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The significance of ricochet marks in finding bullets at the shooting scene and in determining shooter location

Summary

The article offers an overview of the ricochet phenomenon. The authors addresses the issue of examining bullet trajectories that have been deflected as a result of coming into contact with different types of obstacles. Ricochet marks are used by forensic experts to determine bullet trajectory, pattern, caliber and shooter location. Finding the ricocheted projectiles is difficult due to the fact that the angles of incidence (impact) and reflection are not equal.

This article, devoted to ballistics and ricochet phenomenon, is based on the findings of the study conducted by specialists of the MWD Academy, Volgograd, Russia. The above study involved the use of a small semi-automatic 5.45 mm PSM pistol. Experimental firing was conducted with 5.45 mm pistol cartridges with central ignition (MPC); 2.5 g steel-core bullet; 0.15-0.17 g powder charge (Sf 040 gunpowder); muzzle velocity: 315–325 m/s. The shooting targets involved 16 mm particleboards (DSP) covered with laminate and without laminate, removed from old furniture.

The results of 17 experimental firings are shown in this article. For all the firing trials, the muzzle was positioned at a distance of 2 m from the anticipated impact site.

Based on the obtained results, it can be inferred that for all the ricochet incidents, the angle of reflection was greater than the angle of incidence. The projectile penetrated the particleboard over a certain distance and exited out the front site.

The analysis of findings will in the future serve the formulation of the conclusions about the shooting scene, including finding the projectiles. The authors developed the following sequence of recommended expert activities: determining the type of projectile, trajectory, angles of incidence and reflection, shooter position and finally, the search for a projectile.

Keywords ricochet, projectile, ballistics, angle of reflection, firearms, caliber, gunpowder, cartridge, shell, trajectory, ricochet crease, projectile velocity

The ricochet phenomenon has been long known to the art of shooting, also finding a practical use in the military[1]. According to J. Radzicki, a ricocheted bullet is „the projectile that changed its course and travels along a new trajectory as a result of coming into contact with elastic or semi-elastic object. The projectile can rebound centrally or diagonally (...). Ricochet represents the phenomenon of reflection and as such, it follows the same principles. It occurs when:

1. two elastic or semi-elastic objects collide, whereby
2. at least one of the objects is in motion, while the other remains at rest (initial speed equals 0).

Under such circumstances, the initial speed and original trajectory of the projectile change"[2].

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[1] For example during the so called "ricochet firing" used by the straight firing artillery to damage enemy infantry.

[2] J. Radzicki, *Wypadki postrzałowe spowodowane myśliwską bronią palną*, Wydawnictwo Prawnicze, Warszawa 1957, p. 81.

Similar definition of the ricochet was formulated by T.M. Sobalak, P. Jenoch and T. Andrzejczak[3]. In forensic literature, the ricochet phenomenon remained in the focus of S. Kustanowicz, who first noticed the difference between the angles of incidence and reflection[4]. Ricochet phenomenon also remains within the scope of interest of forensic medicine experts, the first being L. Wachholz. Among recent publications, the studies of importance have been delivered by S. Manczarski[5], A. Jakliński, J.S. Kobiela, K. Jaegerman, Z. Marek and Z. Tomaszewska[6]. A significant position of Russian literature is the monograph by W.L Popow, W.B. Szigejew and L.E. Kuzniecow[7]. A common conclusion deriving from all these authors, was the observed extensive tissue damage caused by the distortions of a bullet's rotational motion (mainly bullet's flip over upon impact with soft tissue or bone of the target).

When the initial examination of the scene of incident indicates the possibility of a ricochet by a bullet fired from a firearm, it becomes essential to find the place of contact between the bullet and the obstacle (excluding water surface)[8]. The finding of the place of contact enables the determination of the likely location of a shooter and the bullet's trajectory taken after it has rebounded from the obstacle. It is also possible to identify the type or even the particular piece of the weapon used in the shooting, based on characteristic creases found on the objects or at the scene, the latter involving the ricochet creases generated as a result of rebounding of the projectiles.

An interesting Russian study report aiming at developing certain search schemes appeared, namely a publication by A.A. Pogrebnoj, where the significance of ricochet creases for the projectile search and determining shooter location was discussed[9]. The author reasonably concluded that the ricochet creases can be used in determining the projectile's direction and location after firing, shooter location, type of cartridge as well as other circumstances of the shooting. In order to gather all this information, the presence of a highly qualified specialist is required at the scene. The search for rebounded projectiles is hindered due to the fact that the ricochet phenomenon does not follow the principles of the law of reflection (governing the reflection of sound and light waves). In the event of a ricochet, the complex interactions of various forces lead to the result that the angle of reflection can be larger or lower than the angle of incidence (impact).

On the other hand, some of the sources state that during the search for the projectile, the assumed angle of reflection should be equal to the determined angle of incidence. Certain difficulties are due to the frequent lack of indications as to the size of the angle of incidence, which naturally makes it more difficult to determine the size of the angle of reflection and in consequence, the location of the projectile. This article attempts to address the above problems, thereby providing the knowledge that can be used by investigation teams in search for the projectile and in determining shooter location"[10].

For the purpose of practical verification of research assumptions, the experimental firing was conducted under laboratory conditions. The materials and methods adopted by A.A. Pogrebnoj were the following: small, semi-automatic 5.45 mm PSM pistol; 5.45 mm pistol cartridges with central ignition (MPC); 2.5 g steel-core bullet; 0.15-0.17 g powder charge (Sf 040 gunpowder); muzzle velocity: 315–325 m/s. Both laminated and non-laminated 16 mm thick wooden particleboards (DSP) coming from appx. 10-year-old indoor furniture were used as obstacles.

The front sides of the firmly affixed particleboards were shot at. The distance between the muzzle and the obstacle was 2 m. A series of 17 shots were fired at angles between 2 to 15 degrees to the obstacle (at 2-3 degree increments)"[11]. According to the author of this article, the obtained results should also be representative for other pistols designed for the use of 7N7 5.45 caliber cartridge, including: IŻ-75 (ИЖ-75); OC-23 „Dziryt" (ОЦ-23 «Дротик»); OC-26 (ОЦ-26); „Świder" («Дрель»).

The measurements applied by A. Pogrebnoj were the following: the angle of incidence was measured with an accuracy of 1 degree by using a protractor and a laser pointer affixed to the slide of the pistol. The angles of reflection were measured based on the position of the creases made by rebounded bullets on the cardboard screens positioned 1 m from the obstacle. An angle of incidence/reflection was defined as the angle between the line drawn through the centre

3 T.M. Sobalak, P. Jenoch, *Polujmy bezpiecznie*, Wyd. PPHU GRANDEL, Piła 2011, p. 71.

4 S. Kustanowicz, Badanie broni palnej, wyd. Zakładu Kryminalistyki Komendy Głównej Milicji Obywatelskiej, Warszawa 1959, p. 219, also see С. Д. Кустанович Судебнаябаллистика, Госюриздат, Москва 1956, стр. 258.

5 St. Manczarski, *Uszkodzenia postrzałowe*, wyd. WINW Warszawa 1938, passim; Medycyna sądowa w zarysie, wyd. PZWL, Warszawa 1954, p. 101.

6 A. Jakliński, J.S. Kobiela, K. Jaegerman, Z. Marek, Z. Tomaszewska, *Medycyna sądowa*, Wyd. PZWL, Warszawa 1972, p. 150. Wydania.

7 Л. Попов, В. Б. Шигеев, Л. Е Кузнецов Судебно-медицинская баллистика, Изд Гиппократ 2002, passim.

8 S. Kustanowicz, *op. cit.*, p. 219.

9 А.А. Погребной Значение следов рикошета для поиска пуль на месте происшествия и определния местоположения стрелявшего, с. 20–25, «Эксперт-криминалист» № 4 от 2013 г., Федеральный научно-практический журнал, соучредитель – Московский Государственный Юридический Университет им. О.Е. Кутафина (МГЮА).

10 Ibidem, p. 20–21.

11 Ibidem, p. 21.

of gravity of the bullet and the surface of the obstacle before and after the collision, respectively. The dimensions of creases were measured with a sliding caliper with 0.1 mm accuracy.

According to the report, the test series of 17 shots (in all instances the muzzle was positioned at a distance of 2 m away from the anticipated site of impact) yielded the following results:

– at a 2° angle of incidence:

a. first projectile – angle of reflection: 7°; dimensions of the ricochet crease (L x W x D): 62 mm x 7 mm x 1,2 mm. (Fig. 1 – Ricochet crease)[12]

Fig. 1. Ricochet crease (shown below is a cm-graduation).

b. second projectile - angle of reflection (changed): 5°; dimensions of the ricochet crease (changed) (L x W x D): 47 mm x 5 mm x 0.4 mm. (Fig. 2 – ricochet crease shown below)

Fig. 2.

– at a 5° angle of incidence:

c. first projectile – angle of reflection: 10°; dimensions of the ricochet crease (L x W x D): 58 mm x 6 mm x 3 mm. (Fig. 3 – ricochet crease shown below)

Fig. 3.

d. second projectile - angle of reflection (unchanged): 10°; dimensions of the ricochet crease (changed) (L x W x D): 47 mm x 5.5 mm x 1.2 mm. (Fig. 4 – ricochet crease shown below)

Fig. 4.

12 In all the figures (1-11) the bullet's direction of travel was marked with an arrow.

– at a 7° angle of incidence:

e. first projectile – angle of reflection: 13°; dimensions of the ricochet crease (L x W x D): 60 mm x 6 mm x 3 mm. (Fig. 5 – ricochet crease)

Fig. 5.

f. second projectile - angle of reflection (changed): 12°; dimensions of the ricochet crease (changed) (L x W x D): 46 mm x 5 mm x 1.6 mm. (Fig. 6 – ricochet crease)
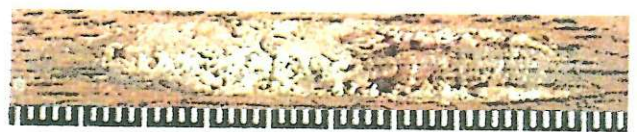

Fig. 6.

– at a 10° angle of incidence:

g. first projectile – angle of reflection: 18°; dimensions of the ricochet crease (L x W x D): 57 mm x 7 mm x 2.9 mm. (Fig. 7 – ricochet crease);
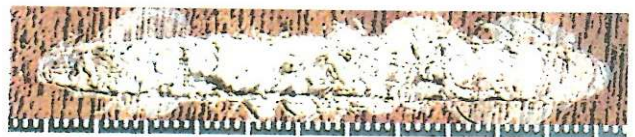

Fig. 7.

h. second projectile - angle of reflection (changed): 14°; dimensions of the ricochet crease (changed) (L x W x D): 46 mm x 6 mm x 2 mm;

i. third projectile - angle of reflection (changed): 16°; dimensions of the ricochet crease (L x W x D): 52 mm x 6.5 mm x 3.4 mm. (Fig. 8 – ricochet crease);

Fig. 8.

j. fourth and fifth projectile - stuck in the obstacle without rebounding; dimensions of the ricochet crease were: (L) 87 mm, 57 mm and (W) 10 mm, 9 mm, respectively (Fig. 9 – ricochet crease);

k.

Fig. 9.

– at a 12° angle of incidence:

l. first projectile – angle of reflection: 20°; dimensions of the ricochet crease (L x W x D): 106 mm x 10 mm x 5.5 mm. (Fig. 10 – ricochet crease);

Fig. 10.

m. second, third and fourth projectiles - stuck in the obstacle without rebounding; dimensions of the ricochet crease were: (L) 72 mm, 97 mm, 44 mm and (W) 9 mm, 11 mm, 8 mm, respectively (Fig. 11 – ricochet crease);

Fig. 11.

– at a 15° angle of incidence:

n. first and second projectile - stuck in the obstacle without rebounding; dimensions of the ricochet crease were: (L) 32 mm, 39 mm and (W) 6 mm, 6 mm, respectively.

Figures 1-11 present ricochet creases (the bullet's direction of travel: left to right; two types of DSP boards are shown: covered with textured paper and coated with varnish).

To summarize the results of the experiment, in all the cases the angle of reflection was 1.5-3 fold greater than the angle of incidence. After impact, the bullet penetrated the particleboard over a certain distance and exited out the front side. When the angle of incidence exceeded 12-13°, the bullet usually did not perforate the board but instead, got stuck inside at about 6–15 cm from the entry hole. At angles of 15° and greater, the bullet perforated the obstacle without

a ricochet effect and fell nearby. It should be noted that the 7N7 (МПЦ 7Н7) cartridge used in the experiments carries a steel core that makes it capable of piercing a level 1 bulletproof vest when fired from the TT pistol (2nd class of defense, according to GOST L 50744-95 standard). The Makarov 9 mm pistol was classified as having lower piercing power.[13]

The results of the experiment conducted by A.A. Pogrebnoj are summarized on the figure below.
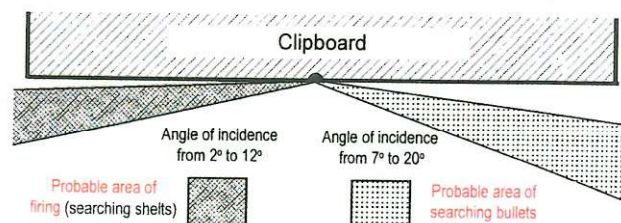

Fig. 12. Angles of incidence (shell location) and reflection (bullet location).

According to the author, an analysis of data gathered at the shooting scene can allow to formulate opinions (results) concerning the shooter's location and direction of search for the shells and projectiles. A.A. Pogrebnoj points out that „the probable type of cartridge can be determined based, inter alia, on deformed projectiles, projectile fragments or shells recovered at the scene. The lateral profile of the bottom of a ricochet crease does not correspond to the bullet size and therefore, the attempts to determine the bullet's cross-sectional radius (and thus the caliber) based on the crease can be misleading"[14].

The bullet's direction of travel should be determined on the basis of visual differences between the entry and exit end of the crease. According to the author, the widest and deepest part of the crease is usually its exit end (sometimes the center). The inclination of the bottom is milder at the end of an entry. The side walls of the crease are approaching each other at a sharper angle on the entry end. The bullet's movement causes the separation of the outermost layers (hot-pressed chips soaked in binding agent) of non-laminated boards from the bottom of the crease near the entry end. The direction of travel is marked by "curved folds whose convex sides face the direction of travel (see Fig. 9). The same orientation is also characteristic of the convex fragments of varnish coating"[15].

A.A. Pogrebnoj recommends that the shooter's location be determined by comparing the data on the projectile's direction of travel and angle of incidence, whereas the projectile's location after firing should be estimated based on shooting direction and angles

13 А. Григорян. Боевые пистолеты России. ТТ Макаров ПСМ Стечкин. Изд. GELEOS 2005 с. 192.

14 *Ibidem*, p. 192; for information on the GOST, refer to http://www.npo-sm.ru/stand.php, of 12.07.2014.

15 А. Григорян, op. cit., p. 192.

of incidence and reflection. Additionally, a converse problem can be tackled, namely, given a known angle of reflection, one can also attempt to determine the angle of incidence and location of the shooter. However, the estimates may be inaccurate in this case, since with a decreasing speed of the bullet, the probability of occurrence of a multiple-ricochet effect increases.

A phenomenon relevant to the search for the projectile at the shooting scene is the internal ricochet described by J. Radzicki. The internal ricochet occurs when a bullet penetrates the obstacle, wherein it changes its course (sometimes by an unexpectedly high degree) upon contacting an internal layer of a harder material. For example, the bullet can enter a tree trunk on the side which is exposed to sunlight and is softer, change its internal path upon encountering harder tree rings and then, after exiting the tree, continue along the modified pathway that differs significantly from the original one (see Fig. 13)[16].
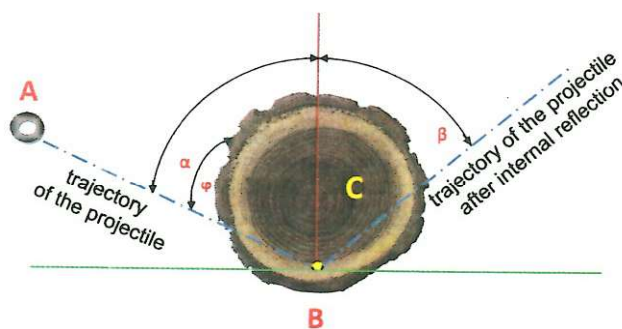

Fig. 13. Deflection of the bullet pathway inside the tree.

In his article, J. Radzicki refers to a fatal incident which took place during a hunt. Namely, one of the hunters missed his shot at the wild boar and instead, the bullet (Brennecke-type) fired fatally hit his fellow hunter after ricocheting inside the birch tree and undergoing deformation.
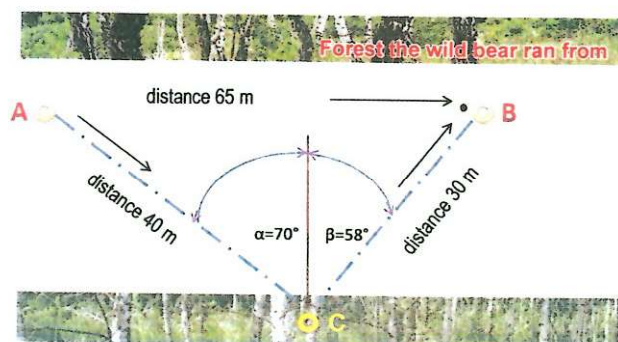

Fig. 14. Determining the shooter's position and search for the bullet.

16 Radzicki J.: *Wypadki postrzałowe spowodowane myśliwską bronią palną*, Wydawnictwo Prawnicze, Warszawa 1957, p. 87.

"The inlet hole on the tree was lined up with the position of the shooter, whereas the exit hole opened up in the victim's direction. The victim was struck in his left buttock from where the bullet's channel extended through the buttock's muscles, wing of ilium, peritoneum near the lesser (true) pelvis, abdominal cavity (damaged small and large intestine as well as both iliac arteries near the site of bifurcation) to end blindly inside the right psoas major muscle. The deformed lead bullet got stuck inside the right quadriceps"[17].

Further analysis of this case will allow to formulate conclusions concerning spatial relationships between the shooter and the position of the recovered bullet. A sequence of activities recommended for forensic experts at the scene is the following:

Step 1. Determining the type of cartridge

The type of cartridge can be determined based on the projectiles or paper hulls recovered at the scene, other traces or witness testimonies. The measurements of the bottom area of the ricochet crease are usually useless for bullet size determination since these dimensions poorly correspond to the factual size.

The 5.45 mm MPC cartridge is compatible with PSM, JWC-75, OC-23 „Drotik", OC-26 and „Dpiel" pistols. All the above models have a similar muzzle velocity, between 315–326 m/s.

It can be therefore assumed that the bullets fired from these pistols will ricochet in a similar manner.

Step 2. Determining the bullet's direction of travel

The bullet's direction of travel can be determined based on differentiation between the entry and exit end of the ricochet crease or based on other specific traces.

The widest and deepest part of the crease is usually its exit end (sometimes the center). The inclination of the bottom is milder on the entry end. The side walls of the crease are approaching each other at a sharper angle on the entry end.

The traveling bullet causes the separation of scale-like fragments of the textured cover on the entry side.

The stress marks on the textured cover take forms of the curved folds, whose convex sides face the direction of travel. Such an orientation is also characteristic of the convex fragments of varnish.

Step 3. Determining incidence and reflection angles

The angle of incidence can be determined in one of the following two manners:

- if a shooter's location is known, it needs to be connected with the ricochet crease with a string or a laser beam and the angle at the point of contact should be measured using a protractor;
- if a shooter's location is not known, the angle of incidence can be determined by assessing the

17 Radzicki J., *op.cit.*, p. 86–87.

characteristics of the ricochet crease (bottom and side walls).

As incidence angles equal to or less than 8°, the side walls remain relatively smooth with little varnish coating separation, whereas above 8°, they amass the splinters originated from the upper layer of the particleboard near the center and the exit end of the crease. In the case of the DSP boards covered with textured paper, the cover remained intact or almost intact for incidence angles up to 7°, whereas varnish coated DSP surfaces remained undamaged for up to 2° incidence angles.

For big angles of incidence, the cover/coating remains intact only on the entry and exit end or only on the entry end.

Considering the low number of ricochet creases that differentiate the angle of incidence and a narrow angular range of ricochet supporting angles, while investigating the scene of shooting, it is advisable to assume a range of 2–12° for the angle of incidence and 7–20° for the angle of reflection.

If the angle of incidence was determined based on known location of the shooter, the range for the putative angle of reflection can be narrowed down.

Step 4. Determining shooter location and the search for bullet

The final step is a logical consequence of all preceding steps. The location of the shooter is determined based on the bullet's direction of travel and the size of the angle of incidence. The location of the bullet is estimated by determining the shooting direction and angles of incidence and reflection. Since the angle of incidence is estimated to be within a certain range, the assumed shooter and bullet locations correspond to certain areas rather than precise points.

Conversely, given a known angle of reflection, one can also attempt to determine the angle of incidence and location of the shooter. On the other hand, the estimates may be inaccurate in this case, since with a decreasing speed of the bullet, the probability of occurrence of a multiple-ricochet effect increases.

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Source

Figs. 1–11: courtesy of the MWD Academy, Volgograd
Figs. 12–14: authors

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