# STUDY OF THE CORRELATION OF BALLISTIC IMPACT VELOCITY, BULLET DEFORMATION AND DAMAGED PATTERNS ON ROOFING MATERIALS FOR MAKING TRACE EVIDENCE IN SHOOTING INCIDENTS

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**Abstract:** The objective of this study is to determine the correlation between the impact velocity, bullet deformation and characteristic damages of roofing materials from a designated bullet impact. The relationship between the residual velocities categorized as the long range shooting of the deformed bullets and the specific patterns of damages on the various types of roofing materials were investigated. The threshold velocities of bullet perforating the selected roofing materials were experimented. The values found were used to evaluate the ballistic impact resistance of the roofing materials. This provides valuable information for forensic implications and shooting incident reconstructions. The long range shooting experiments could be arranged by firing the bullets with altering amounts of bullet propellant to the roof samples; namely, galvanized steel sheets, fiber cement tiles and monier tiles. The experimental results demonstrated that the threshold velocity of bullets could only be found from the shooting at monier tiles. In addition, the perforating bullets in case of the monier tiles lost most of their kinetic energy during the impact in contrast to the bullets perforating the fiber cement tiles and galvanized steel sheets. In the latter case, the bullets still had high residual velocities and extremely lethal to whatever left behind the roofs.

**Introduction:** Roof is the uppermost part of a residential construction. For most parts of the world, common damages on the roof are caused by natural disturbances such as radiation, wind, rain and hail. However, for some parts of the world including Thailand where the shooting firearm into the air is still a common but illegal practice in celebrations, a distinct damage to the roof can also be observed. This is caused by falling bullets. There are many case reports that the falling bullets had fallen into residential areas and causing injuries to people and damaging impacted properties. Without a proper database of the evidences, such as the deformed bullets, the damaged roofing materials and probably the injured person, this becomes a very hard task for an officer to investigate the incident. The evidences collected by the investigator have to be examined thoroughly so as to find obvious interrelation between the deformed bullet and the damage roofing material. The discovery can provide the officer with the range of shooting estimates where the gun and ammunition are known [1].

Theoretically two major forces decelerating a shot bullet in flight are gravitational force and air drag. The gravitational force is constant while the air drag depends on the bullet velocity. This indicates that, for a long range fire, a bullet velocity upon impact the target obviously depends on how long the bullet has travelled through the air. The longer time of flight the bullet is in the air, the greater the air resistance acts on the bullet resulting in a reduction of the bullet velocity until it reaches the target. Note that this conclusion is valid if an intervening object obstructing the bullet path to the target is not included.

This leads to the objective of this study which is to find the interrelation between the deformed bullets having residual velocities categorized as long range shots and the specific damaging patterns of selected roofing materials. In addition, the so-called threshold velocity where the bullet is just able to perforate selected roofing materials will be determined. This would allow an estimation of the firing range according to the residual velocities of the perforating bullets.

**Theoretical Background:** The major forces acting upon a moving bullet mass *m* with a velocity $\vec{v}$ after being fired from a gun's barrel following the trajectory at any moment of flight are the gravitational force $\left(\vec{G}\right)$ and the resistance force or air drag $\left(\vec{D}\right)$ as can be seen from Figure 1.

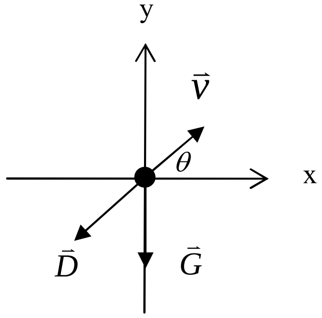



**Figure 1.** Major forces acting upon the fired bullet moving at an angle of $\theta$ with respect to the horizontal direction

The general public are not aware of the huge effect due to air drag on an object trajectory. Figure 2 clearly shows a bullet trajectory with and without the air drag made by Excel

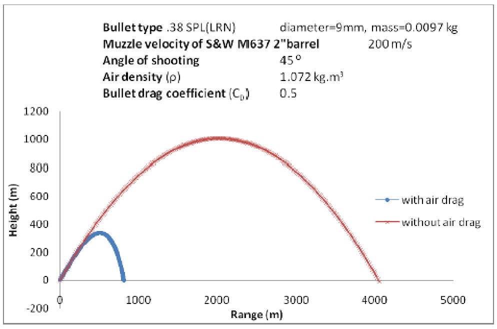



**Figure 2.** Two-dimensional trajectory of a bullet comparing motion with and without air resistance by Excel

Once the angle of departure is changed, the bullet impact velocity is changed accordingly. Figure 3 shows the maximum ranges for .38 SPL (LRN) with a typical muzzle velocity of 200 m/s shot from different shooting angles under an identical influence of air drag. An approximate numerical solution written in Excel was used to determine the bullet trajectories.

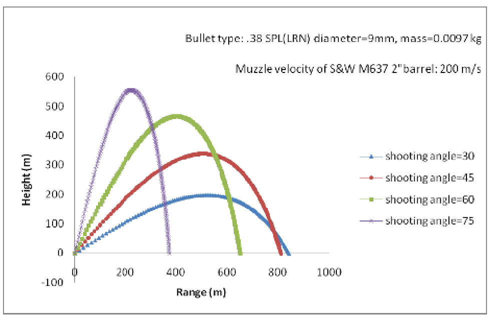



**Figure 3.** Trajectories plotted for .38 SPL (LRN) according to an approximate numerical solution by Excel.

The shooting incident of interest in this research is the long range shooting. A specific manner of the bullet in the long range shooting is typically illustrated by the bullet curved path as shown in Figure 3. The results from the numerical analysis suggest that this is highly unlikely to perform the shooting with a full distance range in practice due to a long shooting range of a bullet shot from a pistol and a hard-to-predict impact site of a falling bullet. So, in this study, only the bullet flight approaching a target is arranged. This can be done by shooting directly onto a target with different impact velocities obtained by varying the amount of propellant. This imitates different impact velocities of long range shot bullets from different angles of departure. The different impact velocities affected the bullet deformations [1] and the damaged patterns of the roofing materials [4].

Essentially, there are three possible outcomes of the perpendicular and near perpendicular impacts to most roofing materials made by a falling bullet. They include (1) the bullet is stopped without penetrating the material, (2) the bullet penetrates the material where it may become lodged or disintegrate and the fragment rebound from the material, and (3) the bullet perforates the material [3]. A possible outcome to a roofing material depends on the impact velocity of the falling bullet and the impact resistance of the roofing material. Specific changes in a particular bullet and the impacted roofing materials are expected. This creates interrelation between the deformed bullet and the damaged roofing material.

**Materials and Methods:** Smith & Wesson M637 2” barrel revolver pistol was used for the experiments. The tests were conducted on targets composed of 3 selected new roofing materials, 33 x 42 x 1.5 cm of monier tile (concrete roofing tile), 40 x 60 x 0.5 cm of fiber cement tile and 45 x 60 cm of corrugated galvanized steel sheet (thickness = 0.3 mm) shown in Figure 4.


**Figure 4.** Selected target samples; Monier tile, Fiber cement and Corrugated galvanized steel. They are three most roofing materials popularly used in Thai residential constructions.

The experimental setup is illustrated in Figure 5.

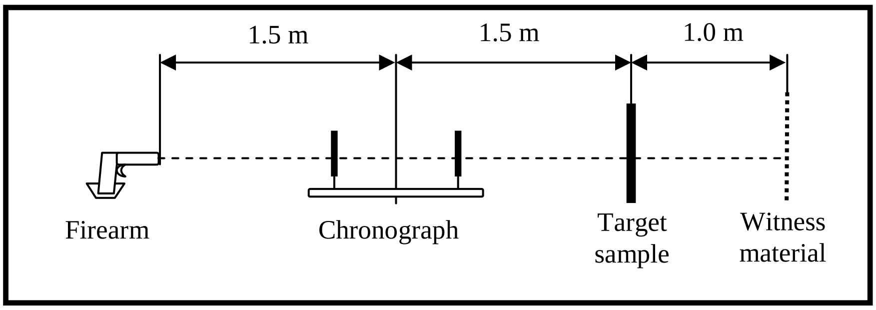



**Figure 5.** Arrangement for the first and second experimental parts

The experiment was divided into two parts. The objective of the first part, so called the bullet velocity calibration part, was to prepare bullets that could provide desired impact velocity. Straightforwardly, this could be achieved by varying the mass of the propellant. The velocities of fired bullets were measured by a commercial chronograph

(Shooting Chrony Model F-1) positioned away from the pistol about 1.5 m. A calibration curve representing the velocity (m/s) of the bullet versus the varied mass of propellant was plotted. The relation between an amount of propellant and bullet velocity was used as a reference for preparing bullets used in the second experimental part. The objective of the second part was to study particular characteristics on changes of the falling bullets and the damaged roofing materials. Ammunitions .38 SPL. (LRN), with varying amounts of propellant were fired at the targets of each type of roofing material. The measurement of the impact velocity by a chronograph was conducted at a half way between the shooting distance. The range of testing impact velocities covered 50-180 m/s to simulate the long distance shooting. It should be noted that, in this study, the bullet impact angle was chosen to be orthogonal or near orthogonal to the roof surfaces.

**Results:** All shooting experiments were carried out at Commando shooting range, Wanganont in Bangkok. In the first part of the experiment, the tests for the bullet velocity calibration were performed. Eighteen bullets were reloaded with the proportional decreasing mass of propellant. The reloaded powder contents included 0.24, 0.22, 0.20, 0.18, 0.16, 0.14, 0.12, 0.10 and 0.08g. They then were fired and their velocities just after the gun's barrel were measured by a chronograph. The relationship between the bullet velocities and corresponding propellant contents is shown in Figure 6.

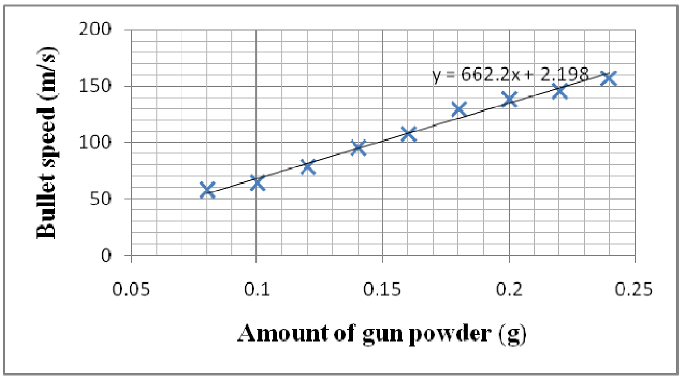
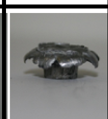
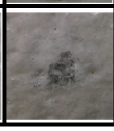
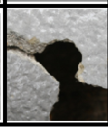
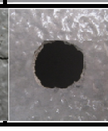
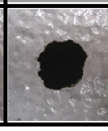
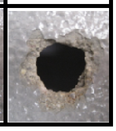



**Figure 6.** The relationship between the amounts of propellant and the bullet velocities of fired bullets measured by a chronograph

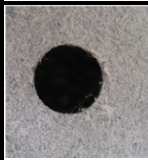
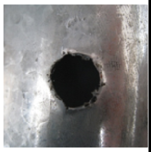
In the second experimental part, bullets with different amounts of propellant causing different impact velocities were fired at roofing materials. The experimental results in Table 1 and Table 2 present the changes of bullets and the damaged pattern of roofing materials.

**Table 1.** Deformed bullets and damaged patterns of monier tiles

| Impact velocity (m/s) | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|
| Bullet |  |  |  |  |  |  |  |  |  | N/A |
| Monier (impact surface) |  |  |  |  |  |  |  |  |  |  |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Monier (distal surface) | No damage | No damage | No damage | No damage | No damage |  |  |  |  |  |

**Table 2**. Deformed bullets and damaged patterns of fiber cements tiles and corrugated galvanized steel sheets

| Roofing material | Bullet | Low velocity | | High velocity | |
|---|---|---|---|---|---|
| Fiber cement tile |  |  |  |  |  |
| Corrugated galvanized steel sheet |  |  |  |  |  |

**Discussion:** In each case, the changes of the deformed bullets and the damaged roofing materials are quite unique as can be seen from the descriptions in Table 3. The main reason to this is the different physical properties of the roofing materials such as elasticity, density, impact resistance and the material thickness.

**Table 3.** Description of deformed bullets and damaged roofing materials for different impact velocities

| **Roofing materials** | **Bullet velocities (m/s)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **50** | **60** | **70** | **80** | **90** | **100** | **110** | **120** | **130** |
| **Monier tiles** | **Bullets** : deformation of the bullet shape; i.e. totally flattened bullets, increasing in diameter and decreasing in length<br><br>**Roof** : no significant damage, rebound bullets caused only coloured marks or scratch marks on the roof surfaces | | | | | **Bullets** : complete deformation of the bullet shape and lodged in the roof<br><br>**Roof** : hole on the roof surfaces | **Bullets** : complete deformation of the bullet shape<br><br>**Roof** : perforated with smooth round holes, small fragments of monier tile punched out on the backside | | |
| **Fiber cement tiles** | **Bullets**: small impact deformation of the bullet shape; i.e. flattened noses and visible scratches on its body occurred during impact,<br><br>**Roof**: perforated with smooth round holes, circular shaped fragments of fiber cement tiles punched out on the backside, the bullet fired at higher velocity caused the sharp edged hole and less damage on the distal surface | | | | | | | | |
| **Corrugated galvanized steel sheets** | **Bullets** : no impact deformation of the bullet shape<br><br>**Roof** : perforated with jagged holes, no fragments occurred on the backside, smaller and rounder holes for higher impact velocities | | | | | | | | |

The damaged patterns of the impacted and the distal surfaces of monier tiles were specific to the ballistic impact. The exit point or damage on the distal surface was larger compared to the entrance hole on the impacted surface. The shape of the hole was beveled. The small fragments of monier tile punched out on the backside. The bullet deformations caused by the different impact velocities lower than threshold velocity were apparent. The bullet diameter was increased and its body was shortened for increasing impact velocities. These were not occurred to the bullets fired to fiber cement tiles and corrugated galvanized steel sheets. There were no significant deformations of the impacted bullet for different impact velocities. The damaged patterns on fiber cement tiles and corrugated galvanized steel sheets could be used to classify the low and high impact velocities of bullets as shown in Table 2.

Note that because of thin roofing materials such as corrugated galvanized steel sheets (thickness ≈ 0.3 mm) and fiber cement tiles (thickness ≈ 0.5 cm), the perforating bullets are still lethal. Obviously, the bullets still have high kinetic energy and can cause further damages to what left behind at the backside of the roof. Also the bullets deflection can occur if they hit the slanted part of the roof. For a thick roofing material like monier tiles (thickness ≈ 1.5 cm), the perforating bullets lose most of their kinetic energy while impacting the roof. The bullets become less energetic and may pose less risk to what left behind at the backside of the roof.

No threshold velocity of the bullet can be determined for the corrugated galvanized steel sheets and fiber cement tiles because the roofing materials were perforated by bullets with impact velocities exceeding the minimum designed velocity (50 m/s). With this result, a preferred trajectory of the falling bullet according to the simulation program is not obvious. This is because all bullet paths that give impact velocities in the range of 50 to 180 m/s are possible for a shooting incident. Only the shooting at the monier tiles, the threshold velocity of the bullet could be found. This can be seen from Table 1 that the bullet with impact velocities exceeding 100 m/s can perforate the roofing material. The value corresponds to the threshold velocity for the monier tiles. This result can be used to estimate a possible trajectory of bullet by way of a computer simulation.

**Conclusion:** In conclusion, the bullet deformation and characteristic damages of roofing materials depend on the impact velocity of the bullet and the characteristics of the roofing material. Method of reloading the gun propellant was used to simulate the long range shooting incident. Unique characteristics from both deformed bullets and damaged roofing materials can be very helpful for the trace evidences and shooting reconstruction in the falling bullet incident. Additional information from this study in terms of the estimated bullet trajectory, under influences of gravity and air resistance, obviously provide a mapping location indicating a possible shooting location relative to the crime scene.

**References:**

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**Keywords:** bullet, roofing material, ballistic impact resistance, trajectory, shooting incident reconstruction