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INFLUENCE OF THE SHOOTING DISTANCE ON THE DEPTH OF PENETRATION OF THE BULLET INTO THE REPLACEMENT MATERIAL FOR AIR GUN WEAPONS

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Abstract

In the last few years, it has been possible to see an increasing trend of aggression in society, leading to the more frequent use of weapons in conflicts. The using of air weapons is also increasing. But are these weapons really dangerous, and what is the effect of shooting distance on the depth of the shot? The article tries to answer these questions. The paper uses ballistic experiment to gain knowledge on which a qualitative evaluation is used. The shooting experiment is based on the firing of physical substitution models made of 20% ballistic gelatine from an air gun with a calibre of 4.5 mm, at a distance of 5, 10, 15, 20 and 25 m. The impact velocities of the projectile were measured using optical ballistic gates and using high-speed cameras were recorded missile passes ballistic gelatin. The depths of the shots were then measured using callipers, and the maximum dimensions and the shape of the temporary cavities of the shots were determined using optical recordings from the high-speed camera. It was found that the depth of the shot decreases with increasing shooting distance. The same applies to the maximum volumes of temporary cavities. These trends are almost linear and are associated with a drop in the impact velocity of the projectile hitting the test target. This pilot experiment serves for the initial verification of the hypothesis of the effect of shooting distance on the depth of shot in air gun weapons and provides essential information for further in-depth investigation.

Keywords: air rifle; ballistic gelatin; bullet; shot depth.

1. Introduction

Over the past few years, there has been an increase in aggression in society, and there have been instances of assaults using weapons. As evidenced by examples from the Czech Republic, USA, France and other countries, the number of cases where a weapon of lower efficiency such as an airsoft gun, a paintball gun, a Flobert gun or an air rifle appears. However, are these weapons really dangerous? Or what is the danger of shooting from 5 m and what is the danger of shooting from 20 m? These questions are trying to answer wounded ballistics. This article and other articles that are produced in our research are focused on the impact of the shooting distance on the depth of the shot and, in a broader context, the wounding potential of the air rifle.

This particular research may rely on publications such as:

Airsoft gun-related ocular injuries: long-term follow-up. [1] from Khalaila et al., where they examined eye injuries caused by airsoft guns. This publication was followed by an article by a group led by Kartik Dandu entitled A 10-Year Analysis of Head and Neck Injuries Involving Nonpowder Firearms. [2] The risks associated with airsoft guns is also discussed in the articles Traumatic iridoid analysis from an Airsoft pellet in an aviator by Pearce [3] and Penetrating Facial Injury with an “Airsoft” Pellet by Strong and Coady. [4]

Stefanopoulos et al., In Wound Ballistics 101: The Mechanisms of Soft Tissue Wounding by Bullets [5], focused on soft tissue injuries caused by bullets.

Interesting is also the publication Evolution of indoor bullet trap design by Tikal. [6] The use of ballistic gelatin is discussed in The Use of Gelatine in Wound Ballistics Research by Carr, Stevenson, and Mahoney. [7]

The publication Investigation and comparison of the performance of some air gun projectiles with nose shape modifications by Salimipour, Teymourtash and Mamourian [8] or Brain death of an infant caused by a penetrating air gun injury from a team led by Simon [9] deal directly with air guns. Interesting is also the Prediction of the Air Gun Performance by Horák et al. [10] and Air weapon fatalities from Milroy, Clark, Carter, Rutty and Rooney.[11]

The publications of prof. Juříček, such as the Czech-Slovak terminology dictionary of terms in the field of firearms, ammunition, wounded ballistics, pyrotechnics and forensic medicine [12], Wounded ballistics. Technical, forensic, and forensic aspects [13], The wounding potential of small-calibre projectiles and its evaluation [14], Physical models of human biological systems in a ballistic experiment to evaluate the wounding effects of a small-calibre missile [15], Simulation and evaluation of the impact of small-calibre projectiles on the live force.[16]

Interesting is also the article Detecting Differences At A Selected Shooting Weapon And Its Freely Available Copies by Gracla et al. [17]

The initial hypothesis is that the depth of shot and wounding potential will generally decrease with increasing shooting distance, and this trend could be linear.

This article deals with the effect of shooting distance on the depth of the shot of an air weapon.

2. Methods

To obtain the data, the experiment, which was to prove the underlying assumption that the depth of penetration of missiles into the test gelatin block (shot) and generally wounding potential decreases with increasing shooting distance, was conducted. Furthermore, it was assumed that the relationship between the shooting distance and the depth of penetration of the missile into the gelatin block could have a linear course.

The experiment consisted of a substitution test block made of 20% gelatin solution in the shape of a cuboid with dimensions of 15x15x30 cm. Individual blocks were gradually shot from a distance of 5, 10, 15, 20 and 25 m with the recording of the impact velocity of the diabolo pellet vi using ballistic optical gates and capture the passage of missiles through the replacement material using a high-speed camera.

The following tools were used in the experiment:

- 20% ballistic gelatine was used as a replacement material, manufactured according to the procedure
  - Crystalline gelatin was mixed into room temperature water with gentle stirring (to prevent bubble formation).
  - The mixture was aged for 2 hours on a 10 °C in the fridge.
  - Subsequently, the gelatin container was placed in a bath of a larger water tank at 40 °C, and the gelatin was dissolved entirely (without bubbles) while stirring and gradually heating.
  - The gelatin was then poured into a preformed form (erased with silicone or transparent fat).
  - The gelatin was placed in the fridge at a temperature of approximately 10 °C.
  - After solidification and visual inspection, the gelatin was removed from the form and wrapped in polyethylene foil and placed in a 4 °C fridge to temper for 36 hours.
  - The gelatin, used in the experiment, was at room temperature (20oC).
- The density of gelatin was 1,066 kg.m-3, which is very close to the density of human muscle (1,100 kg.m-3),
- Caldwell Matrix shooting stool with an air gun - Gamo Shadow DX calibre 4.5 mm with the type of ammunition used - Gamo Magnum Energy calibre 4.5 mm with conical face,
- Ballistic Optical Gates Shooting Chrony Beta Master with measuring range 9 - 2,100 m.s-1. They were built 10 cm from the ballistic gelatin.
- Olympus I-SPEED FS high-speed camera with a resolution of 1280 x 1,024, the maximum speed of 1,000,000 fps. A 10,000 fps scan rate was selected for the experiment,
- camera,
- Laser rangefinder and
- Digital calliper.

During the ballistic experiment, five rounds were fired from each distance.

Fig. 1. Gamo Magnum Energy 4.5 mm calibre.

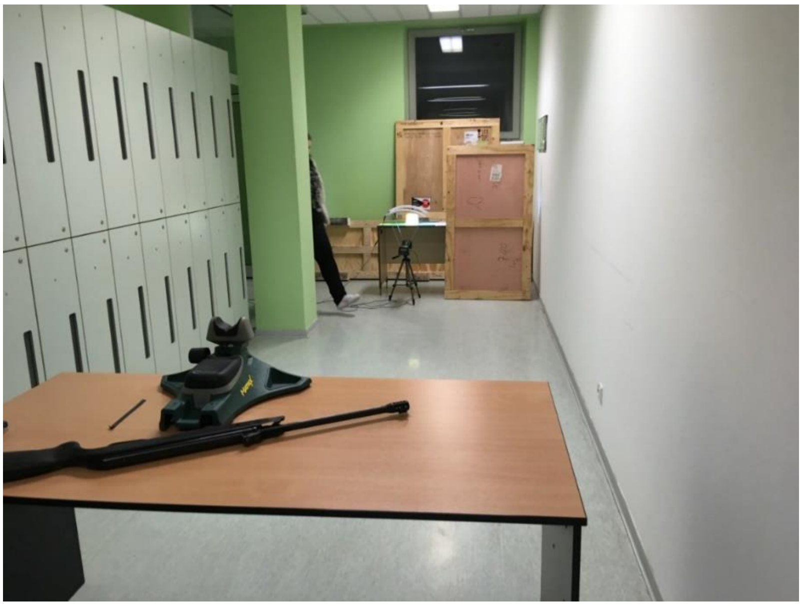


Fig. 2. Arrangement of the workplace 1.

Fig. 3. Arrangement of the workplace 2.

Fig. 4. Arrangement of the workplace 3.

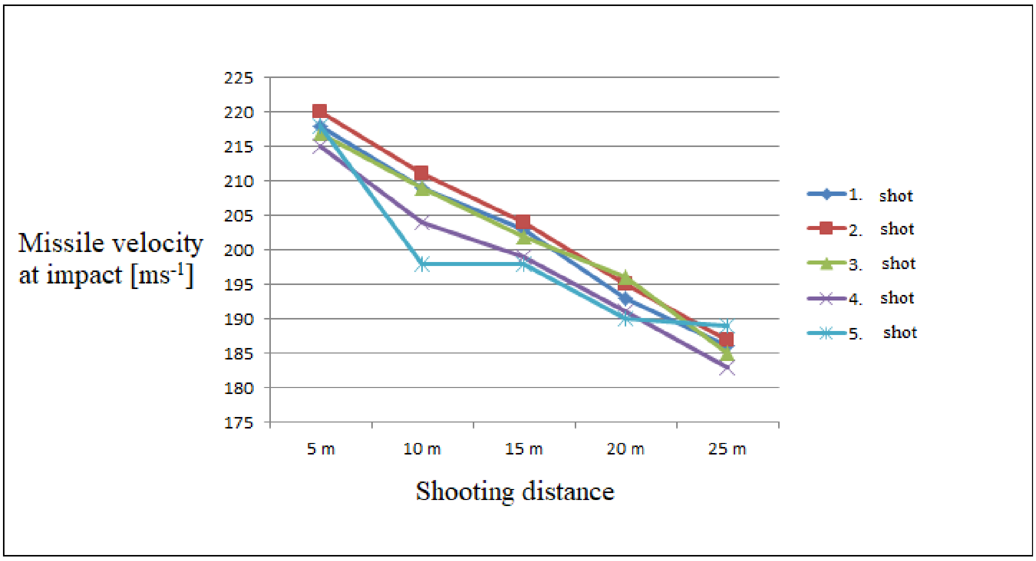
3. Results

The following data were obtained from the experiment described above.
The impact velocity of missiles v_i

The impact velocity of the missiles was measured by ballistic gates. The gates were placed 10 cm in front of the replacement material block, and therefore, the measured velocity can be considered as the impact velocity.

distance	5 m	10 m	15 m	20 m	25 m
Missile velocities v_i at the moment of impact on the test block [$m.s^{-1}$]					
1. shot	218	209	203	193	186
2. shot	220	211	204	195	187
3. shot	217	209	202	196	185
4. shot	215	204	199	191	183
5. shot	218	198	198	190	189

Table 1. Impact velocities of missiles at 5 m, 10 m, 15 m, 20 m and 25 m.



Graph 1. The development of the velocity of shots depending on the shooting distance.

The graph and the table show that the velocity of missiles is not entirely proportional to the shooting distance. However, since the weight of each missile is slightly different, and it cannot be detected and guaranteed that each shot is fired with the same strength, it can be said that the relationship is almost linear.

Missile weight m_q

The weight of the bullets m_q used for firing was gradually measured using a KERN PCB precision digital scale (1,000-2; 1,000 g / 0.01 g). The measured missile weights are listed in Table 2.

distance	5 m	10 m	15 m	20 m	25 m
Missile weight [g]					
1. shot	0,486	0,486	0,487	0,493	0,489
2. shot	0,497	0,485	0,489	0,492	0,499
3. shot	0,486	0,484	0,489	0,485	0,497
4. shot	0,481	0,484	0,485	0,489	0,493
5. shot	0,489	0,488	0,481	0,498	0,489

Table 2. Weights of missiles mq fired at a certain distance.

Impact kinetic energy E_i of a missile

Using the data in Tables 4 and 5, the kinetic energy of the incident missile E_i can be determined. Since the bullet has completely stopped in the replacement material block and the shot has been recorded, the impact kinetic energy value of the bullet represents its total kinetic energy transmitted E_{TR}.

Calculation of the kinetic energy of the projectile can be done according to Newton's mechanics as:

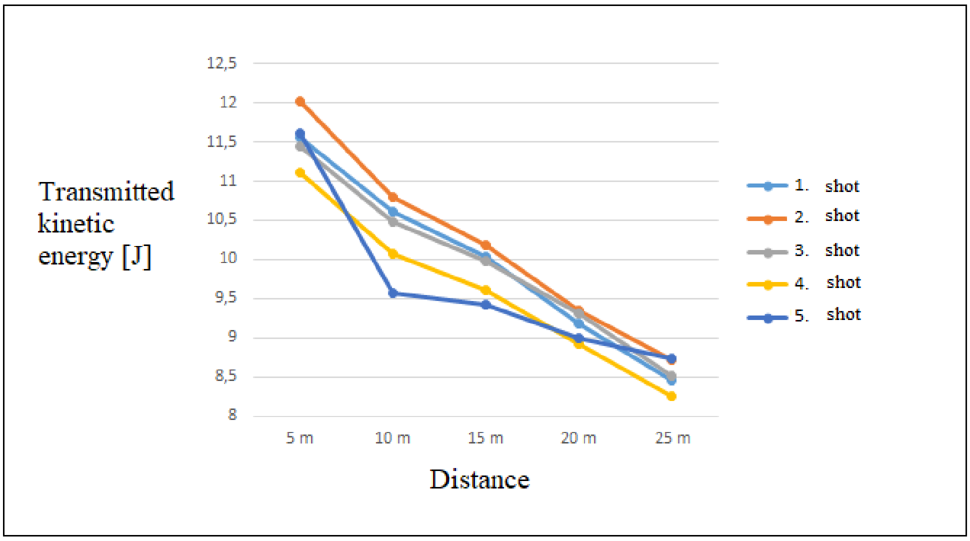
$$E_k = \frac{1}{2} m v^2 \quad (1)$$

where E_{TR} [J] is kinetic energy, m_q is the weight of the bullet and v_i is the velocity of the incident bullet.

After the values of the velocities and weights of the missiles corresponding to the individual shooting distances have been achieved, the values of the transmitted kinetic energy E_{TR} of the bullet to the replacement material can be calculated.

distance	5 m	10 m	15 m	20 m	25 m
Transmitted kinetic energy of the projectile [J]					
1. shot	11,548	10,614	10,034	9,182	8,459
2. shot	12,027	10,796	10,175	9,354	8,725
3. shot	11,443	10,471	9,977	9,316	8,505
4. shot	11,117	10,071	9,603	8,920	8,255
5. shot	11,620	9,566	9,429	8,989	8,734

Table 3. Transmitted kinetic energy of missiles fired at a certain distance.



Graph 2. Transmitted kinetic energy.

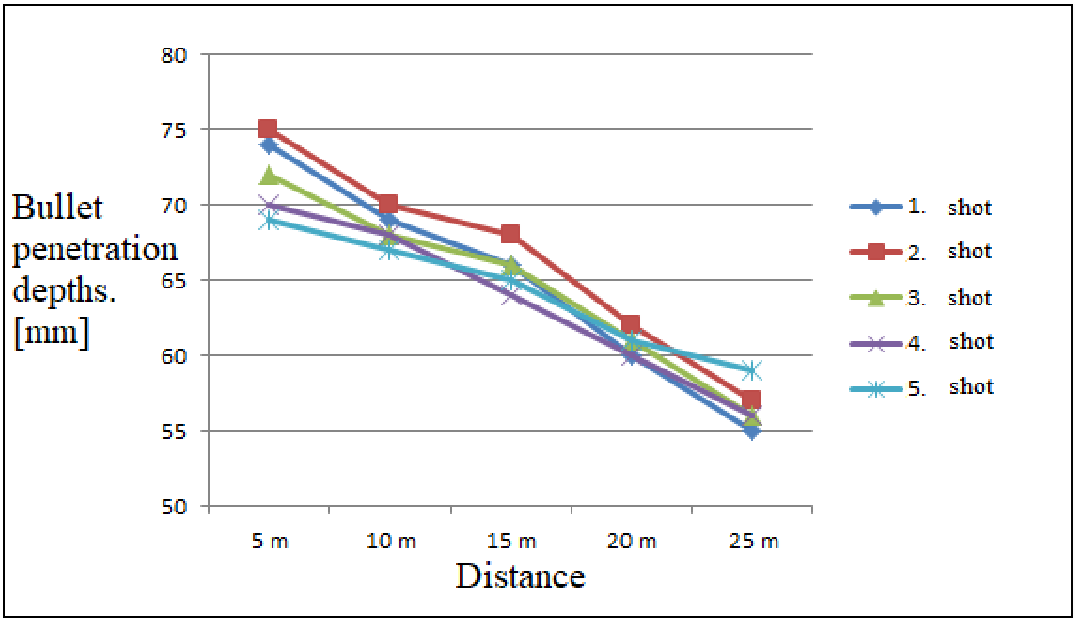
The graph and table show that the transmitted kinetic energy decreases with the shooting distance. It is difficult to determine the trend of descent because each bullet has a different weight and rate of fire. If extremes are excluded and differences are taken into account, the drop is similar to direct proportion.

Depth of penetration of a missile s

Shot depth was measured using a digital calliper.

distance	5 m	10 m	15 m	20 m	25 m
Depth of penetration missiles s [mm]					
1. shot	74	69	66	60	55
2. shot	75	70	68	62	57
3. shot	72	68	66	61	56
4. shot	70	68	64	60	56
5. shot	69	67	65	61	59

Table 4. Values of penetration depths of missiles fired from a certain distance.



Graph 3. Bullet penetration depths.

As can be seen from Graph 3 and Table 7, the depth of penetration of individual missiles is not entirely proportional to the shooting distance. However, since the weight of each missile is slightly different and within a certain tolerance, and it is not possible to ensure that the projectile is fired from the air rifle with the same strength each time, it can be stated that the proportionality is linear with a certain dose of tolerance.

Temporary cavity dimension w_{TC}

The dimension of the temporary cavity, represented by its maximum width w_{TC}, was measured using an optical method. Specifically, high-speed camera recordings were analysed. Unfortunately, at the time of the experiment and preparation of this article, specialized software for image analysis was not available, and therefore, the method of pixel measurement was used.

An object of known size is identified in the image. Then, the number of pixels is determined, and the size of the object is divided by the number of pixels. This determines the size of one pixel. The number of pixels at the desired length of the temporary cavity is then determined and multiplied by the size of one pixel. The dimension of the temporary cavity is thereby obtained.

For the sake of clarity, images are shown only for the first missiles at given distances and only the maximum dimension of the temporary cavity represented by its maximum width is measured. Images are cropped to show only temporary cavity and missile. The dimensions of all temporary cavities are given in Table 5 and then converted to Graph 4.

Fig. 5. The dimension of the maximum width of the temporary cavity for the first missile at a distance of 5 m.

Fig. 6. The dimension of the maximum width of the temporary cavity for the second missile at a distance of 10 m.

Figure 8 shows the second bullet fired from a distance of 10 m due to unreadable record of the first missile. The second bullet penetrated near the first bullet, and so it can be seen that the temporary cavity of the second bullet pulsation acts on the permanent cavity of the first bullet, which can be significantly affected. The temporary cavity of the second bullet thus creates another temporary cavity even in the cavity formed by the first bullet.

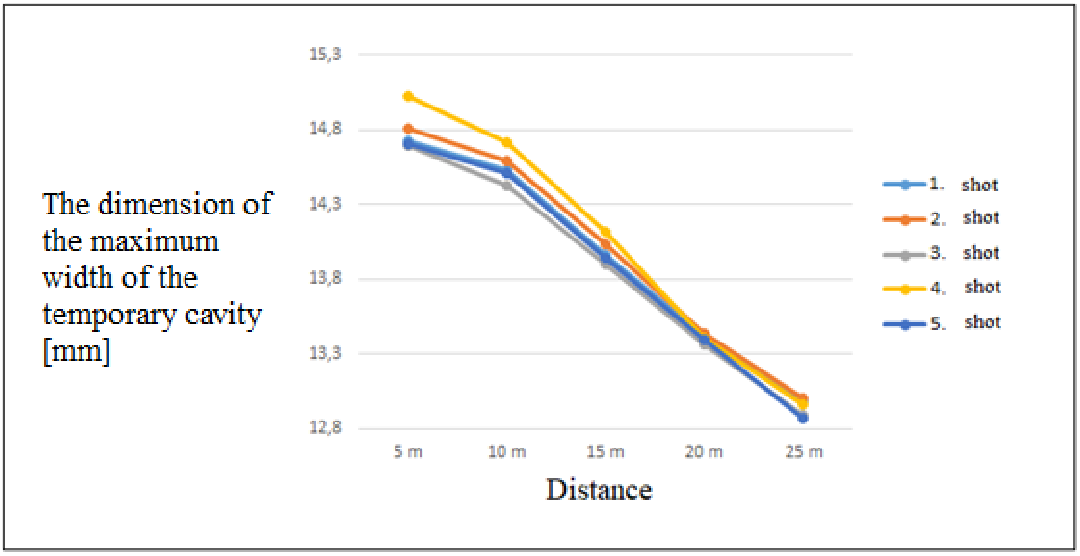
Fig. 7. The dimension of the maximum width of the temporary cavity for the first missile at a distance of 15 m.

Fig. 8. The dimension of the maximum width of the temporary cavity for the first missile at a distance of 20 m.

Fig. 9. The dimension of the maximum width of the temporary cavity for the first missile at a distance of 25 m.

distance	5 m	10 m	15 m	20 m	25 m
Maximum temporary cavity width values w_{TC} [mm]					
1. shot	14,72	14,53	13,96	13,41	12,98
2. shot	14,81	14,59	14,03	13,43	13,00
3. shot	14,69	14,43	13,90	13,36	12,89
4. shot	15,02	14,71	14,12	13,40	12,96
5. shot	14,70	14,51	13,94	13,39	12,87

Table 5. The maximum width of the temporary cavity for the missiles fired at a certain distance.



Graph 4. The dimension of the maximum width of the temporary cavity [mm].

Interestingly, the descent trend in the first 5 meters is different from the rest of the measurement. Besides, the descent is almost linear and confirms trends in missile velocity and transmitted kinetic energy.

4. Conclusion

This article deals with the effect of shooting distance on the depth of the shot of an air weapon. From the above findings, it can be stated that the original assumption has been confirmed and that the wounding potential depending on the shooting distance decreases linearly. The results of experimental ballistic measurements confirmed this hypothesis. It should be noted that more detailed experimental ballistic measurements may result in some differences. The weight of the "Diabolo" missiles ranged from 0.481 g to 0.499 g. Impact velocities vi and transmitted kinetic energy E_{TR} when shooting from a distance of 5 m ranged between 215 - 220 ms^{-1} and 11.117 - 12.027 J, per 10 m: 198 - 211 ms^{-1} and 9.566 - 10.796 J, at 15 m: 198 - 204 ms^{-1} and 9.429 - 10.175 J, at 20 m: 190 -196 ms^{-1} and 8.920 - 9.354 J and at 25 m: 183 - 189 ms^{-1} and 8.255 - 8.734 J. Maximum temporary cavity width per 5 m: 14.69 - 15.02 mm, 10 m 14.43 - 14.71 mm, 15 m 13.90 - 14.12 mm, for 20 m 13.36 - 13.43 mm and for 25 m 12.87 - 13.00 mm.

The maximum temporal cavity dimension data are crucial for assessing the missile potential of the projectile. It is always located near the bullet entry into the replacement material block. Moreover, the maximum dimension for given distances shows that the wounding potential is not negligible, but is relatively small. Nevertheless, it is necessary to objectify further this area. The results of this article provide a solid basis for further research in the field that the authors are planning to perform.

5. Acknowledgments

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