caused by an interlane screen should be set equal to –4 dB in all 1/1-octave bands 31.5–8000 Hz, provided that the screen is absorption lined and acts as an effective screen according to geometry. (cf Chapter 5). This correction is a supplement to the correction of the firing shed, and is applied only in directions where the firing shed is effective (ΔL_h < 0 dB). In other directions the interlane barrier is regarded as a regular screen. (cf Ch. 5).

Shooting halls with extended side walls but without an extended roof may be treated in one of two ways:

- either actual measured data for the correction of the particular type of shooting hall or data from Appendix B may be used,
- or the data for an ordinary, non-extended shooting hall (type Z in /1/) is used in directions behind the muzzle (with Φ > 90°), while the effect of the side screen is calculated separately as described in Chapter 5 and is used in directions in front of the muzzle (with Φ < 90°). In this way it must be ensured that the calculation is continuous around 90°; the correction of the shooting hall should not be less than that of a very long screen of same height as the actual side screen but extended in directions behind the muzzle.

Note that when the effect of shooting halls is included the source height shall be increased as indicated in Figure 5. The increased source height (h_{sh}) shall be applied when calculating corrections for screening, ground effects and vegetation, and is valid for all values of Φ where the shooting hall is effective (ΔL_h < 0 dB).

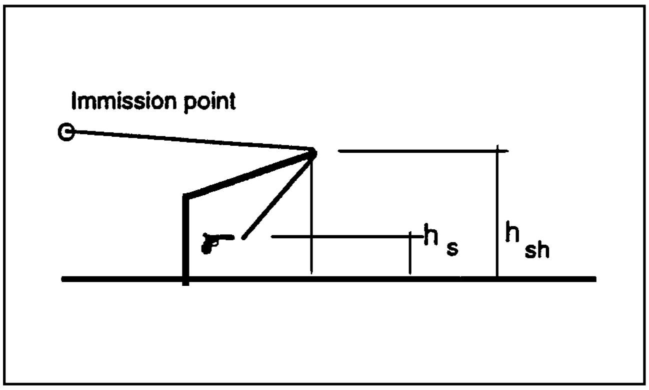

Figure 5. Source height with hall: h_{sh}. Source height without hall: h_s.

Symbols in Chapter 3:

h_s	Source height without shooting hall	(m)
h_{sh}	Source height with shooting hall (equals height of roof in front of the weapon)	(m)
ΔL_h	Correction for shooting hall	(dB)
Φ	Immission direction	(°)

4 DISTANCE

The distance dependent factors are divided into:

I Divergence, different for muzzle noise and bullet noise.

II Air absorption, same correction (dB/m in 1/1 octave bands) for muzzle noise and bullet noise.

The distance for muzzle noise is d_M and for bullet noise d_B, cf Figure 3.

4.1 Divergence, ΔL_d

Correction for divergence ΔL_d is frequency independent:

Muzzle noise:

$$\Delta L_d = -20 \lg (d_M/10) \tag{13}$$

Bullet noise (/4/):

$$\Delta L_d = -12.5 \lg (d_B/10) \tag{14}$$

4.2 Air absorption, ΔL_a

Correction for air absorption ΔL_a for muzzle noise and bullet noise is frequency dependent and is calculated according to (15) and (16) respectively. The coefficient α_a is found in Table 1. (/2/)

Table 1. Attenuation coefficient α_a, 15 °C, 70 % RH.

1/1 octave bands (Hz)	α_a(dB/m)
31.5	0.0000
63	0.0001
125	0.0002
250	0.0007
500	0.0019
1000	0.0044
2000	0.0068
4000	0.0169
8000	0.0564

Muzzle noise:

$$\Delta L_a = -\alpha_a d_M \tag{15}$$

Bullet noise:

$$\Delta L_a = -\alpha_a d_B \tag{16}$$

Symbols in Chapter 4:

d_B	Bullet noise immission distance	(m)
d_M	Muzzle noise immission distance	(m)
ΔL_d	Correction for divergence	(dB)
ΔL_a	Correction for air absorption	(dB)
α_a	Air absorption coefficient	(dB/m)

5 SCREENS, ΔL_s

The screen correction ΔL_s is frequency dependent and equal (in 1/1 octave bands) for the muzzle noise and the bullet noise. When calculating the screening of muzzle noise the source position is S_M while for bullet noise screening is calculated with source position S_B (cf Figure 3).

Use the "terrain profile" drawn through the source (S) and the immission point (I) as shown in Figure 6. Hilltops, screens and barriers penetrating the straight line S-I are treated as single (thin) screens. The calculation for screen correction identifies two different situations:

I Only one screen. Correction according to Clause 5.1. (/2/)

II More than one screen. Correction according to Clause 5.2. (/6/)

It is assumed that the screen length is much larger than the screen height. Care should be taken to ensure that the

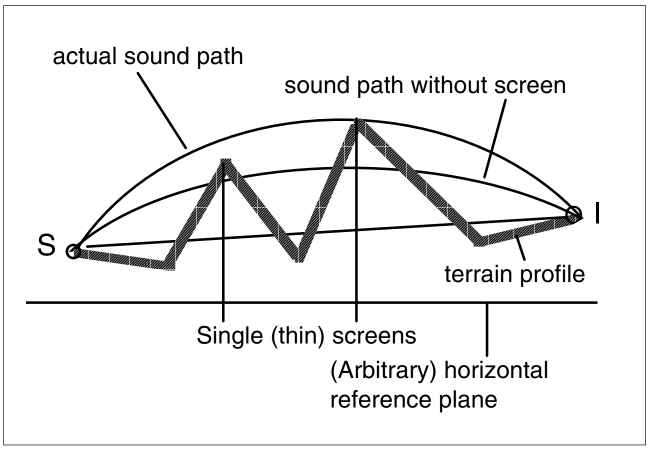

Figure 6. Terrain profile and screen simplification.

"effective length" of barriers and terrain etc. is more than 3 times larger than the "effective height". (See below). If this is not the case, correction for screen length shall be calculated according to /2/. For screening of bullet noise it is necessary that the screen is sufficiently long. ΔL_S for the bullet noise is 0 dB if the effective length of the screen is less than 3 times the effective height (h_e).

5.1 Single screens

This case represents the basic screening situation to which all other configurations are referred. The procedure is described below in step 1 to 3. Figure 7 explains the basic geometry:

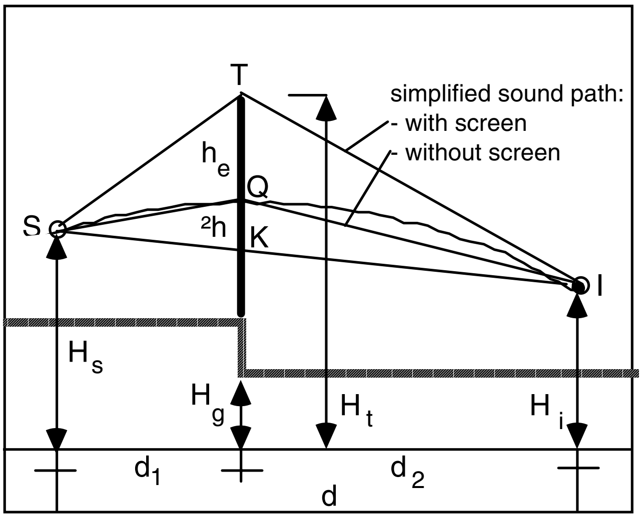

Figure 7. Geometrical parameters for single screen.

1. Refer to Figure 7: Determine the positions of the points K, Q, and T. Point Q is always situated above point K, the distance QK being:

   $\Delta h = (d_1 \bullet d_2) / (16 \bullet d)$ (17)

   The distance QT is the effective height h_e of the screen. If Q is situated below T, h_e is positive. If Q is situated above T, h_e is negative by definition:

   $h_e = KT - \Delta h$ – if K is below T (18)

   $h_e = -(KT + \Delta h)$ – if K is above T (19)

2. Refer to Figure 7: Determine the transmission path difference, δ

   $\delta = ST + TI - SQ - QI$ – if K is below T (20)

   $\delta = 2SI - SQ - QI - ST - TI$ – if K is above T (21)

3. Determine the value of ΔL_s:

   $\Delta L_s = -10\ C_h\ \lg\ (0.94 \cdot \delta F + 3)$ (22)

   – If $\Delta L_s > 0$ dB, then ΔL_s is set equal to 0 dB

   – If $\Delta L_s < -20$ dB, then ΔL_s is set equal to –20 dB

   $C_h = F(H_t - H_g)/250$ (H_t, H_g: cf Figure 7) (23)

   – If $C_h > 1$ then C_h is set equal to 1.

5.2 Multiple screens

In the case of multiple screens, ie two or more screens having positive effective heights ($h_e \geq O$), it is allowed to calculate for two screens according to procedures given below.

The two screens here represent the situation with one screen (or barrier) less than about 50 m away from the source and one screen further away, formed by the terrain. Two (or more) terrain screens should not normally be considered as multiple screens, but the most effective one should be chosen as single screen.

The following procedure is used for calculating multiple screen corection $\Delta L_{s:}$

1. Determine the transmission path difference δ for all terrain screens ($h_e \geq 0$) considered as single screens.
2. Choose the most effective single terrain screen. (i.e the screen with the largest transmission path difference δ).
3. A second screen (or barrier) less than about 50 m away from the source may be combined with this most effective terrain screen for multiple screen correction:

   $\Delta L_s = \Delta L_{s1} + \Delta L_{s2}$ (cf Figure 8) (24)

   ΔL_{s1} and $\Delta L_{s2,h}$ are calculated for single screens according to Clause 5.1.

   In some cases reciprocity, ie changing the source with the receiver, gives a different result from Eq. (24). Therefore both calculations shall be performed, and the most effective value for ΔL_s shall be chosen.

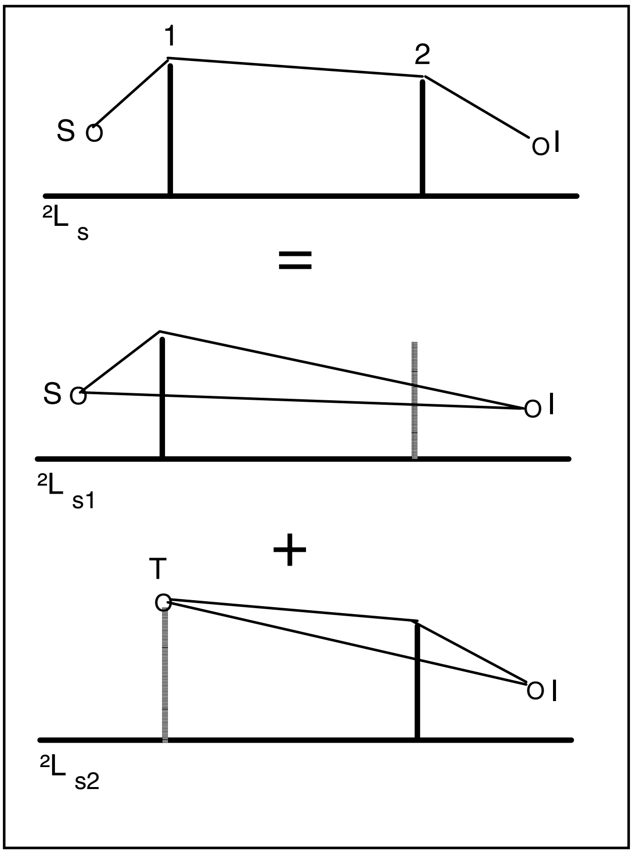

Figure 8. Calculation of multiple screen correction.

If a very large attenuation is obtained by this procedure, care should be taken to ensure that the noise level in the immission point is not dominated by reflected sound paths (cf Appendix A of this report). In practice, diffuse reflections will tend to limit the obtainable screen correction.

Symbols in Chapter 5:

C_h	Correction factor related to height of screen	
F	Centre frequency of 1/1 octave band	(Hz)
H_s	Source height above an arbitrarily chosen horizontal plane	(m)
H_g	Height of lowest ground surface adjacent to screen above (an arbitrary) horizontal plane	(m)
H_t	Screen top height above an arbitrarily chosen horizontal plane	(m)
H_i	Immission point height above an arbitrarily chosen horizontal plane	(m)
K	Intersection between screen and the straight line S-I	(m)
I	Immission point	
T	Top edge of screen	
Q	Intersection between screen and curved sound path (without screen)	
S	Source position. (Source is either muzzle or bullet)	
d	Horisontal distance source – immission point	(m)
d_1	Horisontal distance source – screen	(m)
d_2	Horisontal distance screen – immission point	(m)
h_e	Effective height	(m)
Δh	Curved sound path height above the straight line S-I (at screen position)	(m)
ΔL_s	Correction for screen	(dB)
ΔL_{s1}	Correction for screen 1 by multiple screen calculation	(dB)
ΔL_{s2}	Correction for screen 2 by multiple screen calculation	(dB)
δ	Transmission path difference	(m)

6 THE GROUND, ΔL_g

The ground correction ΔL_g is frequency dependent and equal (in 1/1 octave bands) for the muzzle noise and the bullet noise. The source positions are respectively S_M or S_B, cf Figure 3. The correction is identical to the ground correction in the general method /2/.

Basically the correction ΔL_g due to the effect of ground is calculated as a sum of three terms, each being related to the properties of different parts of the ground surface between the source and the immission point, cf Figure 9. For small distances the source part and the immission point part may overlap, giving no central part. Cf /2/ for details.

The values of the correction terms depend upon source and immission point height, type of ground surface, distance between source and immission point, and whether or not screening occurs along the transmission path.

The ground is characterised by a ground factor G = [0,1], depending on the ground being hard, porous or partly porous, cf Table 2:

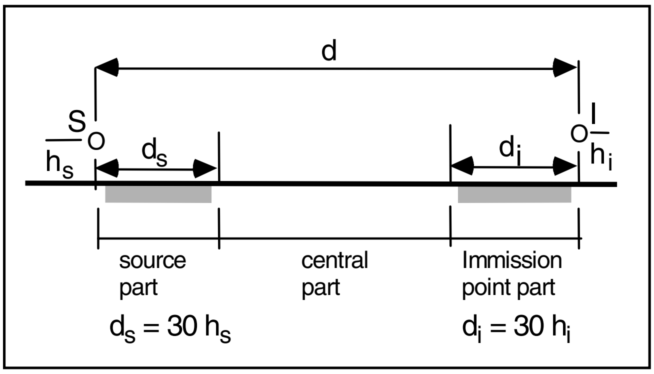

Figure 9. Geometrical parameters for the ground.

Table 2. Ground surface type and Ground factor G.

Ground surface type	G	Characterisation
Hard ground	0	Asphalt, pavement, concrete, water, rock, and ground surfaces with many scattering obstacles considered acoustically hard. Ground factor: G = 0
Porous ground	1	All surfaces on which vegetation could occur and on which only a few scattering obstacles exist are regarded acoustically porous, ie grassland, agricultural ground with and without vegetation, woods, moors and gardens. Ground factor: G = 1
Partly porous ground	p/100	If a percentage p of the ground surface is porous and the rest is hard, the ground factor G is found by interpolation Ground factor: G = p/100

The ground correction ΔL_g consists of three contributions each of which can be attributed to one surface part, one immission point part and one central part:

$$\Delta L_g = \Delta L_{g,s} + \Delta L_{g,i} + \Delta L_{g,c} \tag{25}$$

The values of each of the contributions in Eq. (25) can be calculated in 1/1 octave bands by means of the expressions summarised in Table 3.

$\Delta L_{g,s}$: To calculate $\Delta L_{g,s}$ from the source part, substitute G and h in the expressions in Table 3:

$$G = G_s \tag{26}$$

$$h = h_s\ ,\quad \underline{\text{or}} \tag{27}$$

$$h = h_s + h_{e1}\ (1 - d_{s1}/d) \tag{28}$$

Eq. (28) is shall be used instead of Eq. (27) when, h_s < 5m <u>and</u> significant screening occurs, ie when the effective height h_{e1} of the closest screen is positive.

$\Delta L_{g,i}$: Calculation of $\Delta L_{g,i}$ from the immission point part is analogous to the calculation of $\Delta L_{g,s}$ (above). Substitute G and h in the expressions in Table 3:

$$G = G_i \tag{29}$$

$$h = h_i\ ,\quad \underline{\text{or}} \tag{30}$$

$$h = h_i + h_{e2}\ (1 - d_{i2}/d) \tag{31}$$

Eq. (31) is shall be used instead of Eq. (30) when, h_i < 5m <u>and</u> significant screening occurs, ie when the effective height of the screen h_{e2} is positive.

$\Delta L_{g,c}$: $\Delta L_{g,c}$ from the central part is calculated as indicated in Table 3.

In many cases the central part can not be considered as a plane (horizontal) surface (like the one shown in Figure 9). Then the average height of the central part (above the arbitrary horizontal reference plane) is calculated as shown in Figure 10. Corrected heights (h_{sc} and h_{ic}) for h_s and h_i according to Eq. (32) and Eq. (33) are used in the expression for *m* in Table 3:

$$h_{sc} = h_s + (H_{si} - H_{gg}) \quad (32)$$

$$h_{ic} = h_i + (H_{si} - H_{gg}) \quad (33)$$

If $H_{gg} > H_{si}$ then h_{sc} is set equal h_s and h_{ic} is set equal h_i.

If h_s (h_{sc}) or h_i (h_{ic}) is less than 5m <u>and</u> significant screening occurs, ie $h_e > 0$, the corrected height(s) from Eq. (28) and Eq. (31) is (are) used in the expression for *m* in Table 3.

Table 3. Expressions to be used in Eq. (25).

Centre frequency in 1/1 octave band, (Hz)	$\Delta L_{g,s}$ or $\Delta L_{g,i}$ (dB)	$\Delta L_{g,c}$ (dB)
31.5	1.5	3 *m*
63	1.5	3 *m*
125	1.5 – G *a*(h)	3 *m* (1 – G_c)
250	1.5 – G *b*(h)	3 *m* (1 – G_c)
500	1.5 – G *c*(h)	3 *m* (1 – G_c)
1000	1.5 – G *d*(h)	3 *m* (1 – G_c)
2000	1.5 (1 – G)	3 *m* (1 – G_c)
4000	1.5 (1 – G)	3 *m* (1 – G_c)
8000	1.5 (1 – G)	3 *m* (1 – G_c)

$a(h) = 1.5 + 3.0\, e^{-0.12\cdot(h-5)\wedge 2}\, [1 - e^{-d/50}] + 5.7\, e^{-0.09\cdot h\wedge 2}\, [1 - e^{-2.8\cdot 10\wedge(-6)\cdot d\wedge 2}]$

$b(h) = 1.5 + 8.6\, e^{-0.09\cdot h\wedge 2}\, [1 - e^{-d/50}]$

$c(h) = 1.5 + 14.0\, e^{-0.46\cdot h\wedge 2}\, [1 - e^{-d/50}]$

$d(h) = 1.5 + 5.0\, e^{-0.9\cdot h\wedge 2}\, [1 - e^{-d/50}]$

m = 0 when $d \le 30$ (hs + h_i)

$m = 1 - 30\,(h_s + h_i)/d$ when $d > 30\,(h_s + h_i)$

if m < 0: m is set equal to zero

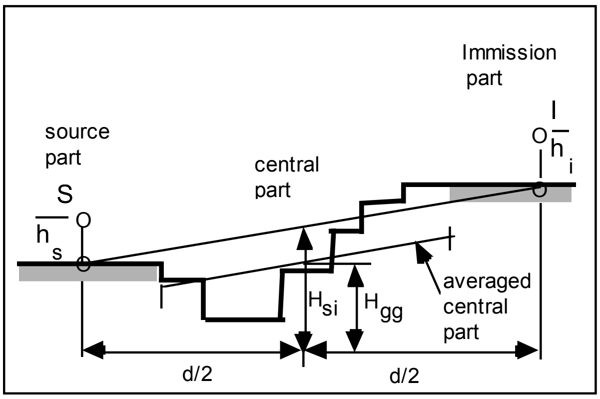

Figure 10. Central part of varying height.

Symbols in Chapter 6:

G	Ground factor (Table 2)	[0,1]
H_{gg}	Average height of central ground part above reference plane	(m)
H_{si}	Average height of source and immission ground part above reference plane	(m)
a(h)	Parameter (Table 3)	
b(h)	Parameter (Table 3)	
c(h)	Parameter (Table 3)	
d(h)	Parameter (Table 3)	
d	Horizontal distance source - immission point	(m)
d_i	Immission point part of d	(m)
d_s	Source part of d	(m)
d_{s1}	Horizontal distance between the source and the nearest screen included in the screen correction	(m)
d_{s2}	Horizontal distance between the immission point and the nearest screen included in the screen correction	(m)
h	Height above ground of source or immission point (Table 3)	(m)
h_e	Effective screen height	(m)
h_{e1}	Effective height of screen no.1 (see d_{s1})	(m)
h_{e2}	Effective height of screen no.2 (see d_{s2})	(m)
h_i	Immission point height	(m)
h_{ic}	Corrected immission point height	(m)
h_s	Source height above ground	(m)
h_{sc}	Corrected source height	(m)
m	Parameter (Table 3)	
p	Porous part of the ground	(%)
ΔL_g	Ground correction	(dB)
$\Delta L_{g,c}$	Ground correction, central part	(dB)
$\Delta L_{g,i}$	Ground correction, immission point part	(dB)
$\Delta L_{g,s}$	Ground correction, source part	(dB)

7 VEGETATION, ΔL_v

The vegetation correction ΔL_v is frequency dependent and equal (in 1/1 octave bands) for the muzzle noise and the bullet noise. The correction is different from /2/ due to the influence of time weighting constant (I) on the actual impulse noise signals.

A curved transmission path is considered. The transmission path height above the straight line between the source and the immission point is given by Eq. (17).

If part of the transmission path (d_v) passes through dense vegetation of trees and bushes, a correction ΔL_v should be included according to Eq. (34). In the case of several groups of trees, the transmission paths d_v for all groups are added. The vegetation height should exceed the height of the curved transmission path by 1 m or more, cf Figure 11.

$$\Delta L_v = -d_v\,(4\alpha_v + 5) / 200 \quad (34)$$

If d_v > 200 m, then d_v is set equal to 200 m.

The attenuation coefficient α_v is found in Table 4. (/2/)

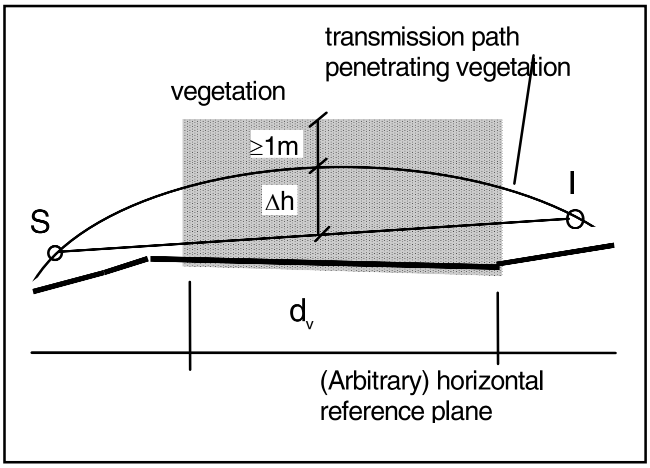

Figure 11. Vegetation geometry.

Table 4. Attenuation coefficient α_v.

1/1 oct. center frequency (Hz)	α_v (dB)
31.5	0
63	0
125	0
250	1
500	1
1000	1
2000	1
4000	2
8000	3

In situations where both screening and vegetation occur, d_v is calculated according to the principle shown in Figure 12, where the source is moved from S to T, and the transmission path from screen top (T) to the immission point (I) is calculated by Eq. (17).

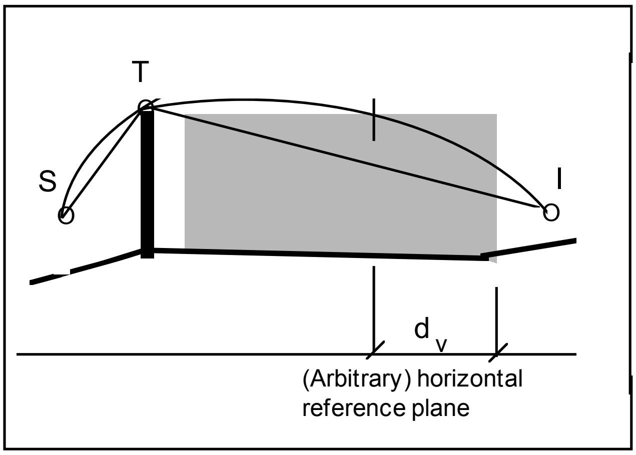

Figure 12. Vegetation in combination with screen.

Symbols in Chapter 7:

I	Immission point	
S	Source position	
T	Top of screen	
d_v	Horizontal projection of (part of) transmission path through vegetation	(m)
ΔL_v	Correction for vegetation	(dB)
Δh	Height of curved sound path above direct line of sight S-I	(m)
α_v	Attenuation coefficient	(dB)

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APPENDIX A. REFLECTIONS, ΔL_r

Due to directivity of weapon noise the reflected contribution may dominate over the direct sound. The same may be the case when the direct sound is screened and the reflected sound is unscreened. Noise contribution(s) from reflected sound may be calculated in an immission point, using Chapters 1 to 7 in the prediction method together with the principles described below.

In the absence of actual acoustical data the reflection correction ΔL_r may be considered frequency independent and equal for the muzzle noise and the bullet noise. The correction is based on /2/ and limited data from /7/. The correction for reflections from a mountainous slope is considered as a rather coarse method.

Calculation of a reflected contribution in an immission point is performed according to step 1–4:

1. The reflections from obstacles and mountainous slopes are treated by simple acoustical mirror principles in the horizontal plane, using straight lines and taking into consideration a reflected sound field scatter of approx. 10°. The height of the top of the reflecting surface above the horizontal reference plane should fulfil at least one the criteria given by Eq. (i) and Eq. (ii), cf Figure 7:

   $H_0 > H_s + d_{r1}/16$ (i)

   $H_0 > H_i + d_{r2}/16$ (ii)

   The principle is illustrated in Figure A1. Reflections may occur within the shaded area. (ie the muzzle noise). For bullet noise care must be taken to ensure that the reflecting surface is within the bullet noise region, cf Figure 2.

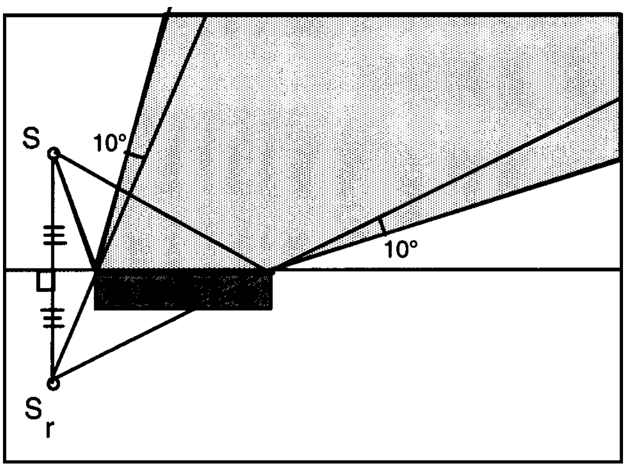

Figure A1. Mirror reflection principle. Geometry. 10° reflection scatter.

2. The reflected sound is considered coming from a mirror source, either a muzzle noise source $S_{M,r}$ or a bullet noise source $S_{B,r}$. The reference noise level is $L_{pl}(\Phi_r,10m)$ or $L_{pl}(S_B,10m)$ respectively. The sound transmission path to be considered is $d_{M,r}$ or $d_{B,r}$ respectively, cf Figures A2 and A3.

   $d_{M,r} = d_{M,r1} + d_{M,r2}$ (Muzzle noise) (iii)

   $d_{B,r} = d_{B,r1} + d_{B,r2}$ (Bullet noise) (iv)

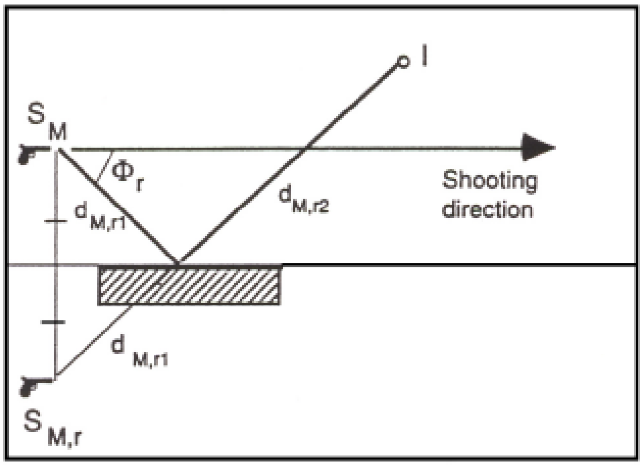

Figure A2. Muzzle noise reflection. Geometry.

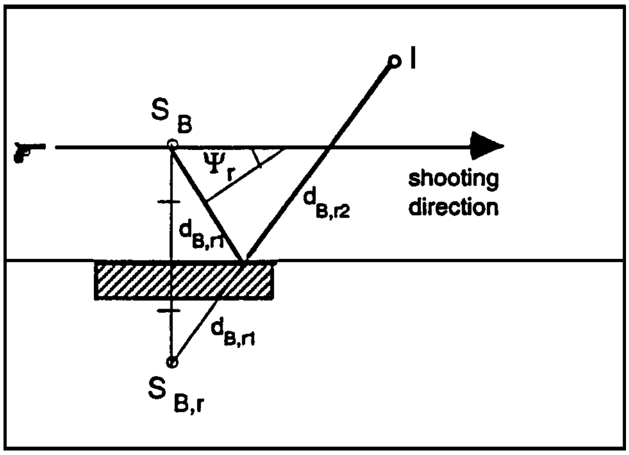

Figure A3. Bullet noise reflection. Geometry.

3. Corrections for shooting halls and firing sheds, distance, screens, the ground, vegetation, are made according to Chapters 3 to 7 in the prediction method.

4. The correction ΔL_r is due to scatter and absorption in the reflecting surface. The reflection coefficient ρ in Eq. (v) may in absence of actual data be taken from Table A1. If acoustical (frequency dependent) data for the reflection coefficient are available, these may be used instead of data from Table A1. Such data shall be documented.

   $\Delta L_r = 10 \lg(\rho)$ (v)

Table A1. Reflection coefficient ρ.

Reflecting surface	ρ
Plane and acoustically hard wall	1.0
Buildings etc. with openings in the order of magnitude of 50% of the wall area	0.4
Building with windows and small irregularities	0.8
Security baffles, hard surface	0.2
Security baffles, absorbing surface, absorption coefficient = α	0.2 $(1-\alpha)$
Dense forest edge	0.025
Partly wood covered mountain slope	0.015

Symbols in Appendix A:

$L_{pI}(\Phi_r,10m)$	Emission 1/1 octave band sound pressure level in direction Φ_r, at 10 m distance from the muzzle. Free field. Time weighting constant I	(dB re 20 µPa)
$L_{pI}(S_B,10m)$	Emission 1/1 octave band sound pressure level at 10 m distance from the bullet noise source point S_B. Free field. Time weighting constant I	(dB re 20 µPa)
S_B	Bullet noise source	
$S_{B,r}$	Bullet noise mirror source	
S_M	Muzzle noise source	
$S_{M,r}$	Muzzle noise mirror source	
$d_{B,r}$	Total length of transmission path for reflected bullet noise	(m)
$d_{B,r1}$	Incident transmission path length for reflected bullet noise	(m)
$d_{B,r2}$	Transmission path length for reflected bullet noise	(m)
$d_{M,r}$	Total length of transmission path for reflected muzzle noise	(m)
$d_{M,r1}$	Incident transmission path length for reflected muzzle noise	(m)
$d_{M,r2}$	Transmission path length for reflected bullet noise	(m)
d_{r1}	Incident transmission path (for both noise sources)	(m)
d_{r2}	Reflected transmission path (for both noise sources)	(m)
H_0	Height of a reflecting obstacle above an arbitrarily chosen horizontal plane	(m)
H_i	Immission point height above an arbitrarily chosen horizontal plane	(m)
H_s	Source height above an arbitrarily chosen horizontal plane	(m)
ΔL_a	Correction for air absorption	(dB)
ΔL_d	Correction for divergence	(dB)
ΔL_g	Correction for ground effect	(dB)
ΔL_h	Correction for shooting hall	(dB)
ΔL_r	Correction for reflection	(dB)
ΔL_s	Correction for screening	(dB)
ΔL_v	Correction for vegetation	(dB)
α	Absorption coefficient	[0,1]
Φ_r	Bullet noise immission direction via reflecting surface	(°)
Ψ_r	Mach angle via reflecting surface	(°)
ρ	Reflection coefficient	[0,1]

APPENDIX B

B1. SHOOTING HALLS AND FIRING SHEDS, DL_h

The correction due to attenuation of firing sheds has been found from different investigations. The main results are summarised in this Appendix to form the background of the estimates which will have to be made to determine the correction for firing shed ΔL_h in each concrete case.

Generally, the measurements have been made at a distance of about 100 m, where the correction was found as the difference between the noise from the weapon (in all cases a military 7.62 mm rifle) fired inside the shed and fired from the open, outside the shed. A negative correction signifies an attenuation from the firing shed, while a positive value means that the noise level is increased (due to reflections, etc).

The following data are shown:

Jægerspris [8]. An experimental firing shed was investigated with two different lengths, where the side walls were 7.3 m and 20.3 m respectively in front of the firing stand. The shed had a highly absorbing roof and somewhat absorbing walls. Two firing stands were used: the least screened (Right) and the most screened (Left). The latter may be regarded as representative of a firing shed with (highly absorbing) inter-line dividing walls between every second firing stand.

Setnesmoen and **Gansrød** [9]. Two different shooting halls with long interlane dividing walls in front of the firing stands, and where the roof continued above (most of) the side walls. In this way shooting took place through long, absorbing ducts. Setnesmoen was a lightweight building whereas Gansrød was made from concrete elements. In both sheds the interior surfaces were covered with absorbing material.

Råvatn [10]. A small shed without interlane walls in front of the firing stands, but with absorbing roof and walls. Results are shown for the nearest (least screened) and the middle stand.

Lv 6 [11]. A shooting hall with interlane walls in front of the firing stands, but without the roof continuing above these walls. Only results expressed as L_{pAI} are shown for this shed, no octave band data were available.

The appearance of the firing sheds is shown in Figure B1, and the main dimensions are given in Table B1.

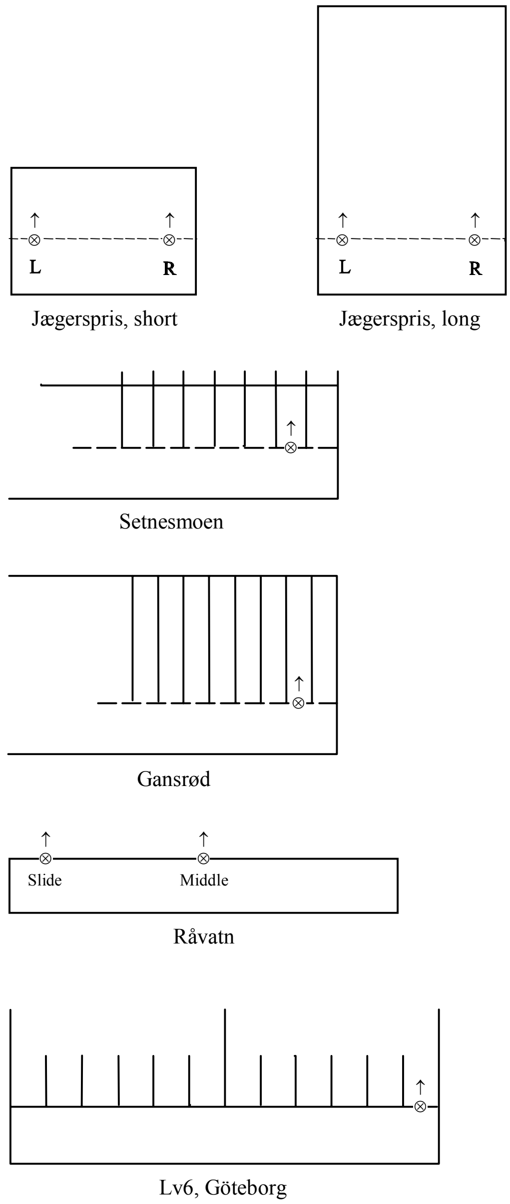

Figure B1. Sketches of the firing sheds; main dimensions appear in Table B1.

Table B1. Main dimensions of firing sheds, where measured corrections appear in Tables B2 and B3. Length <90° describes the length of side walls (or interlane walls) in front of the firing stand. Roof <90° signifies whether the roof continues in front of the firing stand. Height is the height of the shed above the floor, in most cases the firing stand is elevated 0.5 m above the floor. All the sheds had absorbing material on walls and roof. The firing sheds are also illustrated in Figure B1.

	Length <90° m	**Roof <90°**	**Height m**	**Distance to wall m**	**Duct width m**
Jægerspris, short, R	7.3	yes	4.6	12	(16)
Jægerspris, short, L	7.3	yes	4.6	3	(16)
Jægerspris, long, R	20.3	yes	4.6	12	(16)
Jægerspris, long, L	20.3	yes	4.6	3	(16)
Setnesmoen	7.5	yes	2.4	2	3
Gansrød	12	yes	2.6	1.8	2.5
Råvatn, side	0	no	2.8	1	(38)
Råvatn, mid	0	no	2.8	19	(38)
Lv 6, Göteborg	10	no	2.8	(least screened)	3.3

Estimates of the A-weighted corrections for firing shed ΔL_h are given in Table B2 below, while the detailed 1/1-octave measurement results for the sheds (apart from Lv 6) are shown in Table B3.

Table B2. Correction due to attenuation of firing sheds and shooting halls for $L_{pA,I}$ in dB, measured at approx. 100 m distance. Direction is relative to the direction of shooting. Values in brackets are estimated. The firing sheds are described in Table B1 and Figure B1.

	15°	**30°**	**45°**	**60°**	**75°**	**90°**	**105°**	**135°**	**180°**
Jægerspris, short, L	–4	–10	–14			–14			–25
Jægerspris, short, R	–1	–1	+2			–8			–20
Jægerspris, long, L	(–6)	(–10)	(–17)		–25	–27			–22
Jægerspris, long, R	(+10)	(+7)	(–11)		–24	–24			–23
Gansrød		–11		–14		–19		–26	
Setnesmoen	–4	–10	–8	–14	–13	–15			
Råvatn, mid pos.	(0)	(0)	(0)	(0)	(0)	–18	–19	–16	–19
Råvatn, side pos.	(0)	(0)	(0)	(0)	(0)	–4	–5	–11	–16
Lv 6, Göteborg	–2		(–1)	–3		–16		–15	–15

Table B3. Measured correction due to attenuation of firing sheds [dB]. Difference between noise level (in octave bands, time weighting impulse) from a rifle in a screened position inside the shed and in an unscreened position outside the shed; average values of 10 shots.

Octave band, Hz	63	125	250	500	1000	2000	4000	8000	A-tot
Jægerspris, Short shed, closed absorbing roof									
15° R	–4.4	–4.8	+0.5	+4.2	–2.5	–1.0	+0.7	+1.8	–0.6
15° L	–4.2	–7.4	–8.2	–1.0	–5.3	–2.5	–0.5	–0.8	–3.5
30° R	–2.2	–3.7	–1.9	+2.3	–2.6	–1.6	+0.5	–3.5	–1.2
30° L	–5.0	–8.7	–5.7	–4.7	–11.1	–13.8	–11.6	–16.0	–10.0
45° R	–1.2	–4.5	–4.1	+1.1	+5.0	+2.8	+4.1	+1.5	+2.1
45° L	–6.9	–9.7	–12.7	–12.2	–12.3	–16.4	–14.8	–17.3	–13.9
90° R	–13.3	–15.3	–13.8	–4.6	–7.8	–8.1	–7.8	–10.6	–7.5
90° L	–8.2	–15.6	–14.8	–15.9	–13.9	–10.0	–10.7	–11.4	–14.1
180° R	–6.6	–6.5	–7.0	–14.7	–23.2	–21.2	–21.7	–20.9	–20.1
180° R, reflex	–12.5	–12.5	+3.4	–4.2	–14.6	–15.4	–16.0	–17.3	–11.3
180° L	–8.4	–14.7	–14.2	–21.4	–26.8	–23.8	–26.3	–27.6	–24.9
180° L, reflex	–7.8	–8.7	+0.1	–5.2	–16.7	–17.1	–17.6	–18.3	–13.3
Jægerspris, Long shed, closed roof with baffles									
75° R	–15.5	–14.7	–17.3	–20.4	–25.3	–27.1	–26.2	–27.5	–24.0
75° L	–11.4	–13.9	–17.4	–25.5	–25.3	–25.0	–24.3	–27.8	–24.9
90° R	–12.8	–14.9	–17.1	–25.2	–28.0	–25.7	–30.4	–38.1	–26.9
90° L	–10.7	–11.7	–11.9	–22.6	–26.3	–22.6	–28.2	–34.9	–24.2
180° R	–9.7	–15.2	–8.3	–20.0	–23.2	–23.6	–20.0	–23.5	–21.9
180° L	–11.4	–15.1	–13.2	–23.2	–22.7	–22.0	–23.8	–24.9	–22.6
Gansrød – heavy building									
0°	+6.5	–7.3	–8.8	–2.6	+2.6	+0.1	+1.0	–0.6	–0.3
30°	+2.1	+0.1	–16.1	–17.0	–14.0	–5.3	–3.0	–4.3	–10.6
60°	–2.0	–21.2	–23.6	–23.3	–14.1	–13.0	–8.9	–9.5	–13.8
90°	+9.9	–12.3	–21.5	–28.9	–22.5	–17.2	–11.3	–16.3	–18.5
135°	–0.2	–25.7	–13.9	–30.2	–33.0	–36.4	–31.1	–31.2	–25.9
Setnesmoen – lightweight building									
0°	+3.1	+0.2	–4.7	–6.4	–7.3	–1.9	–5.1	–10.1	–5.8
15°	–0.1	–2.8	–17.2	–6.9	–1.3	+0.7	+1.2	+0.5	–3.5
30°	–1.1	–0.1	–13.8	–11.3	–12.8	–6.6	–6.0	–7.8	–10.2
45°	–0.3	–10.1	–14.9	–8.5	–8.2	–5.4	–4.0	–4.3	–7.6
60°	–25.7	–16.2	–17.7	–17.4	–16.4	–12.1	–9.3	–11.7	–14.6
75°	–23.7	–22.3	–28.3	–16.0	–13.4	–12.5	–11.1	–13.9	–13.4
90°	–21.9	–12.3	–26.1	–18.3	–17.0	–14.2	–6.1	–15.5	–15.4
Råvatn, shed without front walls									
90° gr. side	–3.2	–3.6	–6.4	–5.3	–2.7	–5.4	–6.2	–3.2	–4.2
90° gr. mid	–6.4	–10.3	–17.8	–26.7	–21.0	–13.1	–13.7	–15.1	–18.4
105° gr. side	–10.0	–2.4	–8.7	–2.9	–5.8	–7.9	–9.9	–9.0	–5.3
105° gr. mid	–3.8	–2.1	–9.4	–19.3	–20.5	–19.5	–22.0	–24.1	–19.1
120° gr. side	+2.7	–1.8	–7.0	–2.7	–6.3	–8.9	–10.3	–12.4	–6.5
120° gr. mid	+0.8	–1.3	–6.7	–16.3	–19.1	–22.0	–25.7	–28.2	–18.8
135° gr. side	+13.0	–1.7	–1.9	–10.0	–10.1	–14.3	–13.6	–12.9	–11.3
135° gr. mid	+5.1	–0.5	–5.3	–13.3	–18.5	–17.5	–23.1	–26.1	–16.1
180° gr. side	–0.1	–0.4	–13.1	–15.0	–13.9	–21.7	–16.8	–16.1	–16.2
180° gr. mid	–5.2	–7.8	–14.6	–18.6	–19.9	–21.9	–20.0	–19.6	–19.3

B2. SHOOTING HALLS AND FIRING SHEDS, ΔL_h

The correction due to attenuation of a standard firing shed with extensions of 3 m and 5 m has been investigated at Dalgas Shooting Centre. The firing shed is made of 22 mm plywood with sound absorbing material on the walls and the ceiling. The roof is typically made of corrugated sheets of asbestos cement. The sides and the roof of the extension of the firing shed are made of 22 mm plywood with absorbing material; alternatively the roof can be made of corrugated sheets of asbestos cement. The absorbing material has an absorption coefficient of approx. 0.85 in the frequency range from 500 Hz to 2000 Hz. The distance between separations is 1.2 m.

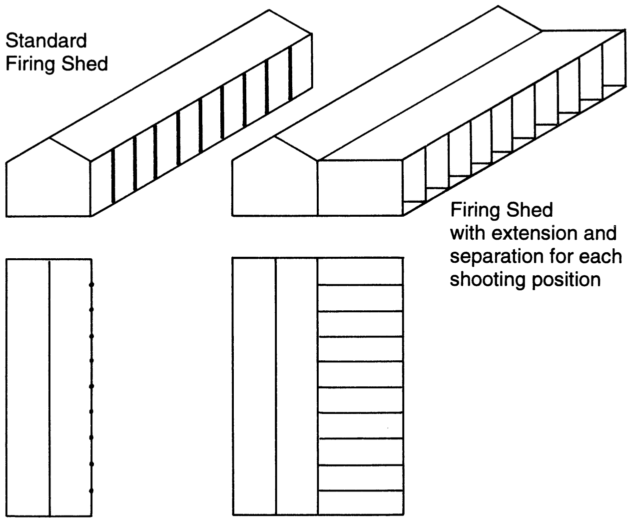

Figure B2. Sketches of the firing shed; main dimensions appear in Table B4.

Table B4. Main dimensions of the firing shed, where measured corrections appear in Table B5 and B6. Length <90° describes the length of the side walls (or interlane walls) in front of the firing stand. Roof <90° signifies whether the roof continues in front of the firing stand. Height is the height of the shed above the floor, in most cases the firing stand is elevated 0.5 m above the floor. The shed has absorbing material on walls and ceiling. The firing shed is illustrated in Figure B2.

	Length <90°	**Roof<90°**	**Height m**	**Distance to wall m**	**Duct width m**
Dalgas 5 m	5	yes	2.4	0.6	1.2
Dalgas 3 m	3	yes	2.4	0.6	1.2

Estimates of the A-weighted corrections for firing sheds ΔL_h are given in Table B5 below, while detailed 1/1-octave measurement results for the sheds are shown in Table B6.

Table B5. Correction due to attenuation of firing shed with extension for $L_{pA,I}$ in dB, measured at distances from approx. 70 m (135°, 180°), 300 m (20°–80°) and 1000 m (0°). Direction is relative to the direction of shooting. Values in brackets are estimated. The weapon used for the measurements was a Sauer 6.5 mm rifle. The firing shed is described in Table B4 and Figure B2.

	0°	**20°**	**40°**	**80°**	**135°**	**180°**
Dalgas 5 m	–5	–6	–12	–15	–24	–21
Dalgas 3 m	(0)	–6	–4	–9	–19	–19

Table B6. Measured correction due to attenuation of firing sheds [dB]. Difference between noise level (in octave bands, time weighting impulse) from a rifle in a screened position inside the shed and in an unscreened position outside the shed.

Octave band, Hz	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**A-tot**
Dalgas 5 m extension									
0º	0.4	–2.3	–9.1	–8.7	–1.8	–1.2	0.4	8.3	–4.5
20º	1.0	0.2	–12.5	–5.0	–7.3	–5.7	–4.9	–5.3	–6.3
40º	3.4	1.8	–15.5	–12.7	–12.1	–11.1	–10.4	–13.6	–12.0
80º	–1.8	–4.5	–9.5	–16.8	–19.1	–10.9	–9.2	–4.7	–15.1
135º	–8.7	–3.3	–6.0	–25.1	–23.6	–32.3	–35.9	–34.2	–23.7
180º	–32.3	–24.0	–21.4	–18.5	–19.4	–24.5	–29.9	–32.7	–20.8
Dalgas 3 m extension									
0º	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20º	1.1	0.4	–7.2	–6.5	–6.1	–5.1	–4.4	–5.4	–5.8
40º	2.7	0.3	–5.6	–6.3	–2.0	–5.1	–5.3	–7.6	–3.9
80º	0.7	–4.6	–2.2	–9.9	–9.8	–7.8	–6.8	–5.3	–9.0
135º	–6.9	–6.4	–6.2	–15.4	–20.3	–25.5	–27.5	–28.3	–19.1
180º	–22.7	–18.1	–11.6	–18.8	–18.4	–23.4	–28.0	–28.3	–19.1

APPENDIX C. MEASUREMENT OF REFERENCE NOISE LEVEL, $L_{pl(\Phi,10m)}$

To obtain data on noise emission from small-bore weapons, to be used together with the Nordic prediction method for noise from shooting ranges, a number of measurement conditions must be fulfilled. The necessary specifications for layout of the emission measurement, signal analysis, and data treatment have not yet been given in sufficient detail to allow reproducible measurements to be made. This appendix is an attempt to specify the conditions that experience has shown to be most important for the measurement results.

The measurement method is adapted to the revised version of the Nordic prediction method for noise from shooting ranges. Thus, no method for determination of "spectrum class", which is a necessary parameter for the original dB(A) version of the Nordic prediction method for noise from shooting ranges [1], is included.

1. **The measurement site** must be level and free of reflecting obstacles. Reflecting obstacles causing a total (reflected) path length in excess of 20 m may be disregarded in this connection.
2. **The weapon** must be fixed with horizontal shooting direction at 1.5 m height above level ground (for shotguns other elevations and heights may be relevant or necessary).
3. **Measurement positions** are arranged 10.0 m from the muzzle in the following directions relative to the shooting direction: 0°; 45°; 90°; 135°; and 180° (range 170°–180° as needed to minimise the influence from the operator). The directions are measured relative to the projection of the trajectory on the ground, whereas the measurement distance is measured as the slant distance from the microphone to the muzzle.
4. **The microphone** is placed on the ground on a reflecting horizontal board (size at least 1.0 m by 1.5 m), more than 0.1 m from any line of symmetry or from the edge. The centre of the microphone shall be less than 7 mm above the board, and it shall be protected by a cut through foam wind screen. The microphone shall be directed so that its axis is perpendicular to the direction to the muzzle.
5. **The measurement equipment** shall conform to IEC 651 type 1**I**, and for the octave band filters (real time analyser) also IEC 225. The linear frequency response shall be linear within ±1 dB in the range 40 Hz – 10 kHz. For the larger calibre weapons it may be relevant to extent the frequency range down to 20 Hz, including the 31.5 Hz octave band. The measurement equipment (in particular the microphone and its preamplifier) shall be suitable for correctly measuring the high sound pressure levels.

   The equipment shall be calibrated by the user for at least one frequency at regular intervals, at least before and after the measurements. During long measurement sessions the calibration shall be repeated at less than 2-hour intervals. The equipment shall be checked regularly and be calibrated with traceability to a national or primary standards laboratory. The maximum time from last traceable calibration shall be:

   - acoustic calibrator (12 months)
   - microphone (24 months)
   - data recording / playback system (24 months)
   - sound level meter (24 months)
   - spectrum analyser (36 months).
6. **The weather** shall be dry, and the wind speed at 2 m height shall be less than 2 m/s.
7. **Measurement results.** The noise level from 10 shots in each measurement position shall be measured and analysed as follows:

   - maximum, unweighted (linear) peak sound pressure level
   - octave band levels from 63 Hz to 8 kHz, unweighted, with time weighting constant I (for larger calibre weapons it may be relevant to analyse the octave band level in the 31.5 Hz octave band as well).

   The bullet noise (and possible reflected sound from obstacles) shall be disregarded. Normally this calls for a gating technique to be used prior to the analysis, or for a (digital) recording of the time/pressure signal, where the signal from the bullet (and from possible reflections) can be removed by editing. Due to fundamental signal analysis, octave band levels with centre frequencies below 250 Hz cannot be measured directly with time weighting constant I, which for a single pulse corresponds well to a linear averaging time of 36.4 ms. Instead a signal can be generated (by use of a gate or an edited version of the time/pressure signal) where the muzzle noise is surrounded by quiet periods to make up a total duration of 200 ms. This integration period is sufficient to obtain reliable results of the 63 Hz octave band level for many types of 1/1-octave filters. The levels analysed in this way shall be corrected to time weighting I by addition of 7.4 dB (10 log 200/36.4), as the duration of the signal is less than 36.4 ms.

   The peak sound pressure level is preferably read from the time/pressure signal, whereby the error due to limited high frequency response of the equipment can be corrected.

   The measurement results from the 10 shots are averaged (on an arithmetic basis). All sound pressure levels are corrected to free field values by subtraction of 6.0 dB.

   From the (free field) peak sound pressure level, a correction for nonlinear sound propagation, ΔL_{unl}, is read from Figure C1. The correction is based on [12]. This correction varies from 0 dB (for $L_{p,peak}$ less than 131 dB) to −6.1 dB (for $L_{p,peak}$ = 165 dB).

   The octave band with the highest (linear) sound pressure level is identified and called f_0. The correction ΔL_{unl} (which is negative) is added to the levels in all octave bands with centre frequency higher than f_0. The level in the octave band containing f_0 is not corrected, and the levels in the octave bands with centre frequencies below

f_0 are corrected by **subtraction** of half the correction ΔL_{unl}. In these octave bands the noise levels are increased in order to correct for nonlinear sound propagation.

8. **Report.** In the measurement report the octave band level and the peak level of each shot shall be shown with an explanation of the measurement condition for these (pressure doubling, integration period, etc); the main results are the averaged octave band levels, corrected to time weighting I, corrected to free field, and corrected for nonlinear sound propagation.

   A description shall be given of the way the noise from supersonic bullets (and reflections) has been omitted, and the octave band analysis has been performed. All measurement equipment shall be specified together with the date of the most recent traceable calibration. At least one time/pressure signal from each measurement position shall be shown.

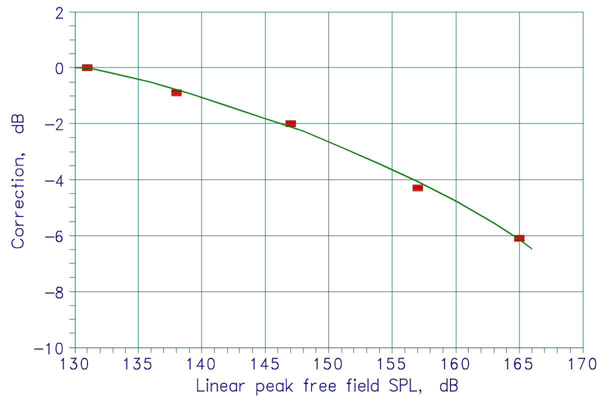

Figure C1. Correction for unlinear sound propagation, ΔL_{unl} in dB, as a function of the linear peak free field sound pressure level, dB re 20 µPa. [12]