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Forensic based empirical study on ricochet behaviour of Kalashnikov bullets (7.62 mm × 39 mm) on 1 mm sheet metal

Bandula Nishshanka[a,b,*], Chris Shepherd[d], Paranitharan Paranirubasingam[c]

[a] Cranfield University, UK
[b] University of Kelaniya, Sri Lanka
[c] Faculty of Medicine, University of Kelaniya, Sri Lanka
[d] University of Kent, UK

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ABSTRACT

Bullet ricochet off a surface in a shooting scene occurs in diverse conditions and affected by array of factors. Therefore ricochet analysis of a particular incident demands case by case analysis supported by the knowledge of existing subject knowledge and empirical testing. In this view, existing empirical test results on bullet ricochet experiments have become always assisted and referred by investigators during scene reconstruction and in Courts.

This forensic based research was aimed to understand the ricochet behaviour and related aspects of Kalashnikov bullets (7.62 mm × 39 mm) on 1 mm sheet metal. 1 mm sheet metal was selected as the target surface of the study, based on its greater possibility of existing in concurrent urban environments as vehicle bodies, electrical appliances, road signs, boundary walls, partitions, walls of mobile houses etc. The research added brand new knowledge to the firearm investigation field in general and specifically to AK shooting investigations and scene reconstruction. The ricochet angles and critical angle of 1 mm sheet metal and AK bullets, relationship of different impact feathers and angle of incidences are some of the main findings of the research. The double head impact mark which produces as a result of bullet's interaction with the target and it's specific relationships with the incident angles is the other most important results of the research which has not reported so far in a bullet ricochet study. In addition to the contribution of knowledge to the field of forensic sciences in general and forensic ballistic in particular, this research further emphasises the need for case by case empirical study to understand the ricochet behaviour of different bullet and target combinations. On the other hand, this study very deeply convinced firearms investigators on the risk of applying general bullet ricochet theory on yielding and nonyielding surfaces to reconstruct all bullet ricochet incidents which would result in wrong interpretations, critical errors in shooting scene reconstruction and finally for false testimonies.

1. Introduction

Police forces, crime investigators and forensic scientists frequently encounter shooting incidents where fired bullets have ricocheted off particular surfaces killing or injuring people. Ricochet can be defined as the rebound of a projectile off any surface [1] and occurs accidently or intentionally during shooting incidents. When a bullet ricochet may possess evidential value, shooting investigators conduct analysis to understand the ricocheted bullet's pre- and post-trajectories, impact site details, shapes of the ricocheted bullets and trace evidence on the bullets and surfaces to derive maximum information from the event ([2], pp 31–59).

Bullets ricochets are affected by a wide range of factors [3]. This means that each different ricochet analysis demands individual consideration, supported by existing subject knowledge and empirical testing to facilitate any investigators from scene reconstruction through to court presentation.

However, considering the high numbers of bullet ricochet incidents reported worldwide, it is surprising to find a very limited number of published works on this important subject area. Although limited literature published since 1975 up to now describes ricochet phenomenon of different bullet and surface combinations (i.e Backman et al., 1978 sited in [4–6]), ricochet studies on some of the most frequently reported bullets and target

* Corresponding author.
E-mail addresses: bmsnishshanka@yahoo.com (B. Nishshanka), c.shepherd@kent.ac.uk (C. Shepherd), paran28@gmail.com (P. Paranirubasingam).

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combinations in recent crime scenes and shooting incidents are surprisingly not available for reference purposes. Avtomat Kalashnikov (or AK) variant rifles discharging 7.62 mm × 39 mm rounds at 1 mm steel sheet metal is one such common bullet/target combination where ricochet data is not currently available.

Developed in 1947 and first used by Soviet forces in 1949, AK-47 assault rifles are now used in many countries around the world [7]. These guns, popularly known as “AK” or “Kalash” rifles, have become an enduring image of contemporary conflicts from major conventional battle grounds to gang wars [8] and have been extensively popular among criminals and terrorists. The widespread availability and use of these rifles and their ammunition (7.62 mm × 39 mm) in the world has been continuously reported, especially in urban shooting incidents in the recent past. In addition to the recent considerable numbers of AK shooting incidents reported in Europe, a continuously increasing number of incidents are reported around the world, predominantly in African and Middle Eastern regions where conflicts and terrorist-related crimes regularly take place. Studies conducted at the beginning of the 21th Century revealed that “out of the estimated 500 million firearms worldwide at the time,

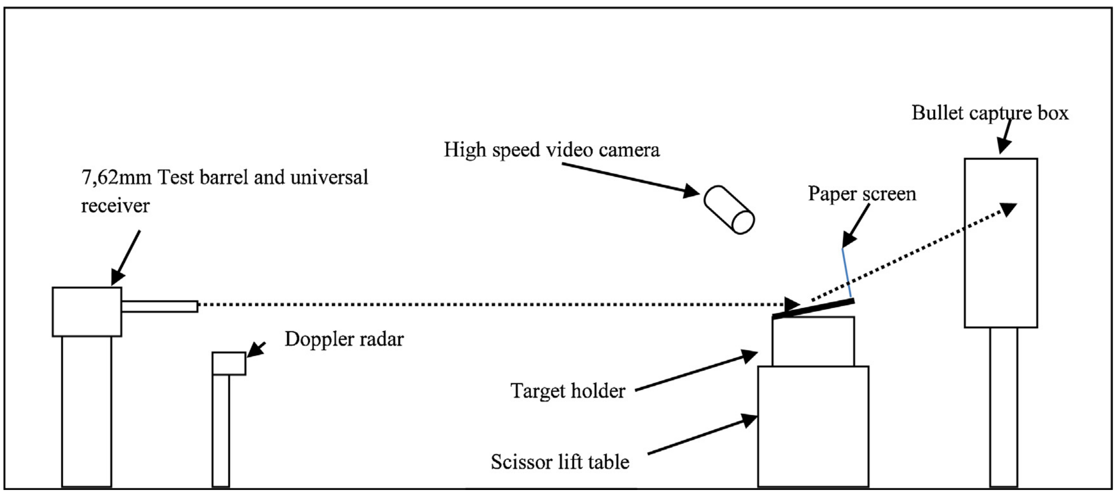

Fig. 1. Experimental Arrangement.

Fig. 2. Universal receiver firing assembly and target holder.

approximately 100 million belonged to the Kalashnikov family, three-quarters of which were AK-47s" [9].

In this study, the ricochet behaviour and related aspects of Kalashnikov bullets (from 7.62 mm × 39 mm FMJ BALL ammunition) on 1 mm steel sheet metal has been interrogated. Such 1 mm steel sheet metal is abundant in most urban environments in the form of vehicle bodies, electrical appliances, road signs, boundary walls, partitions, walls of mobile houses etc. and is therefore a commonly encompassed impact surface in urban shooting incidents.

2. Material and methods

A 7.62 mm test barrel securely mounted to a universal receiver was used to horizontally fire bullets from 7.62 × 39 mm Standard BALL rounds (Siberian FMJ bullets with a copper jacket and lead core) at an angled target holder which held 1 mm metal sheets of 1.5 feet × 1.5 feet at varying angles. The sheet metal was not supported directly underneath the impact sites. The bullets were soft-captured in a box containing Kevlar fabric after ricochet. The distance from the muzzle to target was 10 m and the average muzzle velocity was 760.62 m/s with 1.89 m/s standard deviation, measured using Döppler Radar. The experimental arrangement can be seen in Figs. 1 and 2.

Data was collected for firings at sheet metal panels held at an initial incident angle of 3-degrees above the horizontal and then at gradually increasing angles until 100 percent perforation was observed and ricochet no longer occurred. 10 shots were repeated at each incident angle but no more than 5 shots were impacted on any given sheet metal panel, with the target holder shifted in sufficient increments from left to right to maintain the same range but also ensure that any given impact event did not influence the next. Distances from the ricochet mark to the paper screen (distance from the end of the ricochet mark to paper screen (Fig. 3, from C to B) and vertical height of the impact mark on the paper screen (distance from the bottom line of the paper screen to the bottom of the impact mark on paper screen; Fig. 3, from B to A) were measured in order to calculate ricochet angles using basic trigonometry, making the assumption that the velocity of the bullets was sufficient such that any effects due to gravity were negligible over the distance travelled post-ricochet. Deflection of the bullets laterally to the left or right was investigated, however no such deflections were observed within these experiments. Measurements were taken shot by shot and any other observation noted. The arrangement of target material, paper screens and the calculation of ricochet angle (β) are illustrated in Fig. 3.

3. Results and discussion

It is important to emphasise that the ricocheted bullets in this experiment behaved quite differently from any behaviour

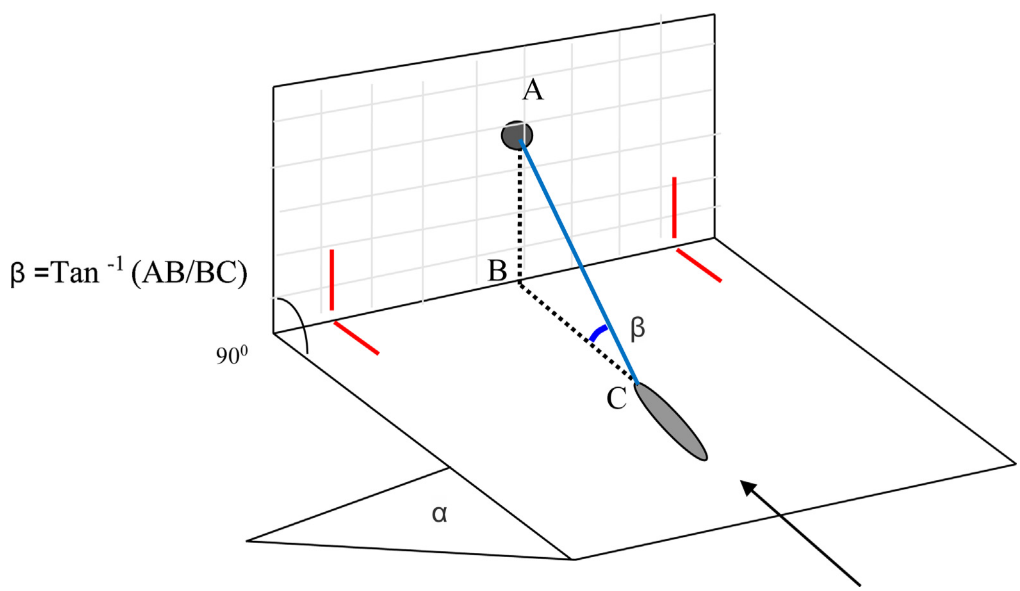

Fig. 3. Measurements and calculation of the ricochet angle using basic trigonometry.

Table 1
A summary of the ricochet observations occurred.

Incident Angle	Results	Remarks	Was a rupture produced?
3°	True Ricochet	• Clear bullet hole on paper screen with no fragments. • One side flattened bullet with core and jacket intact recovered.	No
5°	True Ricochet	• Deformed and slightly fragmented bullet parts (jackets and cores intact) were recovered.	Yes
8° to 20°	Partial ricochet/partial perforation	• Bullets fragmented. A clear impact mark of the ricocheting jacket observed on the paper screen with ricocheting and perforating fragments. • Full perforation was observed in 2 instances out of 10 shots in 20-degrees.	Yes
21°	Full perforation	• Bullets fragmented and perforated the surfaces	Yes

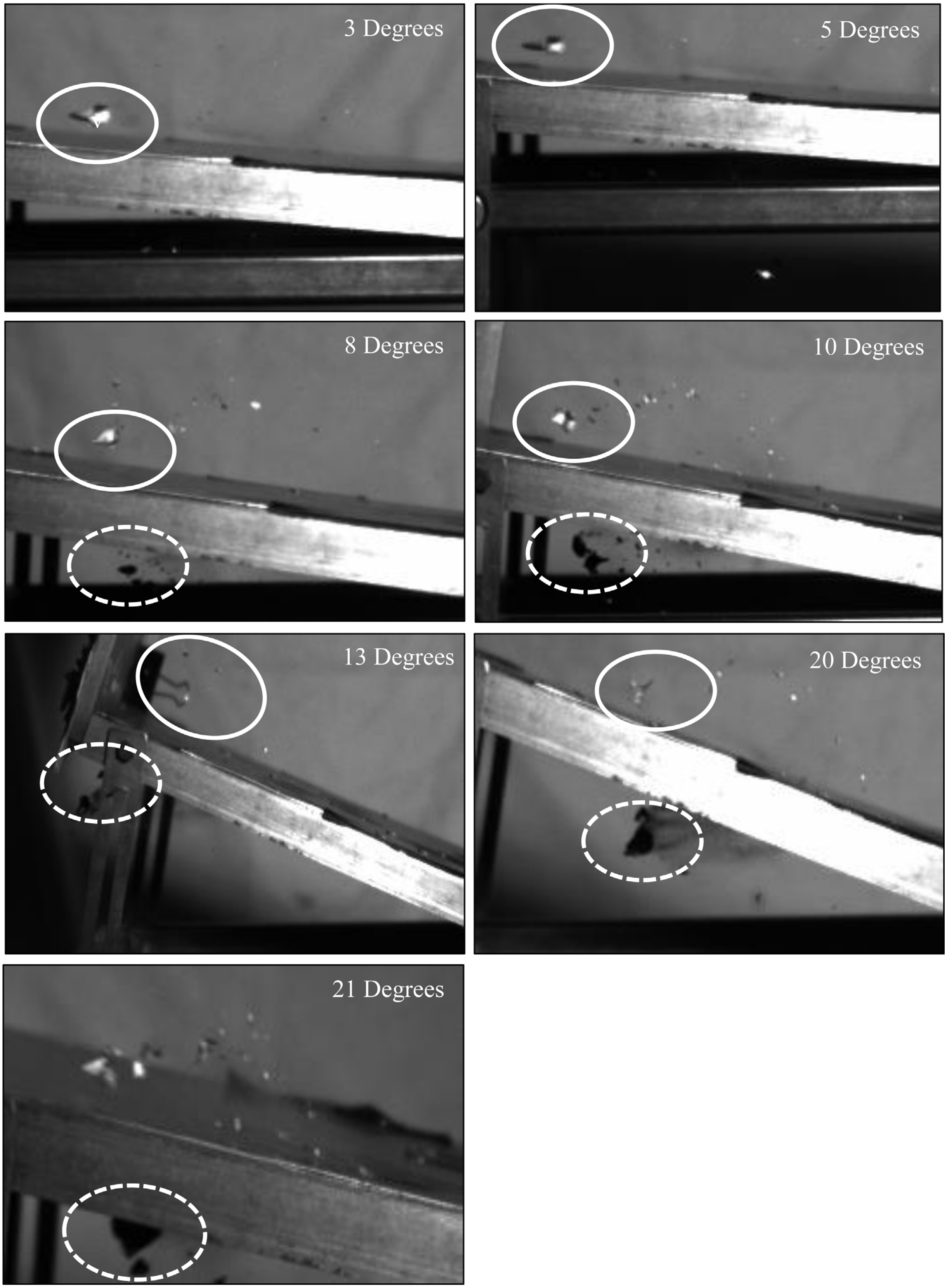

Fig. 4. Ricochet phenomenon of bullets from 3 to 21 degrees after impact with a 1 mm sheet metal surface, showing ricocheted fragments (solid circles) and perforated fragments (dotted circles).

previously described in the literature, showcasing a more complex behaviour. At the 3-degree incident angle, bullets ricocheted off as one piece (true ricochet) with clear cratering but no rupture of the sheet metal. A true ricochet also occurred at 5-degrees but this time there was a rupture of the sheet metal. At 8-, 10-, 13- and 20-degree incident angles, the bullets fragmented and displayed partial ricochet and partial perforation behaviour, producing clear ruptures through the metal sheets. However, major portions of the bullets (jackets) were always seen among the ricocheted fragments except at 21-degrees when full perforation typically occurred. These phenomena are summarised in Table 1 below:

Still images from high-speed video footage illustrating the discussed phenomena in Table 1 are shown in Fig. 4. The main projectile fragment that ricocheted (the copper jacket) is circled with solid lines and perforating fragments (mostly lead alloy core) are highlighted with dotted lines. All images were taken after the bullets impacted the sheet metal surface.

3.1. Ricochet angles

The ricochet angles that were calculated using basic trigonometry (as per Fig. 3) are summarised in Fig. 5. The angles of ricochet

Incident Angle (degrees)	Average Ricochet Angle (degrees)	Remarks
3	1.84	True Ricochet
5	2.38	
8	3.74	Ricocheting angle of the main fragment (jacket)
10	3.79	
13	3.48	
20	4.47	

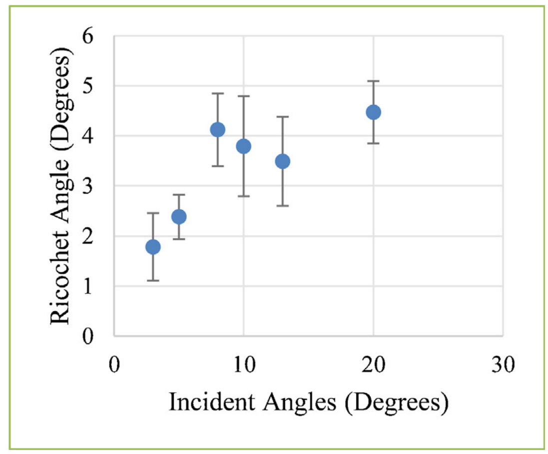

Fig. 5. Ricochet angle results with standard deviations based on 10 experiments for each angle of incidence.

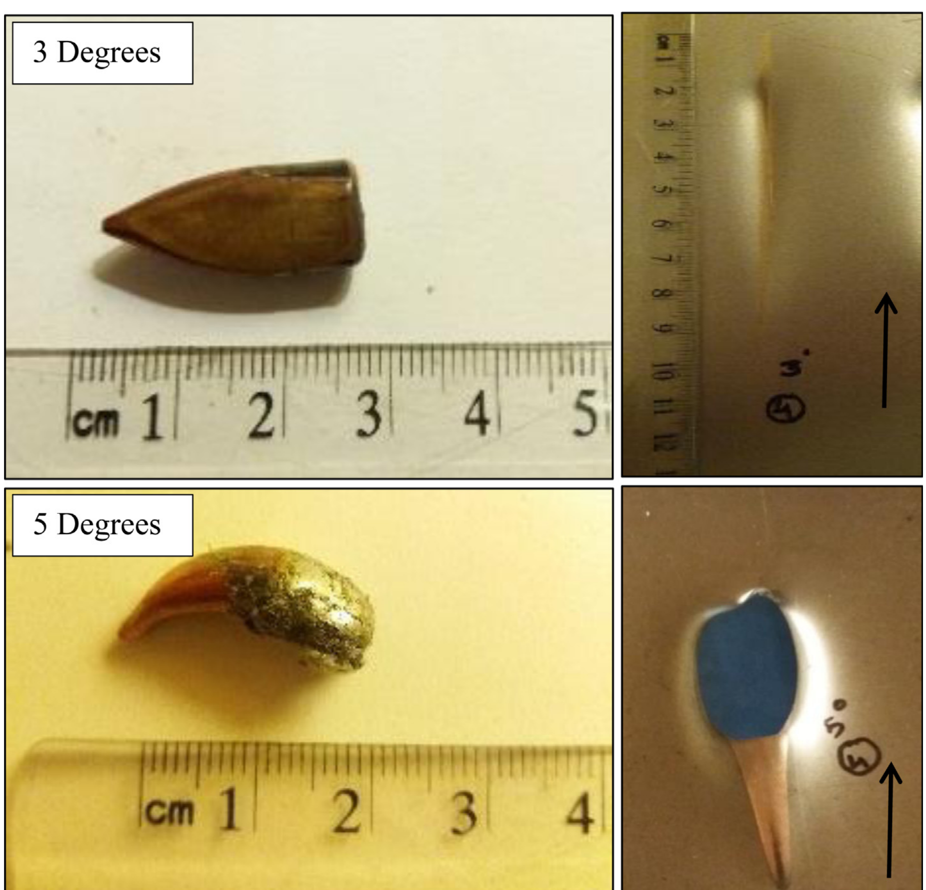

Fig. 6. Recovered bullets and associated impact marks on sheet metal at 3- and 5-degrees.

presented represent the average obtained for 10 observations recorded for each angle of incidence. A fair degree of consistency was observed in each set of data for the corresponding ricochet angles with larger errors experienced for the impacts where the core and jacket had separated to differing extents at incident angles of 8° or more.

3.2. Low ricocheting angles than incident angles in 3 and 5 degrees

It was observed that the ricochet angles (true ricochet) in 3 and 5 degrees were lower than the incident angles and therefore, the data was not in line with the existing theories presented in the literature on bullet ricochet angles on yielding surfaces (Haag and Haag [2]. No rupture had been produced at 3-degrees and a rupture was observed in 5-degrees. At 3-degrees, which is a very shallow angle, bullets did not enter the surface matrix but the long body was instead sliding on the surface before ricocheting off (the surface acted like a non-yielding surface). This was clearly indicated by the length of the ricochet creases, which were comparatively long (8–10 cm) when referenced against the lengths of the impact marks at higher incident angles (typically 2–4 cm) and flattened body of the collected bullets. The low incident angles at 3 and 5-degrees, combined with the long body of the bullet, encouraged a 'skidding' effect of the bullet across the target surface leading to minimal energy transfer and subsequently fairly minimal surface creasing. At 5-degrees, there was a sufficient

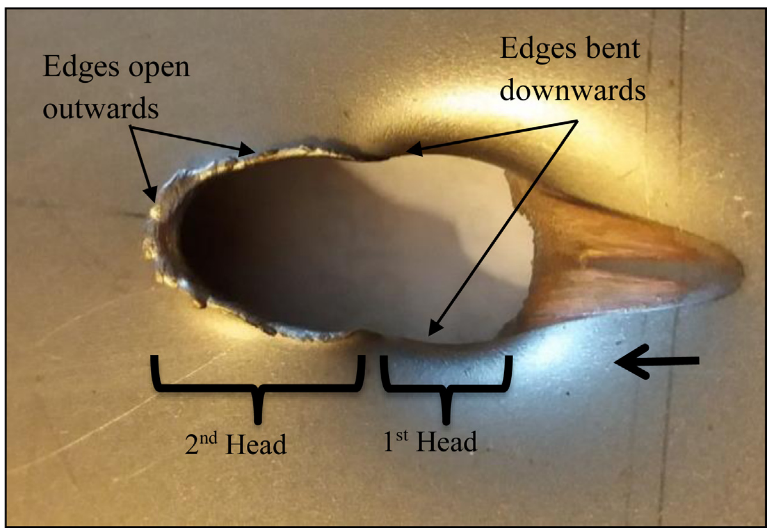

Fig. 7. Production of a double head mark at 13-degrees and its main features.

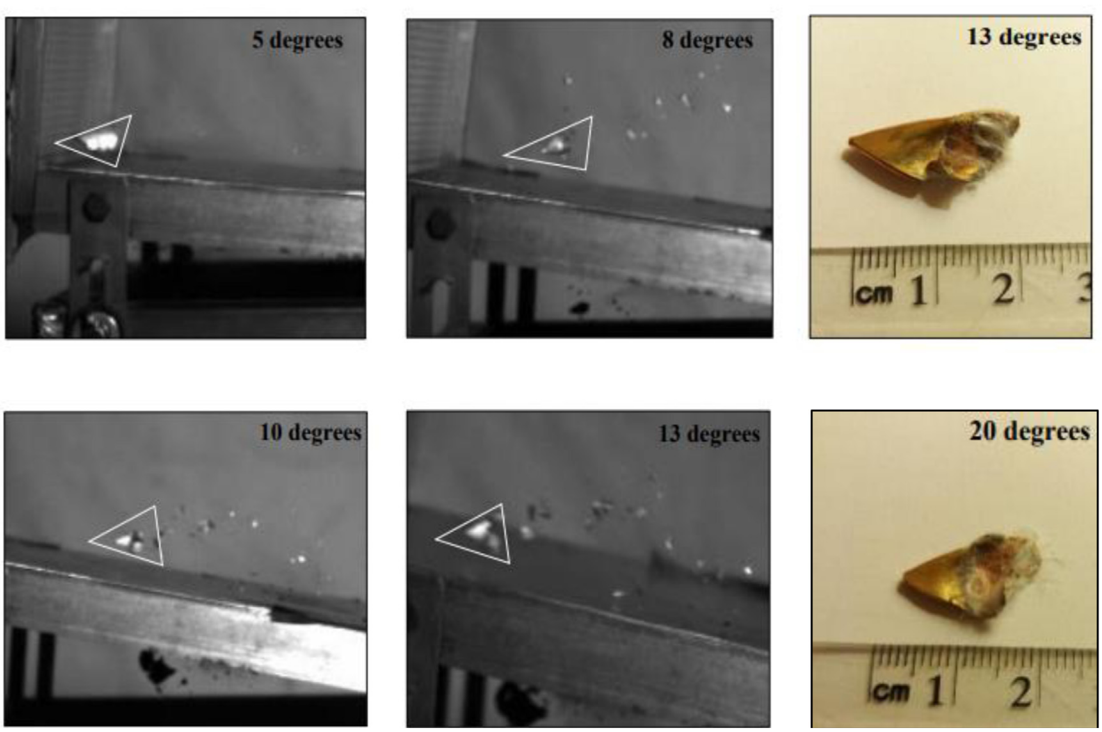

Fig. 8. Some of the ejected triangular nose fragments in 5-, 8-, 10- and 13-degrees and nose fragments with cutting effects at 13- and 20-degrees.

component of the bullet's energy being directed into the target surface to permit the creation of permanent deformation in the form of a clear rupture, composed of an initial crease leading to a clear hole where the surface has been ruptured. Interestingly, despite such a clear hole being formed, the bullet only fragmented very slightly and most of the main bullet structure (core and jacket) underwent ricochet rather than passing through the newly created hole. This suggests that the sheet metal surface was able to sufficiently resist perforation for most of the interaction time with the bullet and only underwent full rupture after the bullet had started its ricochet process, then being redirected upwards and away from the surface. A pictorial illustration of the ricochet mark and a recovered bullet in 3 and 5-degree impacts are shown in Fig. 6.

3.3. 8–21 degrees

For impact angles of 8–21 degrees the bullets fragmented and showed a half-ricochet/half-perforation phenomenon. However, bullet jackets were always seen among the ricocheting fragments, producing a triangular shaped impact mark on the paper screen. The core was fragmented and seen both in ricocheting and perforating fragments, which may be expected due to the relatively soft nature of the lead alloy that makes up the core. The main observation in the 8–21 degree incident angles was the production of a unique ricochet impact mark on the sheet metal and this was clearly observed in all ricochet impact mark samples. The unique impact mark, not previously described in the existing literature, will be referred to as the "double-headed ricochet mark" henceforth. This impact mark was slightly observed in a few of the 5-degrees shots, but not consistently. The structure of this double-headed ricochet mark consists of an initial lead-in crease and two clear ruptures (heads) as can be seen in Fig. 7.

The edges of the 1st rupture (1st Head) adjoining the lead-in mark have bent downwards and the second rupture (2nd Head) has its edges open outwards. This phenomenon can be explained in two phases as follows:

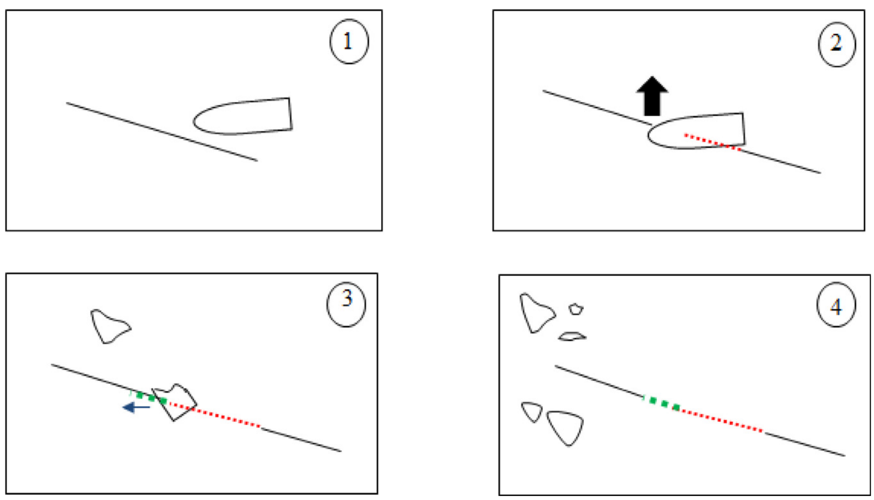

Fig. 9. A diagram showing the formation of double head mark. Red colour line indicates the 1st head and the green colour line indicates the 2nd head (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Angle of Incidence (Degree)	Average length of the 1st Head (mm)	Average length of the 2nd Head (mm)
8	17.62	6.91
10	13.42	8.14
13	10.35	10.40
20	6.78	9.15
21	6.60	8.64

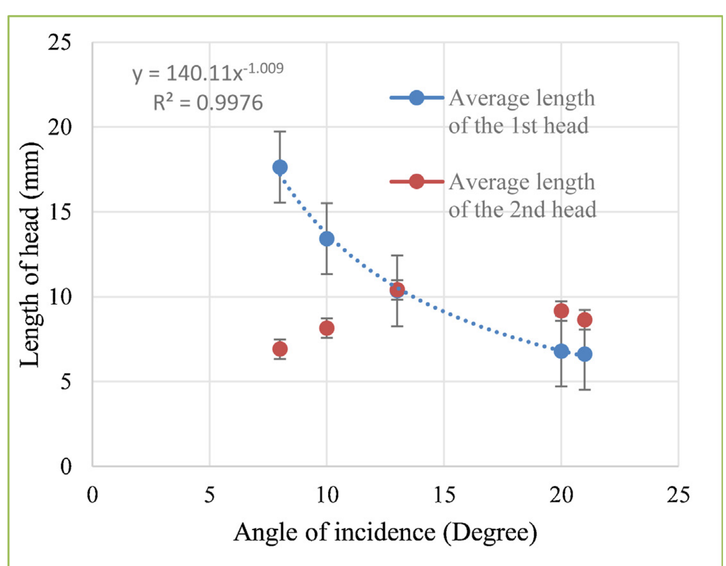

Fig. 10. Relationship of incident angle against average lengths of heads.

Phase I - When the bullet interacts with the surface, its continuous forward thrust with high velocity and energy presses the sheet metal down to break and produce the first rupture.

Phase II - Due to the low incident angle, reaction of the surface to the bullet's interaction, shape and length of the projectile, the bullet starts to change its direction upwards. At this moment, the nose of the projectile is under the sheet metal and due to the upwards thrust, the sheet metal breaks once again producing the second crate, where the sheet is seen to lift upwards. This action is believed to induce the subsequent velocity loss and low ricocheting angle. This phenomenon was reconfirmed through collected triangular nose fragments from ricocheted fragments and high-speed video footages (Fig. 8). The consistent shape and sharp nature of these fragments may also suggest that the sharp edges of the sheet metal double-headed ricochet mark may be creating a cutting effect on the bullet jacket. A diagram showing how the double-headed mark is developed is illustrated in Fig. 9.

When further looking at the relative length of the two head structures, a clear decrease in the length of the first head with an increase in the incident angle was observed. The relationship was shown to be almost exactly inverse. The length of the second head did not show as much of a relationship with incident angle and stayed relatively consistent as the angle varied. At a 13-degree incident angle, the average sizes of both the heads depicted very similar values (10.35 mm and 10.40 mm). A graphical representation is given in Fig. 10 with the measured average lengths of two heads.

3.4. Relationship of incident angle vs length of the impact mark and lead-in mark

Lengths of the full impact marks and lead-in marks were separately measured using a digital caliper (±0.005 mm) and a strong relationship was observed with the corresponding angles of incidence (Fig. 11). This was also confirmed in the findings of

Angles of incidences (in degrees)	Average length of the ricochet mark (a) (mm)	Average Length of Lead in mark (b) (mm)
3	94.73	-
5	64.91	41.8
8	47.84	23.37
10	42.31	21.59
13	36.65	17.55
20	26.72	11.06
21	26.09	10.67

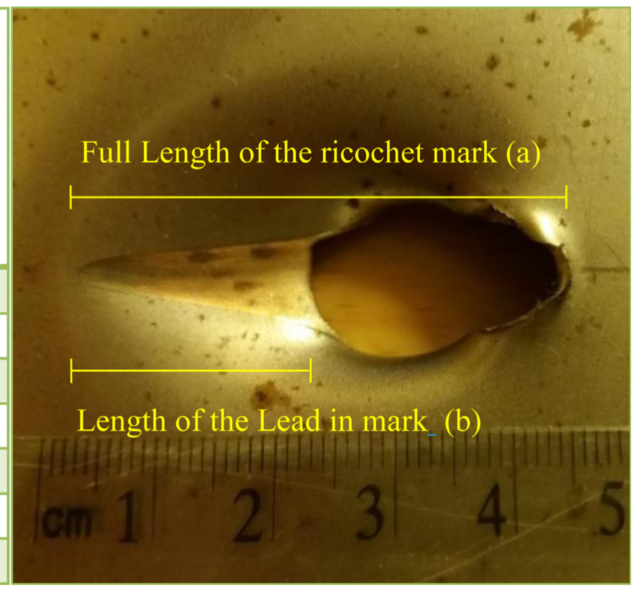

Fig. 11. Measurements of lengths of the impact marks.

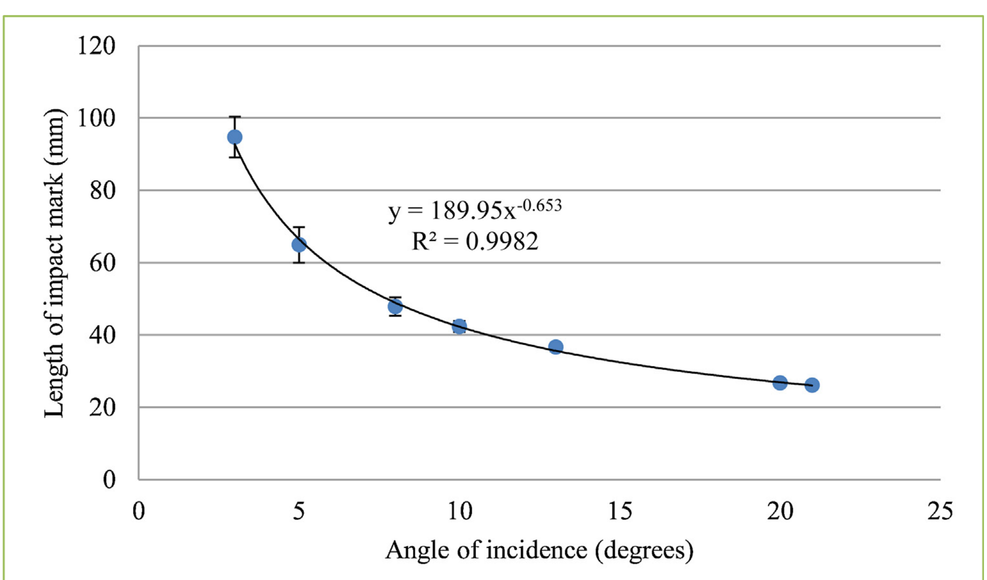

Fig. 12. The angle of incidence vs average length of impact mark.

Rathman [10], in which the lengths of bullet impact marks at low incident angles reported longer than high incident angles. A statistical analysis was performed separately, modelling the lengths of the ricochet mark and lead-in mark as a function of the incident angle. Figs. 12 and 13 illustrate the results of the analysis performed which indicates a strong relationship between the incident angle and both the length of the impact mark and the length of the lead-in mark. The bullet impact marks produced at the 3-degree setting were not considered as they indicated a different phenomenon and features.

3.5. Bullet stability and orientation after ricochet

Bullet stability was studied using the high-speed video footages that were made of the shots at various angles and also by studying the impact features on the paper screens. At 3 and 5-degrees, clean bullet holes were seen on the paper screens and the videos depicted a stabilised secondary trajectory of the ricocheted bullets with forward pointing nose. In all other incident angles, the bullets fragmented either fully or partially after they ricocheted off the surface and the ricocheting main fragment showed approximately side-on impact on the paper screens having undergone a 90-degree rotation. This has been caused by the natural instability induced during the impact event and would likely have a significant effect on the trajectory of the projectile fragments. This would add unpredictable complexity to any attempts at reconstructing any given shooting event involving similar ricochets. Fig. 14 illustrates the similarity of these angular impact marks and how they all point to the right for different incident angles.

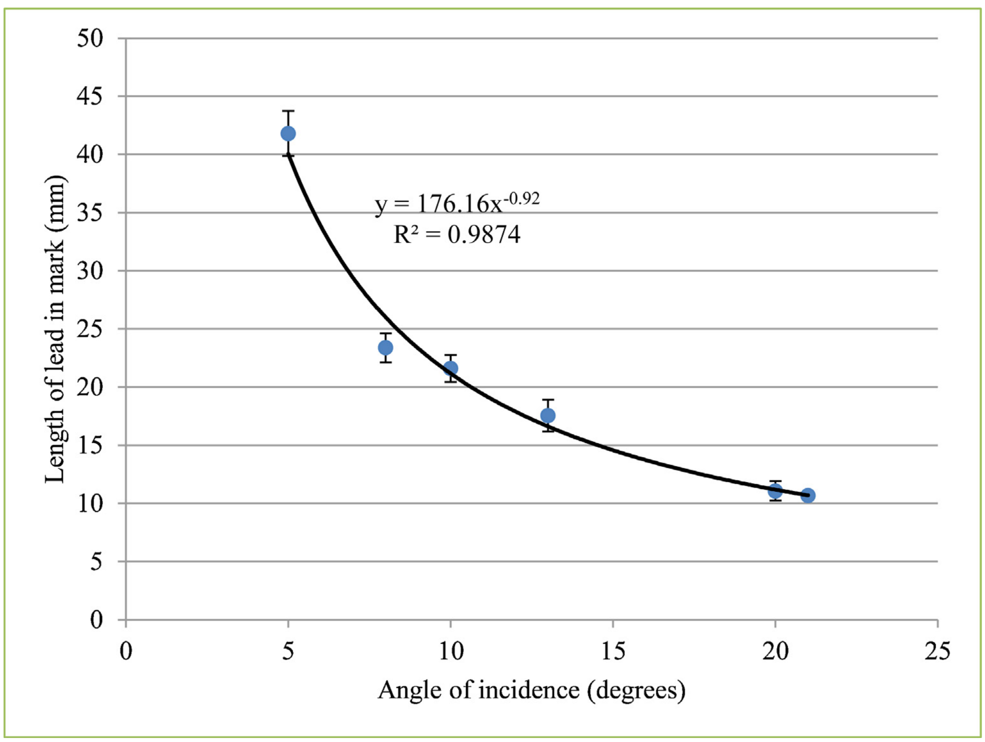

Fig. 13. The angle of incidence vs average length of lead-in mark.

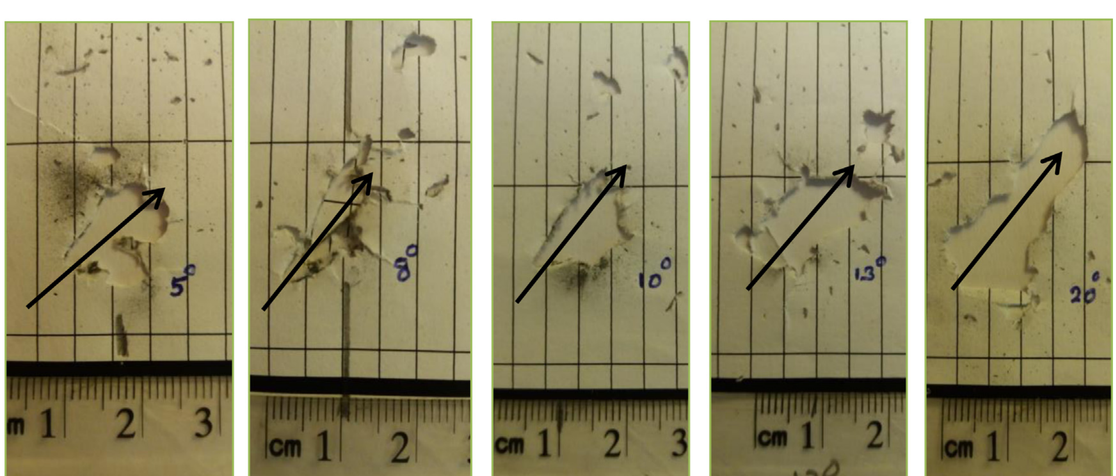

Fig. 14. Impact feature on the paper screens angled to the right in all incident angles.

4. Conclusion

7.62 × 39 mm FMJ Kalashnikov rounds have been fired at sheet metal at a range of angles between 3- and 20-degrees. A full ricochet was observed at 3- and 5-degrees and a partial ricochet/partial perforation phenomenon was observed from 5- to 20-degrees. The bullets consistently fragmented for impacts at angles greater than 5-degrees and the ricocheting jacket fragments showed an interesting triangular morphology, resulting from laceration by the sharp edges of the sheet metal. This paper has also demonstrated the first observation of a 'double headed' impact mark produced during a ricochet event, thought to be a function of the bullet impact properties and the mechanical nature of the thin metal sheet leading to a change in direction of the bullet after an initial perforation has occurred. 100 percent perforation was observed for impacts at 21-degrees.

As per the general bullet ricochet theory on yielding surfaces ([2], p.144), it was expected to observe higher ricochet angles than incident angles, however, the experiment recorded the opposite for 3- and 5-degree impacts, where true ricochet occurred. Calculated ricochet angles for the main bullet fragment for 8 to 20-degree impacts also reported the same results, however, with a partial perforation.

Clear relationships have been demonstrated between the angle of incidence and various measurements relating to the ricochet phenomena, including the lead-in crease length, length of the first head (in the double headed mark) and the overall length of the impact mark. Overall, this paper has demonstrated a complex ricochet behaviour that was not documented in the existing literature.

The findings of the research are specifically applicable to 7.62 × 39 mm lead cored FMJ bullets but may be applicable to other similar ammunition types. Future research in this area could suggest whether the newly observed double-headed ricochet mark is purely a function of the 7.62 × 39 mm FMJ bullets with lead core or of the 1 mm sheet metal target, as there are many varieties of 7.62 × 39 mm bullets with different configuration exist (i.e Armour Piecing; AP). This research has provided new knowledge for the firearm investigation and shooting reconstruction fields. The novel findings in relation to the impact behaviour of the projectile and impact substrate used here further emphasises the need for case by case empirical study to understand the ricochet behaviour of different bullet and target combinations during investigation of individual shooting cases to avoid critical errors and potentially false testimonies.

Authorship contributions

Category 1

Bandula Nishshanka: Conception and design of study.

Bandula Nishshanka, Chris Shepherd, Paranitharan, Paranirubasingam: acquisition of data.

Bandula Nishshanka, Chris Shepherd, Paranirubasingam, Shepherd : analysis and/or interpretation of data.

Category 2

Bandula Nishshanka, Chris Shepherd, Paranitharan, Paranirubasingam: Drafting the manuscript.

Chris Shepherd : revising the manuscript critically for important intellectual content.

Category 3

Bandula Nishshanka, Chris Shepherd, Paranitharan, Paranirubasingam: Approval of the version of the manuscript to be published.

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