Reduction of shooting noise

on

Clay Target Shooting

- AFEMS Multi Task Study -

May 2012
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Executive Summary

Ten years of challenging work and detailed research have been necessary for the Multi Task Project aimed at the best scientific comprehension of the sound emission from firearms, the ballistic of the pellet shot cloud, the breaking process and the hitting probability of the clay targets.

A first important result of the studies, conducted by most renowned acoustic experts, has been the production and the publication of five new ISO standards on impulse sound at shooting ranges. Thanks to this efforts, nowadays sound energy emitted by a shot can now be precisely measured using worldwide standardized parameters.

A further key development was the study of the radial distribution of the pellets in the shot cloud by the most sophisticated technologies. With the help of the latter technology the shot pattern has been analyzed in order to identify the radial position of circa 300 pellets.

Regarding the sound emission it has been found that for muzzle velocities, above 380 m/s, the sound emitted is basically influenced by the projectile sound, whereas around or below 380 m/s the muzzle blast sound is playing the fundamental role.

Another key point was to define how a clay target could be broken by the second shot at Olympic trap shooting, when the pellet velocities fly below 170 m/s at point of impact and the measured breaking velocity of the clay target is at 190 m/s or above. A numerical simulation was possible using the measured shot patterns and the detailed ballistic information of the shooting tables.

The results obtained have demonstrated that the performance are depending by the radial density of the pellets in the shot cloud and that simultaneous hits up to 9 pellets are possible while, on the other hands, with one pellet only the hitting probability is practically inexistent. This finding implied the modification of the breakability test in order to perform it with two and three pellets simultaneously.

The test results showed that to have 95% probability to break a clay target with the second shot at 45 m distance, minimum three simultaneous pellets on the target are requested.

Furthermore, detailed examinations of the radial structure of shooting patterns showed that the radial spread increases with increasing muzzle velocities. This brought to the assumption, based on numerical simulations, that muzzle velocities, somewhat lower, might be better performing at Olympic Trap shooting, and in parallel to have the advantage of emitting less sound energy.
Several field tests have been conducted in a real shooting range by a great number of shooter teams, using different types of ammunition. The results achieved proved that the best balance between shooting performances and emitted sound energy could be obtained using ammunition with muzzle velocity of around 380 m/s (see the detailed ammunition parameters at paragraph 7.5).

The sound emission of ammunition with muzzle velocities of around 380 m/s is lower of about 2.6 dB when compared with ammunition with muzzle velocities of around 420 m/s.

When using ammunition with muzzle velocity of 380 m/s, shooting ranges could fire circa 60% more shots in order to reach the same rate of sound levels, and having in parallel higher score probabilities.

1. Introduction

Clay target shooting has a long tradition going back to the 19th century and is an Olympic discipline. This sport is mainly performed outdoors. Frequently, the distance from the shooting range to the nearest neighbourhood, where people are living, is less than 2 km. This means that every shot could be heard by people being outdoors or indoors with open or partly open windows depending on the meteorological situation and noise from other sources such as road, rail or air traffic or industrial noise. Different from those latter sources shooting noise is always impulsive, which means that due to the shot the sound level increases within a few milliseconds by 30 or 40 dB depending on the given situation. Compared on the basis of energy equivalent averaged levels, which are usually used for noise assessment shooting noise is far more annoying due to this impulsiveness compared to similar equivalent levels produced by other sources. This fact has led to different approaches for the assessment of shooting noise in relation to other sources, which varies considerably from country to country. In Germany the maximum value of each shot using time weighting “FAST” is assumed to last 5 seconds instead of the 125 ms, whereas in Denmark the maximum level of the loudest shot is used for the assessment alone independent of the number of shots. In Switzerland a uniform addition is applied to express the impulsiveness. Basically, the regulations for the assessment of the environmental sound produced in the neighbourhood are different and a uniform international approach or within the European Union is very unlikely at present. Therefore the question of assessment of shooting noise is not a part of this report, which will concentrate on the sound emission produced by shot guns used for clay target shooting and how it may be reduced.
The muzzle blast is produced by the hot powder gas of the propellant when leaving the muzzle at supersonic velocity radiating sound from its surface when reaching the velocity of sound. The projectile noise is produced by the pellets in the shot cloud when moving with supersonic velocity. This part is included in the muzzle blast for shot guns, due to the fact that when leaving the muzzle the velocity of the shot cloud drops quickly over a very short range below the sound speed of the surrounding air. This report will aim to describe possible reduction of the sound energy emitted by these non stationary processes into the ambient air.

Certainly, a number of mitigation measures can be used, to reduce the noise from shooting ranges such as walls, berms and similar constructions to shield the sound emitted from the shots, when travelling in the direction of the sensitive neighbourhood. However, to estimate the effects of noise shielding, it is necessary to describe the sound emission of these non stationary shooting events, which differs from the sound emission of stationary sources (industrial, aircrafts, trains or motor vehicles). The latter sources are considered to emit the sound continuously over a specific period of time. The sound emission is expressed in these cases by the sound power in Watt or by decadal logarithm of this in relation to 10⁻¹² Watt in decibel. Exactly this continuity can not be assumed for a shot. To circumvent this problem, different approaches were used in the past such as to measure at a specific distance the maximum level with a time weighting of 1 s (slow) or 125 ms (fast) or using the impulse weighting of 35 ms. An example of this approach can be found in [2.1] chapter 9, where all references are given. The first number refers to the chapter number (here 2) and the second to the paper in this subchapter.

Due to the fact that these methods do not allow to characterize the sound emission of non stationary sources and their directivities a new and international accepted approach was needed to achieve a description of those sources in accordance with the state of the art. AFEMS the European Manufacturers of Sporting Ammunition an international non governmental organisation asked CEN (European Committee for Standardization) to draw up a standard for the measurement and prognosis of noise from shooting ranges. CEN has asked ISO (International Standard Organisation) to take up this task in 1995. Up till now, the standardization process has been finalized and produced five standards [7.1 to 7.5].

The most important step for the standardization of the measurement of the muzzle blast has been done in ISO 17201 Part 1 [7.1]:

Acoustics — Noise from shooting ranges —
Part 1: Determination of muzzle blast by measurement,
which is an ISO standard since 2005, by introducing the sound energy to describe the muzzle blast, which is expressed in Joule. This means that theoretically the sound is measured over a finite time period, which is long enough to enclose the total sound energy emitted in all directions. The available standard can be applied for small fire arms as well as for weapons using up to 20 g or explosive TNT equivalent, which is sufficient for all civil shooting ranges. Basically, the same method is also applicable for more heavy weapons. This standard includes the measurement of the directivity of the muzzle blast, which is very important for the prognosis of the sound in the neighbourhood. This standard does not include the measurement of the sound energy emitted by the projectile sound. This is covered in 17201 part 4 [7.4]:

**Acoustics — Noise from shooting ranges —**

**Part 4: Prediction of projectile sound,**

which deals solely with the projectile sound. For the prognosis of the noise resulting from a specific shooting range acoustic data are usually only available for few weapon ammunition combinations. Therefore, a standard was needed, which allows to estimate the sound energy of the muzzle blast as well as its directivity and the projectile sound from data such as propellant mass, barrel length etc. This is covered by ISO 17201-2 [7.2]:

**Acoustics — Noise from shooting ranges —**

**Part 2: Estimation of muzzle blast and projectile sound by calculation,**

which has been finalized in 2009 and allows to include unmeasured weapons and ammunition combinations in a prognosis.

When the sound energy is known and the directivity, a standard is needed to explain how the ISO standard 9613-2 [8.1] on sound propagation outdoors can be applied on shooting sound and how the different time weightings can be in cooperated. This standard ISO 17201-3 [7.3]:

**Acoustics — Noise from shooting ranges —**

**Part 3: Guidelines for sound propagation calculations**

is available since 2010. Furthermore, the management of a shooting range in view of the sound immission in the neighbourhood is important to avoid transgression of legal limits on a day to day basis. This is dealt with in ISO 17201-5 [7.5]:

**Acoustics — Noise from shooting ranges —**

**Part 5: Noise management.**
The noise management is based on either calculated or measured shooting sound immission of the different parts of a shooting range depending on the activities and usage of the different parts.

The basic structure of the five standards was known by 2000 and has led to the question whether or not it might be possible to reduce the sound emission of clay target shooting. From 17201-2 [7.2] it was obvious that, a reduction of the propellant mass would reduce the sound energy emitted. On the other hand, it was reasonable to assume that an increase in the propellant mass would increase the force by which the pellets hit the clay target and break it and therefore increase the success rate of the shooter especially for the second shot, where the clay target moves at greater distances. It is also obvious, that a faster moving shot cloud will hit the target at a shorter distance compared to a shot with a slower moving shot cloud.

A higher velocity at the muzzle means a higher pressure in the barrel resulting not only into higher velocity in the shooting direction, but also in a higher radial velocity of the shot cloud reducing the pellets density at the centre and as a consequence of this the hitting probability. From this consideration it seems possible that there might exist an optimum in relation to the propellant energy and the hitting probability.

On the other hand, a reduction of the muzzle blast sound and projectile sound energy by 3 dB would mean that the number of shots can be doubled producing the same rating level for the shooting range at any position in the neighbourhood independent of the rating processes applied by different countries.

In view of this, it seemed worthwhile to study the whole process in more details. For this purpose, AFEMS decided in 2001 to set up a Multi Task Study Group to do the research to clarify the question whether or not a reduction of the propellant energy producing a lower muzzle velocity can be recommended without reducing the shooting performance. The name of the group derived from the fact that special knowledge was needed on items such as ballistics of the shot cloud, ballistics for the clay target, behaviour and mechanical stability of the flying and rotating clay target when being hit and of course in acoustics.

These different tasks will be dealt with in the following chapters separately. Chapter 2 will explain the measurement methods for the sound energy and the results from different weapon and ammunition combinations including how the different radiation processes can be visualized. To use this knowledge on acoustics, one has to understand how trap shooting is performed, the ballistic behaviour of the shot cloud and clay target (chapter 3), which allows to calculate the distances, where hitting may be expected (chapter 4) and the relative velocity of the pellets to the clay targets.
A total separate item is the description of the breakability of the clay target, which depends on its mechanical stability during the flight when hit in relation to the laboratory test methods and its statistical description (chapter 5). This leads directly to the question of the distribution of the pellets in the shot cloud, which can be estimated from shot pattern measured using paper sheets (chapter 6) and the possible shape of the clay target exposed to the shot cloud, which allows to simulate numerically the impact of the flying pellets on the flying and rotating clay target on a realistic basis allowing to estimate the performance of a shooter under real conditions. This has led to perform field tests, whether or not the simulation results are realistic (chapter 7).

The final chapter deals with the results of three field tests, where different teams of top shooters tested ammunition with different muzzle velocities and two brands of clay targets. After testing the statistical success rates of the teams have been calculated. From these results recommendations will be formulated for possible noise reduction (chapter 8) and conclusions drawn.

**Remark:**
The whole report is based on the references given in chapter 9. The references are organized according to different tasks from 1 to 7 and after the dot the specific report. Not all reports are referenced in the text, but are given to be used for additional research. General references to other texts are given starting with number 8.

### 2. Sound energy

For technical application a source is usually characterized by its sound power, which describes the sound energy being continuously emitted from sources per second. To obtain this quantity, the equivalent levels $L_{eq}$ at a certain distance $r_m$ over a sufficient long time, $T$, has to be measured:

$$L_{eq}(r_m) = 10 \log \left( \frac{1}{T} \int_0^T \frac{p^2(t')}{p_0^2} dt \right)$$  \hspace{1cm} (2.1)

with $p_0 = 2 \cdot 10^{-5}$ Pa. In most cases it can safely be assumed that the source has no or only a minor directivity and the sound power level is obtained:

$$L_p = L_{eq} + 10 \log \left( 4\pi \frac{r_m^2}{r_o^2} \right) = 10 \log \frac{S_p}{S_0}$$  \hspace{1cm} (2.2)

where $r_o = 1$ m, $S_p$ the sound power and $S_0 = 10^{-12}$ W.
The muzzle blast is a discontinuously emitting source, which cannot be described by a continuous sound power but by its total emitted sound energy, which means that one has to integrate over the time period $T$ of the whole event to obtain the sound exposure level:

\[(2.3) \quad L_{E}(r_m) = 10 \log\left(\frac{1}{\rho_0^2} \int_{t_0}^{T} \frac{p^2(t)}{\rho_0^2} \, dt\right),\]

where $p_0$ is the reference sound pressure of 20 $\mu$Pa and $t_0$ equals 1 s. If the source has no directivity, the sound source energy level is obtained by:

\[(2.4) \quad L_Q = L_E + 10 \log(4\pi * r_m^2 / r_o^2) = 10 \log(Q / Q_o),\]

where $Q$ is the emitted sound energy and $Q_o = 10^{-12}$ J. However, shooting sound is emitted with a very high directivity, which has to be in-cooperated into the measurement procedure.

### 2.1 Measurement method of the sound energy

In the introduction of ISO 17201-1 [7.1] it is noted that reliable data for the prediction of shooting sound levels at a reception site can only be achieved, if the emitted sound energy of the muzzle blast and its directivity known. The muzzle blast is produced by the propellant gas expelled from the barrel with supersonic fluid velocity; with the increasing volume of the propellant gas the surface velocity is reduced until the pressure reaches the value of the surrounding air. The sound radiated from the surface of this gas bubble can only move with the sonic velocity of the surrounding air. Therefore, measurable sound travelling into the surrounding occurs, when the surface velocity reaches sonic velocity [8.4].

Furthermore, due to the fact that the propellant cloud is not spherical and moves with an overall average velocity, the radiation of the sound energy is not spherical, showing a high frequency depending directivity. Therefore, one has to measure in all directions $\alpha$ at a distance $r_m$, which deviate from the line of fire (see Fig. 2.1.1) at a height above ground $h_m$, which is usually chosen to be identical, for the muzzle and the microphone. If the gun is fired more than 0.5 m above ground, it can safely be assumed that the directivity is rotational symmetric with respect to the line of fire (angle $\beta$ as depicted in Fig. 2.1.1).
Instead of the energy equivalent level $L_{eq}$ the sound exposure level $L_E$ is measured depending on angle $\alpha$:

$$L_E(r_m, \alpha) = 10 \log \left( \int_0^T \frac{p^2(r_m, \alpha, t) dt}{p_0^2 t_0} \right)$$

with $t_0 = 1$ s and $p(r_m, \alpha, t)$ the sound pressure at position $r_m, \alpha$ as a function of time.

The integration is taken over the time span $T$ to include the complete time history of the muzzle blast at $(r_m, \alpha)$. The term exposure relates to the fact that the event is uniformly related to $T_0 = 1$ s. Depending on the distance $r_m, T$ might be a few milliseconds or a few seconds due to reflexions, scattering etc. To obtain the sound energy, distances of less than 50 m are chosen, which means that not only the sound directly travelling from the muzzle is measured, but also frequency dependent reflections from the ground.

The angular source energy distribution level $L_q(\alpha)$ independent from ground reflections is given by:

$$L_q(\alpha_m) = L_E(r_m, \alpha_m) + 10 \log \frac{r_m^2}{r_0^2} + A_{gr} - 11 + A_z$$

with $r_0 = 1$ m. $A_{gr}$ is a frequency depended correction due to ground reflection and $A_z$ a correction for standard meteorological conditions. Due to the fact that the measurements are taken at
distances up to 50 m from the muzzle, air absorption and meteorological effects can well be neglected.

Furthermore, it should be noted, when measuring rifles, the velocity of the projectile is well above 500 m/s. This means that the first part of the signal observed at the microphone positioned in the shooting direction results from the projectile sound. This part of the signal can be removed using the time delay to the muzzle blast sound. For shot guns the muzzle velocity of the shot cloud at 0.5 m distance from the muzzle is usually less than 440 m/s and reduces to velocities lower than the speed of sound at a distance of less than 12 m. This part of the signal can not be eliminated due to the fact that the time delay is too small. Therefore, this projectile sound is included in the muzzle sound. However, this may lead to a shift of centre of the blast and its sound energy from the muzzle up to a distance between 1 and 2 m in front of the muzzle, which has to be included in the estimation of the sound energy.

$A_z$ is a correction to transform $L_q(\alpha)$ to standard meteorological conditions:

\begin{equation}
A_z = -10 \lg \left( \frac{B \cdot aT_k}{B_0 \cdot aT_{k0}} \right),
\end{equation}

where $B$ is the air pressure and $T_k$ the absolute temperature in K under the measurement conditions. The reference pressure $B_0 = 1013$ hPa and $T_{k0} = 296$ K. $A_z$ is important when measurements are done 1000 m above sea level or measurements performed close to sea level are applied to a shooting range at 1000 m height.

The last factor $A_{gr}$ describes the effect of ground reflection depending on the ground above which the measurements are performed. Usually one can assume that the measurements are performed above hard ground, where according to Wempen [8.2] the flow resistance of the ground and the spherical nature of the source have been accounted for leading to corrections, which are for a ground with grass cover for a distance of 10 m and a source and reception height of 1.5 m:

\begin{table}[h]
\begin{tabular}{cccccccccc}
Frequency & 31.5 & 63  & 125 & 250 & 500 & 1k  & 2k  & 4k  & 8k  & Hz  \\
$A_{gr}$  & -5.6 & -4.9 & -2.6 & 4.3 & -1.7 & -0.4 & -0.4 & -0.6 & -1.7 & dB \\
\end{tabular}
\caption{Ground correction source at 1.5 m and reception point 1.5 m at 10 m distance}
\end{table}

Flow resistance 100 kP·s/m²

The negative sign means that the level has to be reduced to account for the reflection of the ground. The positive sign for the correction of 4.3 dB in the 250 Hz octave means that the reflected and direct waves partly cancel each other in this frequency region. For hard ground this range
shifts to 400 Hz. If the measurements are taken over other ground types, the values given above have to be changed accordingly \[8.5\].

With the above correction one obtains the angular source energy distribution level for \( L_q(\alpha) \) for different angels, \( \alpha \), usually equally separated by at least 30° from \( \alpha = 0° \) to \( \alpha = 180° \).

The angular source energy distribution level \( \overline{L_q(\alpha)} \), which is a continuous function of angle \( \alpha \), is obtained by:

\[
(2.1.4) \quad \overline{L_q(\alpha)} = a_0 + \sum_{j=1}^{N-1} a_j \cdot \cos(j \cdot \alpha),
\]

where \( N \) is the number of angles, for which \( L_q(\alpha) \) has been measured. The process obtaining the \( a_j \) may be chosen by different methods such as least square fit, fourier transform, splining or any other approximation method.

The sound source energy of the muzzle blast is obtained by integrating over the angle \( \alpha \) and \( \beta \). Due to the fact that the ground reflection has been removed, \( \overline{L_q(\alpha)} \) is independent in \( \beta \) and one obtains the source energy level \( L_Q \):

\[
(2.1.5) \quad L_Q = 10 \log(\frac{1}{\pi} \int_{0}^{\alpha/2} 10^{\alpha/10} \overline{L_q(\alpha)} \cdot \sin \alpha \cdot d\alpha) + 8 \text{ dB},
\]

which describes the emitted sound energy as a level relative to \( Q_0 = 10^{-12} \text{ J} \).

The directivity is obtained by:

\[
(2.1.6) \quad D(\alpha) = \overline{L_q(\alpha)} - (L_Q - 11) \text{ dB},
\]

where the factor 8 in eq. 2.1.5 results from \( 10 \log(2\pi) \) and 11 in eq. 2.1.6 from \( 10 \log(4\pi) \).

The complexity of determining the sound source energy of the muzzle blast including the ground correction and its directivity is an indication why simple standardization efforts in the past were not successful.
2.2 Measurement results

The measurements by deBAKOM [2.2] of the muzzle blast were also a test for the ISO standard 17201-1 [7.1]. The measurements used ammunition loaded according to the specification given in the memorandum [1.6] from Beretta Holding, Fiocchi, STAS and BNP. The specification was aiming for ammunition with a muzzle velocity (measured 0.5 m in front of the muzzle) of

- 420 m/s
- 400 m/s
- 380 m/s
- 360 m/s

to be shot using different weapons, two with a barrel length of 670 mm and two with 720 mm and a cylindric muzzle (CYL) and a full choked muzzle (FCH). In the following table the actual muzzle velocities as measured at the Italian Proof House [8.3] are given:

<table>
<thead>
<tr>
<th>Ammunition Barrel</th>
<th>Muzzle velocity m/s</th>
<th>Distance where 340 m/s is reached in m 3 d order regression</th>
<th>Ø in 3.50 m dm</th>
<th>Time delay ms</th>
<th>Source position M</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1W71 FCH</td>
<td>435</td>
<td>13.2</td>
<td>0.50</td>
<td>4</td>
<td>3.2</td>
</tr>
<tr>
<td>G1W71 CYL</td>
<td>425</td>
<td>9.0</td>
<td>1.50</td>
<td>3</td>
<td>2.7</td>
</tr>
<tr>
<td>G1W67 FCH</td>
<td>432</td>
<td>12.3</td>
<td>0.75</td>
<td>4</td>
<td>3.1</td>
</tr>
<tr>
<td>G1W67 CYL</td>
<td>428</td>
<td>10.0</td>
<td>1.50</td>
<td>3</td>
<td>2.9</td>
</tr>
<tr>
<td>G2W71 FCH</td>
<td>415</td>
<td>10.9</td>
<td>0.25</td>
<td>3</td>
<td>2.8</td>
</tr>
<tr>
<td>G2W71 CYL</td>
<td>403</td>
<td>9.5</td>
<td>1.25</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>G2W67 FCH</td>
<td>411</td>
<td>9.8</td>
<td>0.25</td>
<td>3</td>
<td>2.7</td>
</tr>
<tr>
<td>G2W67 CYL</td>
<td>402</td>
<td>8.4</td>
<td>1.50</td>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>G3W71 FCH</td>
<td>393</td>
<td>7.0</td>
<td>0.25</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>G3W71 CYL</td>
<td>392</td>
<td>6.0</td>
<td>1.50</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>G3W67 FCH</td>
<td>394</td>
<td>7.3</td>
<td>0.75</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td>G3W67 CYL</td>
<td>389</td>
<td>5.8</td>
<td>1.50</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>G4W71 FCH</td>
<td>357</td>
<td>3.1</td>
<td>0.75</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>G4W71 CYL</td>
<td>354</td>
<td>2.2</td>
<td>1.25</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>G4W67 FCH</td>
<td>357</td>
<td>3.0</td>
<td>0.50</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>G4W67 CYL</td>
<td>355</td>
<td>2.2</td>
<td>1.50</td>
<td>0.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 2-2-1: Ammunition weapon combination, muzzle velocity, distance, where the speed of sound is reached and diameter dm of the pellet cloud at a distance of 3.5 m
The ammunition in those four groups is indicated by 420, 400, 380 and 360.

The distance where 340 m/s was reached by the pellet cloud was calculated on the basis of the measurements using third order regression analyses. The acoustic measurements of the angular source distribution level $L_{q}(\alpha)$ were performed at 13 angles separated by 15°. The position at 0° was shifted 5° from the line of fire.

In Fig. 2.2.1.a and b the A-weighted result of the measurements using barrel lengths of 670 and 710 mm FCH and 480-ammunition is presented:

![Graph showing directivity (A-Level) and source energy level (A-Level)]

**Source energy level (A-Level)**

<table>
<thead>
<tr>
<th>Angle</th>
<th>Directivity</th>
<th>Index</th>
<th>Fourierc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12.5 dB</td>
<td>0</td>
<td>-2.68 dB</td>
</tr>
<tr>
<td>15</td>
<td>8.2 dB</td>
<td>1</td>
<td>9.04 dB</td>
</tr>
<tr>
<td>30</td>
<td>6.1 dB</td>
<td>2</td>
<td>2.39 dB</td>
</tr>
<tr>
<td>45</td>
<td>2.6 dB</td>
<td>3</td>
<td>1.10 dB</td>
</tr>
<tr>
<td>60</td>
<td>-1.0 dB</td>
<td>4</td>
<td>0.60 dB</td>
</tr>
<tr>
<td>75</td>
<td>-3.2 dB</td>
<td>5</td>
<td>-0.01 dB</td>
</tr>
<tr>
<td>90</td>
<td>-4.6 dB</td>
<td>6</td>
<td>0.19 dB</td>
</tr>
<tr>
<td>105</td>
<td>-6.2 dB</td>
<td>7</td>
<td>0.27 dB</td>
</tr>
<tr>
<td>120</td>
<td>-7.6 dB</td>
<td>8</td>
<td>0.38 dB</td>
</tr>
<tr>
<td>135</td>
<td>-8.9 dB</td>
<td>9</td>
<td>0.36 dB</td>
</tr>
<tr>
<td>150</td>
<td>-9.6 dB</td>
<td>10</td>
<td>0.30 dB</td>
</tr>
<tr>
<td>165</td>
<td>-9.6 dB</td>
<td>11</td>
<td>0.27 dB</td>
</tr>
<tr>
<td>180</td>
<td>-9.5 dB</td>
<td>12</td>
<td>0.27 dB</td>
</tr>
</tbody>
</table>

**Fig. 2.2.1.a:** A weighted sound energy level and directivity for a FCH barrel of 670 mm and a muzzle velocity in the range of 420 m/s
Fig. 2.2.1.b: A weighted sound energy level and directivity for a FCH barrel of 710 mm and a muzzle velocity in the range of 420 m/s

In Figures 221.c and d the results for 380-amunition are shown:

Fig. 2.2.1.c: A weighted sound energy level and directivity for a FCH barrel of 670 mm and a muzzle velocity in the range of 380 m/s
Fig. 2.2.1.d: A weighted sound energy level and directivity for a FCH barrel of 710 mm and a muzzle velocity in the range of 380 m/s

It is noteworthy that A-weighted sound source energy for a 670 mm barrel and 710 mm barrel is practically identical. However, the directivity shows in both cases for the longer barrel a rather smoother directivity.

In Fig. 2.2.2.a to d, the same is presented for a CYL barrel and 480 and 380 m/s ammunition.
Fig. 2.2.2.a: A weighted sound energy level and directivity for a CYL barrel of 670 mm and a muzzle velocity in the range of 420 m/s

Fig. 2.2.2.b: A weighted sound energy level and directivity for a CYL barrel of 710 mm and a muzzle velocity in the range of 420 m/s
Fig. 2.2.2.c: A weighted sound energy level and directivity for a CYL barrel of 670 mm and a muzzle velocity in the range of 380 m/s

Fig. 2.2.2.d: A weighted sound energy level and directivity for a CYL barrel of 710 mm and a muzzle velocity in the range of 380 m/s
The CYL barrel leads to a higher sound energy of 1.5 dB on the average and a stronger directivity in the shooting direction, if one compares the directivity of $\alpha = 0$ and $\alpha = 15$ for choked and cylindrical barrels. For the choked barrel the drop is 3.9 dB and for the cylindrical barrel 0.4 dB.

In 2011 deBAKOM has performed new measurements with FCH barrels only [2.12].

In table 2-2-2 the overall results of the measurements in 2002 and 2011 [2.12] are presented:

<table>
<thead>
<tr>
<th>Muzzle velocity 2002</th>
<th>Source energy 2002</th>
<th>Muzzle velocity 2011</th>
<th>Source energy 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCH m/s</td>
<td>CYL m/s</td>
<td>FCH dB(A)</td>
<td>CYL dB(A)</td>
</tr>
<tr>
<td>433</td>
<td>427</td>
<td>136.3</td>
<td>137.8</td>
</tr>
<tr>
<td>413</td>
<td>403</td>
<td>135.8</td>
<td>137.5</td>
</tr>
<tr>
<td>394</td>
<td>390</td>
<td>133.8</td>
<td>135.9</td>
</tr>
<tr>
<td>357</td>
<td>355</td>
<td>133.8</td>
<td>134.7</td>
</tr>
</tbody>
</table>

Table 2-2-2: Measured A-weighted source energy levels 2002 and 2011

During the measurements in 2011 the muzzle velocity was directly measured on the same day under the actual climatic conditions, whereas the ammunition in 2002 was measured separately in Italy for the tests in the Italian Proof House. The results in 2002 were averaged over different barrel lengths due to the fact that the differences for muzzle velocity above 380 m/s are 0.5 dB or less and for 360 m/s 0.65 dB. Taking this into account, the FCH measurements 2002 and 2011 are very close in the range of 0.5 dB. This proofs that the ISO standard 17201-1 can provide results with a high repeatability.

The CYL barrel produces a sound energy level about 1.4 dB larger than that for a FCH barrel and the ammunition with a muzzle velocity of 420 m/s is about 2.5 dB to 2.9 dB louder than an ammunition with less than 390 m/s muzzle velocity. Studying the data in more details shows that the assumption of a linear relationship between muzzle velocity and sound energy is not be given.
Looking at ISO 17201 part 2 [7.2] the muzzle blast sound energy can be calculated from the chemical energy incorporated in the load, but before doing this, the whole radiation mechanism is examined.

2.3 Acoustic photography

The theory how the muzzle blast of a gun radiates the sound into the environment has been studied by Weber [8.4] in the late 30th of the last century. It is assumed that the hot gas expands from the muzzle with an expansion velocity of well above the speed of sound. Any sound radiated in this situation into the surrounding will be caught by the expanding cloud of highly pressurised gas with corresponding high temperature. At a certain point the expanding surface of this gas cloud reaches the velocity of sound. At that moment the cloud radiates acoustic energy into the surrounding. This model is simple and explains well the frequency structure of the muzzle blast sound, however it does not explain the directivity, which is caused by the fact that the hot gas moves in the shooting direction.

It can be assumed from the point of view of energy of the propellant of the ammunition that different muzzle velocities are directly correlated to the energy of the shot cloud. The measurements show that a drop in the sound energy of the muzzle blast from 420 to 400 m/s is proportional to the change in energy of 0.45 dB and that from 380 to 360 m/s. However, the drop from 400 to 380 m/s is not proportional to the change in the energy of the shot cloud. The drop is in the order of 2.5 dB.

The measured difference might be explained by assuming that the cloud of the hot gas moves in the beginning with a velocity well above the speed of sound up to a distance of about 0.5 m (Weber radius) and moves at reduced velocity up to about 4 m. The shot cloud for a muzzle velocity of 420 m/s looses its energy down to 380 m/s with the 5th power of the velocity producing heat and sound energy which cannot occur for the slower ammunition.

In recent years, a new measurement technology was developed called

Acoustic Photography,
which uses a microphone array not only to measure the sound pressure as a function of time but also the acoustic field.

Fig. 2.3.1: Microphone array with 76 microphones on a ring, video camera at the center
From there it is possible to calculate the acoustic pressure amplitudes in an image plane as a function of time. This way it is possible to see from where the sound pressure is radiated using a time resolution of few milliseconds. The task of the measurements was to demonstrate

a) that acoustic photography can be used to study the mechanism of acoustic radiation due to the muzzle blast of a shot gun,

b) that the above described interaction between the exhaust gas and shot cloud explains the outer ballistic as given in the RUAG Ammotec study and

c) that the Weber theory can be demonstrated to describe the physics of the sound radiation from the muzzle blast.

d) Furthermore, one expects that the shot cloud itself produces sound which may be made visible.

e) Finally, the measurements should provide information about the measurement set up which may be used for future measurements using acoustic photography.

Three types of ammunition (Rottweil Super Trap 438 m/s 24 g, Fiocchi 380 m/s 24 g, Rottweil subsonic 28 g) were shot using a FCH 71 barrel.

In Fig. 2.3.2 on the left hand side the sound pressure of microphone 67 is depicted. The violet band gives the time period which is used to describe the sound radiation (middle) after the trigger of the gun has been pulled. On the right the color scale for the measured amplitudes in dB are given.
Fig. 2.3.2: Muzzle velocity 438 m/s, 19.53 m/s after pulling the trigger

With a level of 58 dB(A) the sound radiated from the gun arrived at the microphone array shortly after the trigger has been pulled. The sound source is at -4.25 m left from the zero point of the projection plane and 0.18 m below this point. The muzzle is at approximately -4.0 m. This means that we see the radiation from the barrel.

In Fig. 2.3.3 we see the source which has its centre at -4.0 m close to the muzzle position:

Fig. 2.3.3: Source at muzzle position, 19.53 ms
This can be used as a starting position for the measurements. It takes about 1 ms until the source at the muzzle shows an object which moves away, as depicted in Fig. 2.3.4.

In Fig. 2.3.5 we see the situation at 23.00 ms 3.5 ms after the sound emission from the barrel is observed; the front source is well removed from the barrel area. Muzzle blast reflection can be seen in the middle between muzzle and the front source:

Fig. 2.3.5: The front source has been completely removed from the rest 3.5 ms after observation of the sound radiated from the barrel
Now one observes sound from the shot cloud. This image clearly shows that the flying projectile emits sound into the surrounding in addition to the muzzle blast, which has been observed in Fig. 2.3.4 and from reflections in Fig. 2.3.5.

In Fig 2.3.6 one sees the same situation for the Fiocchi ammunition:

![Image](image.png)

Fig. 2.3.6: After 20.833 m/s at -2.72 Fiocchi 380 m/s about 3 ms after the observation of the radiation from the barrel

Similarly, one observes for the subsonic ammunition sound from the shot cloud, however, far low in intensity:
Fig. 2.3.7: After 20.833 m/s at -2.72 Rottweil subsonic about 2.7 ms after the observation of the radiation from the barrel

These observations have led to the conclusion that the amount of acoustic energy radiated from the shot cloud should be further examined by measuring at different distances.

2.4 Evaluation of the 2011 measurements for different distances

The measurements for ammunition Type A (425 m/s) and Type C (385 m/s) were performed at 10 and 20 m distances over highly absorbing ground of grass cover ($F_r$, flow resistance of the ground = 50 kPa·s/m²). The 20 m measurements were taken as a reference assuming that the level drops by 6 dB from 10 to 20 m. Taking this into account one obtains for the difference of the measurements the values given in table 2-4-1 for ammunition A and C:
<table>
<thead>
<tr>
<th>Direction</th>
<th>Ammunition Type</th>
<th>31 Hz dB</th>
<th>62 Hz dB</th>
<th>125 Hz dB</th>
<th>250 Hz dB</th>
<th>500 Hz dB</th>
<th>1 kHz dB</th>
<th>2 kHz dB</th>
<th>4 kHz dB</th>
<th>8 kHz dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>A</td>
<td>-0.7</td>
<td>-2.7</td>
<td>6.4</td>
<td>11.5</td>
<td>5.5</td>
<td>5.9</td>
<td>10.1</td>
<td>11.9</td>
<td>12.1</td>
</tr>
<tr>
<td>0°</td>
<td>C</td>
<td>-0.5</td>
<td>0.8</td>
<td>0.0</td>
<td>9.9</td>
<td>1.3</td>
<td>6.4</td>
<td>6.6</td>
<td>5.6</td>
<td>4.7</td>
</tr>
<tr>
<td>15°</td>
<td>A</td>
<td>-1.5</td>
<td>-0.6</td>
<td>-0.4</td>
<td>1.9</td>
<td>1.1</td>
<td>3.7</td>
<td>5.4</td>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td>15°</td>
<td>C</td>
<td>-0.4</td>
<td>-1.4</td>
<td>-2.5</td>
<td>-2.3</td>
<td>1.2</td>
<td>-1.4</td>
<td>2.0</td>
<td>2.6</td>
<td>1.5</td>
</tr>
<tr>
<td>30°</td>
<td>A</td>
<td>-2.5</td>
<td>-3.1</td>
<td>-3.4</td>
<td>-0.1</td>
<td>1.6</td>
<td>-2.7</td>
<td>-1.0</td>
<td>-1.1</td>
<td>-2.8</td>
</tr>
<tr>
<td>30°</td>
<td>C</td>
<td>-2.0</td>
<td>-2.0</td>
<td>-2.2</td>
<td>-0.2</td>
<td>0.5</td>
<td>-0.4</td>
<td>2.4</td>
<td>1.3</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Table 2-4-1: Level difference in the octave bands

For the 0° direction, where the pellet cloud passes the microphone at 1 or 1.5 m distance, the differences for the faster ammunition is at low frequencies less than 3 dB to go up to more than 10 dB for higher frequencies. The same effect is observed for the slower C ammunition. However, the differences go not beyond 10 dB.

For the 15° measurements the differences are about 1/3 of the 0° measurements and completely disappear for larger angles. The differences for this direction could be minimized by shifting the centre of the muzzle blast in the shooting direction. However, if this is done the deviations observed for the 0° and 15° direction will not be reduced due to the fact that a second source for the radiation of the pellet cloud at supersonic speed has to be considered as a second source dominating the frequencies above 100 Hz for the A ammunition and from 200 Hz for type C.

Comparing the measured sound exposure levels for the 0° measurements, one obtains
<table>
<thead>
<tr>
<th>0° Ammunition Type</th>
<th>125 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1 kHz</th>
<th>2 kHz</th>
<th>4 kHz</th>
<th>8 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>121.6</td>
<td>134.2</td>
<td>133.3</td>
<td>135.0</td>
<td>134.5</td>
<td>133.3</td>
<td>130.5</td>
</tr>
<tr>
<td>C</td>
<td>121.0</td>
<td>131.6</td>
<td>130.5</td>
<td>134.8</td>
<td>132.3</td>
<td>126.6</td>
<td>121.2</td>
</tr>
<tr>
<td>Difference</td>
<td>0.6</td>
<td>2.6</td>
<td>2.8</td>
<td>0.2</td>
<td>2.2</td>
<td>6.7</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Table 2-4-2: Sound exposure levels for differences from 125 Hz up to 8 kHz for the 0° direction of the A and C ammunition

At 20 m distance the difference at 8 kHz reduces from 9.3 dB to 1.9 dB or at 500 Hz from 2.8 dB to 1.0 dB, which means that at this distance the sound emission of the pellet cloud is small. This is an agreement to the fact that ammunition A reaches the speed of sound at 13 m, whereas ammunition C at 7.5 m.

That at supersonic speed the shot cloud can radiate projectile sound can be seen from Fig. 2.4.1

![Fig. 2.4.1: Shot cloud at 2 m distance, length of the cloud: 0.2 m, wad on the left side](image)

which shows the pellet cloud about 1 m from the muzzle. Due to the fact that at supersonic velocity the shot cloud increases its length of 1 m up to a distance of 10 m, the projectile sound produces by the shot cloud is broad band with a lower frequency given by the length of the cloud.
Due to the fact that the velocity reduction at supersonic velocity is proportional to the fifth power of the velocity compared to the third power at subsonic speed, the sound emission of ammunition A compared to C is dominated by sound emission by the shot cloud for the radiation direction $\alpha$ between $0^\circ$ and $90^\circ$.

An indirect indication for this fact can be obtained from the calculation of the sound energy of the muzzle blast alone.

### 2.5 Calculation of the muzzle blast

Using ISO 72001 Part 2 for a 24 g ammunition one obtains for the source energy levels measured (see Table 2-2-2) the following calculated results:

<table>
<thead>
<tr>
<th>Muzzle velocity m/s</th>
<th>Measured dB(A)</th>
<th>Calculated dB(A)</th>
<th>Projectile noise dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>433</td>
<td>136.3</td>
<td>134.4</td>
<td>131.8</td>
</tr>
<tr>
<td>425</td>
<td>136.7</td>
<td>134.3</td>
<td>132.9</td>
</tr>
<tr>
<td>413</td>
<td>135.8</td>
<td>133.9</td>
<td>131.3</td>
</tr>
<tr>
<td>405</td>
<td>136.7</td>
<td>134.0</td>
<td>133.3</td>
</tr>
<tr>
<td>394</td>
<td>133.8</td>
<td>133.8</td>
<td>0</td>
</tr>
<tr>
<td>385</td>
<td>133.8</td>
<td>133.6</td>
<td>120.3</td>
</tr>
</tbody>
</table>

Table 2-5-1: Comparison measured and calculated sound energy and estimation of the projectile noise

The estimation of the projectile sound is obtained from the difference between the measured and calculated results given in the last column. This table clearly indicates that below 400 m/s muzzle velocity the projectile noise is of minor importance.
2.6 Conclusion

The obvious conclusion from the measured results in chapter 2.2 is that a reduction of the muzzle velocity of about 25 m/s would reduce the ambient noise by at least 2.0 dB by eliminating the projectile sound and reduction of the muzzle blast sound energy. This would mean that the number of shots could be increased by app. 60 % producing the same rating level compared to the situation with ammunition of 410 m/s and more. This statement is independent from the local regulations used to assess the ambient shooting noise sound levels due to the fact that this reduction will reduce the time weighted sound levels accordingly.

Furthermore, when looking at the difference between the CYL and FCH barrels one should note that the sound energy level is dominated by sound energy radiated in the shooting direction. Beyond 30° the difference between CYL and FCH gets smaller. This means that for angles $\alpha > 90°$ both barrel types radiate the same sound energy approximately. Due to the fact that the radiation between 0 and 20° is usually directed at a wall or berm, which means screening in this direction the overall effect of reducing the muzzle velocity should be very similar for both muzzle types. Reducing the muzzle velocity means that the velocity of the pellets hitting the target is reduced as well and the distance, where the hit occurs, gets greater. The question whether or not this has an appreciable effect on the success rate can only be answered by looking at the ballistic of the small shots and the clay targets.

3 Ballistics

Overall measurements of the velocity of the shot cloud go back to the early 20th of the last century [8.5]. However, detailed and systematically obtained data on the flight path of the first or last pellet of the shot cloud or its expansion velocity depending on the load and type of barrel were not available.

3.1 Outer ballistics of the pellet clouds

Outer ballistics means the description of the movement of the shot cloud outside the barrel over a distance of up to 60 m. The velocity of the ammunition is not characterized by the velocity at the muzzle position but at a distance of 0.5 m or 1 m in front of the muzzle or at 2.5 m, which can easily be measured compared to larger distances.
3.1.1 Measurements Italian Proof House

The first measurements were performed at the Italian Proof House in Gardone by Beretta Holding, BNP, Fiocchi and STAS in 2001 [1.6] with ammunition described in chapter 2 of this report. The distance covered by 8 light screen pairs was between 2 m and 30 m, as depicted in Fig. 3.1.1.1

Standardized ammunition with 12 gauge cartridges and lead shots of 2.4 mm were used having a nominal muzzle velocities of 420 m/s, 400 m/s, 380 m/s and 360 m/s +/- 5 m/s at 1 m in front of the muzzle. The barrel length was 710 mm full choke (10/10 mm) and a cylindrical barrel both with a bore diameter between 18.3 and 18.5 mm. The data evaluation was done using two approximations, a third order regression for the time dependence of the flight distance and velocity and a third order regression for the dependence of velocity from the flight distance. The latter was
used to extrapolate for distances beyond the measurement range of 30 m, which is important for the second shot. From the time of firing the second shot (see chapter 3.5 for more details) it was concluded that the second shots are well beyond the distance of 30 m. The velocity difference found at 30 m distance for the 420 m/s and the 360 m/s ammunition using a FCH-barrel was 22 m/s about one third of the difference of the muzzle velocities.

Furthermore to evaluate the breakability of clay targets the relative velocity between the target and the shot cloud is needed. Therefore the WTD 91 (TECHNICAL MILITARY SERVICE FOR ARMS AND AMMUNITION German Federal Army, Meppen) was asked to measure both, the shot cloud as well as the clay target using radar Doppler measurements.

### 3.1.2 Radar Doppler measurements [3.1]

The calibrated Doppler tracking radar antenna used can be seen from Fig. 3.1.2.1.

![Doppler Tracking Radar Antenna](image)

**Fig. 3.1.2.1:** Doppler Tracking Radar Antenna

In order to measure the velocity of the pellet cloud a firing stand was used to which two shot guns were fixed with horizontal direction 0° and 19.68°. The measurements were triggered using a
photoelectric cell placed on the muzzle of the weapons. The 420 m/s, 400 m/s and 380 m/s ammunition were used with both cylindrical and full choked barrels.

Cascade diagrams were prepared to interpret the results of the measurements, as can be seen from Fig. 3.1.2.2, which shows shot number 72 as an example. It was possible to measure the flight of the shot cloud over 4 seconds. An additional signal (red arrow), which represents the end of the shot cloud with lower velocities can be seen from the measurement for approximately 1 second.

Fig. 3.1.2.2: Cascade diagram of the time as a function of velocity

Another presentation of the values measured in the DTI (Doppler Time Information) is given in Fig. 3.1.2.3. This diagram shows the velocity of the object under examination as a function of time. The amplitude of the Doppler signal is expressed by different colours. A wide range of velocities in the time space between 0.1 and 2.0 seconds after shot fired can be seen clearly. An additional signal can also be seen here in the lower range of velocities up to approximately 1 second after the start of the test. This results from the separation of the wad from the pellets.
Fig. 3.1.2.3: Velocity as a function of time

The trajectory of the shot 72 is given in Fig. 3.1.2.4.

Fig. 3.1.2.4: Velocity of the shot cloud as a function of time
The trajectory data may be considered acceptable up to a distance of 100 m. The above data for the velocity of the centre of gravity of the shot cloud indicate a non linear change with respect to time, which is caused by the fact that the air drag of a ball shaped pellet is proportional to 3rd power of velocity, if the velocity is below speed of sound. As can be seen from Fig. 3.1.2.3 the precision of the measurement in the region below 0.3 s is insufficient to differentiate between the different ammunitions. Therefore, in 2004 armasuisse was asked to do measurements, due to the fact that they can measure close to the muzzle up to 48 m.

3.1.3 armasuisse [3.8]

Two ammunition types with muzzle velocities of 420 m/s and 380 m/s 24 g and a pellet mass of 0.08 g (n ~ 300 pellets) were used. For the first measurements 6 pairs of light screens were used at the distances given Fig. 3.1.3.1:

This way the whole rang of distance under interest for trap shooting has been covered (see Chapter 4), where hitting the clay target either with first shot or the second shot may be expected.

At the 30 and 50 m position high velocity cameras were installed. Due to the fact that the velocity drop has its maximum close to the muzzle, it turned out that additional measurements in this region were needed. In a second measurement campaign in August 2004 the velocity loss between 2.5 m and 12.5 m was measured with 6 light screens. Furthermore, the tip and the end of the shot cloud were measured.
The measurements and data evaluation done by armasuisse is different from those described above. The data evaluation is not based on a polynomial approximation, but on the exterior ballistic differential equation [3.3] of a ball shaped body:

\[
\frac{dv}{dt} = -c_D \frac{\rho}{2} v^2 \frac{1}{q}
\]

where \(dv/dt\) is the de-acceleration of the pellet, which is negative as a function of the square of the pellet velocity \(v\), the air density \(\rho\), the air drag coefficient \(c_D\) and the cross section density \(q\).

By definition, the air drag coefficient \(c_D\) is independent from the size of the object, if the shape is unchanged during the flight. However, at least in the beginning the cross section density \(q\) of the whole shot is variable due to the fact that at the start the pellets move in a conical compact shape due to the barrel and the wad. As can be seen from the following picture taken with a high velocity camera at a short distance from the barrel:

![Fig. 3.1.3.2: Pellet cloud and wad at a short distance from the muzzle, at about 2 m (see Fig.4.2.1)](image)
With increasing distance the uniform movement of the pellets disintegrates to smaller units, until the pellets fly approximately independent from each other. In view of the ballistic equation, it is far simpler - writes armasuisse - to assume the value for the cross section density \( q \) to be that of a free flying pellet (\( q = 0.017753 \) g/mm\(^2\)) and to include the variability into the air drag coefficient \( c_D \). Using \( \nu = dx/dt \), Eq. 3.1.3.1 can be rewritten in

\[
(3.1.3.2) \quad \frac{d\nu}{dx} = -c_D \frac{\rho}{2} \frac{\nu}{q}
\]

Due to the fact that the measured path changes \( \Delta x \) and the velocity changes \( \Delta \nu \) are finite, one obtains:

\[
(3.1.3.3) \quad c_D = \frac{2 \cdot \Delta \nu \cdot q}{\Delta x \cdot \rho \cdot \nu_m}
\]

where \( \nu_m \) is the average velocity over the distance \( \Delta x \), which is the distance of the light screens at 2.5 m, 5 m etc. (see Fig. 3.1.3.1).

The determination of the air drag coefficient was performed for the tip and the end of the shot cloud. Typical approximations can be seen from Figures 3.1.1 und 3.1.2.

The result for the tip of the shot cloud is shown in Fig. 3.1.3.4:

**Fig. 3.1.3.4:** Air drag coefficient \( c_D \) of the first pellet for \( 420 \) m/s and \( 380 \) m/s and FCH barrel
and for the end of the shot cloud:

![Graph showing Air drag coefficient (c_D) of the last pellet for 420 m/s and 380 m/s and FCH barrel.]

It can be seen from both figures, that at lower velocities of 0.9 Mach (less than 310 m/s) the overall behavior of the first and last pellet is that of a sphere (see red line), whereas above 1 Mach for the first pellet an increase in the c_D value with decreasing velocity is observed, which is explained by armasuisse, that the reference area decrease leads to an increase of c_D, due to the fact that the number of pellets flying uniformly in a group become smaller until the lower limit of one pellet in the tip of the shot cloud is reached.

The air drag coefficient is defined by

\[ c_D = \frac{2 \cdot \overline{F}_W}{\rho \cdot \overline{v}^2 \cdot A} \]

where A is the reference area and \( \overline{F}_W \) the force acting on the moving object. A is the cross section area of the pellets. At Mach 1.1 at a distance of 5 m or less from the muzzle the force acting on the end pellet is twice the force acting in the first pellet.
Having the air drag coefficient as a function of velocity between Mach 0.5 and 1.3 for the two barrel and ammunition types allows a ballistic calculation of the trajectory of the first and last pellet, the movement of this centre can be calculated as well.

3.2 Standardized Trajectories [3.9]

In Fig. 3.2.1 a typical light screen signal is depicted:

Tip of shot cloud

![Graph showing light screen signal at 20.57 m for FCH Ammunition 420 m/s and 380 m/s without late pellets (armasuisse). The green bars depict the tip and end of the shot cloud and the red bar the centre of gravity.]

Fig. 3.2.1: Light screen signal at 20.57 m for FCH Ammunition 420 m/s and 380 m/s without late pellets (armasuisse). The green bars depict the tip and end of the shot cloud and the red bar the centre of gravity.
The tip of the shot cloud is indicated by the beginning of signals on the left side of Fig. 3-2-1, the end by the beginning of pauses in the signal, meaning that this indicates the end. For FCH barrels the centre of gravity is measured to be at the 38% point of cloud length behind the tip. The centre of gravity (red bar) for CYL barrels is estimated to be at the 50% behind the tip of the shot cloud.

Based on this and the measurements done by armasuisse, as described in chapter 3.1, the following three standard trajectories with different initial velocities are obtained for a projectile of 2.35 mm diameter with a mass of 0.08 g for the Mach number at 15 °C and an air density of 1.225 kg/m³ and a sound speed of 340.3 m/s:

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**Table 3-2-1:** Standard trajectories for FCH barrel with a length of 710 mm and a nominal muzzle velocity of 420 m/s (Mach number at 15 °C and an air density of 1.225 kg/m³ and a sound speed of 340.3 m/s) with the abbreviations: x horizontal direction [m], y vertical direction [m], t time [s], v velocity [m/s], E energy [J], L length of shot cloud [m]
Table 3-2-2: Standard trajectories for FCH barrel with a length of 710 mm and a nominal muzzle velocity of 400 m/s (Mach number at 15 °C and an air density of 1.225 kg/m³ and a sound speed of 340.3 m/s), x, y etc. see Fig. 3-1-1

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Table 3-2-3: Standard trajectories for FCH barrel with a length of 710 mm and a nominal muzzle velocity of 380 m/s (Mach number at 15 °C and an air density of 1.225 kg/m³ and a sound speed of 340.3 m/s), x, y etc. see Fig. 3-1-1

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<td>50.60</td>
<td>149.1</td>
<td>44.73</td>
<td>131.3</td>
<td>48.25</td>
<td>142.00</td>
<td>52.5</td>
</tr>
<tr>
<td>0.23</td>
<td>52.07</td>
<td>145.4</td>
<td>46.03</td>
<td>128.0</td>
<td>49.65</td>
<td>138.44</td>
<td>55.0</td>
</tr>
<tr>
<td>0.24</td>
<td>53.49</td>
<td>141.8</td>
<td>47.26</td>
<td>125.0</td>
<td>51.00</td>
<td>135.11</td>
<td>57.5</td>
</tr>
<tr>
<td>0.25</td>
<td>54.87</td>
<td>138.5</td>
<td>48.45</td>
<td>122.1</td>
<td>52.30</td>
<td>131.97</td>
<td>60.0</td>
</tr>
</tbody>
</table>

Table 3-2-3: Standard trajectories for FCH barrel with a length of 710 mm and a nominal muzzle velocity of 380 m/s (Mach number at 15 °C and an air density of 1.225 kg/m³ and a sound speed of 340.3 m/s), x, y etc. see Fig. 3-1-1
Fig. 3.2.2 depicts three velocities of the center of gravity versus distance for initial velocities of 420, 400 and 380 m/s.

A comparison performed by Kneubuehl with radar measurements [3.10] and the measurement at the Italian Proof House [1.6] shows a close agreement with the above given data.
3.3 Photographic measurements

The above given shooting tables allow to estimate the velocity of the first and last pellet at greater distances. According to table 3-2-2 the velocity of the center of gravity at 45 m is 164.4 m/s; the first pellet would be at 50.05 m and the last at 39.95 m. If the centre of gravity is at 40 m the first pellet is at 44.6 m having a velocity of 180 m/s and if the centre of gravity is at 50 m the last pellet 44.57 m having a velocity in the order of 151 m/s, which means that the velocity change from first to last pellet is in the order of 30 m/s at the distance of 45 m. This might have a considerable influence on the breaking probability, whether the first or the last pellet is hitting the target. To check whether or not this estimate of the velocity range is correct, Beretta [3.11-3.14] established a test set up with the intent to measure for each shot fired:

- the initial velocity of pellets (2,5 meters from muzzle)
- the position in the space (3D) of each single pellet at 45 meters from muzzle
- the velocity of each single pellet at 45 meters from muzzle

To achieve these goals, two high speed cameras, 2 meters apart each other, both looking at the same point, positioned on the line of fire at 45 meters from muzzle were used. A reference grid was positioned parallel to the line of fire, 1 meter apart on the opposite side of the two cameras. A paper target at 50 meters from the muzzle was able to record all pellet impacts. A velocity metering device was positioned at 2.5 meters from shotgun muzzle to record, for each shot fired, the initial velocity of the pellets.

The two cameras were synchronized and the shutter speed was set to 40,000 frames per second for both of the cameras. Pellets traveling in a defined portion of space were seen in the same time by both of the cameras; the apparent position on the reference grid of the same pellet from the two cameras was obviously different due to the distance separating the two cameras, as in any stereoscopic view.

From the two apparent positions it was easy to calculate the real position in space of each single pellet in a specific time. At this point pellet velocity was easily calculated looking at the apparent velocity on the reference grid and adjusting the apparent value for the real position of the pellet.
Fig. 3.3.1: Measuring scheme with two high speed cameras at 45 m with two lamps and a light screen pairs at 2.5 m distance

Fig. 3.3.2: Cameras, target an reference grid set up
Fig. 3.3.3: Shot gun and velocity measurement set up

Fig. 3.3.4: Pellet cloud as seen by both cameras at the same time, the reference grid is visible in the background.
The following results for the velocity of the centre of gravity were obtained in comparison with shooting tables 3-2-1 and 3-2-2:

<table>
<thead>
<tr>
<th>Ammunition</th>
<th>Distance</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel</td>
<td>2.5 m</td>
<td>45 m</td>
</tr>
<tr>
<td>Type A FCH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 3-2-1</td>
<td>403.6 m/s</td>
<td>167.8 m/s</td>
</tr>
<tr>
<td>Beretta</td>
<td>408.7 m/s</td>
<td>171.8 m/s</td>
</tr>
<tr>
<td>Difference</td>
<td>-4.9 m/s</td>
<td>-4.0 m/s</td>
</tr>
<tr>
<td>Type B FCH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 3-2-2</td>
<td>368.8 m/s</td>
<td>164.4 m/s</td>
</tr>
<tr>
<td>Beretta</td>
<td>359.2 m/s</td>
<td>160.7 m/s</td>
</tr>
<tr>
<td>Difference</td>
<td>10.6 m/s</td>
<td>3.7 m/s</td>
</tr>
</tbody>
</table>

The variance of the measurements given by Beretta for ammunition A was 5.2 m/s and for B 9.2 m/s. This means that the observed differences between the photographic measurements and the shooting tables was well within the measurement deviations and the deviations of the ammunition from it specifications.

The velocities ranges of the first and last pellets are compared with the shooting tables 3-2-3 and 3-2-4):
<table>
<thead>
<tr>
<th>Ammunition Barrel</th>
<th>pellet</th>
<th>span m/s</th>
<th>shooting table m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A FCH first</td>
<td>174.1 – 187.6</td>
<td>183</td>
<td></td>
</tr>
<tr>
<td>Type B FCH first</td>
<td>166.3 – 182.9</td>
<td>179.4</td>
<td></td>
</tr>
<tr>
<td>Type A FCH last</td>
<td>134.2 – 156.4</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>Type B FCH last</td>
<td>129.6 – 156.8</td>
<td>151</td>
<td></td>
</tr>
</tbody>
</table>

For the first pellets the values of the shooting tables are close to the middle of the range from the Beretta measurements, whereas the for the last pellets the value of the shooting tables fall into the upper 10% of the span obtained by Beretta. Looking at the photograph in Fig 3.1.3, which were taken close to the muzzle, show that the end of the shot cloud is rather difficult to identify, compared to the tip of the shot cloud. Furthermore, the assumption that the tip and end of the shot cloud are symmetric to the center of gravity is not well supported by the photographic evidence. Due to the fact that the flight of the last pellet is determined from the number of hits with other pellets in the cloud, it can safely be assumed that frequently the last pellet is travelling well behind the shot cloud as suggested from Fig. 3.1.3.2.

### 3.4 Radial distribution

To obtain the radial expansion of the shot cloud, the light screens were fitted with solid paper screens. The spread in diameter in the rosette produced by the shot cloud from the first to the second screen was measured. The pellet cloud did not become larger than the area of the optical screen for the cylindrical barrel at 10 m and the choked at 20 m.

The radial expansion for the choked barrel could be estimated by an armasuisse correlation coefficient of 0.3 for a choked barrel as:

$$\nu_r(x) = 4.5 - 0.02 \cdot x \text{ m/s}$$
and for a cylindrical barrel with a correlation coefficient of 0.8

\[ \nu_r(x) = 9.6 - 0.2 \cdot x \text{ m/s} \]

which means that with increasing distance \( x \) the radial velocity decreases. For a choked barrel the above result means that at 40 m the shot cloud has a diameter of 1.3 m. If a uniform distribution is assumed this would mean a pellet density of 2 pellets per dm². However a correlation coefficient of 0.3 means no correlation and that of 0.8 only a small correlation.

The above relationship provides an estimate of the radius of the shot cloud with increasing distance. Under Section 6 the radial distribution is examined in more details. It shows a significant difference in concentration of pellets in the centre of shot clouds between the fast ammunition Type A and the slower ammunition Type B, which is explained by the fact that a higher muzzle velocity means a higher muzzle pressure and also an increase of air pressure impact on the shot pellets which result in a higher radial velocity. These effects will reduce the pellet density in the centre of the shot cloud and therefore the hitting probability – especially at longer shooting distances for the second shot.

To obtain the impact velocity of the shot cloud relative to clay target the ballistic of the target is needed.

### 3.5 Ballistic of clay targets [3.1]

The measurements of the clay target trajectories were performed as mentioned in chapter 3.1.2 by WT91 the Technical Military Service for Arms and Ammunition in Meppen, Germany [3.1]. The measurement method used was the Doppler Tracking Radar Method.

A typical result of this measurement method is shown in Fig. 3.5.1.
Fig. 3.5.1:  x launching direction, y height above launcher and z side movement perpendicular to the x, y plane

and the velocity drop of the clay with increasing distance:

Fig. 3.5.2:   Velocity of a clay target as a function of time
Following the data measured by WT91 DEVA [3.7] derives a general approximation for the distance of clay targets in the x direction \( x_w \) [m] from the launcher as a function of time:

\[
x_w = a \cdot t^2 + bt + c
\]

where 
\( a = -1.81 \)
\( b = 24.6 \)
\( c = 0.13 \)

If the throwing direction of the launcher and the position of the shooter are known, the horizontal distance between the clay target and the shooter can directly be calculated and therefore, if the time lapse between the launching of the target and the first or second shot is known, the impact of the pellet cloud.

4 Trap Shooting

4.1 Olympic Trap Shooting Regulations

An Olympic Trap range comprises a trench 15 m in front of the shooting line that conceals 15 clay target launchers called traps arranged in 5 groups of three. The traps are set to fire going away clay targets to a distance of about 75 m at maximum elevation. The elevation range is between 1,5 and 3,5 m above ground level and range of horizontal angle is between 0 and 45° either side of the centre line.

Six shooters competing at a time, while five shooters positioned on stand 1 – 5 behind the related trap position and one shooter is waiting behind the shooting line. The shooter on stand 1 begins with the competition. The target will be launched immediately upon the shooters call and it is randomly selected from any of the three traps directly in front of the shooter. Shooters take tunes to shoot a clay target at each stand and then move clockwise along the shooting line from stand 1 through stand 5.

The scoring is based on one point per kill – regardless of whether this is achieved with the first or second barrel. The definition of a kill is when the clay target is loosing a visible piece after the shot. Each shooter will shoot five qualifying rounds of 25 clay targets; the total score is 125 scheduled over a time period of two days. After finishing qualification the best six shooters of all competitors have been qualified for the Final Competition – 25 clay targets (special flash targets) for each shooter, one barrel can be used only in this Final Competition.
A side view is given in the following figures for a trap shooting range, Ciele Aperti in Italy:

**Fig. 4.1.1:** Shooting range side view.

The target launcher is shown schematically in Fig. 4.1.2.
Fig. 4.1.2: Clay target regulation for elevation

The launching direction are depicted in Fig. 4.1.3

Fig. 4.1.3: Three launching machines for each trap stand
A shooter with in the cabin at Cieli Aperti with the distance markings:

**Fig. 10.2.1:** View from the shooting cabin with the distance markings

4.2 **Hitting distance first and second shot [3.7]**

Microphones are installed in front of the shooters to receive the command to launch a clay target. The order to launch is given by the microphone unit to the launcher, which starts randomly one of the three launcher units. For the time measurement an additional relay contact was installed at the activation contact of the launcher, which starts recording the sound using a second microphone and storing the data. This way the time elapsed from the start of the launcher to the first and second shot were measured by DEVA [3.7] to be

- first shot : 643 ms
- second shot : 1170 ms.
This does include the time, which the sound of the muzzle blast needs to reach the microphone at the launcher in a distance of 15 m. However, this does not include the 77.8 ms the launcher needs to eject the target above ground level. This leads to:

First shot : 565 ms
Second shot : 1092 ms.

Using equation 3.5.1, the distance from the launcher at these moments is 13.5 m and 24.8 m respectively.

For a horizontal angle \( \alpha = 0 \) at the moment of the first and the second shot, the clay target is at a distance of

\[
\begin{align*}
d_1 & : 28.0 \text{ m} \\
d_2 & : 39.3 \text{ m}
\end{align*}
\]

from the muzzle assuming that the muzzle is 14.5 m behind the trap. Using the shooting tables and equation 3.5.1 the distance of impact can be calculated by iteration. It indicates the following values for the impact velocity of the centre of gravity of the shot cloud.

<table>
<thead>
<tr>
<th>shot</th>
<th>muzzle</th>
<th>muzzle velocity m/s</th>
<th>impact velocity m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>first</td>
<td>FCH</td>
<td>420</td>
<td>233*</td>
</tr>
<tr>
<td>second</td>
<td>FCH</td>
<td>420</td>
<td>188*</td>
</tr>
<tr>
<td>first</td>
<td>FCH</td>
<td>380</td>
<td>225*</td>
</tr>
<tr>
<td>second</td>
<td>FCH</td>
<td>380</td>
<td>184*</td>
</tr>
<tr>
<td>first</td>
<td>CYL</td>
<td>420</td>
<td>215*</td>
</tr>
<tr>
<td>second</td>
<td>CYL</td>
<td>420</td>
<td>182*</td>
</tr>
<tr>
<td>first</td>
<td>CYL</td>
<td>380</td>
<td>214*</td>
</tr>
<tr>
<td>second</td>
<td>CYL</td>
<td>380</td>
<td>176*</td>
</tr>
</tbody>
</table>

Table 4-2-1: Impact velocity based on the shooting tables 3-5-1 to 3-2-4
Furthermore, one has to subtract the velocity of the moving clay target at both distances, which can be obtained by differentiating $x_w(t)$. The velocity of the clay target is

$$23.4 \text{ m/s for the first shot}$$

and

$$22.5 \text{ m/s for the second shot.}$$

This means that the relative impact velocity for the first shot is between

$$210 \text{ and } 191 \text{ m/s}$$

and for the second shot between

$$166 \text{ and } 154 \text{ m/s.}$$

If the reaction time is 70 ms longer, the relative impact velocities are lowered by about 20 m/s as can be seen from the tables 3-2-1 to 3-2-4.

5 Breakability of clay targets

The targets are usually in the shape of an inverted saucer, made from a mixture of pitch and pulverized lime stone rocks designed to withstand being thrown from a trap at a velocity up to 30 m/s, but at the same time being easily broken when hit by just a few pellets from a shot gun [Wikipedia]. International disciplines of clay target shooting have clays with a diameter of 110 mm as can be seen from Figure 5.1:
According to ASTMC (RTMBEEDA Lab) the compressive strength is 57 MPa, the elastic modulus 14.8 GPa and the poisson ratio 0.3. The elastic module describes the linear change of an object under stress and the poisson ratio expresses the ratio of compression by a force in one direction to the resulting expansion perpendicular to this direction.

5.1 Mechanical stability

When launched the clay target rotates about 2500 rpm. As measurements using high velocity cameras (see Beretta [4.4]) show, the change of this rotational velocity can be expected to be less than 5 % during flight. The acceleration from zero rotation to 2500 rpm lasts about 78 ms. This must be considered to be the highest force acting on the clay target, which is shown in Figure 5.1.1 based on a finite element method (FEM), which subdivides the clay target in finite very small elements and calculates the stress for each of those elements.
The FEM analysis shows that stress during the flight is about 1% of the material strength and can therefore not really affect the breakability. Further examinations of the vibrations of clay targets during the flight can be seen from Figure 5.1.2:
It shows that the internal vibrations do not influence the probability of breaking the target.

The key of the breaking process are the overall features in respect to the compressive strength, which is strongly influenced by the production process. This leads to the next question, how the breakability can be tested.

5.2 **Langley test method**

The first question under the rule of clay target shooting relates to the conditions when a clay target is considered to be broken. Such a target is depicted in Figure 5.2.1:

![Broken clay target](image)

**Fig. 5.2.1:** Broken clay target

However, frequently clay targets with a hole can be found as shown in Figure 5.2.2.
Fig. 5.2.2: Non broken clay targets

Such targets are considered to be unbroken.

To test the breakability, the clay target is mounted on a holder in a position, which is most likely to occur, when the target is hit during flying.

Fig. 5.2.3: Clay target mount; left side view, right front
From a specific distance of a few meters the pellets are shot at the mounted clay using an air pressured barrel with the diameter of the pellets. The pellet velocity is measured by an optic screen. The Langley test method represents a measuring scheme, which allows a precise estimation of the pellet velocity $v$, when 50 % of the targets are broken. To achieve this, a upper and lower limit ($v_u, v_l$) is estimated, where all targets are broken and no target is broken. The scheme can well be seen from the following table of a measurement performed by STAS [4.10].

<table>
<thead>
<tr>
<th>Item</th>
<th>Clay target</th>
<th>Test N.</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot N.</td>
<td>004</td>
<td>Units of Measure</td>
<td>m/s</td>
</tr>
<tr>
<td>Stimulus</td>
<td>Velocity</td>
<td>Launcher</td>
<td>Code</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td>Set-Up</td>
<td></td>
</tr>
<tr>
<td>Tests Number</td>
<td>(10 - 50)</td>
<td>20</td>
<td>Confidence Level (90%,95%,99%)</td>
</tr>
<tr>
<td>Min. Stimulus</td>
<td>Level</td>
<td>110.000</td>
<td>Outcome</td>
</tr>
<tr>
<td>Max. Stimulus</td>
<td>Level</td>
<td>190.000</td>
<td>Outcome</td>
</tr>
</tbody>
</table>

Notes:
- motionless clay target
- obliqueness 30 deg.
- position of clay target lm
- velocity measured at 50cm

Date (dd/mm/yyyy) 05/04/2005  Operator e.q.

<table>
<thead>
<tr>
<th>X</th>
<th>Confidence Interval</th>
<th>19.086</th>
</tr>
</thead>
<tbody>
<tr>
<td>147.925</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sd</td>
<td>Confidence Interval</td>
<td>27.635</td>
</tr>
<tr>
<td>32.816</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability Level</td>
<td>Safety Coeff.</td>
<td>3.000</td>
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<tr>
<td>255.588</td>
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<tr>
<td>Likelihood Ratio</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
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<td>6</td>
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<td></td>
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<td>32</td>
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<tr>
<td>8</td>
<td>165.300</td>
<td>1</td>
<td>33</td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>149.300</td>
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<td></td>
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<tr>
<td>10</td>
<td>124.000</td>
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<td>11</td>
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<tr>
<td>12</td>
<td>155.400</td>
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<td>37</td>
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<td></td>
</tr>
<tr>
<td>13</td>
<td>152.400</td>
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<td>14</td>
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<td>41</td>
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<td>18</td>
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<td>144.800</td>
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<td>25</td>
<td></td>
<td></td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STAS - Ballistic Instrumentation - Brescia - Italy

Table 5-2-1: Langley one shot test results, X stands for the measured pellet velocity, E for the result
\( \nu_0 \) is given to be 190 m/s and \( \nu_1 \) to be 110 m/s. The first shot is taken at

\[
\nu_1 = \frac{(190 + 110)}{2} = 150 \text{ m/s}.
\]

The actual velocity was \( \nu = 146 \text{ m/s} \) due to the fact that the pellet diameter varies leading to slightly deviating velocities actually measured by the light screen. The first shot has broken the target with the result \( E = 1 \). Due to this the next shot should have a velocity of the average of \( \nu_1 = 110 \text{ m/s} \) and \( \nu_0 = 146 \text{ m/s} \) to be \( \nu_2 = 128 \text{ m/s} \). \( \nu_2 \) was actually 123.8 m/s. The target has been broken and the next shot is taken from the average \( \nu_2 \) and \( \nu_0 \) to result in \( \nu_3 = 114 \text{ m/s} \) the target not broken \( E = 0 \). In the subsequent tests the general method is that shot \( k+1 \) will have a velocity equal to the average of the velocities \( \nu_k \) and \( \nu_r \) of the \( k \)-th shot, for which there are equal numbers of success and failures in the interval between \( k \) and \( r \), which means in our example for the fourth shot \( \nu_4 = \frac{(114.0 + 123.8)}{2} = 118.9 \text{ m/s} \), which was measured to 114.3 m/s and \( E = 0 \). For the fifth shot \( \nu_5 \) 119 m/s was calculated, with \( \nu_5 = 125 \text{ m/s} \) no break was achieved, which would have meant \( \nu_5 = 135 \text{ m/s} \), however, 150.9 m/s was measured. For the next shot \( \nu_6 \) is used for the upper limit. No break was achieved and therefore \( \nu_o \) is used next etc. This scheme aims for an infinite number of measurements to obtain \( \nu_{50} \) the pellet velocity, where 50 % of the targets are broken. This 50 % value can be estimated from the mean value of the measured velocities on the basis of the maximum likelihood method based on a normal distribution for the breakability \( b \):

\[
(5.2.1) \quad b(\nu) = \frac{1}{\sigma \sqrt{2\pi}} \int_{-\infty}^{\nu} e^{-\frac{(\nu-\nu)^2}{2\sigma^2}} \, d\nu
\]

or on a logistic distribution

\[
(5.2.2) \quad b(\nu) = \left(1 + e^{(\nu-\nu_0)/\beta}\right)^{-1}
\]

to be fitted to the measured data.

The above measurement performed in 2005 leads to the following result for one pellet:

\[
(5.2.3) \quad \nu_{50} = 150 \text{ m/s}
\]

with a standard deviation of 15 m/s.
As has been pointed out above in chapter 4.2, the clay target may be hit at 39 m distance with the second shot where the pellets have according to table 4-2-1 FCH barrels and 420 m/s ammunition a velocity of 188 m/s and for the 380 ammunition of 184 m/s. To obtain the relative impact velocity, the velocity of the clay target of about 22 m/s (see Fig. 3.2.2) has to be subtracted which results in 166 m/s and 162 m/s impact velocity. This means that the probability that one pellet breaks the target is in the order of 70 % or \( p_1 = 0.7 \) for the above measured result.

A perfect shot means that the centre of gravity of the shot cloud hits the mid point of the visible area of the clay target (see Fig. 5.2.3 left side). This does not necessarily mean that one of the pellets in the shot cloud hits the target due to the fact that with increasing distance the radial expansion of the shot cloud increases. This will be studied in more details in chapter 6.

If two pellets hit the above measured target, the breaking probability, \( p_2 \), will be 0.91, for three pellets 0.973 and for \( n \) pellets:

\[
(5.2.4) \quad p_n = 1 - (1 - p_1)^n
\]

This relationship is correct, if we can assume that \( \nu_{30} \) remains unchanged independent of the number of pellets hitting the clay target at more or less the same moment. However, from a mechanical point of view this assumption is unreasonable, especially if one considers the fact that with each additional pellet hitting the impact increases accordingly. However, up to this point the testing for breakability was only performed with one pellet. If the target was unbroken, a second or third shot was fired, which is an unrealistic approach due to the fact that the pellets out of a shot cloud will hit within less than 10 milliseconds. STAS modified the shooting device such as it could load and shoot more than one pellet at a time. This is depicted in Fig. 5.2.4.

![Fig.5.2.4: Shooting device and target position with a three pellets shot](image-url)
Using this device two clays were tested denoted with A and B using the above described evaluation procedure:

<table>
<thead>
<tr>
<th>BREAK TEST</th>
<th>1 pellet, Ø 2.4, Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBIT</td>
<td>LOGIT</td>
</tr>
<tr>
<td>( V_{50} )</td>
<td>( \beta_0 )</td>
</tr>
<tr>
<td>SIG</td>
<td>( \beta_1 )</td>
</tr>
<tr>
<td>DMU</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>175</td>
</tr>
<tr>
<td>B</td>
<td>193</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BREAK TEST</th>
<th>2 pellet, Ø 2.4, Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBIT</td>
<td>LOGIT</td>
</tr>
<tr>
<td>( V_{50} )</td>
<td>( \beta_0 )</td>
</tr>
<tr>
<td>SIG</td>
<td>( \beta_1 )</td>
</tr>
<tr>
<td>DMU</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>139</td>
</tr>
<tr>
<td>B</td>
<td>161</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BREAK TEST</th>
<th>3 pellet, Ø 2.4, Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBIT</td>
<td>LOGIT</td>
</tr>
<tr>
<td>( V_{50} )</td>
<td>( \beta_0 )</td>
</tr>
<tr>
<td>SIG</td>
<td>( \beta_1 )</td>
</tr>
<tr>
<td>DMU</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>112</td>
</tr>
<tr>
<td>B</td>
<td>140</td>
</tr>
</tbody>
</table>

Table 5-2-2: Break test results clay target brand A and B

The results in table 5-2-2 show that the data evaluation via the probit or logit distribution are very close. Rather surprising is the reduction of \( V_{50} \) by about 40 m/s per additional pellet hitting the target, which is about 2.5 of the average standard deviation of 17 m/s.
The above figures indicate very clearly that the quality of the clay target has a strong influence on the breaking probability, which is larger than the velocity reduction from the 420 ammunition to the 380 m/s ammunition, which is in the order of 4 m/s for the second shot at a distance of 39 m and beyond (see Tab. 3-2-1 and Tab.3-2-2).

The above given figures relate to the velocity of one pellet moving in the shot cloud with the average velocity of the centre of gravity. The probability that two pellets hit the target with the same velocity can be assumed to be absolutely unrealistic due to the fact, that the velocity in the shot cloud varies, those in the tip having the higher velocities compared to those in the end.

However, if we assume that the pellets hit with the average velocity of the center of gravity of 139 m/s relative to the moving clay, target A will break based on $v_{50} = 175$ m/s for one pellet and its standard deviation of 15 m/s with a very small probability of:

$$p_1 = 0.82\%.$$

Even if another pellet hits with the same velocity of 139 m/s, according to eq. 5.2.4 the total probability would still be very small:

$$p_2 = 1.6\%.$$

The measurement of the simultaneous hits tells us (see tab. 5-2-2) that for this velocity $p$ will be:

$$p = 50\%,$$

which means an increase by a factor of more than 30!

This example demonstrates the importance of the drop of 34 m/s of the $v_{50}$-value for two simultaneous hits compared to one and explains why for larger distances the clay targets are broken. This can be seen from another example. Tab. 4-2-1 indicates for 420 FCH a velocity at impact for a fast shooter of 176 m/s, subtracting the velocity of the clay target of 21 m/s leads to an impact velocity of

$$155 \text{ m/s},$$

which relates to a breaking probability of A-targets of

$$6.5\% !$$

This figure clearly indicates that breaking of the clay targets with the second shot beyond a distance of 39 m from the shooter must result from multiple shots hitting the target simultaneously.
However, the faster ammunition must have also a larger radial velocity leading to a reduced pellet density at the center of gravity.

Therefore, the distribution of the pellets in the radial direction and density close to the centre of gravity will have a strong influence on the probability that more than one shot hit the target.

Kneubuehl measured the radial dispersion using a few shot paper screen looking at the rosette of paper holes produced by the shot cloud. However, systematic measurements with a large number of repetitive measurements were not performed. This leads to the next chapter.

6 Shot pattern and hitting probability

If three pellets hit the target with 155 m/s relative to its movement, the breaking probability goes up for target A to 97 % and for target B to 61 %. These figures for the breaking probability were calculated using an average standard deviation as given in Table 5-2-2. These figures show that a breaking probability close to 100 % at a distance of 39 m or beyond is only possible, if at least more than one pellet hit the target. Furthermore, beyond three simultaneous hits the target quality is not very important. On the other hand, target A has a higher breaking probability for a two pellets simultaneous hit compared to target B with 3 pellets. Due to the fact, that one has to assume that the probability of multi hits decreases with increasing numbers, the difference between A and B-targets is significant and has a higher influence on the success rate compared to the velocity difference of ammunition 420 FCH to 380 FCH. The difference of 4 m/s (see Tables 3-2-1 and 3-2-2) leads to a reduction of the breaking probability for one pellet hitting target A from 32.3 % to 24.9 % and for B from 4.9 % to 3.5 %, for two from 96.6 % to 94.0 % and 64.4 % to 57.1 % respectively and for three pellets from 99.98 % to 99.94 % and 96.99 % to 93.33 % respectively. These results mean that the concentration of the pellets in the centre of the shot cloud has a considerable influence for the success rate of the second shot. To study this in more detail rosette pattern of the pellet cloud hitting a paper screen were examined.

6.1 Shot pattern measurements [5.1]

Beretta has mounted in 2005 at a distance of 30 m perpendicular to the shooting direction a paper screen 1200 by 1200 mm. For each shot fired using a hand held gun the pattern produced was automatically measured with respect to its y,z coordinates of each pellet hole. 36 shots of 24 g ammunition and 71 cm barrel types (cylindrical: CYL, chocked: FCH) were shot with type A
ammunition, where the muzzle velocity tested with a cylindrical barrel was \( v_1 = 404.7 \text{ m/s} \) and Type B \( v_1 = 374.8 \text{ m/s} \).

The counting machine counted holes outside the range given by the size of the paper which means that not in all cases the paper was positioned in the centre of the counting machine. The machine provided a list which contains the position of the holes, which could be read and displayed on the screen as seen from figure 6.1.1:

![Fig. 6.1.1](image)

**Fig. 6.1.1:** One shot Type B FCH (033BFCH.doc) with a barrel length of 71 cm at 30 m distance, red circle depicts the standard deviation the blue one twice the standard deviation. The centre of the pellets is depicted by the red cross.

The next step was to read all 36 shots and depict it on the screen (see Fig. 6.1.2):
Each individual pattern of a shot out of the total of 36 has been positioned at the centre according to its average values in the X and Y direction. The number of pellets per shot is a little more than 300, which means that 10800 shots should have been counted. For the FCH barrel about 2300 pellets are missing and for the CYL barrel about 3800 or 21% and 35% of the total number of pellets.

In 2008 [5.4] the measurements were repeated by Beretta with a new counting machine with a higher resolution which lead to a counting result close to 100%.
A simple statistical evaluation leads to the following results, where the radius of the shot cloud was estimated from the radius within which 99.5% of the pellets (299.5 pellets) were found. This radius was estimated by linear extrapolation for CYL-shots from the two highest percentiles:

<table>
<thead>
<tr>
<th>Ammunition Barrel</th>
<th>muzzle velocity m/s</th>
<th>sd mm</th>
<th>pellets 1*sd %</th>
<th>pellet 1/44 cm² 1</th>
<th>pellets 2*sd %</th>
<th>radius mm</th>
<th>year</th>
</tr>
</thead>
<tbody>
<tr>
<td>B FCH</td>
<td>&lt; 374.8</td>
<td>200</td>
<td>38</td>
<td>4.6</td>
<td>86</td>
<td>636</td>
<td>2005</td>
</tr>
<tr>
<td>A FCH</td>
<td>&lt; 401.7</td>
<td>213</td>
<td>37</td>
<td>4.7</td>
<td>87</td>
<td>655</td>
<td>2005</td>
</tr>
<tr>
<td>B CYL</td>
<td>374.8</td>
<td>284</td>
<td>31</td>
<td>1.8</td>
<td>89</td>
<td>573</td>
<td>2005</td>
</tr>
<tr>
<td>A CYL</td>
<td>401.7</td>
<td>290</td>
<td>30</td>
<td>2.5</td>
<td>90</td>
<td>579</td>
<td>2005</td>
</tr>
<tr>
<td>B FCH</td>
<td>380</td>
<td>161</td>
<td>44</td>
<td>9.7</td>
<td>86</td>
<td>567</td>
<td>2008</td>
</tr>
<tr>
<td>A FCH</td>
<td>420</td>
<td>165</td>
<td>42</td>
<td>9.1</td>
<td>86</td>
<td>561</td>
<td>2008</td>
</tr>
<tr>
<td>B CYL</td>
<td>380</td>
<td>256</td>
<td>36</td>
<td>3.3</td>
<td>86</td>
<td>596</td>
<td>2008</td>
</tr>
<tr>
<td>A CYL</td>
<td>420</td>
<td>256</td>
<td>37</td>
<td>3.4</td>
<td>85</td>
<td>616</td>
<td>2008</td>
</tr>
</tbody>
</table>

Table 6-1-2: Standard deviation SD and the % of pellets within a radius of the standard deviation, and within twice the standard deviation. The last column is the radius estimated either by the 99.5% or by linear extrapolation from radiiuses of the two highest percentiles.

The standard deviation of the CYL barrel is about 1.8 of the standard deviation of the FCH barrel and the percentage of pellets within a circle of the size of the standard deviation is 18% higher for FCH barrels compared to CYL barrels. The latter means that the circle is smaller but also that more pellets are within that circle. The main difference between the 2005 and the 2008 measurements is, that in 2008 practically all pellets were counted, whereas in the 2005 measurements between 20 to 35% were missed. Due to the fact that those missed pellets are close to other pellets, it is not surprising that the 2005 measurements underestimate the pellet number in the centre up to a factor of 2 as can be seen from Table 6.1.2, column “Pellets 1/44 [1/cm²]”. Therefore, only the 2008 measurements are taken for further considerations.
The number of pellets per 44 cm$^2$ in Table 6-1-2 is calculated for a round area of radius 37.4 mm around the centre. This is approximately the projected area of the clay target seen by the shot cloud (see Fig. 5.2.3 left side). The 2008 ammunition shot with a FCH barrel shows an increase of about 5% for the slower ammunition at the centre, which means simultaneous hits are more likely if the clay is at the centre for the slower ammunition. The increase of shots at the center between FCH and CYL-barrels is in the order of 3. This leads to the question, how the pellets in the cloud are distributed. For this purpose the 2008 shots are analyzed in more details. This is given in the following four tables for the two barrel and ammunition types.

**A-FCH**

**Standard deviation: 164.65 mm  Percentage of shots: 42 %  2xStandard deviation: 86 %**

<table>
<thead>
<tr>
<th>Radius (Mm)</th>
<th>Pellets %</th>
<th>Pellets n</th>
<th>Normal %</th>
<th>Distribution Pellets n</th>
<th>Radius of Sphere (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>3.0</td>
<td>9.1</td>
<td>2.5</td>
<td>7.5</td>
<td>356.0</td>
</tr>
<tr>
<td>102</td>
<td>20.1</td>
<td>60.2</td>
<td>17.6</td>
<td>52.8</td>
<td>355.0</td>
</tr>
<tr>
<td>130</td>
<td>29.9</td>
<td>89.8</td>
<td>27.1</td>
<td>81.2</td>
<td>359.0</td>
</tr>
<tr>
<td>158</td>
<td>40.0</td>
<td>120.1</td>
<td>37.3</td>
<td>112.0</td>
<td>365.0</td>
</tr>
<tr>
<td>185</td>
<td>49.8</td>
<td>149.4</td>
<td>47.4</td>
<td>142.1</td>
<td>371.0</td>
</tr>
<tr>
<td>217</td>
<td>59.7</td>
<td>179.2</td>
<td>58.7</td>
<td>176.0</td>
<td>384.0</td>
</tr>
<tr>
<td>252</td>
<td>69.9</td>
<td>209.6</td>
<td>69.6</td>
<td>208.9</td>
<td>397.0</td>
</tr>
<tr>
<td>291</td>
<td>79.8</td>
<td>239.5</td>
<td>79.6</td>
<td>238.8</td>
<td>409.0</td>
</tr>
<tr>
<td>352</td>
<td>89.7</td>
<td>269.1</td>
<td>90.2</td>
<td>270.7</td>
<td>440.0</td>
</tr>
<tr>
<td>561</td>
<td>99.5</td>
<td>298.6</td>
<td>99.7</td>
<td>299.2</td>
<td>585.0</td>
</tr>
</tbody>
</table>

Table 6-1-3: A-ammunition FCH barrel 71 cm, pellet distribution at 30 m
B-FCH

Standard deviation: 160.38 mm  Percentage of shots: 44 %  2xStandard deviation: 86 %

<table>
<thead>
<tr>
<th>Radius (Mm)</th>
<th>Pellets %</th>
<th>Pellets n</th>
<th>Normal %</th>
<th>Distribution Pellets n</th>
<th>Radius of Sphere (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>3.2</td>
<td>9.7</td>
<td>2.6</td>
<td>7.9</td>
<td>345.0</td>
</tr>
<tr>
<td>96</td>
<td>20.0</td>
<td>60.0</td>
<td>16.7</td>
<td>50.0</td>
<td>335.0</td>
</tr>
<tr>
<td>124</td>
<td>30.0</td>
<td>90.0</td>
<td>26.5</td>
<td>79.4</td>
<td>342.0</td>
</tr>
<tr>
<td>150</td>
<td>39.9</td>
<td>119.6</td>
<td>36.4</td>
<td>109.1</td>
<td>348.0</td>
</tr>
<tr>
<td>177</td>
<td>49.8</td>
<td>149.4</td>
<td>46.8</td>
<td>140.3</td>
<td>355.0</td>
</tr>
<tr>
<td>207</td>
<td>59.7</td>
<td>179.1</td>
<td>57.8</td>
<td>173.5</td>
<td>367.0</td>
</tr>
<tr>
<td>243</td>
<td>69.9</td>
<td>209.7</td>
<td>69.6</td>
<td>208.8</td>
<td>383.0</td>
</tr>
<tr>
<td>281</td>
<td>79.7</td>
<td>239.2</td>
<td>79.7</td>
<td>239.0</td>
<td>396.0</td>
</tr>
<tr>
<td>343</td>
<td>89.6</td>
<td>268.8</td>
<td>90.7</td>
<td>272.1</td>
<td>429.0</td>
</tr>
<tr>
<td>567</td>
<td>99.5</td>
<td>298.5</td>
<td>99.8</td>
<td>299.5</td>
<td>592.0</td>
</tr>
</tbody>
</table>

Table 6-1-4:  B-ammunition FCH barrel 71 cm, pellet distribution at 30 m
A-CYL

Standard deviation: 255.90 mm  Percentage of shots: 37 %  2xStandard deviation: 85 %

<table>
<thead>
<tr>
<th>Radius (Mm)</th>
<th>pellets %</th>
<th>pellets n</th>
<th>normal %</th>
<th>distribution pellets n</th>
<th>radius of sphere (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>1.1</td>
<td>3.4</td>
<td>1.0</td>
<td>3.1</td>
<td>592.0</td>
</tr>
<tr>
<td>172</td>
<td>20.0</td>
<td>60.1</td>
<td>20.5</td>
<td>61.4</td>
<td>599.0</td>
</tr>
<tr>
<td>220</td>
<td>29.9</td>
<td>89.6</td>
<td>31.4</td>
<td>94.2</td>
<td>608.0</td>
</tr>
<tr>
<td>268</td>
<td>40.0</td>
<td>119.9</td>
<td>42.9</td>
<td>128.8</td>
<td>620.0</td>
</tr>
<tr>
<td>318</td>
<td>50.0</td>
<td>149.9</td>
<td>54.7</td>
<td>164.0</td>
<td>637.0</td>
</tr>
<tr>
<td>364</td>
<td>59.8</td>
<td>179.3</td>
<td>64.6</td>
<td>193.7</td>
<td>644.0</td>
</tr>
<tr>
<td>416</td>
<td>69.7</td>
<td>209.2</td>
<td>74.2</td>
<td>222.7</td>
<td>656.0</td>
</tr>
<tr>
<td>472</td>
<td>79.6</td>
<td>238.9</td>
<td>82.6</td>
<td>247.7</td>
<td>666.0</td>
</tr>
<tr>
<td>544</td>
<td>89.7</td>
<td>269.0</td>
<td>90.2</td>
<td>270.5</td>
<td>680.0</td>
</tr>
</tbody>
</table>

Table 6-1-5: A-ammunition CYL barrel 71 cm, pellet distribution at 30 m
B-CYL

Standard deviation: 256.14 mm  Percentage of shots: 36 %  2xStandard deviation: 86 %

<table>
<thead>
<tr>
<th>Radius</th>
<th>pellets</th>
<th>pellets</th>
<th>normal</th>
<th>distribution pellets</th>
<th>radius of sphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mm</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>mm</td>
</tr>
<tr>
<td>37</td>
<td>1.1</td>
<td>3.3</td>
<td>1.0</td>
<td>3.1</td>
<td>599.0</td>
</tr>
<tr>
<td>180</td>
<td>20.1</td>
<td>60.3</td>
<td>22.6</td>
<td>67.7</td>
<td>626.0</td>
</tr>
<tr>
<td>228</td>
<td>30.1</td>
<td>90.2</td>
<td>34.2</td>
<td>102.5</td>
<td>627.0</td>
</tr>
<tr>
<td>273</td>
<td>39.8</td>
<td>119.5</td>
<td>45.4</td>
<td>136.1</td>
<td>633.0</td>
</tr>
<tr>
<td>314</td>
<td>49.8</td>
<td>149.4</td>
<td>55.2</td>
<td>165.7</td>
<td>630.0</td>
</tr>
<tr>
<td>365</td>
<td>59.8</td>
<td>179.3</td>
<td>66.3</td>
<td>198.9</td>
<td>646.0</td>
</tr>
<tr>
<td>417</td>
<td>69.7</td>
<td>209.1</td>
<td>75.9</td>
<td>227.6</td>
<td>658.0</td>
</tr>
<tr>
<td>474</td>
<td>79.7</td>
<td>239.2</td>
<td>84.1</td>
<td>252.3</td>
<td>667.0</td>
</tr>
<tr>
<td>535</td>
<td>89.6</td>
<td>268.8</td>
<td>90.4</td>
<td>271.2</td>
<td>669.0</td>
</tr>
</tbody>
</table>

Table 6-1-6: B-ammunition CYL barrel 71 cm, pellet distribution at 30 m

The standard deviation $\sigma_p$ has been directly calculated from the original measured data. The areal distribution $\rho_F(r,\varphi)$ is given by:

\[
(6.1.1) \quad \rho_F(r,\varphi) = \frac{1}{(2\pi \sigma_p)^2} e^{-r^2/(2\sigma_p^2)}
\]

and the number of pellets within radius $r$ is given by:

\[
(6.6.2) \quad R(r) = N_L * (1 - e^{-r^2/(2\sigma_p^2)})
\]
where \( N_0 \) is the number of pellets per load assumed to be 300.

As can be seen from the above four tables, the model of the normal distribution underestimates for the center area the number of pellets for the FCH shots by 22% and for the CYL shots by 8%. For the FCH-ammunition the radius where the actual number of pellets becomes equal to that obtained by the normal distribution is at 250 mm and for CYL-ammunition at 300 mm.

To describe the pellet distribution at the centre other models might be used instead of the normal distribution.

### 6.2 Areal distribution of the pellets

The measurements of the rosette provide the distribution of the pellets in the \( z, y \)-plane, when \( x \) is the shooting direction. It can safely be assumed that the shooting cloud is rotational symmetric around the shooting direction axis at \( P(x,0,0) \). The distribution of the spatial density \( \rho \) is given by:

\[
\rho(x,y,z) \tag{6.2.1}
\]

where \( \rho \) describes the number of pellets in a unit volume \( dV \). Integrating over the \( x \) coordinate leads to the aerial distribution \( \rho_F \):

\[
\rho_F = \rho_F(y,z) \tag{6.2.2}
\]

which is rotational symmetric around the origin and is measured by the rosette patterns. The mean position \( \langle y \rangle \) and \( \langle z \rangle \) are given by:

\[
\langle y \rangle = \int \rho_F(y,z) \cdot y \cdot dy \cdot dz \tag{6.2.3}
\]

\[
\langle z \rangle = \int \rho_F(y,z) \cdot z \cdot dy \cdot dz \tag{6.2.4}
\]

\( \langle y \rangle \) and \( \langle z \rangle \) describe the best estimate for the shooting direction. If those values are zero the standard deviation is given by:

\[
\sigma_y^2 = \int \rho(y,z) \cdot y^2 \cdot dy \cdot dz \tag{6.2.5}
\]

\( \sigma_z^2 \) is defined accordingly. The symmetry assumption means that \( \sigma_z^2 = \sigma_y^2 \).

The spatial distribution must fulfill the following relationship:
(6.2.6) \[ N_L = \int_V \rho(x, y, z) \, dx \, dy \, dz \]

where \( N_L \) is the number of pellets in one shot and \( V \) the volume. Similarly one obtains:

(6.2.7) \[ N_L = \int_F \rho(y, z) \, dy \, dz \]

where \( F \) is the total area of the rosette \( \rho_F(y, z) \) in the \( y, z \)-plane.

Since the rotational symmetry is assumed the aerial density depends only on distance \( r_F \) from the origin. The radial density, \( \rho_r \), is obtained:

(6.2.8) \[ \rho_r(r) = \int_0^{2\pi} \rho_F(r, \varphi) \, r \, d\varphi = 2\pi r \rho_F(r) \]

The radial density can now be integrated to obtain radial sum distribution \( R(r) \):

(6.2.9) \[ R(r_F) = \int_0^r 2\pi r \rho_F(r_F) \, r \, dr \]

where \( R(r_F) = N_L \) and \( r_0 \) is the radius of the volume which includes all pellets. The latter might be a definition of the radial size of the shot cloud. The above formulas can be used for different model shot clouds to calculate \( R(r) \) either by analytical integration or numerically.

Different assumption on the distribution of the pellets in the shot cloud can reasonably be assumed. A very general approach is to assume that the pellet density in the shot cloud is inverse proportion to the distance \( r \) to the power of \( \varepsilon \) and adjustable parameter between 0 and 2:

(6.2.10) \[ \rho_F(x, y, z) = \frac{c}{r^\varepsilon} \]

where \( \varepsilon = 0 \) means that the pellet density is constant within the sphere of radius \( r_0 \) and \( \varepsilon = 2 \) that the pellet density reduces proportional the square of the distance.

The number of pellets \( N_L \) is related to constant \( c \) under the assumption of spherical symmetry by:

(6.2.11) \[ c = N_L / (4\pi)(3 - \varepsilon) r_0^{\varepsilon-3} \]
The parameters $r_0$ and $\varepsilon$ can be varied to obtain an optimal approximation to the measured data:

<table>
<thead>
<tr>
<th>Ammunition</th>
<th>$\varepsilon$</th>
<th>$r_0$</th>
<th>measured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 mm</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>A FCH</td>
<td>1.0</td>
<td>368</td>
<td>90</td>
</tr>
<tr>
<td>B FCH</td>
<td>1.15</td>
<td>360</td>
<td>92</td>
</tr>
<tr>
<td>A CYL</td>
<td>0.80</td>
<td>587</td>
<td>~ 95</td>
</tr>
<tr>
<td>B CYL</td>
<td>0.80</td>
<td>609</td>
<td>~ 95</td>
</tr>
</tbody>
</table>

Table 6-2-1: Approximation of the radial distribution of the shot cloud in the y,z plan

The measured percentage of pellets within $r_0$ is obtained from tables 6-1-3 to 6-1-6.

The result indicate that the CYL A and CYL B ammunition are very similar, were as FCH B has a smaller size expressed by $r_0$ and a higher concentration at the centre, which is expressed by $\beta$ values 15% higher compared to the FCH A $\beta$-value.

The quality of the approximations can be seen from Fig. 6.2.1 for the FCH B ammunition on the basis of the radial density $R(r)$ measured and approximated:
The measured radial distribution (brown) as function of the radius has been averaged over 10 mm. The distribution still shows a considerable variance, which can only be explained by the limited number of shots (12) used for the measurement. Averaging over greater distances might lead to a distribution produced by this averaging and therefore the averaging was limited to the 10 mm.

The approximations for the other shot types look very similar, especially the reproduction of the situation for smaller radiiuses below 100 mm from the center. This means that a realistic numerical simulation should be done using the measured data instead of an approximation such as given above, for which - due to the limited number of 12 shots – no hard statistical proof can be given.

For the first shot the distance where the shot hits the target is close to 30 m. As can be seen from the above tables simultaneous hits are very likely with pellet velocities beyond 200 m/s. However, as has been pointed out in chapter 4.2 the point of of impact the second shot is beyond 39 m up to 50 m. Depending on the radial velocity in the y,z –plane the radius of the shot cloud will increase.
To obtain information about this radial velocity additional rosette pattern measurement were performed by Beretta May 2011 which lead to the following results [5.4, 5.5]:

<table>
<thead>
<tr>
<th>Distance m</th>
<th>Type B $V_{2.5}$ 375 m/s</th>
<th>Type C $V_{2.5}$ 358 m/s</th>
<th>Type B Flight time s</th>
<th>Type C Flight time s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radius 187.5 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>140.5</td>
<td>160.8</td>
<td>0.104</td>
<td>0.116</td>
</tr>
<tr>
<td>45</td>
<td>39.0</td>
<td>51.0</td>
<td>0.185</td>
<td>0.200</td>
</tr>
<tr>
<td>Radius 375 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>273.6</td>
<td>299.1</td>
<td>dito</td>
<td>dito</td>
</tr>
<tr>
<td>45</td>
<td>123.0</td>
<td>152.0</td>
<td>dito</td>
<td>dito</td>
</tr>
</tbody>
</table>

Tab. 6-2-2: Number pellets found at 30 m and 45 m distance within a circle of 187.5 mm and 375 mm including the flight time obtained from shooting tables 3-2-1 and 3-2-2 for the muzzle velocity at 2.5 m of 375 m/s for ammunition B and 358 m/s for ammunition C.

The 30 m values correspond well for ISO B to the results of 2008 given in table 6-1-4.

If the radial velocity is proportional to the distance from the centre the reduction of the number of pellets is proportional to square of $t_{30}/t_{45}$. Using the number of pellets at 30 m one obtains for the 45 m distance:

<table>
<thead>
<tr>
<th>Radius mm</th>
<th>Type B pellets measured</th>
<th>Type B pellets calculated</th>
<th>Type C pellets measured</th>
<th>Type C pellets calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>187.5</td>
<td>39</td>
<td>44</td>
<td>51</td>
<td>54.1</td>
</tr>
<tr>
<td>375</td>
<td>123.0</td>
<td>86</td>
<td>152</td>
<td>100.6</td>
</tr>
</tbody>
</table>

Tab. 6-2-3: Measured and calculated number of pellets within circled areas of radius 187.5 mm and 375 mm.
The above results fit within 10% for the inner circle of 187.5 mm but underestimate the pellet numbers for 375 mm by 50%. This latter observation fits with the description of the shot clouds FCH density by an exponential factor β of 1.1 to 1.15 (see eq. 6.2.11), due to the fact that a proportional increase to the square of time leads directly to $\beta = 2$. The results above indicate that the radial velocity within the shot cloud does not increase proportional to the distance to the center. However, due to the measured fact that the number of pellets in the inner circle behave within 10% according to the above assumption $(t_{30}/t_{45})^2$, the assumption can be used for the simulation due to the fact that this part of the shot cloud determines, whether or not a shot can break a clay target.

### 6.3 Numerical simulation

The basic idea for the numerical simulation is to understand the whole process of hitting and breaking the target in more details. To be as realistic as possible the measured rosettes of 2008 are used, assuming that for the calculated hitting distance the pellets increase the distance $r$ from the centre by $d_c$ proportional to flight time of the shot cloud $t_{30}$ to 30 m and the hitting distance $t_h$:

$$r = d_c \frac{t_h}{t_{30}}.$$

This assumption leads - as we have seen in the last chapter - to a small underestimation of the pellet density around the centre. Furthermore, it is assumed that the centre of gravity of each shot is normally distributed with a variance equal to 37.5 mm the averaged radius of the area of the clay target exposed to the shot cloud. Furthermore, the rosettes are rotated around the shooting direction at random. The numerical simulation uses measured rosettes, each with 1,000 shots varied at random.

Additionally, we have to consider that the time of the second shot fired is less for a top shooter compared to an average shooter as it has been measured by DEVA (see chapter 4.2). The flight time of the shot cloud also depends on the angle alpha under which the clay target is thrown. The probability of breaking the target depends on the breaking velocity, which is chosen according to table 5-2-2 for target type B $v_{50}=193$ m/s and a variance of 21 m/s including the reductions for simultaneous hits.

For a fast shooter an angle alpha = 45° the hitting distance from the muzzle is for FCH A 39.2 m and for a slower shooter 41.0 m. For FCH B one obtains 39.3 m and 41.1 m respectively.

Under those conditions we obtain the following distribution of hits:
Fig. 6.3.1: A FCH alpha 45° $v_0 = 193$ m/s $\sigma = 21$ m/s. Green line percentage broken targets, black line number simultaneous hits and red line percentage of unbroken clay targets, fast shooter.

The black line depicts the percentage hit with one, two etc. pellets simultaneously. The green line gives the percentage broken and the red line the non-broken. The highest probability of hitting the target simultaneously is 5. The total percentage broken is 95.7 %. The total success rate is limited by the fact that about 2.5 % of the shots hit only with one pellet and no target broken (green line).

Under same conditions using FCH B one obtains:
For the slower B ammunition an increase of 2 % of the success rate is observed and the maximum number of simultaneous hits is 6. This means that for this situation the slower ammunition has a slight advantage, which is caused by the reduction of the number of single hits.

The largest distance between the muzzle of the shooter and the impact position is under alpha = 0 and for an average shooter. One obtains for FCH A:
Fig. 6.3.3: A FCH alpha 0° $v_{50} = 193$ m/s sigma = 21 m/s. Green line percentage broken targets, black line number simultaneous hits and red line percentage of unbroken clay targets, slow shooter

The breaking probability is 81.6 % governed by 2 % missed and 10 % unsuccessful single hits and 6 % unsuccessful double hits, whereas for the slower B-ammunition:
For the slower ammunition the breaking probability increases to 87.9 %, which means that even the slower shooter can improve his success rate using slower ammunition producing more simultaneous hits with no increase of those missed. If the $v_{50}$ value of the breakability goes down to the value of target A of 176 m/s and a variance of 12.5 a small increase to 92.2 is observed.

The clear message of this simulation is, that without considering other aspects such as the recoil of the faster ammunition - which necessarily increases the variance of the shots – the slower ammunition increases the success rate of the shooter independent weather it is a fast or a slow shooter. This leads to the next question, whether or not this difference can be observed under the condition of a shooting range.
7 Field test [9.6]

7.1 Introduction and task

Measurements of the sound source strength expressing the sound emission of different shot guns and ammunition types (420, 400, 380, 360 m/s) showed that reducing the muzzle velocity leads to a reduction of the sound emission. Reducing the muzzle velocity from 400 m/s to 380 m/s showed the highest drop of the sound emission level, with the least level achieved by the 360 m/s ammunition (see chapter 2).

On the other hand, reducing the muzzle velocity will also reduce the lateral velocity of the shot cloud when hitting the target. The question was whether or not the reduction of the muzzle velocity down to 360 m/s might lead to pellet velocities which are well below the 50 % value for the destruction velocity of the clay target with one pellet.

Numerical simulation done by Kuehner [2.5] (see also chapter 6) show that at 30 m as well as beyond 40 m depending on the barrel used (cylindrical or choked) more than one pellet hits the target frequently. From this simulation based on measured shot pattern ([8.3]) it can also be seen, that with increasing muzzle velocity the radial velocity increases, which means a reduction of the hitting probability.

Due to the fact, that the above described considerations are all based on measurements in the laboratory or computer simulation, a field test was needed to elaborate whether or not the above findings can be proven under realistic conditions in a shooting range and where the optimum can be expected.

Three Field Tests have been performed at the Clay Shooting Range at Cieli Aperti (Bg), Italy December 2009, September and November 2010, which will be reported in the following chapters.

7.2 First field test on clay target shooting – December 2009

7.2.1 Introduction

The first Field Test has been carried out at the Clay Target Shooting Range “Cielo Aperti”, Martinengo (Bg) in Italy on December 10th and 11th 2009.

- The first objective of this test was to evaluate the breakage performance of ammunition with reduced initial velocity compared to ammunition with standard velocities. The criteria are
the breakage performance at shooting distances between 35 and 40 m – using the second barrel with one shot only.

- The second objective of this test was to observe shot pellet markings on missed clay targets after landing on the ground. This examination should show if one or more pellet hits of clay targets will result in no breakage.

- In total 880 clay targets has been launched during the test.

- Ammunition used:
  Hand loaded ammunition: Gauge 12/70, 2.41 mm, 24g by FIOCCHI Munizioni:
  Type A: initial velocity 420 m/s (standard)
  Type B: initial velocity 380 m/s (reduced velocity)

7.2.2 Test

Three professional shooters have been involved in this test. They used two of their own shot guns – second barrel only. 440 clay targets have been launched and shot at with each ammunition type. The shooters fired from stand No. 3 only. Only the centre launching machine of this stand has been activated. The machine was fixed to a launching angle $< \beta/2$, launching elevation app. 15° (see Appendix 10.1, Fig. 10.1.3). Two markings have been built up on the shooting range in a distance between 35 and 40 m in front of the shooters position. This „hitting zone“ marking was an indication for the shooter to hit the clay target in this range (see Appendix 10.2, Fig. 10.2.1).

Shooter No.1 used a Beretta Shot Gun 12/70 Model SO10 Serial No. SOTO16B, Barrel length: 71 cm. Second barrel: full choke 10/10. He fired the second barrel only during the test. Shooters No. 2 and 3 used one Beretta Shot Gun 12/70 Model 682 Serial No.P30164B, Barrel length 81 cm. Second barrel: choke 8/19 two stars. The shooters did load both barrels and missed consciously the clay with the first shot, and aimed and fired on the clay target with the second shot. It is not easy – even not for professional skilled shooters - to hit the clay target on these long distances using the second barrel only, because this shooting technique is completely contrary to the trained shooting technique for Olympic Trap Discipline. A Safety Cabin with a person has been placed on the shooting range at a distance of app. 60 m in front of the shooters position to collect unbroken clay targets after shooting. The person collected an unbroken missed clay target immediately after landing on the ground and checked it for shot pellet markings. The weather conditions were perfect test conditions, no wind, sunny or light clouds and temperatures at shooting range of 10 ± 3°C.
7.2.3 Test results

Detailed results in tabular form are listed in Appendix 10.3 [9.6] and can be summarized as:

The percentage and number of broken clay targets were:

<table>
<thead>
<tr>
<th>Ammunition</th>
<th>broken %</th>
<th>number broken</th>
<th>total fired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>24.1</td>
<td>106</td>
<td>440</td>
</tr>
<tr>
<td>Type B</td>
<td>28.6</td>
<td>126</td>
<td>440</td>
</tr>
</tbody>
</table>

Shot pellet markings found on non broken clay targets:
App. 15% of all not broken clay targets did show 1 pellet marking and app. 4 % did show 2 pellet markings – hits due to impacts of lead shot pellets on the clay targets. There was no difference found for the amount of marked clay targets fired with ammunition types A and B on it.

7.2.4 Discussion

One can state that there is no statistical significant difference in breakage performance between ammunition type ISO A and ISO B using the second barrel only at the distance 35 and 40 m. However, the tendency is that B ammunition is more successful.

It is obvious that the shooter - respectively the shotgun - has an effect on the performance.

It is important to note that a remarkable number of non broken clay targets did show one or two shot pellet markings. This means that the clay targets have been hit by one or two pellets at the distance of 35 to 40 m without breaking. From this follows that a high breakage probability can be achieved with multi pellet hits (minimum 3 pellets) only. This was accounted for in further clay target breakability tests by STAS.

Measurements performed by Quartini in 2010 [4.16] show as described in chapter 6.1, that the 50 % value for breaking the target reduces by about 15 m/s for each additional pellet hitting the target simultaneously. This finding explains why even for larger distances beyond 40 m a considerable success rate of breaking the target can be observed, even when the average velocity is below 165
m/s. It should be noted that the breaking velocity varies considerably due to the quality differences of the clay targets (brands and lots).

It is well known and demonstrated in chapter 6.2 that cartridges with a lower initial velocity result in a shot pattern with higher densities more pellet hits on clay target surface of 44 cm². Therefore it is important to examine shot pattern of both cartridge types at 30 and > 40 m shooting distances with a further field test according to Olympic Trap Regulations with a minimum of 10 shooters using their own shotguns.

7.3 Second field test, September 2010

7.3.1 Introduction

This test was performed again at the shooting range “Cieli Aperti” Matinego, (Bg) Italy on September 20. / 21. September 2010.

The objective of this 2nd field test was to compare the performance of two ammunition types with different initial velocities under realistic trap shooting conditions with several shooters using their own shot guns. The Type A and Type B ammunition used was produced by Fiocchi Munizioni. The data obtained by the ballistic laboratory showed a high velocity range of both cartridge types. Therefore, the velocities of ammunition A and B were checked before the second field test with all shot guns of the 18 shooters measuring at 2, 5 m in front of the muzzle. To calculate the velocities close to the muzzle (v at 0.5 m) a velocity drop of Δ 15 m/s was added to measured values of v at 2.5 m distance.

The average velocity of all shot guns, which have been used during the 2nd field test was for ammunition Type A (v₀.₅ₐₐₙₐ = 437 m/s) which represents the upper velocity level and ammunition Type B (v₀.₅ₐₐₐₐ = 403 m/s) which represents the standard velocity level on the market. The velocity test of both test ammunition types showed too high values compared to values of the test design. Therefore, it was decided to carry out a performance test using this two ammunition types under the same test conditions. The used ammunition types represented “high velocity” and “standard velocity” ammunition. Another objective of the 2nd field test was the evaluation of the clay target quality on its breakage performance. Therefore, two different brands were used named A and B.
During the tests perfect weather conditions were observed with temperatures of 18 to 22 °C, rel. humidity 60 to 70 % and no wind. The ammunition storage conditions were temperatures of app. 20 °C and rel. humidity of app. 60 %.

7.3.2 Test

The shooting teams were provided by FIOCCHI Munizioni, by Beretta and the management of the shooting range. The teams consisted on the first day of 12 shooters, on the second day of 12 shooters again, but six shooters have been substituted by other shooters.

The test firing was carried out again according the Olympic Trap Shooting Regulations.

The shooters fired on the first day 75 series (1875 clays), on the second day 39 series (975 clays) using two brands of clay targets with a 50 to 50 % ratio.

7.3.3 Test results

7.3.3.1 Clay target breakability – depending on different ammunition initial velocities.

Appendix 10.4 [9.6] shows a summary of the test results in tabular form.

7.3.3.2 Statistical evaluation of 2nd field test

The data evaluation was done using a distribution free Bays statistic, which is based on the incomplete ß-function [8.7]. For the evaluation the number of clay targets \( N \) describes the number of events and \( m_1 \) the number of clay destroyed by the first shot and \( m_2 \) the number destroyed with the second shot. The probability of destroying the target is expressed by the estimated 50 % value (success rate), the upper and lower limit of this probability by 5 % and 95 % (lower and upper confidence limits). The probability is expressed in percentage.
Ammunition Type A \( v_{0.5 \text{ m}} 437 \text{ m/s} \)

<table>
<thead>
<tr>
<th></th>
<th>All shots</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>First shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>Second shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>M</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>n_1</td>
<td>m_1</td>
<td>%</td>
<td>%</td>
<td>n_2</td>
<td>m_2</td>
<td>%</td>
</tr>
<tr>
<td>1000</td>
<td>861</td>
<td>84.3</td>
<td>\textbf{86.2}</td>
<td>87.9</td>
<td>1000</td>
<td>776</td>
<td>75.5</td>
<td>\textbf{77.7}</td>
<td>79.8</td>
<td>224</td>
<td>85</td>
<td>32.4</td>
</tr>
</tbody>
</table>

Ammunition Type B \( v_{0.5 \text{ m}} 403 \text{ m/s} \)

<table>
<thead>
<tr>
<th></th>
<th>All shots</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>First shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>Second shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>m</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>n_1</td>
<td>m_1</td>
<td>%</td>
<td>%</td>
<td>n_2</td>
<td>m_2</td>
<td>%</td>
</tr>
<tr>
<td>1850</td>
<td>1614</td>
<td>86.0</td>
<td>\textbf{87.3}</td>
<td>88.5</td>
<td>1850</td>
<td>1461</td>
<td>77.4</td>
<td>\textbf{79.0}</td>
<td>80.5</td>
<td>389</td>
<td>153</td>
<td>35.1</td>
</tr>
</tbody>
</table>

Table 7-3-3-2-1: Statistical evaluation of shooting tests ("\(>\)" denotes 95 % probability that the results are better and "\(<\)" are less;

The statistical interpretation may be explained. For the 1000 shots fired with ammunition A 861 targets were destroyed. The most probable value (50 %) was 86.2 %, however, the probability is 5 % that the value is below 84.3 % or above 87.9 %.

7.3.3.3 Clay target breakability – depending on two different brands

During the field test in September 2010 two different brands A and B clay targets have been included in the ammunition performance tests. Table 7-3-3-3-1 shows the test results for both clay target brands.

<table>
<thead>
<tr>
<th>Ammunition</th>
<th>Clay target band</th>
<th>Breaking probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 %</td>
<td>50 %</td>
</tr>
<tr>
<td>Type A</td>
<td>A</td>
<td>82.7</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>83.9</td>
</tr>
<tr>
<td>Type B</td>
<td>A</td>
<td>84.4</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>85.4</td>
</tr>
</tbody>
</table>

Table 7-3-3-3-1: Comparison of breaking probability of two clay target brands
7.3.4 Discussion

Table 7-3-3-2-1 shows that all success rates show no advantage for the use of “high velocity” ammunition - 86.2 % for high velocity ammunition in comparison to 87.3 % for standard velocity ammunition. The comparisons of the lower and upper confidence limits confirm this statement again, or formulated the other way around, the slower ammunition shows a slight advantage. Furthermore, all shooters stated that the recoil of the fast ammunition type was very inconvenient for the shooters. Therefore the shooters avoided to use ISO A compared to ISO B, which resulted in 1000 shots of Type A compared to 1875 of Type B.

Table 7-3-3-3-1 shows no significant difference in breakage performance between the clay target brands A and B.

Due to the fact that the muzzle velocities were too high, it was decided to perform a third field test with the objective to test the performance of ammunition with lower velocity than standard ammunition.

7.4 Third field test

7.4.1 Introduction

The objective of the 3rd Field Test was to carry out a performance comparison of two cartridge types: standard initial velocity and the other with reduced initial velocity.

7.4.2 Test

The teams were not identical for field tests 2 and 3. 12 shooters have been involved in the 3rd field test. However one shooter was later eliminated from the result of this field test due to the fact that his hitting score was significantly below those of all other team members. This field test was executed under Olympic Trap Regulations - in the same way as the 2nd field test. An additional type Type C ammunition has been loaded by Fiocchi Munizioni for this 3rd field test. Test result at Fiocchi Laboratory: Type C $v_{2.5}$ m = 362 m/s, calculated velocity $v_{0.5}$ m = 377 m/s. Before the 3rd field test has been carried out it was planned to use ammunition Type B from the 2nd field test again as the standard velocity ammunition and the new loaded ammunition Type C. Again during the 3rd field test the muzzle velocities were tested. It turned out, that the velocity of ammunition Type B was about 19 m/s slower than in the 2nd Field Test in September. To distinguish ammunition Type B in the first test from the second, the ammunition is denoted by Type B’ for the second test. The
new ammunition type Type C showed also a remarkable decrease in velocity compared to the expected value in the 3rd field test. The ammunition for the second test is denoted too by Type C'. The remarkable velocity drops were caused mainly by the different ammunition storage conditions due to the fact that shot shell ammunition is very sensitive with respect of temperature and humidity storage conditions.

Due to these circumstances ammunition type Type B' \(v_{0.5} = 384\) m/s represented ammunition according the Multi Task Study requirements with the "ideal velocity range. Ammunition Type C' \(v_{0.5} = 365\) m/s represented an ammunition type with an extreme low velocity level.

### 7.4.3 Test results

Appendix 10.5 shows a summary in tabular of the test results form.

#### 7.4.3.1 Statistical evaluation of 3rd field test

<table>
<thead>
<tr>
<th>Ammunition</th>
<th>Number of clays</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>First shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>Second shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n m % % % n m % % % n m % % % n m % % % n m % % % n m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type B' (v_{0.5} 384) m/s</td>
<td>1275 1133 87.4 88.9 90.3</td>
<td>1275 1002 76.7 78.6 80.5</td>
<td>273 131 42.7 47.6 52.6</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type C' (v_{0.5} 366) m/s</td>
<td>1250 1053 82.5 84.3 85.9</td>
<td>1250 919 71.5 73.6 75.6</td>
<td>331 134 35.9 40.2 44.7</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table 7-4-3-1-1: Statistical evaluation of shooting tests ("\(>\)" denotes 95 % probability that the results are better and "\(<\)" are less;

All the 50 % success rates of ammunition Type B' are significant higher than those of ammunition C'. The probability to destroy a clay target with ammunition C' with first and second shots is lower in comparison with ammunition B'.
7.5 Conclusion of all field tests

As can be seen from Table 7-5-1, where the results are collected, the total success rate of 88.9% has been achieved by using ammunition Type B’ with a velocity of 384 m/s for first and second shot.

The result is significant compared to the next best ammunition B with an upper confidence limit of for the success rate of 88.5%. The highest success rate of 79.0% with the first shot is obtained by Type B with a muzzle velocity of 403 m/s and a rate compared to B’ with 78.6%. However, as can be seen by looking at the upper and lower confidence limits of 5% and 95%, the difference of 0.4% between Type B and B’ is not significant for the first shot. For the second shot the success rate for slower ammunition B’ is 47.6 % compared to 40.2 % of C’, 39.1 % of B and 37.5 % of A, which shows that the faster ammunition has the lowest performance with the second shot. The slower ammunition Type C’ shows the lowest success rate for both shots compared to all the others, which cannot be compensated by the slightly better performance of the second shot compared to Type A and B. It has to be to remarked that the use of “high velocity” ammunition like Type A will not increase the shooters performance rate on the range. The recoil of the weapon is remarkable higher and therefore much more unpleasant for the shooter – especially when he is involved in competition firing 125 clay targets connected with a lower pellet concentration at the center of the shot cloud.

### Results of 2nd and 3rd Field Test in September and November 2010

<table>
<thead>
<tr>
<th>Ammunition</th>
<th>All shots</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>First shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
<th>Second shot</th>
<th>5&gt;</th>
<th>50</th>
<th>&lt;95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>1000</td>
<td>861</td>
<td>84.3</td>
<td>86.2</td>
<td>87.9</td>
<td>1000</td>
<td>776</td>
<td>75.5</td>
<td>77.7</td>
<td>79.8</td>
<td>224</td>
<td>85</td>
</tr>
<tr>
<td>v₀,5 437 m/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Type B</td>
<td>1850</td>
<td>1614</td>
<td>86.0</td>
<td>87.3</td>
<td>88.5</td>
<td>1850</td>
<td>1461</td>
<td>77.4</td>
<td>79.0</td>
<td>80.5</td>
<td>389</td>
<td>153</td>
</tr>
<tr>
<td>v₀,5 437 m/s</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type B’</td>
<td>1275</td>
<td>1113</td>
<td>87.4</td>
<td>88.9</td>
<td>90.3</td>
<td>1275</td>
<td>1002</td>
<td>76.7</td>
<td>78.6</td>
<td>80.5</td>
<td>273</td>
<td>131</td>
</tr>
<tr>
<td>v₀,5 384 m/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type C’</td>
<td>1250</td>
<td>1053</td>
<td>82.5</td>
<td>84.3</td>
<td>85.9</td>
<td>1250</td>
<td>919</td>
<td>71.5</td>
<td>73.6</td>
<td>75.6</td>
<td>331</td>
<td>134</td>
</tr>
<tr>
<td>v₀,5 365 m/s</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>
Table 7-5-1: Statistical evaluation of shooting tests (">" denotes 95 % probability that the results are better and "<" are less;

This means that as a matter of fact the optimum is the ISO B’ ammunition with a muzzle velocity of 384 m/s. The result is in agreement with the numerical simulation given in chapter 6.3.

The optimal ammunition – in respect of shooters performance and sound emission – which has been used in the field test and sound level measurements has the following technical parameters:

**Calibre 12/70 [mm]**

- Lead pellets: ø 2.4 [mm]
- Lead pellet weight: 24 g
- Antimony alloy: 5%

- Average velocity: \( v_{2.5} \): 370 ± 5 [m/s]
- Standard deviation: ≤ 5.5 [m/s]
- Velocity measuring point: 2.5 m from the muzzle on 0,5 m base
- Test barrel: 700 mm CIP Test Barrel, CYL
- Number of test shots: 30

- Emitted Sound Energy level: 134 dB(A) re 10⁻¹² Joule
- Test Barrel: (710 mm FCH)
8 References

9.1 General Reports


[1.2] AFEMS 2002 Gen. Ass..ppt

[1.3] AFEMS 2005 Gen. Ass..ppt


9.2 Reports on Shooting Noise


[2.5] deBAKOM 06.2002.deBakomReport25032002_AFEMS.doc


[2.5.3] 06.2002.deBakomReport A P P E N D I X  C.doc


9.3 **Reports on External Ballistics**


[3.3] armasuisse 05.2005. External Ballistics Attachment

[3.4] DEVA) 05.2006.rev. DEVA Eng. 01.05.06-MW.doc, Determination of data on terminal ballistics for the points of impact between the shot and the clay target for clay target shooting (Olympic Trap) 4.2007 DEVA


9.4 Reports on clay targets


[4.5] STAS 08-clay-steess78ms-mov.avi

[4.6] Beretta 01.09.piattello_modinaturali_03.avi

[4.7] Beretta 01.09.piattello_modinaturali_02.avi

[4.8] Beretta 01.09.piattello_modinaturali_01.avi


[4.10] STAS 03.2009.STAS Clay-target.ppt

[4.11] STAS 2010 STAS -Clay Test Rev. 01.01.pdf, Method of determining the ballistics breakability of clay targets. Stas


9.5 Reports on hitting probability

[5.1] Beretta Addition: 08.07. Torcoli DATA-PROVADO


[5.5] Knappworst 06.11. Kn. Beretta 30 and 45 m Shot Pattern Test Results.xls

9.6 Reports on field test


[6.5] Knappworst 09.2010. Test Results 2.xls

[6.6] Knappworst 11 2010 Nov Test Results.xls


9.7 ISO Shooting noise standards


9.8 Other references


10 List of abbreviations

A  cross section area of pellets in m²
A', B', C'  the prime indicates muzzle velocities as measured on the test day
A_{gr}  correction due to ground reflection
a_j  coefficient for weighting the directivity
A-level  level obtained using A-weighting frequency filter
A_2  correction to standard meteorological condition
B  air pressure in h Pa
B_0  1013 h Pa reference pressure
c_D  air drag coefficient
CEN  European Committee for Standardisation
CYL  cylindrical barrel
D(\alpha)  directivity in dB
dc  expansion coefficient for the shot cloud during numerical simulation
DEVA  Deutsche Versuchs- und Prüfungsanstalt für Jagd- und Sportwaffen e.V.
d\nu/dt  acceleration respectively de – acceleration
E  adjustable parameter for the pellet distribution
FCH  full choked barrel
FEM  Finite Element Method
F_r  flow resistance of the ground
\bar{F_w}  force acting on the moving object in Newton
ISO  International Standard Organization
L_E  sound exposure level
L_{eq}  energy equivalent averaged sound level in dB
L_Q  source energy level
\bar{L_q}(\alpha)  angular energy distribution level
Machzahl  mach number
n  number of clay targets used / number of pellets
N_\alpha  number of angles
N_L  number of pellets in one shot
p  sound pressure in Pascal
p_0  reference sound pressure 2\cdot10^{-4} Pascal
Q  sound energy in Joule
Q_0  reference sound energy in Joule
r  radial distance to the line of fire or centre of gravity of the shot cloud in the y,z plane

\( r_m \)  

distance to the muzzle

\( r_F \)  

radial distance in a plane perpendicular to the shooting direction

\( R(r_F) \)  

radial sum distribution of the pellet

\( r_v \)  

radii of a volume including all pellets

\( S_0 \)  

sound power reference \( 10^{-12} \) W

\( S_p \)  

sound power in Watt

t  

time

\( T \)  

time span of a shooting event

\( T_k \)  

temperature in K

\( t_k \)  

hitting distance

\( T_{k0} \)  

296 K

\( T_0, t_0 \)  

reference time 1 s

Type A  

ammunition with a muzzle velocity of 425 m/s

Type B  

ammunition with a muzzle velocity of 385 m/s

\( t_{30} \)  

flight time of the shot cloud reaching 30 m distance

W71  

barrel length of 71 cm

W68  

barrel length of 68 cm

WTD 91  

technical military service for arms and ammunition of the German Federal Army

x  

coordinate in direction of the line of fire

X  

distance in the line of fire

\( x_w \)  

distance of the clay target from launcher in m

y,z  

perpendicular to x

\(<>\)  

mean value

\( \alpha \)  

angle between shooting direction and the line of observation

\( \beta \)  

angle of rotation around the shooting direction

\( \beta_0, \beta_1 \)  

parameter of the logistic distribution

\( \varepsilon \)  

power factor of radial distribution

\( \lambda \)  

wave length in m

\( \rho \)  

air density in kg/m³

q  

cross section density in kg/m²

\( \Delta \nu \)  

change in velocity in m/s

\( \Delta x \)  

change in distance in m

\( \nu_r \)  

radial expansion in m/s
\( v_u, v_l \) upper and lower velocity where targets are broken by one pellet used in the Langley Test in m/s

\( v_x \) velocity measured at distance \( x \) from the muzzle in m/s

\( b(v_x) \) probability of breaking of a clay target as a function of the pellet velocity \( v_x \)

\( \mu \) mean value of the probability distribution

\( \sigma, S_D \) standard deviation of the probability distribution

\( p_1 \) breaking probability for one pellet in %

\( p_n \) breaking probability for \( n \) pellets in %

\( v_{50} \) pellet velocity where 50 % of the clay targets break in m/s

\( p_F \) areal distribution of the pellet in a plane at a distance \( x \) perpendicular to the line of fire with the centre at the position of the line of fire, \( \varphi \) angle

\( \sigma_p \) standardisation of two dimensional normal distribution of the pellets \( p_F \)

\( p_F \) probability distribution of a two dimensional normal distribution in %

\( p(x,y,z) \) probability distribution of a three dimensional normal distribution in %

\( p_r \) radial probability distribution in %
Acknowledgement

This report has been prepared by Dr. Dietrich Kühner, Germany, with special support by Mr. Juergen Knappworst, (RUAG Germany) and in close cooperation with Mr. Elvio Quartini (Stas Italy).

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