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AK bullet (7.62 x 39 mm) holes on 1 mm sheet metal: A forensic-related study in aid of bullet trajectory reconstruction

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Running head: AK bullet (7.62 x 39 MM) holes on 1 mm sheet metal

Abstract

Bullet holes play a major role in the trajectory determination of fired bullets, potentially suggesting where the shots were fired from. Few methods are currently employed to estimate the angles of incidence of fired bullets using bullet holes. The literature has stressed that knowledge about the impact behaviour of the specific bullet-substrate interfaces, including the most viable method for estimating the angle of incidence of that combination, requires empirical testing to enable successful analysis.

The perforating bullet hole characteristics of AK bullets fired into 1 mm sheet metal over a range of angles of incidence have been documented in this study to aid bullet trajectory determination. A strong inverse relationship has been demonstrated between particular impact mark dimensions and the angles of incidence, revealing the possibility of using these dimensions to predict the angles of incidence for AK bullets perforating 1 mm sheet metal in actual crime scenes. This study has further confirmed the existence of a recently reported phenomenon for impacts related to this projectile-substrate combination, the “double-headed impact mark”, and relationships with the angles of incidence of fired AK bullets.

While suggesting an alternative and confirmative new method to understand the angles of incidence of fired AK bullets in 1 mm sheet metal using measured bullet defects, the study highlights a complex deviation phenomenon and a potential error that could occur when determining bullet trajectories using probing, stringing, or laser methods for the impact conditions described.

KEYWORDS

bullet holes, AK rifles, 7.62 x 39 mm, shooting reconstruction, bullet trajectory determinations, sheet metal

Highlights

- AK bullet hole characteristics from different angles in 1 mm sheet metal are explored in this study.
- The measured AK bullet impact mark on 1 mm sheet metal potentially indicates the incident angle.
- Double-headed bullet impact mark is observed over a wider range of angles than previously reported.
- Low-angled AK bullets perforating 1 mm sheet metal produce misleading secondary bullet defects.

Introduction

Following any shooting incident, bullet holes and their characteristics are considered important sources of evidence. In particular, bullet holes can play a major role in the trajectory determination of fired bullets, potentially suggesting from where the shots were fired (1). In addition to the probing method, which uses the direct line between two consecutive bullet holes to decide the trajectory of a fired bullet (2), previous studies (3) have highlighted two additional methods for determining the trajectory of fired bullets: the lead-in method and the ellipse method. The lead-in method uses the three-dimensional shape of the lead-in portion of a bullet defect to estimate the angle of incidence, while the ellipse method uses the shape of the primary bullet defect to calculate the angle of incidence. Stringing (4) and laser methods (5) can also be used for such analyses and follow a similar general technique to the probing method.

Out of many surface types used for bullet perforation experiments to estimate the angles of incidence of fired bullets, sheet metal has been frequently considered with different ammunition combinations due to its frequent appearance in shooting incidents with bullet holes (2, 3, 6, 7, 8, 9, 10, 11, and 12). These studies have described bullet hole characteristics on sheet metal surfaces in relation to bullet trajectory determination. However, recent studies have highlighted certain issues concerning accuracy, precision, and other potential errors when probing, ellipse, and lead-in methods are used to estimate the trajectories of fired bullets. In general, the best results in terms of accuracy and precision of estimation can be obtained when the probing method is used, whereas both the lead-in and ellipse methods provide better results specifically at shallow impact angles (3). Furthermore, a recent study (12) has highlighted that the bullet’s caliber and surface type also play a major role in providing accurate and repeatable results when the ellipse method is used. Another study (7) has highlighted that bullet impact marks on sheet metal have characteristic error patterns from low- to high-impact angles and that the ammunition type has a significant effect on the error pattern.

In this context, a recent bullet ricochet study has demonstrated the dimensional relationship between angles of incidence and different measurements of AK bullet holes when AK bullets (7.62 x 39 mm BALL/FMJ/ Chinese) ricochet off 1 mm sheet metal (11). The length of the bullet holes, length of the lead-in marks, and length of the first heads of the double-headed impact marks are highlighted features in the study, which proved to have consistent relationships with the angles of incidence during a bullet ricochet event. While highlighting complex behaviours of ricocheting AK bullets in low-incident angles, the authors emphasise the possibility of reliably applying the findings of the study to aid AK-related shooting investigations and, in particular, to extrapolate the incident angles of fired bullets.

All of the above studies have emphasised that the knowledge of the impact behaviour of the specific bullet-substrate interfaces, including the most viable method for estimating the angle of incidence of that combination, is required to enable successful analysis. This is because the impact outcome and the accuracy and precision of the selected method depends on many factors. Therefore, recognising the best method, which provides accurate and precise results for different bullet target surface combinations, and exploring new and alternative methods for trajectory determination of the most frequently reported bullet and target surface types have become a serious concern in the field of shooting reconstructions.

This study is designed to better understand the bullet hole characteristics of AK bullets on 1 mm sheet metal to aid bullet trajectory determination. In an increasing trend, AK rifles discharging 7.62 x 39 mm bullets are regularly reported in assault rifle shooting incidents worldwide, and flat 1 mm sheet metal is seen in urban environments in different forms, such as vehicle bodies, partitioning, house walls, roofs, electronic equipment, and storage equipment. The AK rifle's recent increasing worldwide popularity as the deadliest rifle used in crime scenes is due to many factors, such as the AK's availability, cheap price, reliability, and illegal proliferation. Consequently, in the field of shooting investigations, there will be a high demand for experimental data on these rifles. In view of this, further exploration into how such bullet holes on sheet metal can best be used for trajectory determination efforts during scene reconstructions is considered a contemporary imperative.

The study is also designed as a follow-up and continuation of the bullet ricochet study on the same bullet and target combination (11) to see whether the different numerical relationships observed with the AK bullet hole defects and angles of incidence during the said study are noticeable when AK bullets perforate 1 mm sheet metal. The study also aims to understand how the bullet hole characteristics can best be used for AK-related trajectory determination in shooting reconstructions.

Materials and Methodology

An AK-family assault rifle (Type 56 – MK II) was fired at 1 mm thick zinc-coated automotive steel metal sheets, held over a range of angles (15–90 degrees) and placed at a range of 10 metres. A specially designed target tray held the sheet metal at the required angles, and the rifle was fixed to a stable and levelled firing platform to allow the gun to be fired horizontally each time. The level of the barrel was set exactly horizontally to the ground using a level and was checked regularly between firings. The height of the barrel (from the muzzle end to floor level) was 1.4 m, and the impact point of the target surface was set to align with the barrel height. The horizontal bars of the target frame and firing platform were parallel to the ground, and the level was regularly checked between shots.

Sheet metal samples of 45 x 45 cm were placed in the target tray (sheet metal samples were firmly fitted to the frame of the target tray using four bolts and not supported directly underneath). The angles of the target tray could be adjusted from 0 to 90 degrees. Once the angles were set, the target tray could be locked using two butterfly nuts to ensure no changes to the set angle during firing. An inclinometer was placed on the surface of the sheet metal and was used to set the angles of the target tray. The inclinometer precision was ± 0.15 degrees. Ten shots were fired at each angle, starting at 90 degrees and decreasing in 10-degree regular intervals down to 20 degrees until the critical angle was reached (15 degrees with all 10 shots perforated was also included). Before each shot, the horizontal and vertical levels of the target holders and the angle of the sheet metal samples were checked and confirmed using an inclinometer. The bullets used were 7.62 x 39 mm standard Chinese BALL ammunition with mild steel cores/copper jacket and a steel case. Since a simultaneous ricochet and perforating phenomenon of AK bullets had previously been reported at low-incident angles (11), two hardboard paper screens were also fixed at the edge of the target tray to capture the impacts of any ricocheting and perforating parts of bullets. Perforated bullets were soft-captured for further analysis using a box filled with Kevlar. The velocities of all fired bullets were measured using a chronograph. Shot numbers and angles were marked on the sample sheets using a permanent marker pen. The experimental arrangement and experimental apparatus are shown in Figure 1.

The full lengths of any bullet holes and impact marks were measured using a digital caliper, which was zeroed before each measurement was taken. The bullet impact defects observed at each angle of entry were noted and photographed. After bullets perforated the sheet metal, slight deflections from the original trajectories were observed, based on the secondary impact marks on the hardboard paper screen 2 (see Figure 1). Therefore, a method to calculate the bullet's deviation was designed based on the primary and secondary bullet defects on the sheet metal and hardboard paper screen 2. The method for calculating the bullet's deviation is shown in Figure 2.

Results and Discussion

The average recorded velocity of the bullets fired was 714.4 m/s with 7.6 m/s standard deviation. The critical angle at which the bullets transitioned from perforating the metal sheet to ricochet occurred at 20 degrees. However, the phenomenon observed at 20 degrees did not showcase true ricochets, and all impacting bullets displayed mixed behaviour of half ricochet/half perforation, with the separated jackets from the bullet ricocheting and the deformed and slightly damaged mild steel cores perforating. At 15 degrees, all bullets ricocheted off the sheet metal surfaces. All results between 15 and 90 degrees were analysed for this study.

Shape and size of the bullet impact marks on sheet metal

Bullet impact marks at 90 degrees were circular, and as the angle of incidence decreased, the marks became increasingly elliptical in shape. Figure 3 illustrates the different shapes and systematic expansion of the bullet holes, with decreasing angles of incidence. The average size of the bullet hole produced at 90 degrees was 7.63 mm with a 0.24 mm standard deviation. It was interesting to notice that seven out of 20 bullet holes had lower diameters than the original 7.62 mm diameter of AK bullets (7.54 mm, 7.32 mm, 7.45 mm, 7.21 mm, 7.33 mm, 7.61 mm, 7.53 mm) as "bullet holes caused by high-velocity bullets in sheet metal will typically leave a slightly larger hole than the causative bullet" (2). However, the mean bullet hole diameter reported here is slightly larger than the bullet diameter.

Bullet deviation from its original axis

The bullet's original direction before contact with the sheet metal was observed to change after perforation. A consistent downward or upward deviation of approximately 1 degree was observed in all bullets perforating the sheet metal from 40 to 90 degrees, while a different phenomenon of half ricochet and half perforation was observed from 15 to 30 degrees. In 15, 20 and 30 degree incident angles, AK bullets started to fragment upon impact, making the bullet's core and jacket separate. The cores of the bullets were always seen perforating the sheet metal underneath while the fragmented jacket was ricocheting. This was confirmed through the finding of the separated cores and jacket parts in the Kevlar soft-capture boxes in each repetition. Within this incident angle range, the hardboard paper screens had multiple holes produced by fragments from sheet metal and the bullets; hence, it was difficult to determine the exact secondary impact hole. Figure 4 shows some of the ricocheted jackets and perforated cores collected during the experiment.

This phenomenon had also been reported during the previous study (11) when AK bullets ricocheted off 1 mm sheet metal from 8 to 20 degree incident angles; however, was not measured or evaluated. Further, a triangular-shaped jacket portion of the bullet had been observed ricocheting during the ricochet study (11), and a different fragmentation phenomenon was observed in collected ricocheted jackets in this study (Figure 4: left picture). Two different types of ammunition used in the studies (lead cores and mild steel cores) may have caused this difference. A graphical illustration of the recorded vertical deviations of the bullets and bullet cores is given in Figure 5.

Although lateral deviation of bullets during bullet ricochet events is explained in a few sources (13, 2, 8, 14), numerical values on the post-perforation deviation of bullets or main fragment have not been reported in the literature reviewed for this study. The approximate 1 degree upward or downward deviation of the bullets from the angles of incidence of 40 to 90 degrees is more likely to have occurred as a result of the interaction interface of the bullet and the sheet metal rather than to be an experimental error, since there is clear repeatability in the data collected, with low associated standard deviations.

However, from a trajectory reconstruction point of view, the phenomenon observed below 40 degrees (left of the green line in Figure 5) should be noted as significant. A shot fired into these surfaces at low angles may cause a significant deviation in the bullet's path and consequently lead to major errors in estimated trajectories using trajectory rods, lasers, or strings, all of which tend to operate on the general assumption that the pre-impact trajectory is maintained when bullets pass through intermediate objects. Possible confusions and faulty conclusions based on the impacts of deviated cores and impact marks caused by ricocheting jackets on nearby surfaces in real scenes are also noteworthy to highlight here, as such a phenomenon can lead to severe misinterpretation during scene reconstructions of what exactly happened. Therefore, the trajectory rod method is not recommended to use when the angles of incidence of AK bullets on sheet metal are observed to be very low (up to 40 degrees). Such low-angled impacts may be identified from the double-headed feature of the bullet hole or the expanding length of the bullet holes (a length exceeding the overall length of approximately 15 mm is not recommended), as highlighted in subsequent paragraphs.

Full length of bullet impact mark

A relationship was observed between the full length of the impact marks (including the lead-in mark; see Figure 6) and the bullet's angle of incidence. The full length of the impact marks was observed to systematically increase with a decreased angle of incidence for the bullets. The change observed in average full lengths of impact marks below 30 degrees was particularly significant and was also where the bullets started to showcase a complex behaviour, with the creation of a "double-headed impact mark", as observed by a previous study (11). A summary of the measured full lengths of bullet impact marks and a graphical illustration of the same are shown in Table 1 and Figure 7 respectively.

The trendline equation in Figure 7 seems to suggest a clear inverse law here, with the exponential power being very close to -1 (-0.9725). It also enhances the significance value of these results for use in shooting reconstruction efforts, especially as alternative and confirmative methods for bullet trajectory determination of this bullet target combination.

The average (mean) differences of the estimated incident angles using the length of the bullet holes obtained in this study were compared with the average differences of results obtained through the probing method and ellipse method (using Cloud Compare Software (15)). The summary of the results obtained is given in Figure 8.

The new method for estimating trajectories based on the size of the bullet holes has proven to have the most accurate estimation of the incident angle of AK bullets on sheet metal within the accepted error margin of 5 degrees in bullet trajectory determinations. The results further highlight that the ellipse method is not a reliable method for this bullet and target combination. As a previous study (3) has highlighted that the lead-in method is not viable for estimating the angles of incidences of bullets that perforated single sheet metal surfaces, the new method can be introduced as a viable and non-destructive method to estimate the angles of incidences of AK bullets fired into single sheet metal surfaces. As bullets fired into sheet metal objectives sometimes deviate from their main axis due to interacting with intermediate objectives inside (i.e., car doors, electronic equipment), the new method can also be used as a confirmatory method to understand the angles of incidences of bullets before the probing method is employed.

Double-headed impact mark

The appearance of the primary bullet impact defect expanded from a round shape to an elliptical bullet hole with a visible lead-in mark as the angle of incidence decreased from 90 to 40 degrees.

At 30, 20 and 15 degrees, a special impact feature with two heads was observed. This impact feature, known as a “double-headed impact mark”, was first reported when AK bullet ricochets on 1 mm sheet metal were analysed for impact angles over the range of 8 to 21 degrees, in which the critical angle was reported to be “around 20-degrees”(11). Based on the observation of this unique feature of up to a 30 degree incident angle in this experiment, this further confirms that the double-headed impact mark is a common observation for AK bullets perforating 1 mm sheet metal in low angles, which extends the range of angles over which the phenomenon has been seen.

A strong relationship between the lengths of the first head of the double head impact mark and the incident angles of bullets was also observed. This relationship has been previously reported in the AK bullet ricochet study (11). An example of a double-headed impact mark observed in the experiment for 30 degrees is shown in Figure 9 (left), with a similar impact mark reported in the previous AK bullet ricochet study (right).

Additionally, the average dimensional values for the first heads of the double-headed impact marks in this study, with comparable values from the previous study (11), have revealed a connecting and continuing pattern, from AK bullet ricochet to perforation. A graphical illustration highlighting the connecting pattern of the result on measurement lengths of the first heads of two studies is shown independently and collectively in Figure 10 for better understanding. The overall results demonstrate a strong inverse relationship between the two factors, with the trend line power being extremely close to -1 (0.9914).

It is also important to highlight the data consistency observed here between the two data sets in Figure 10 (when taken independently and as a full set), despite the two experiments being conducted at different locations using two different types of the 7.62 mm x 39 mm caliber ammunition and different average velocities. The previous ricochet experiment was conducted using Siberian 7.62 mm x 39 mm BALL FMJ bullets with a lead core (average velocity 760 m/s), and this study was conducted using Chinese 7.62 mm x 39 mm BALL FMJ bullets with a brass case and mild steel core (average velocity 714.4 m/s). Additionally, a 7.62 mm test barrel had been used for the ricochet study, while a mounted, Type 56-MK II assault rifle was used for the current study. The slight overlapping and deviations of individual curves in the two experiments and the difference of the error bar limits may have occurred due to these differences. However, only 1 degree critical angle variations in the two studies and the constant nature of data and reproducibility demonstrate the usability of such results to estimate the angles of incidences of fired AK bullets into 1 mm sheet metal.

Conclusion

This study was conducted to better understand the bullet hole characteristics and related phenomena of AK bullets on 1 mm sheet metal for bullet trajectory reconstruction. AK bullets (7.62 mm x 39 mm) were fired into 1 mm sheet metal placed at different angles from 15 to 90 degrees.

The average diameter reported for the bullet hole at the 90 degree incident angle was 7.63 +/- 0.24 mm. The study revealed that bullet hole lengths increased as the angle of incidence decreased from 90 to 15 degrees, demonstrating an inverse relationship. To date, this relationship has not been widely used as a method to estimate the angles of incidence of fired bullets and has not proven viable to use with the same bullet target combination in actual crime scenes. A comparison of the estimated incident angles from bullet holes with commonly used ellipse and probing methods suggests additional reliability and the accuracy of these results over the other two methods and the usability of the size of the AK bullet impact mark on sheet metal as a new, alternative or confirmatory method to understand a bullet's incident angle.

The double-headed impact mark was observed at incident angles of 15 to 30 degrees and the length of the first head was shown to have a strong relationship with the angles of incidence for the fired bullets, and this was once again identified as a prominent feature of such impacts at a wider range of angles than previously reported (11). This now means the phenomenon exists for AK bullets impacting 1 mm sheet metal at angles of up to 30 degrees during AK bullet ricochet and perforation events. Since low-angle bullet perforation on flat sheet metal is commonly seen in urban environments (i.e., vehicles, signboards, partitions, steel furniture enclosures etc.), the strong inverse relationships highlighted in this work between dimensions of the double-headed impact mark on 1 mm sheet metal and the angles of incidence of AK bullets may present a viable alternative method to interpret bullets' angles of incidence in a different way to existing trajectory identification methods.

Trajectories for the deviated cores after perforation demonstrated an upward or downward deviation of 1 to 5 degrees from the bullet's primary trajectory, being consistently around 1 degree between 40 to 90 degrees and then increasing to 5 degrees as the angle of incidence decreased from 40 to 20 degrees, with the half ricochet and half perforation phenomenon. Although an approximately 5 degree error cone is acceptable in bullet trajectory determination (16), the reported significant variations for the perforated cores are important to notice to avoid possible confusions and faulty conclusions based on the impacts of deviated cores and impact marks caused by ricocheting jackets on nearby or secondary surfaces in real scenes. Based on the observations, the trajectory rod method is not recommended to use with 1 mm sheet metal surfaces for very low-angled impacts (up to 40 degrees) due to the production of possible multiple perforation sites by fragmented parts of the bullets and surface and production of large and irregular-shaped secondary impact marks where the exact positioning of the trajectory rod is difficult.

The comparative results from the trajectory rod method and ellipse method also highlight that the ellipse method is not viable for this bullet target combination and that the probing method provides the most accurate results. However, the new method has an advantage over the probing method, as it can be reliably employed even when there is a single perforated surface.

The strong relationships demonstrated in this study suggest there is scope to extend this work further to see whether similar phenomena are common to other sheet metal thicknesses with this same AK ammunition or alternative ammunition and gun types with the same metal substrate. Based on the strong relationships identified in this study between the angles of incidence and the marks from AK bullets on sheet metal, the authors of this study are in the process of designing an image analysis based software tool that can instantly scan an AK bullet hole on sheet metal to estimate the causative bullet's incident angle.

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TABLE 1 Average full length of the impact mark and incident angle of bullets (20 shots)

Angle of Approach (Degrees)	Average Full Length of the Impact Mark (mm)	Standard Deviation (mm)	Remarks
90	7.63	0.24	-
80	7.78	0.22	-
70	7.96	0.26	-
60	8.87	0.31	-
50	9.98	0.6	-
40	12.23	0.44	-
30	17.71	0.55	The basic shape of the impact mark started to change after 40 degrees and "double headed mark" with two heads were observed on sheet metal surface from 30 to 15 degrees.
20	27.99	0.82	
15 (All bullets ricocheted off)	37.96	1.56	

Figure Legends

FIGURE 1 Experimental arrangement and some of the experiment apparatus

FIGURE 2 The method for calculating the bullet's deviation

FIGURE 3 Different shapes and systematic expansion of the bullet holes with decreasing angles of incidence. The black arrows indicate the bullet's direction of travel and special deformation features observed such as raised collars as seen in 70, 60 and 50 degrees were similarly observed in all bullet holes for respective angles

FIGURE 4Some of the ricocheted jackets and perforated cores collected during the experiment

FIGURE 5 Angles of incidence for bullets against average deviation of the bullets from 15 to 90 degrees (10 shots for each). The area on the left of the green dotted line indicates the area where a complex behavior of half ricochet and half perforation was observed

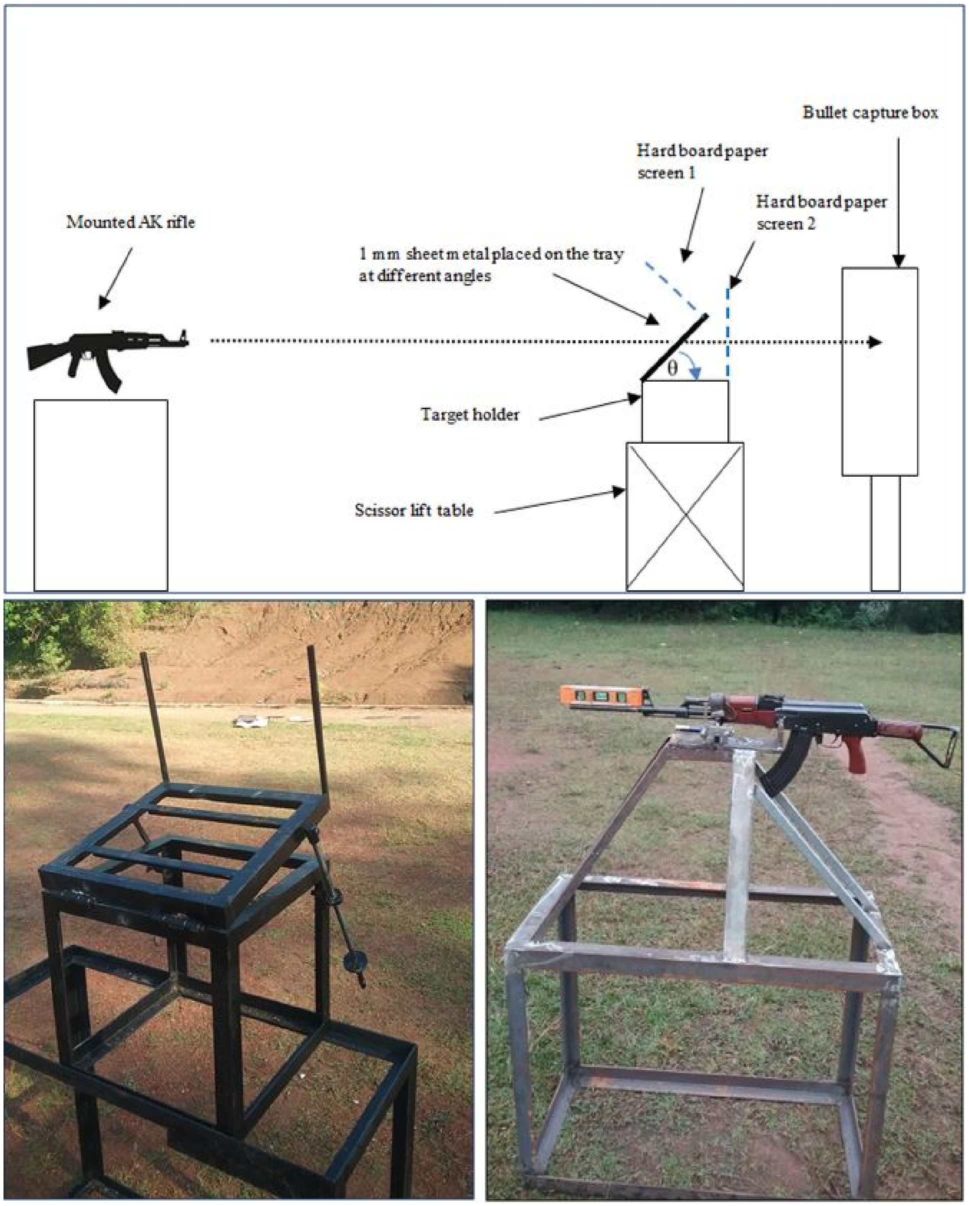
FIGURE 6 An illustration of how the measurements were taken, with the bullet originally travelling from right to left

FIGURE 7 Relationship between bullet angle of incidence and the average full length of the bullet impact marks (from 10 shots). At 15 degrees, all bullets ricocheted off sheet metal

FIGURE 8 A comparison between the mean differences of the estimated angles of incidences using three methods (As the incident angles between 5 and 40 degrees had inconsistent results with the fragmentation and complex behaviour, the angles could not be measured using probe method for the evaluation)

FIGURE 9 An example of a double-headed impact mark observed in this study at a 20 degree angle of incidence (left) and a similar impact mark reported during another AK bullet ricochet study (11) (right). The arrow indicates the direction of the bullet's travel

FIGURE 10 A comparison of the dimensional values observed in the first heads of double-headed impact marks in the experiment (during AK bullet perforation) and results of the ricochet experiment (11), during another AK bullet ricochet experiment). The critical angle observed during the current study was 20 degrees and 21 degrees in the previous ricochet study (11). Red and blue data points with coloured trendlines indicate the results of the two studies and the black dotted trend line indicates the overall combined results



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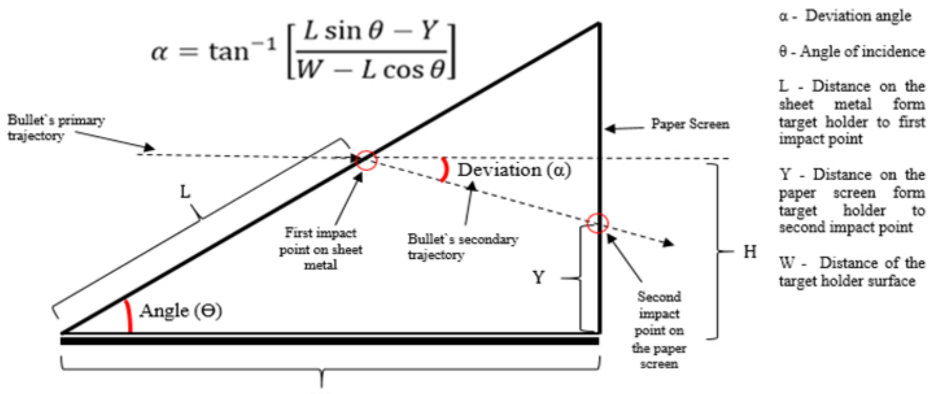

FIGURE 2 The method for calculating the bullet’s deviation

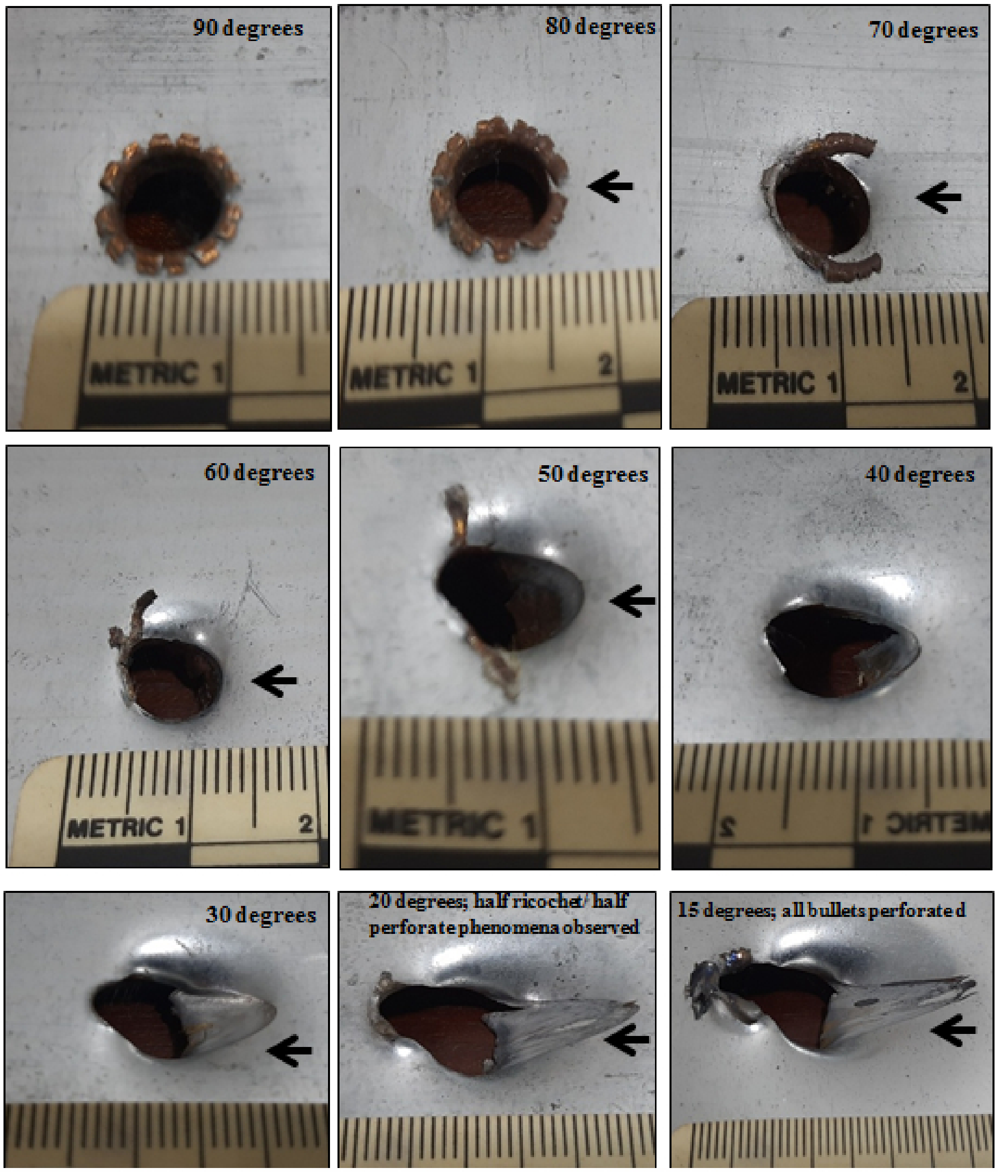

FIGURE 3 Different shapes and systematic expansion of the bullet holes with decreasing angles of incidence. The black arrows indicate the bullet's direction of travel and special deformation features observed such as raised collars as seen in 70, 60 and 50 degrees were similarly observed in all bullet holes for respective angles

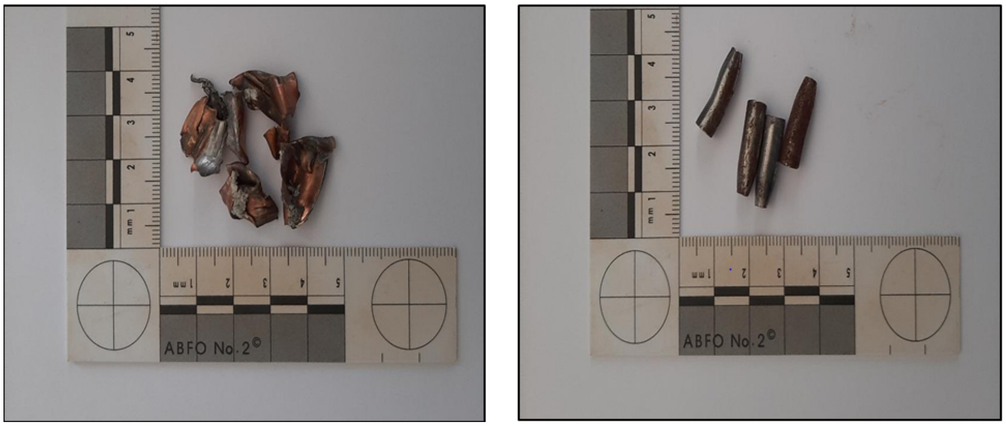

FIGURE 4 Some of the ricocheted jackets and perforated cores collected during the experiment

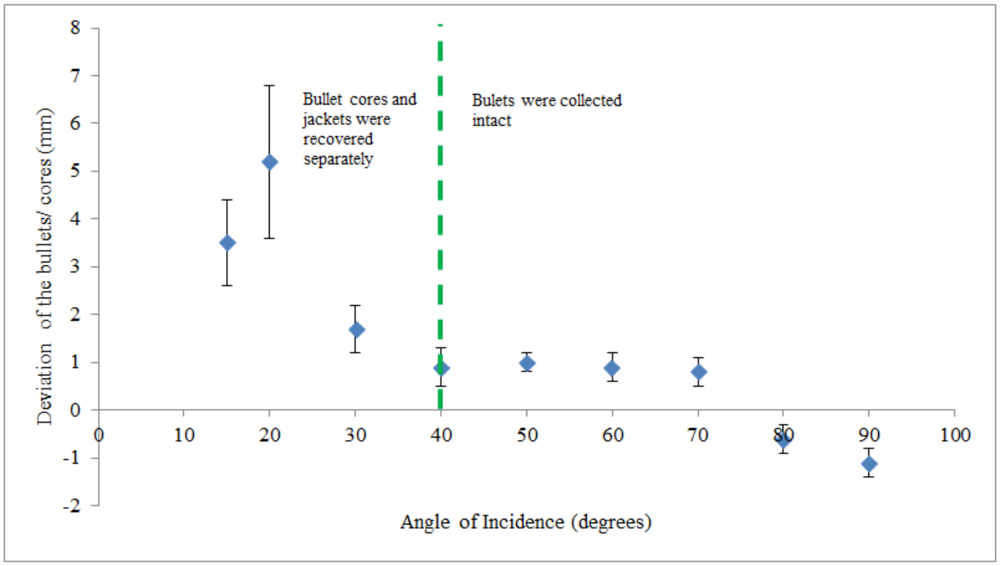

FIGURE 5 Angles of incidence for bullets against average deviation of the bullets from 15 to 90 degrees (10 shots for each). The area on the left of the green dotted line indicates the area where a complex behavior of half ricochet and half perforation was observed

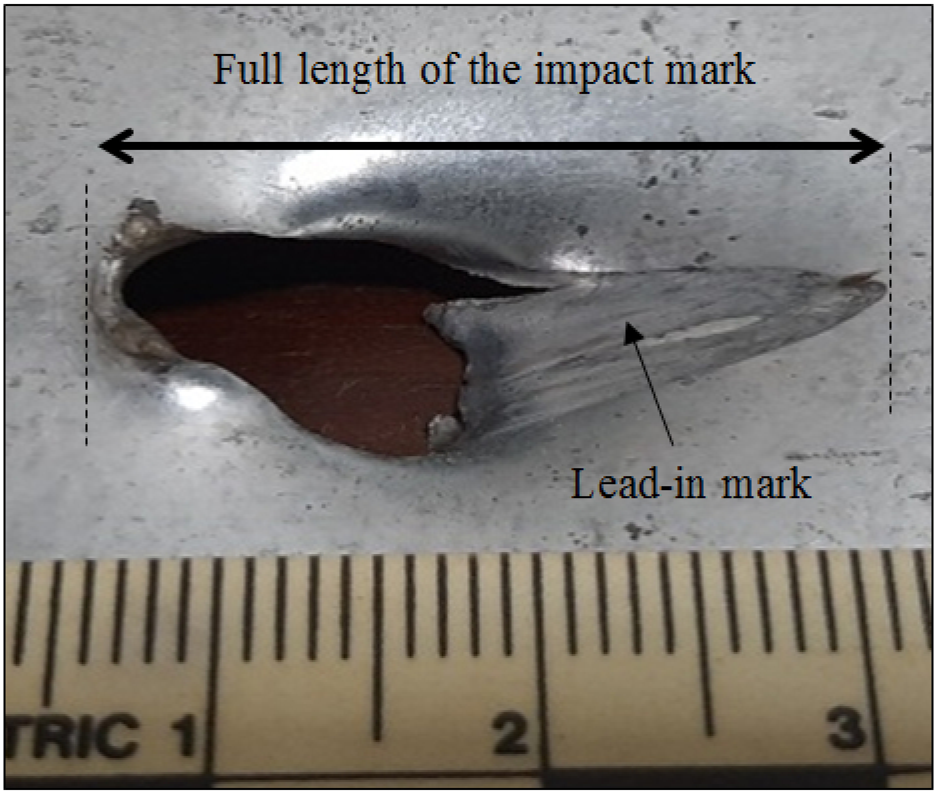

FIGURE 6 An illustration of how the measurements were taken, with the bullet originally travelling from right to left

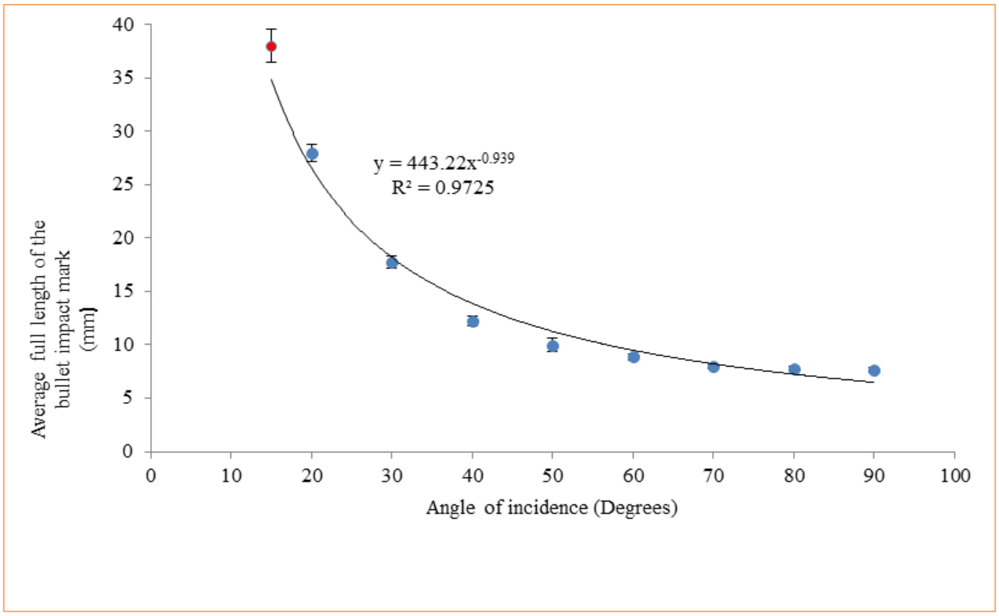

FIGURE 7 Relationship between bullet angle of incidence and the average full length of the bullet impact marks (from 10 shots). At 15 degrees, all bullets ricocheted off sheet metal

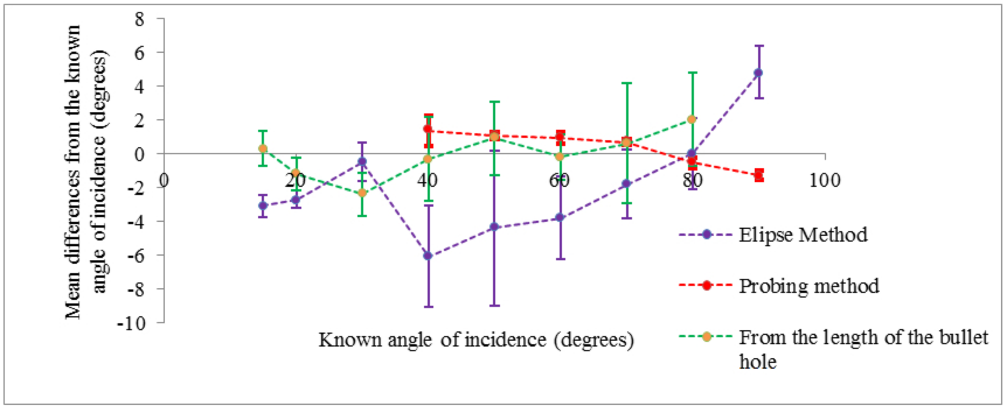

FIGURE 8 A comparison between the mean differences of the estimated angles of incidences using three methods (As the incident angles between 5 and 40 degrees had inconsistent results with the fragmentation and complex behaviour, the angles could not be measured using probe method for the evaluation)

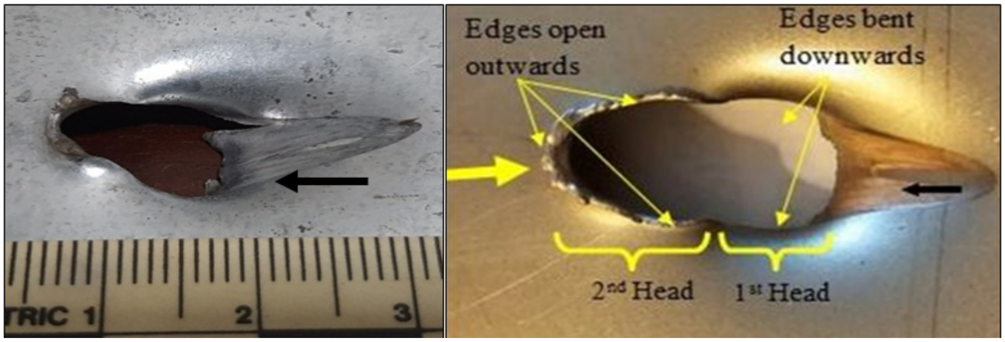

FIGURE 9 An example of a double-headed impact mark observed in this study at a 20 degree angle of incidence (left) and a similar impact mark reported during another AK bullet ricochet study (11) (right). The arrow indicates the direction of the bullet's travel

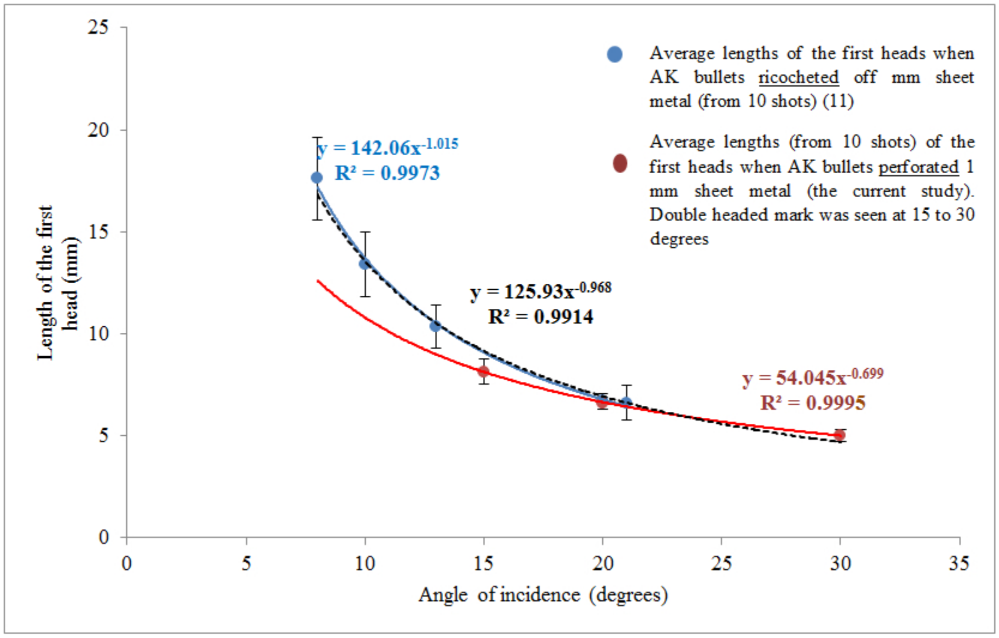

FIGURE 10 A comparison of the dimensional values observed in the first heads of double-headed impact marks in the experiment (during AK bullet perforation) and results of the ricochet experiment (11), during another AK bullet ricochet experiment). The critical angle observed during the current study was 20 degrees and 21 degrees in the previous ricochet study (11). Red and blue data points with coloured trendlines indicate the results of the two studies and the black dotted trend line indicates the overall combined results