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Ricochet Dynamics for the Nine-Millimetre Parabellum Bullet

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ABSTRACT: The presence of extraneous markings on a fired bullet that has ricocheted off water depends on the angle of incidence of the bullet to the water and the depth of the water. An Uzi submachine gun, held in a machine rest, was fired into a large container of water at various controlled angles. The angle of incidence and the angle of departure of the bullet from the water were measured. The critical angle of ricochet, the depth of penetration, and the path of the bullet in the water were measured. The measured critical angle of ricochet of a 9-mm parabellum bullet fired from the above weapon was 6.5°. The maximum depth of penetration into the water during ricochet was found to be 22 mm. The maximum track length in the water was 62 cm.

KEYWORDS: criminalistics, ballistics, water, projectile entry angles, bullets, ricochet, penetration, critical angle, depth

Purpose of the Study

In the authors' laboratory, it is common for the police investigator or the defense attorney to ask ballistic experts if a bullet recovered from a shooting shows any marks which could indicate that the bullet might have ricocheted. A close examination of the bullet often shows extraneous marks which appear to be caused by incidental contact with a hard surface. During the rainy season in Israel, there can be many months when pools of standing water are present on the ground and roads. A shooting of a person that results from a warning shot which ricocheted has a very different significance than a shooting resulting from direct aim at a person. There have been many cases in which the person being charged claimed that the bullet hit the victim on ricochet, although the bullet recovered from the victim showed no extraneous contact marks. As the principal source of expert opinion in Israel, our laboratory found it necessary to examine the dynamics of bullets striking water and ricocheting. We chose the 9-mm parabellum, full metal jacket bullet because it is the most common caliber and shape involved in shootings in this country.

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Materials and Methods

A standard Israeli Uzi submachine gun with a new barrel was selected from our laboratory.[3] It was mounted in a large machine rest (manufactured by F.N., Liege, Belgium) capable of handling large machine guns. The angle of the rest could be adjusted by fine screw adjustments capable of setting the angle to within 0.1°. The weapon was supported at two points and at the butt to ensure that there was no movement between shots. A 144-L, 120- by 30- by 40-cm-deep, rigid steel tank was constructed, placed in front of the mounted Uzi, and filled with water. Three hundred rounds of 9-mm parabellum full metal jacket SMG ammunition, with a bullet weight of 7.4 g, were selected from a single production lot.[4] A Ballistek Model CBL-82 computerized chronograph was used for all velocity measurements and ballistic calculations. Anti-ricochet rubber mats, which are used in our range, were used to support verification paper needed to determine the path of the bullet (see Figs. 1*a* and 1*b*).

Initially, the weapon was fired in a horizontal position 30 times. The bullet flight stability was checked with verification paper at 0.50 and 4.75 m. The velocity was measured at 2 m, and the average velocity and standard deviation for the lot of ammunition were determined. A minimum of 2 minutes was allowed between shots. The roundness of the holes in the paper was examined individually for each shot, and the paper was changed after each shot.

The study of the ricochet was started at 2° (the lowest angle possible with our facilities), and then the angle was increased gradually until the critical angle, at which the bullet no longer ricocheted, was reached. At each angle and with each shot, a piece of computer paper was floated on the entire surface of the water to determine the point of impact and the track of the bullet while it remained in contact with the water. Paper was hung 4.75 m from the muzzle of the Uzi to show the bullet's path after ricochet. The tank was always filled to the top with water, and it was moved so that the bullet always hit in the first quarter of the tank (see Fig. 1). Aluminum window screening, microscopically examined for uniformity, was rigidly held at its edges by a stand and placed at various depths below the surface of the water.[5] The depth of the screen was started at 80 mm below the surface and was raised in 10-mm increments. The aluminum screening was then examined microscopically after each shot at the water to see if there was any bullet contact. If contact was observed, the screen was lowered in 3- to 4-mm increments until there was no sign of bullet contact. A minimum of five shots were fired at each angle.

The angles of incidence and departure relative to the water were calculated by measuring the horizontal and vertical distances from the muzzle to the point of impact on the water and from the point of departure from the water to the verification paper behind the water tank. These measurements were reproducible to within 0.1°.

Results

The 30 test rounds fired in the horizontal position showed no evidence of bullet instability at 0.5 and 4.75 m. This was determined by measuring the roundness of the holes

[3]Two other Uzi submachine guns were briefly used at the beginning of the experiment. We experienced no significant difference between the weapons. The experiment was intentionally limited to a single weapon to reduce statistical variations.

[4]Many other lots of ammunition were tried in the initial part of the experiment. We experienced no significant difference between the lots of ammunition. The experiment was intentionally limited to one lot of ammunition to reduce statistical variation.

[5]Initially, we attempted to perform the experiment using shallow soft aluminum pans. For various angles of incidence, the depth of penetration into the water, within measurement error, was tne same as the depth later measured using the deep container of water. However, the energy transferred to the water and the pans was so great that it precluded measurement of the departure angle and track length because of the partial destruction of the pans.

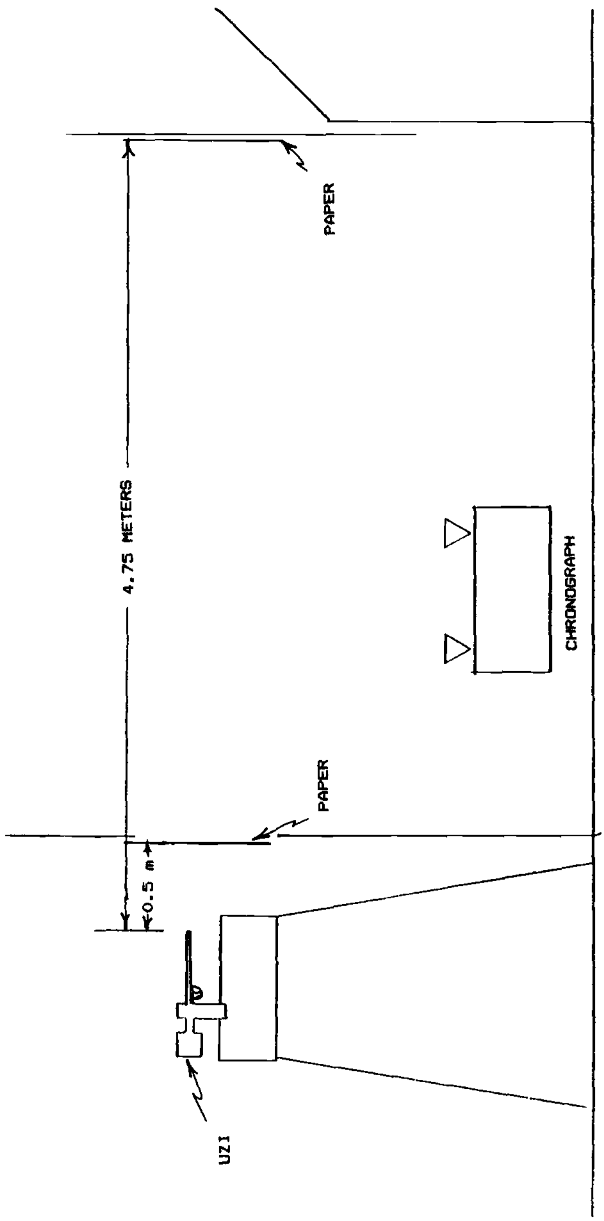

FIG. 1*a*—*Configuration of the test setup for ammunition testing.*

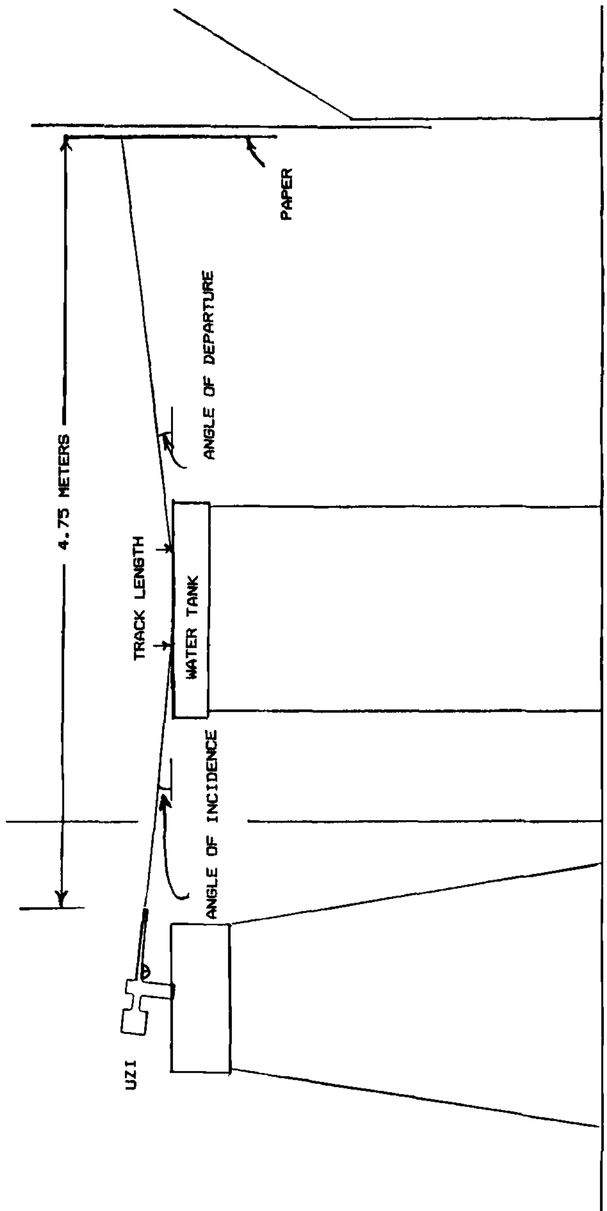

FIG. 1*b*—*Configuration for ricochet testing.*

produced in the 60 sheets of verification paper. All 30 rounds were chronographed; the average velocity was measured at 407 m/s and the standard deviation was 7.7 m/s.

The results of the test firing into water are shown in Table 1. The maximum angle at which the bullets could be made to ricochet off the water was 6.5°. At 6.6°, the bullet always stayed submerged and struck the armor steel plate at the bottom of the tank. The length of the bullet track increased as the angle of incidence increased (see Fig. 2). The bullets left the water in a stable manner for all measurements of 4.1° or less. This was determined by the fact that the line of ricochet was in line with the bore and the holes in the verification paper were round. At the next measurement, at 4.7°, the bullets ricocheted in an unstable manner. All the holes in the verification paper were "keyholes," and the bullet struck the paper 20 to 30 cm to the right of the bore centerline. On multiple shots, the stabilized ricochets of 4.1° incidence or less all struck the paper within 2 cm of each other. At angles of incidence of 4.7° and above, the ricochets hit the paper with an extreme spread of between 6 and 10 cm (see Figs. 3*a* and 3*b*).

The depth of penetration into the water by the bullet increased with the angle of incidence, varying from 4 to 22 mm as the angle varied from 2° to 6.5° (see Fig. 4). The markings on the screen at angles greater than 4.1° showed that the bullet was unstable by the time it struck the screen (see Fig. 5). In our experience, bullets fired into water and bullets

TABLE 1—*Results of firing into water at different angles of incidence.*

Incident Angle, deg	Exit Angle, deg	Bullet Depth, mm	Track Length, cm	Test Firing
2.1	4.8	4	19	B
3.0	5.6	[a]	23	G
4.1	6.5	7	28	A
4.7	2.2	[a]	37	C
6.0	3.4	[a]	55	H
6.5	3.7	22	62	F
6.6	none	bottom	. . .	E
7.4	none	bottom	. . .	D

[a]Not measured.

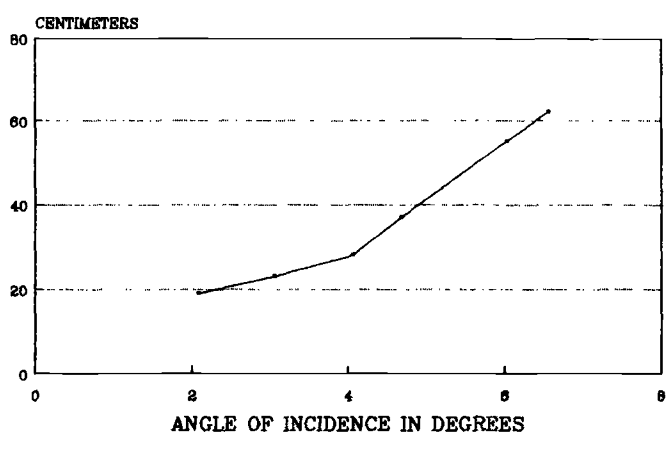

FIG. 2—*Relationship between the angle of incidence of the bullet on hitting the water in comparison with the length of the bullets track in the water.*

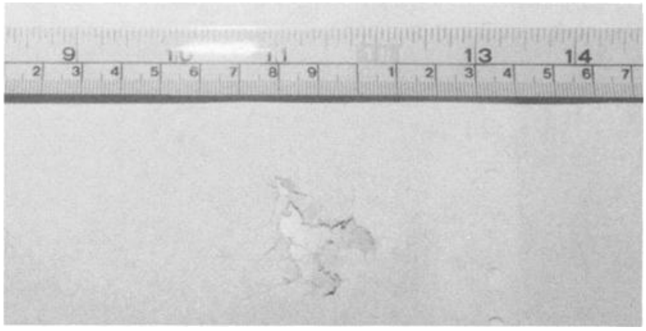

FIG. 3a—*The verification paper after 10 ricochets at 4.1°.*

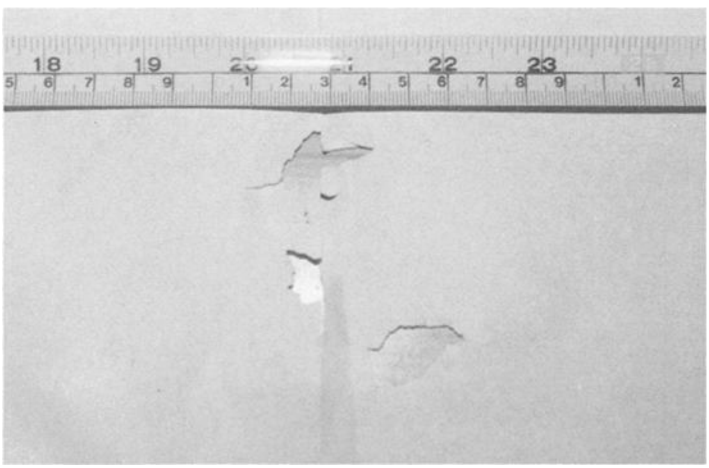

FIG. 3b—*Verification paper for three shots at a 4.7° angle of incidence.*

recovered after ricochet from water show no signs of extraneous contact unless contact with a solid object has occurred.

The ricochet angle increased in a relatively linear fashion until the bullet became unstable at angles greater than 4.1°. The exit angle decreased drastically at incident angles of 4.7° and greater (see Fig. 6). At all angles of measurement, the ricochet angle and impact point *were not affected* when the paper was placed on the surface of the water or when the screen was contacted by the bullet. The ricochet impact point was always within the normal pattern of holes on the verification paper in comparison with the pattern obtained with plain water.

Discussion

The results of the experiment show that a relatively shallow pool of water can ricochet a bullet without the bullet ever coming in contact with the underlying surface. At a weapon height of 1 m, about hip level for a man, a fired bullet can strike water at a distance as close as 8.8 m and remain unmarked if the depth is a mere 2.5 cm. The published literature, which states that the angle of ricochet from water is always greater

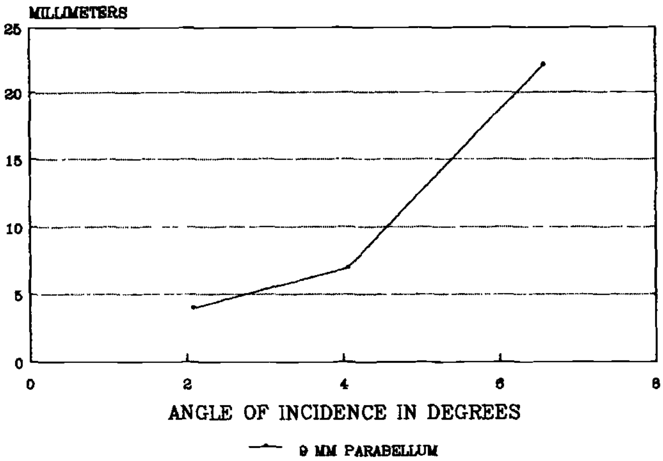

FIG. 4—*This graph shows how the depth of the bullet increases with an increased angle of incidence.*

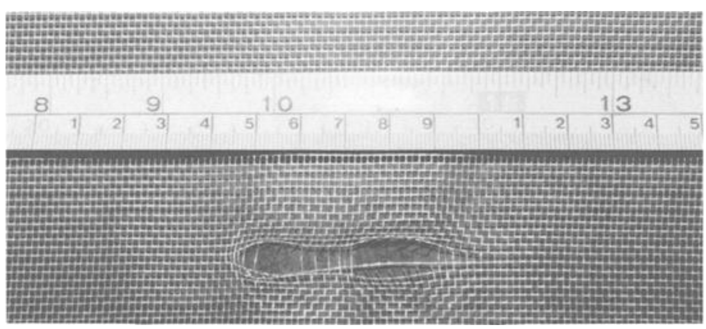

FIG. 5—*Aluminum screening showing unstable bullet contact at a 6.5° angle of incidence.*

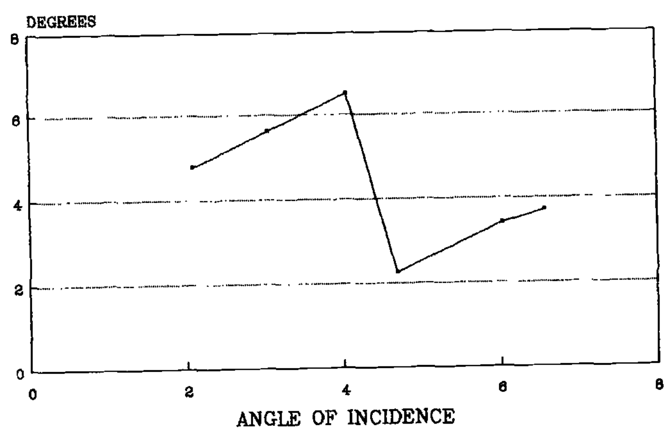

FIG. 6—*This graph shows how the angle of departure changes dramatically as the angle of incidence passes the point where the bullet becomes unstable.*

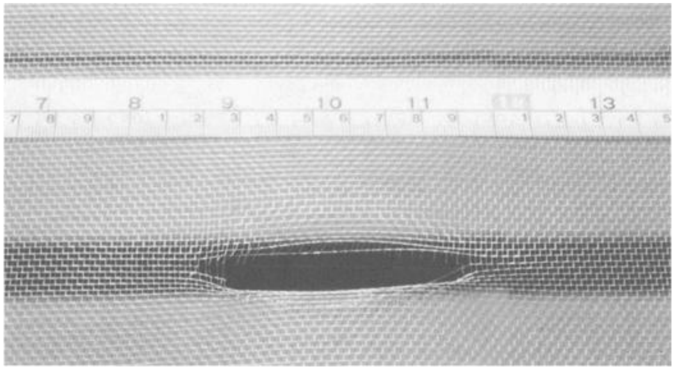

FIG. 7—*Aluminum screen showing stable contact at a 4.1° angle of incidence.*

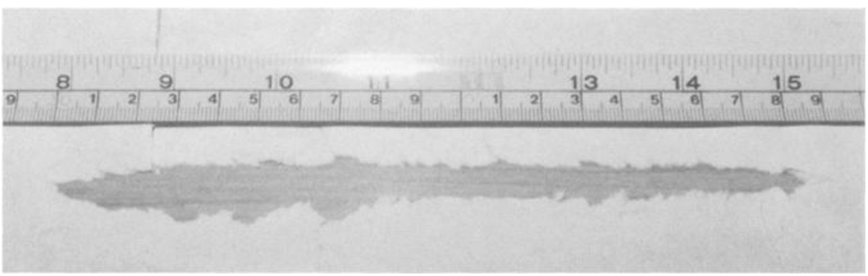

FIG. 8*a*—*Bullet track on the water at a 2.1° angle of incidence.*

than the angle of incidence [*1–3*], and unpublished reports[6–8] seem only to apply to bullets that are in stable flight when they leave the water. From our observations, it appears that the bullet does not skip off the surface of the water as it would off a hard surface. The tracks in the water surface paper and the contact marks of the bullets on the screen seem to indicate that the bullets actually hydroplane on the surface of the water until the angle of the bullet changes enough to allow it to lift off the surface of the water (see Figs. 7, 8*a*, and 8*b*). The greatest depth of penetration into the water was not at the middle of the track but approximately 70 to 80% down the length of the track.

The tracks of the bullets in the paper on the surface of the water were always continuous. In stabilized ricochets, the track started with a small tear, enlarged to a relatively constant width, and then became gradually small again. With the unstable ricochets, the paper showed changing width in the middle and end portions of the paper. Even at angles where the ultimate depth was 22 mm, it appeared that the bullet never became completely covered with water, but rather produced a trough in the water similar to that of a water ski, which rides below the surface of the water but is not covered by the water.

This study is not an attempt to catalog the thousands of combinations of weapons, calibers, and ammunitions that are available. It is a study of the dynamics of ricochet off water. With the knowledge developed here, an investigator can now study any combination of weapons and ammunition needed for a specific case.

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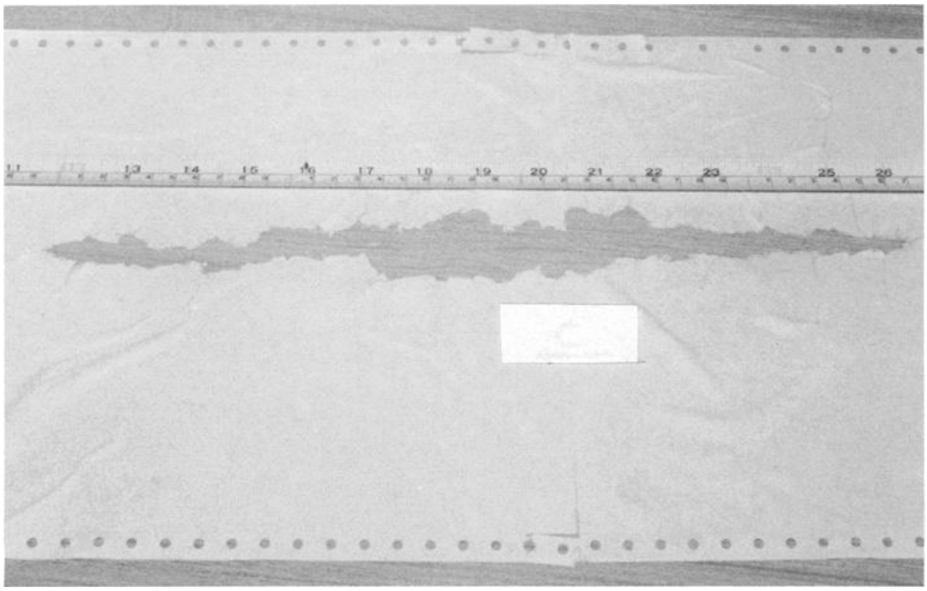

FIG. 8b—*Bullet track at a 4.7° angle of incidence.*

Conclusions

It is evident from the results of this experiment that a bullet unmarked by contact with external material could still have ricocheted off the surface of relatively shallow water. If water was present at the crime scene, it becomes incumbent upon the firearms examiner, if asked about ricochets, to state that the bullet shows no evidence of having ricocheted off a solid surface, but that this does not rule out the possibility of its having ricocheted off relatively shallow water. It also must be remembered that ricochets at relatively high incidence angles may be a considerable number of degrees off to the side of the centerline of the weapon's bore.

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