inter•noise 96
25th Anniversary Congress – Liverpool
INCE: 76.1.1

RECENT ADVANCES IN THE CONTROL AND PREDICTION OF RIFLE NOISE

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1. INTRODUCTION

In Switzerland many people are subjected to the blast noise stemming from rifle shooting. Most communities have their own outdoor shooting ranges (300 m) which are used for military training as well as sporting purposes. Owing to the high population density in Switzerland, these ranges are often situated quite close to residential communities. Consequently the control and prediction of rifle noise have been a concern here for many years. This paper describes recent advances including a special muffler which reduces the muzzle blast substantially. In the area of noise prediction, an improved technique for calculating the screening effect of the clubhouse is described as well as a new method for assessing reflections caused by forests, based on ray-tracing techniques.

2. THE SOURCES OF RIFLE NOISE

Before discussing noise control methods, it is useful to review the separate sources of rifle noise. Firstly, the weapon firing causes a *muzzle blast* which propagates in all directions but predominantly to the front of the rifle. Secondly, since the standard Swiss rifle is fired with a bullet speed of about twice the speed of sound the bullet produces a *ballistic shock wave*. This is highly directional (a coherent line source) and is hence audible only in a specific region in front of the weapon [1]. Finally, both the muzzle blast and the ballistic shock wave can give rise to reflections, stemming for example from buildings or forests. Depending on the location of the receiver, either the muzzle blast, the ballistic wave or reflections from one or the other of these sources can dominate. Behind the clubhouse the direct sound from the muzzle blast is attenuated considerably. In this region therefore, reflections from objects located *in front of* the clubhouse may become the dominating noise source.

3. MUZZLE BLAST MUFFLER

This section describes the control of noise from the muzzle blast. Military and sporting considerations preclude the use of silencers attached directly to the rifle. Noise control efforts have therefore concentrated on the shielding effect of barriers. Until now, the most effective method has been the erection of multiple barriers, each of 4 m length and situated between pairs of shooting positions. Typically, such barriers yield noise attenuations of approximately 10 to 12 dB(A) in the region to the side of the clubhouse [2]. A considerable improvement has now been achieved through the development of a special muzzle blast muffler. Photos of two muffler models are given in Figures 1 and 2. A third model employs a triangular cross-section. In use, the marksman inserts the rifle approximately 15 cm. into the muffler opening. Depending on the model, the total length ranges from 2 to 2.2 m. In the model with the circular cross-section, the outer diameter is 1 m, for the rectangular model the outer cross-sectional dimensions are 57 cm (width) x 68 cm (height). The inner dimensions (36 x 50 cm for the rectangular model) are large enough so that the marksman can easily see the target area.

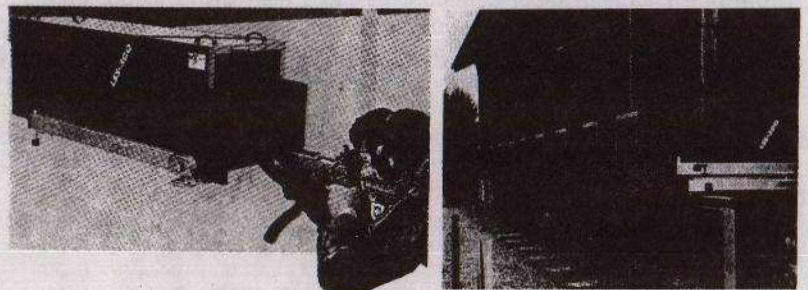


Fig. 1. Muzzle Blast Muffler with rectangular cross-section

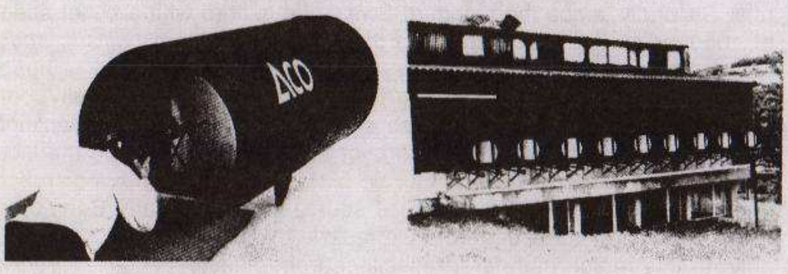


Fig. 2. Muzzle Blast Muffler with circular cross-section

The concept behind these mufflers is straightforward and similar to standard dissipative muffler design. An outer mantle, made of either aluminum or hard plastic provides the necessary transmission loss and an inner lining (fiberglass or mineral wool) covered with a protective layer, the sound absorption. Since the opening is straight and relatively large, the acoustic performance is poorer in the axis of the rifle than to the side. However, this is often unimportant because the region in front of the weapon is subjected anyway to the noise of the ballistic wave. Figure 3 shows the range of attenuation of the muzzle blast achieved by such mufflers. To the side the attenuation amounts to 15 to 20 dB(A) which is clearly better than that provided by multiple barriers. In fact, the mufflers are superior to the barriers at all angles. Since the muffler is closed on the top it also attenuates sound radiating backwards over the roof of the clubhouse toward the rear.

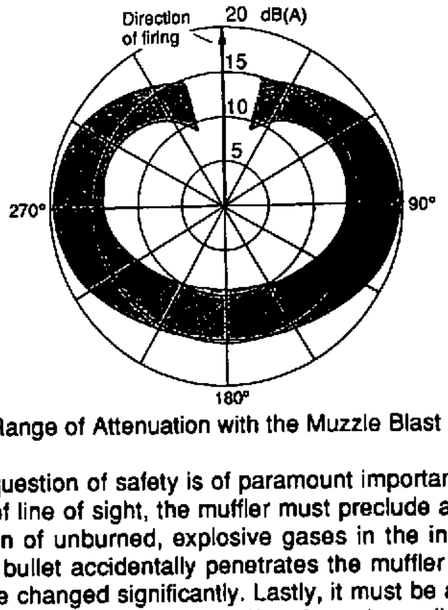


Fig. 3. Range of Attenuation with the Muzzle Blast Muffler

Obviously, the question of safety is of paramount importance. Aside from considerations of line of sight, the muffler must preclude a danger due to the accumulation of unburned, explosive gases in the inner lining. Furthermore, if the bullet accidentally penetrates the muffler wall, the bullet path must not be changed significantly. Lastly, it must be assured that no fragments -- either from the bullet itself or from the wall material -- are hurled backwards to the marksman. Thus, before allowing the mufflers to be marketed, the Swiss Military Department performed extensive investigations. These confirmed the safety of the mufflers for practical use. For more than a year now, the mufflers have been employed in a number of shooting ranges. They have been accepted surprisingly well by the marksmen as they do not detract from the shooting accuracy in any way and in fact improve the lighting conditions (shielding from the sun). The mufflers are normally provided with transport systems so that they can be removed quickly when not in use.

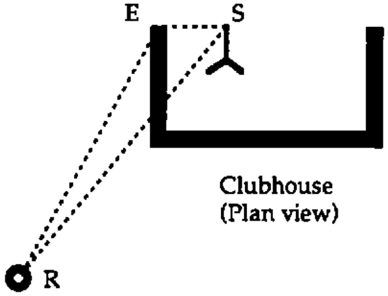
4. SHIELDING EFFECT DUE TO THE CLUBHOUSE

Ignoring the possibility of reflections for the moment, the muzzle blast can reach the region behind the clubhouse in two ways, namely 1) via sound transmission *through* the walls and/or roof and 2) via diffraction i.e. *around* the walls and/or roof. Previously, the Swiss calculation model employed an empirical formula which simply distinguished between solid and lightweight clubhouse structures. However, recent measurements on different clubhouses have shown that in most cases diffraction is more important than sound transmission. As a rule of thumb, if the sound transmission class (STC) of the walls and roof exceed 35 dB, then the sound transmission through the structure may be neglected.

Satisfactory agreement with measurements (± 3 dB(A)) is achieved if the attenuation of the clubhouse is calculated using the well-known Maekawa formula. Assuming a characteristic frequency of 500 Hz for the A-weighted level of the muzzle blast, the clubhouse attenuation D_c is calculated as:

$$D_c = 10 \log (3 + 59\, w)$$

In this formula, w is the path length difference in meters as illustrated in Fig. 4. It is important to take into account the directional characteristic of the muzzle blast (highest levels to the front, lowest to the rear). The sound impinging on the edge of the clubhouse, i.e. the wall or roof is radiated from an angle of 90° to the rifle axis. Thus, although the receiver is actually located at some arbitrary angle behind the clubhouse, the source strength <u>at 90°</u> must always be utilized in calculating the muzzle blast level after attenuation.



w = RE + ES - SR

w = path length difference
R = receiver
E = diffraction edge
S = source

Fig. 4. Calculation of Shielding due to Clubhouse

In calculating D_c it suffices to consider the single path around the clubhouse leading to the smallest value of w. This is normally the path around the closest side wall, but depending on the location of the receiver, the path over the roof may have to be controlled as well. Furthermore, it is advisable to average the results obtained for several marksman positions since the source postition effects the results considerably.

For receiver locations directly behind the clubhouse, double barrier calculations are required. The appropriate formulas will not be discussed in this paper. It is mentioned, however, that the attenuation then usually exceed 20 dB. Here it is important to assure that reflections from objects located in front of the clubhouse do not limit the effective attenuation.

5. REFLECTIONS FROM FORESTS

As already mentioned reflections become increasingly important when the direct sound is attenuated, for example by means of a muzzle blast muffler or by the clubhouse. For solid objects with plane, vertical faces (buildings, walls, etc.) the mirror-image method is well suited for calculating the reflection. However, in the case of forests, the problem is much more difficult, involving scattering from the individual trees and multiple reflections. In an effort to develop a calculation model, research was undertaken, involving several steps. First, controlled reflection measurements were performed on individual trees and forests. These results were then simulated with a computer ray-tracing program. Finally, the results of the ray-tracing program were approximated in the form of simple algebraic formulas and graphs. The measurements and simulation yielded the following observations:

- In the frequency range up to 2,000 Hz the tree trunks, not the foliage determine the reflections; measurements in winter (without foliage) yielded identical results to those in summer.
- The trees can be modelled as cylinders. For the simulation, trees having diameters of 0.4 m and a spacing of 6.0 m between trees were employed.
- Individual trees scatter the sound uniformly over an angle of ± 90° relative to the angle of the impinging sound. To a first approximation, the absorption of the tree trunks may be neglected.
- Reflections from the muzzle blast and ballistic wave are equally important. However, their contributions depend on the receiver location. Although the ballistic wave is heard only in front of the weapon, forest reflections from the ballistic wave propagate in all directions.
- The depth of the forest plays only a secondary role: A depth of 25 m already produces a "full" reflection.
- The forest reflection broadens the time signal considerably. Compared to a duration of about 1 ms for the direct sound, the reflection is heard for one second or longer.

The detailed results are only of limited general interest as they hold only for the Swiss rifle with its specific acoustical characteristics. Nevertheless, for purposes of illustration, two typical graphs are shown: a) for a forest to the side of the clubhouse and b) for a forest in front of the target area (Figures 5 and 6). In these graphs, the contributions of the muzzle blast and ballistic shock wave reflections have been combined. The direct sound is not shown. In accordance with requirements of Swiss regulations the graphs give the maximum A-weighted level (time constant FAST). In general, the predicted reflection values agree with measurements within 2 to 3 dB.

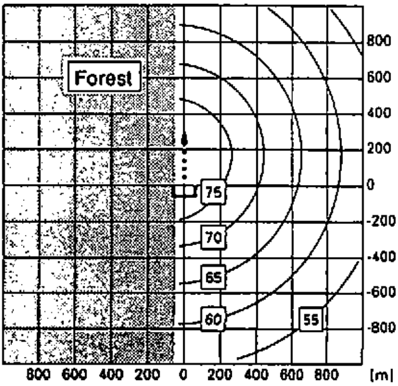


Fig. 5. Reflection from forest (equal level contours in dB(A,FAST))

Forest to the side of the club-house.
Distance from rifle to forest: 50 m

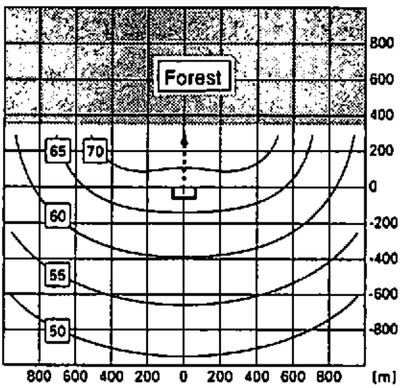


Fig. 6. Reflection from forest (equal level contours in dB(A,FAST))

Forest in front of the target area.
Distance from rifle to forest: 350 m

ACKNOWLEDGMENTS

The authors express their thanks to Markus Strebel and Reto Höin for their assistance in the research program and to Kurt Heutschi for the development of the forest reflection model.

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