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When a bullet strikes a target of sufficient solidarity at low angle it may, while maintaining its integrity, be deflected from its original path as a result of impact and travel in a direction quite different from its original one. Such a deflection of a bullet constitutes a true ricochet.

The *Encyclopaedia Britannica* attributes the discovery of ricochet fire, in which the shot after striking the ground at small angle described for the remainder of its course a series of leaps and falls, to Vauban. In old days this type of fire had the greatest influence both on sieges and on operations in the field. Due to the insufficient mobility of field artillery before Napoleon's time reliance was placed principally on the ricochet of round shot. With the development of artillery and consequent improvement in its mobility ricochet fire was used more and more sparingly and finally driven into oblivion with the appearence of explosive filled shells. In siege warfare also the development and perfection of high angle fire completely obviated the necessity of ricochet fire. However, ricochet fire with delayed action fuses was resorted to even in World War II to obtain air bursts after initial impact. In modern warfare ricochet fire is more or less a dead issue. The mention of ricochet is nowadays made only in connection with small arm projectiles.

According to Hatcher[1] richochet fire used in old days (round cannon balls fired from smooth bore cannons) was about as accurate as direct fire. This has ceased to be so with modern small arm projectiles due to their elongated shape, high velocity, and spin. He regards the phenomenon of bullet ricochet as essentially one of low rather than high velocity because a bullet travelling at high velocity usually breaks on striking a hard target.

Practical experience in the field of Forensic Ballistics shows that the phenomenon of bullet ricochet is not very well understood even amongst the experts. This is so inspite of the fact that this phenomenon plays an important part in criminal investigation. Ricochet marks are very often encountered on targets of diverse nature in shooting incidents and deserve due consideration in crime scene reconstruction. The following are some of the aspects of bullet ricochet that deserve mention and careful consideration:

a. Critical angle for ricochet.
b. Relation between the angle of incidence and ricochet.
c. Relation between the plane of incidence and ricochet.
d. Bullet stability after ricochet.
e. Bullet lethality after ricochet.

A review of literature shows complete lack of data concerning critical angles for ricochet for bullets loaded in common cartridges when fired against targets usually encountered in crimes. There is also no clear understanding regarding the relation between the angle of incidence and ricochet. Equally deficient is information on the other aspects mentioned above. It is, therefore, necessary to carry out a large number of control experiments with common cartridges and targets frequently involved in crimes. An investigation of this nature is not only expected to help in understanding of the phenomenon of bullet ricochet in general but also to provide useful data in respect of the cartridges and the targets used for experiments. The investigation has, therefore, been carried out with different cartridges and targets, and the results obtained in respect of some of the metallic targets have been reported in the present paper.

[1] HATCHER, JURY, AND WELLER, FIREARMS INVESTIGATION, IDENTIFICATION AND EVIDENCE. The Stackpole Company, pp 422–423, 1957.

Definitions and Abbreviations

Referring to Diagram I, let OX, OY, and OZ be a set of three mutually perpendicular axes meeting in origin O. Let the target be represented by the vertical plane YOZ. The plane XOY is another vertical plane perpendicular to the target plane. Let the horizontal plane XOZ be the plane of fire i.e. one containing the line of fire.

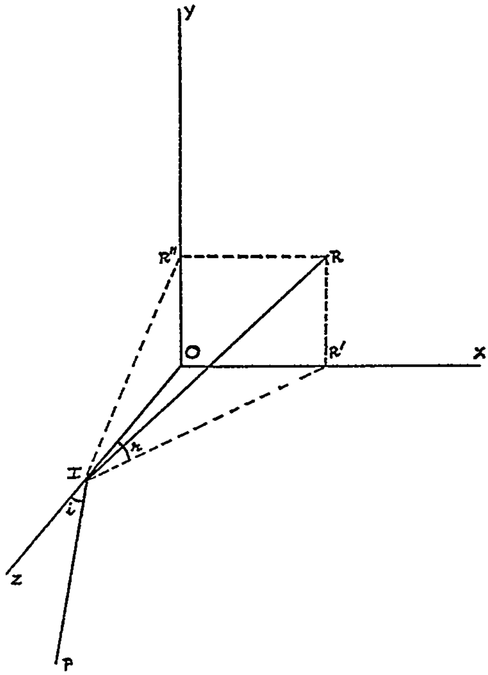

Diagram I

Let a bullet fired along PI strike the target at I and ricochet in the direction IR where R is the point of intersection of IR with the plane XOY. For generality it is assumed that the line IR is not contained in the plane of fire.

The following terms may now be defined:

Plane of incidence is a plane perpendicular to the target plane and containing the line of fire. It is represented here by the plane XOZ and is the same as the plane of fire.

Plane of ricochet is a plane perpendicular to the target plane and containing the line along which the bullet travels immediately after ricochet. It is represented here by the plane IRR″. When the line along which the bullet travels after ricochet lies in the plane of incidence, the plane of incidence and ricochet coincide.

Angle of incidence is the acute angle between the line of fire and the line into which the incidence and the target plane intersect. It is represented here by ∠PIZ.

Angle of ricochet is the projection on the incidence plane of the acute angle between the line along which the bullet travels immediately after ricochet and the line into which the ricochet and target plane intersect. It is represented here by ∠R′IO.

Critical angle for ricochet is the maximum angle of incidence at which the bullet ricochets. Once the angle of incidence exceeds this value the bullet fails to ricochet by either disintegrating or penetrating the target.

The following abbreviations will be used:

i: Angle of incidence.
r: Angle of ricochet.
r_c : Critical angle for ricochet.
L: Lead or unjacketted.
MJ: Metal jacketted.
S: Stable.
US: Unstable.
P: Penetration.
NP: No penetration.

Materials and Methods

The choice of the targets was governed by the frequency of their occurrence in day to day life and easy availability in some suitable form characterizing uniformity. Metal plates of uniform thickness were, therefore, chosen for experimentation. The following are the targets which were used for collecting bullet ricochet data:

a. Aluminium plates measuring 1′ x 1′ x ⅛″ and 1′ x 1′ x $\frac{1}{16}$″.
b. Brass plates with the same dimensions.
c. Steel plates with the same dimensions.

Firearms of typical calibers frequently involved in crimes were selected for conducting experimental firing. The cartridges chosen were essentially low velocity cartridges. This was purposely done for reasons of safety during experiments as well as due to the fact that a high velocity bullet generally disintegrated on striking a hard metallic target like the ones considered here. The firearms and the ammunition together with their ballistic data of interest in relation to the present investigation are given in table 1.

The experimental arrangement is shown in figure 1. The plane YOZ was replaced by the target (refer diagram I) which was held firmly in a

Table 1

Firearm	Ammunition	Bullet Type	Bullet Weight in grains.	Instrumental velocity in ft./sec
.22 Rifle No. 2, Mk 4, S. No. 6278	.22 Long Rifle, K.F.	L	40	1000
.38 W & S Revolver, S. No. 24706	.38 Ball, Mk 2, K.F.	MJ	178	600
.45 Colt Pistol, M1911, S. No. 22383	.45 ACP, Rem-Umc.	MJ	230	800

vertical plane on the horizontal floor of a steel lined bullet recovery box measuring 8′ x 3½′ x 3½′. This was achieved by designing a wooden frame with a flat wooden base attached at right angles to it. The target was put in the frame and the base of the frame was firmly secured to the floor of the bullet recovery box by putting heavy weights on the base and providing checks at its corners. The firmness of the base was confirmed by firing a few rounds on the target before starting the experiment and ensuring that the frame did not budge from its predetermined position.

The line PI was made to coincide with the line of fire by holding the firearm in a vice with its axis horizontal and plane of symmetry vertical. The vice was kept outside the bullet recovery box on a table and secured firmly to it by nuts and bolts. The distance between the muzzle of the firearm and the target was kept to a minimum that would stabilize the bullet before striking the target. The stability of the bullet was checked by first firing on a paper screen kept at the distance of the target and seeing that no keyholes were produced on the screen.

To fix the angle of incidence a long rod fitting snugly into the barrel of the firearm was inserted in the muzzle and extended upto the target. The angle of incidence was then measured by a protractor in the horizontal plane. The angle of incidence was changed by rotating the wooden frame if and when desired.

The plane XOY was replaced by a deal wood

FIGURE 1. Experimental Arrangement

board 1″ in thickness. The deal board was held in a vertical plane near the target and at right angles to it. The board was meant to record the point of impact R of the bullet after ricochet thus facilitating the measurement of the angle of ricochet and study bullet penetration after ricochet. The board was kept very near the target so that the bullet during its passage from the target to the board did not drop significantly due to gravity and also did not deviate from its true direction of ricochet due to possible instability. In such circumstances the line IR represented the true direction of ricochet. Once the position of point R was ascertained one could derive information about the plane of ricochet in relation to the plane of incidence. Whenever I and R were found to be at the same vertical height above the floor of the bullet recovery box it was inferred that the plane of incidence and ricochet were the same. Any movement of the point R upwards or downwards indicated otherwise.

Bullets were fired at different angles of incidence and the position of point R was recorded in addition to observations on penetration in deal board. The angle of ricochet (r) was calculated with the help of the simple relation

$$\angle r = \tan^{-1} \frac{OR'}{IO}$$

The angle of incidence was increased in steps of 15° starting from 15°. The observations between the incidence angle at which the bullet failed to ricochet and the one preceding it were, however, taken at steps of 5° with a view to determine the critical angle for ricochet within close limits. The critical angle thus lay between the maximum angle of incidence for which the ricochet was observed and the minimum angle of incidence for which the bullet failed to ricochet by either disintegrating or penetrating the target. The appearance of the bullet holes on the deal board provided a clear picture of bullet stability after ricochet. This was further checked by interposing a paper screen between the deal board and the target and observing bullet holes on the screen.

Bullet Ricochet Data

The tables 2, 3 and 4 give bullet ricochet data in respect of the targets and ammunition used for experiments. The tables are self explanatory.

Results and Discussion

A review of bullet ricochet data shows that the bullets became unstable after ricochet. During the course of experiments it was observed that the bullets hit the deal board in all possible ways after ricochet i.e. sideways, base forward, etc. To ensure that this instability was due to ricochet and not due to impact on the deal board, paper screens were interposed in the bullet path from the target to the deal board. The holes on the paper screens confirmed that the bullets were indeed unstable after ricochet. The bullets did not appear to be unstable when the angle of incidence was 5° or less (data not reported here). The cartridges used for the present investigation are loaded with base heavy spin stabilized elongated bullets. These bullets are likely to become unstable on impact. However, at extremely small angles of incidence the contact between the bullet and the target could be soft enough so as not to produce any observable instability under the experimental conditions. This was very probably the reason for the lack of instability exhibited at these angles.

An examination of the fired bullets revealed that they were invariably deformed. The amount and the nature of deformation depends upon several factors such as bullet material, target, angle of incidence, velocity, etc. A combination of hard target, soft bullet material and high velocity is likely to promote greater deformation assuming other factors to be constant. The bullets got flattened on the sides which bore the brunt of impact. In one instance in case of .22 lead bullet when fired on ⅛″ steel plate at 30° incidence this flattening led to the formation of a sharp edge. The hole in the deal board in this particular case was found in the shape of a vertical thin slit. It can be very well visualized that such bullets are likely to create wounds which may easily be mistaken as incised wounds. This will be even more likely if the bullet fails to lodge itself in the body. Atypical wounds of entrance are therefore expected from ricocheting bullets.

As a bullet not only becomes unstable on account of ricochet but also is deformed, it is clear that it is bound to have an erratic path after ricochet and lose velocity at a rapid rate. The bullet initially lost energy by striking a target which was relatively at rest, and this loss was further accentuated on account of its deformation and instability. The conclusion that the wounding power and the lethal range of a bullet is likely to

Table 2

Firearm: .22 Rifle No. 2, Mk 4, S. No. 6278

Ammunition: .22 Long Rifle, K.F.

Target	i in degrees	r in degrees	Ricochet plane in relation to incidence plane	Bullet stability after ricochet	Bullet penetration in 1" deal board after ricochet	r_0 in degrees	Remarks
Aluminum 1/16"	10	6	Same	US	P	10–15	—
	15	—	—	—	—		Bullet disintegrates and a portion passes through the target creating a hole.
Aluminum 1/8"	15	2	Same	US	P	30–35	—
	30	3	Same	US	NP		—
	35	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Brass 1/16"	15	3	Same	US	P	25–30	—
	20	8	Same	US	P		—
	25	6	Same	US	P		—
	30	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Brass 1/8"	15	3	Same	US	P	20–25	—
	20	2	Same	US	P		—
	25	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Steel 1/16"	15	2	Same	US	P	30–35	—
	30	3	Same	US	NP		—
	35	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Steel 1/8"	15	Almost zero	Same	US	P	30–35	—
							—
	30	1	Same	US	P		—
	35	—	—	—	—		Bullet disintegrates without creating a hole in the target.

be considerably reduced after ricochet seems inevitable.

The bullets of each one of the cartridges used for experiments are capable of penetrating several boards of 1" thick deal wood when fired directly. However, it will be noted (see tables 2, 3 and 4) that in many instances especially at higher angles of incidence the bullets failed to penetrate even one board after ricochet; at smaller angles of incidence they could penetrate one board. The bullets were, however, unstable at both the higher and the lower angles of incidence. It is true that instability and deformation affect penetration to a great extent but it also appears that the loss of velocity and hence energy was also responsible for the loss of penetration. At higher angles of incidence the impact is expected to be harder as compared to that at lower angles, and thus a bullet is likely to suffer more loss of energy at higher than at lower angles of incidence.

The angles of ricochet reported represent an average of a number of observations taken at each angle of incidence. A fair degree of consistency was observed between these values. Further each single value of the angle of ricochet was less than the corresponding angle of incidence. The difference between the angle of ricochet and the corresponding angle of incidence was also several degrees.

Table 3
Firearm: W & S Revolver, S. No. 24706
Ammunition: .38 Ball, Mk 2, K.F.

Target	i in degrees	r in degrees	Ricochet plane in relation to incidence plane	Bullet stability after ricochet	Bullet penetration in 1″ deal board after ricochet	r_c in degrees	Remarks
Aluminum 1⁄16″	15	5	Same	US	P	20–25	—
	20	10	Same	US	NP		—
	25	—	—	—	—		Bullet disintegrates and a portion passes through the target creating a hole.
Aluminum 1⁄8″	15	4	Same	US	P	35–40	—
	30	7	Same	US	NP		—
	35	8	Same	US	NP		—
	40	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Brass 1⁄16″	15	7	Same	US	P	60–65	—
	30	10	Same	US	NP		—
	45	20	Same	US	NP		—
	60	37	Same	US	NP		—
	65	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Brass 1⁄8″	15	4	Same	US	NP	35–40	—
	30	8	Same	US	NP		—
	35	9	Same	US	NP		—
	40	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Steel 1⁄16″	15	3	Same	US	NP	50–55	—
	30	7	Same	US	NP		—
	45	15	Same	US	NP		—
	50	17	Same	US	NP		—
	55	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Steel 1⁄8″	15	3	Same	US	NP	50–55	—
	30	6	Same	US	NP		—
	45	8	Same	US	NP		—
	50	9	Same	US	NP		—
	55	—	—	—	—		Bullet disintegrates without creating a hole in the target.

It is, therefore, fair to conclude that the angle of ricochet is less than the angle of incidence. At the same time it can also be seen that the amounts by which the angles of ricochet fall short of the corresponding angles of incidence do not follow any systematic pattern. It has been stated above that instability and deformation led the bullet to take an erratic path after ricochet. However, it is unlikely to exhibit this erratic behavior in close proximity of the target and is likely to travel in its true direction of ricochet. The drop due to gravity is also insignificant within this small distance. These considerations were mainly responsible for keeping the path of the bullet from the target to the deal board after ricochet to a minimum. The reduction of this path at the same time reduced the accuracy of measurement of the angle of ricochet. This can be visualized by referring to the

Table 4
Firearm: .45 Colt Pistol, M1911, S. No. 22383
Ammunition: .45 ACP, Rem-Umc.

Target	i in degrees	r in degrees	Ricochet plane in relation to incidence plane	Bullet stability after ricochet	Bullet penetration in 1" deal board after ricochet	r_c in degrees	Remarks
Aluminium 1/16"	10	7	Same	US	P	10–15	—
	15	—	—	—	—		Bullet penetrates the target.
Aluminium 1/8"	15	5	Same	US	P	25–30	—
	20	8	Same	US	P		—
	25	12	Same	US	P		—
	30	—	—	—	—		Bullet penetrates the target.
Brass 1/16"	15	11	Same	US	P	25–30	—
	20	12	Same	US	P		—
	25	19	Same	US	NP		—
	30	—	—	—	—		Bullet penetrates the target.
Brass 1/8"	15	7	Same	US	P	50–55	—
	30	12	Same	US	P		—
	45	13	Same	US	NP		—
	50	16	Same	US	NP		—
	55	—	—	—	—		Bullet disintegrates without creating a hole in the target.
Steel 1/16"	15	7	Same	US	P	30–35	—
	30	10	Same	US	P		Bullet hole in the target without the passage of bullet.
	35	—	—	—	—		Bullet penetrates the target.
Steel 1/8"	15	1	Same	US	P	30–35	—
	30	3	Same	US	P		—
	35	—	—	—	—		Bullet disintegrates without creating a hole in the target.

equation used for the calculation of the angle of ricochet. The size of the bullet recovery box, which could not be dispensed due to reasons of safety, also imposed restriction on this distance. The length of the bullet path from the target to the deal board was in fact the best compromise after taking these factors into consideration. Thus the relationship that the angle of ricochet is less than the angle of incidence holds good for the true direction of ricochet along which the bullet travels immediately after ricochet and may not hold if, for the calculation of the angle of ricochet, the point of impact on deal board is recorded at some considerable distance from the target when the erratic behavior of the bullet stemming out of its instability and deformation comes into play. It, therefore, appears that the unpredictability of ricochets is inter alia due to the erratic path taken by the bullet on account of instability and deformation.

The plane of ricochet was found to be the same as the plane of incidence. In the experimental set up adopted here any deviation of the bullet to the left or to the right in the horizontal plane due to spin is likely to be absorbed in the angle of ricochet. If, however, the target is kept horizontal, deviation on account of spin, if any, may exhibit itself in the form of a plane of ricochet different from the plane of incidence. It is proposed to investigate this aspect in the future. Further if the plane of ricochet is determined by recording the point of impact on the deal board at sufficiently large distance so as to make drop due to gravity significant the plane of ricochet may again appear to be different from that of incidence. The relationship that the plane of ricochet is the same as the plane of incidence, therefore, holds good so long as the plane of ricochet is defined with respect to the true direction of ricochet along which the bullet travels immediately after ricochet.

The critical angles for ricochet are generally different for different combinations of firearm, ammunition, and the target. These values may also be affected to some extent by the manner in which the target is held. Thus whereas the values given here cannot be treated as standard under all experimental conditions they definitely give a very good idea of the order of magnitudes involved.

Experiments showed that .22 lead bullets and .38 jacketted bullets could only penetrate aluminium targets (1/16" & 1/8") and not the other ones when "Normal Firing" was undertaken from the same distance as adopted in ricochet studies. The .45 jacketted bullets could not penetrate brass and steel targets (1/8") but could penetrate the others under similar conditions. It is obvious that a bullet fails to ricochet by disintgerating on targets which it is incapable of penetrating. It will fail to ricochet by penetrating or disintegrating on those targets which it is capable of penetrating. In some cases penetration and disintegration may simultaneously occur and only a part of the bullet may actually pass through the hole. A glance at the Remarks column of tables 2 to 4 shows this to have happened. When the .45 jacketted bullet was fired on 1/16" Steel plate at 30° incidence the bullet ricocheted, but at the same time the target gave way and an elongated hole was produced without the passage of bullet (see Figure 2). The phenomenon of bullet hole without the passage of bullet may have interesting forensic implications.

FIGURE 2. Bullet Hole Without the Passage of the Bullet (.45 jacketted bullet against $\frac{1}{16}$" steel plate at 30° incidence)

The results stated above mostly hold good for the targets, firearms, and ammunition under the existing experimental conditions. It is not possible to make generalizations at this stage when the data itself is so meagre. The experimental set up also offers scope for improvement. It is, however, believed that the present investigation will provide the neccessary ground work and stimulate further research in this field using many other targets, firearms, and ammunition. Work on these lines is in progress.

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