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Gunshot Residue Particle Velocity and Deceleration*

ABSTRACT: The velocity of over 800 gunshot residue particles from eight different sources was determined using high speed stroboscopic photography (spark gap light source). These particles were found to have an average velocity of 500 to 600 ft per second. Many particles acquired considerably higher velocities. Thus, the particles have sufficient energy to embed themselves within certain nearby targets like skin or fabric. The relatively high velocity that the particles acquire explain the formation of stippling on skin in close proximity to a muzzle discharge. These findings also indicate little influence of air currents on particle behavior near the muzzle. The deceleration of less than 100 particles during a 100-microsecond interval was also calculated. The particles experienced rapid rates of deceleration which would explain why few particles are found in test firings beyond 3 ft from the muzzle of a discharged firearm. Because of their relatively high velocity, normal wind velocity would not be expected to significantly influence their motion near the muzzle.

KEYWORDS: forensic science, criminalistics, gunshot residue, firearms discharge patterns, propellant particles, velocity, deceleration, stippling, high-speed stroboscopic photography

For several decades, the analysis of gunshot residue (GSR) has played a significant role in the criminal justice system because of the prevalence of the use of firearms during the commission of crimes, and in particular, homicides. The main thrust of the use of GSR analyses has been in the areas of the estimate of the muzzle-to-target distance, and the interpretation of GSR residue on the shooter = s hands. The presence of gunshot residue on nearby objects has received much less attention. The techniques employed for estimating the muzzle-to-target distance have been generally accepted by the forensic scientific community and used over the past sixty years with little controversy (1). Conversely, the interpretation of GSR on the hands of the shooter have been subject to some debate and sporadic research attempts to solve analytical and interpretative problems (2,3). What the role of GSR analysis in criminalistics will play ultimately is unclear. Both areas of GSR analyses could benefit from additional high speed photographic experiments to study the dynamics of formation and deposition. The purpose of the high-speed experiments reported here was to study the gunpowder residues (propellant particles) examined as part of the various "Walker" tests used commonly in criminalistics today.

Although there have been several high-speed photographic studies conducted concerning firearms discharge, there does not appear to have been any downrange studies concerning the magnitude or distribution of velocities obtained by propellant particles (4,5). Additionally, there have been no reports regarding how fast propellant particles decelerate. Stippling has been reported to be produced by the impact of particles with the skin. If the stippling arises specifically from the impact of gunpowder the phenomenon has been referred to as "A powder tattooing." The tattooing is observed in the form of punctate abrasions, as opposed to Apowder burns@ (6,7). The particles may even become embedded in the skin. Since the punctate wounds are due to the impact, it can be inferred that the ability to produce these are due to particle velocity. While this hypothesis is entirely reasonable, there has been no detailed study of the propellant particle velocity and distribution as presented and discussed here. If the particles were found to travel at relatively high velocities, that is, approaching bullet velocities, these findings would support the aforementioned hypothesis. Additional questions that should be considered are the influence of wind, movements of the suspect or victim, and other factors, on particle behavior. Using high speed, multiple-flash (stroboscopic) photographic methods, this study aimed to address some of these questions and help provide a stronger scientific basis for shooting reconstructions.

Often, when taking the short duration high-speed flash photographs, the bullet could be easily seen by the unaided eye amongst a large number of propellant particles. The ability to see the bullet and the propellant particles in actual flight provided a valuable guide to setting up the equipment for flash delay, flash intervals, and the horizontal positioning of camera along the bullet trajectory. The observer also acquires a certain amount of appreciation for the interrelationship of these objects, from seeing them in three-dimensional space as they exist, a dynamic process that is difficult to demonstrate photographically.

Methods and Materials

A high speed flash system consisting of a spark gap light source (Palflash 500), a sequencer (Palseq) for precise timing, and a trigger (Mazof VIS II) purchased from the Cooke Corporation, Tonawanda, NY, was used to obtain stroboscopic photographs of the particles.

The Palflash 500 is a short duration multiple spark gap light source, manufactured by Photonics Analysis, Ltd. of Waterloo, Ontario, Canada, and was designed for photography of rapidly

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moving objects. It utilizes up to four discharge arcs that deliver an extremely short burst of intense visible light. All experiments reported here were conducted in conjunction with a flow of argon gas through the gap of the electrodes. A flash duration of approximately 500 ns permitted crisp photographs of projectiles and gunshot residue particles traveling at relatively high velocities to be taken. A vibration sensitive detector was mounted on the weapon being discharged to trigger the flash sequence. The light output of the condenser was collimated with a 90 mm focal length lens.

The Palseq sequencer (manufactured by Photonics Analysis, Ltd., Ontario, Canada) was used to select and control the duration of each interval between successive light flashes. Repeatable delays from microseconds to seconds are possible. Up to four sequential flashes at precise intervals were used.

The Model VIS II trigger (manufactured by Mazof Inc., England), and was utilized to initiate the circuit to trigger the Palflash. This is a multi-sensor unit designed for high-speed photography. It has a built-in sound receiver, a wide spectrum optical sensor, and a vibration probe, which is detachable. The vibration probe was used for all the experiments reported here. The trigger possesses a built-in delay with three different ranges. The "F" range (2 μs to 0.5 ms) was utilized, since it was designed to provide the fastest response for ultra fast events. It was always set on the minimum delay (2 μs).

The timing of the flash system was calibrated with a Tektronix oscilloscope (model TDS 340) by the authors. It was also calibrated by the manufacturer on two occasions (when a spark gap failed to discharge). The behavior of the system was monitored for each shot by the examination of the multiple bullet images in the photographs (this provided an "internal standard"). If an image was missing, or appeared where it should not, the data from that photograph was not used. Also, as an additional check on the system, the muzzle velocity of the bullets was regularly calculated and compared to the nominal or published values.

Oscilloscope

The oscilloscope is a digital real-time unit that has a maximum sampling rate of 500 megasamples/second. The calibration conditions were: rapid response photosensor attached to Channel One lead on oscilloscope. To initiate the calibration the Palflash was manually triggered from the switch on the Palseq (sequencer). Timing on the sequencer was set at 200, 210, 220, 230 μs using 10 × range (2000 to 2300 μs). This was the approximate setting selected for measuring particle velocities. The oscilloscope settings were: Y-axis 100 mv/box; x-axis 50 μs/box.

Digital Flowmeter

A Humonics digital flowmeter (Model Optiflow 520) was used to measure the argon gas flow rate for the atmosphere in the Palflash 500.

Cameras and Related Accessories

A Pentax Spotmatic, 35 mm SLR, f/1.8 lens as well as other 35 mm SLR cameras, lenses and tripods were used. Kodak Ektapress 400 35 mm film (pushed twice to ASA 1600 using C-41 development) was used for all experiments. Based on numerous experiments, grain characteristics of the film were considered excellent compared to other films of equal sensitivity, and the film was always push-processed two stops. Without the increased sensitivity the particle images were much too faint to study and measure.

TABLE 1—*Sources of propellant particles photographed.*

Federal 357 Magnum, 110 Grain, JHP
CCI 357 Magnum, 158 Grain, JHP
CCI .38 + P, 125 Grain, JHP
CCI 9 mm, 115 Grain, TMJ
Remington 9 mm + P, 115 Grain, JHP
Magtech 9 mm, 124 Grain, FMC
Winchester .38 + P, 158 Grain, HP
Federal .38 + P, 125 Grain, JHP
PMC 357, 125 Grain, JHP

Note: JHP = jacketed hollow point; TMJ = total metal jacket; FMC = full metal case; HP = hollow point.

Digital Caliper

A digital caliper (Digimatic Model CD-6″ BS, manufactured by Mitutoyo Co.) was used for measuring the photographic images of particles.

Handgun Machine Rest

A Ransom Rest®, manufactured by Ransom International Corporation, was used to safely and consistently hold whatever handgun was being discharged.

Firearms

A S&W 357 Magnum Revolver, Model 19 was used for the discharge of all 357 Magnum and .38 caliber ammunition and a 9 mm semi-automatic Heckler & Koch Model VP70Z was used for the discharge of all 9 mm ammunition. See Table 1 for the ammunition discharged for this study.

Atmosphere

Argon gas was used for all experiments to purge the atmosphere of the Palflash and provide argon discharge illumination. The argon discharge allowed a significantly more brilliant flash output than a discharge in air. The use of argon resulted in more stable arcs, and provided a longer life to the gap electrodes. A flow valve was affixed to the gas line. The flow rate was set at 5–15 mL per minute using a digital flowmeter. This flow rate was maintained for all experiments, after some initial experimentation and optimization at different rates.

Photographic Arrangement

The arrangement used for these experiments is illustrated in Fig. 1. The camera was positioned on a tripod with the optic axis of the lens perpendicular to the bullet trajectories. A non-reflective black velvet cloth was used as the background. The pistol or revolver to be used was affixed to a Ransom Rest®. For certain photographic frames the conditions were changed by repositioning the camera and the flash parallel to the line of fire to photograph particles at different distances from the muzzle. The distance from the muzzle was documented by means of a 48 in. steel rule placed on the bench with its zero position at the muzzle. The rule was oriented so that its longitudinal axis was aligned with the line of fire. For the preliminary set up the camera was focused on a wooden dowel protruding from the barrel of the firearm. A vibration sensor was placed between the frame of the weapon and the Ransom rest grip insert which holds the weapon. The wire lead from the sensor was placed into the corresponding terminal of the triggering device. The sensitivity of the flash trigger was adjusted so that the vibration

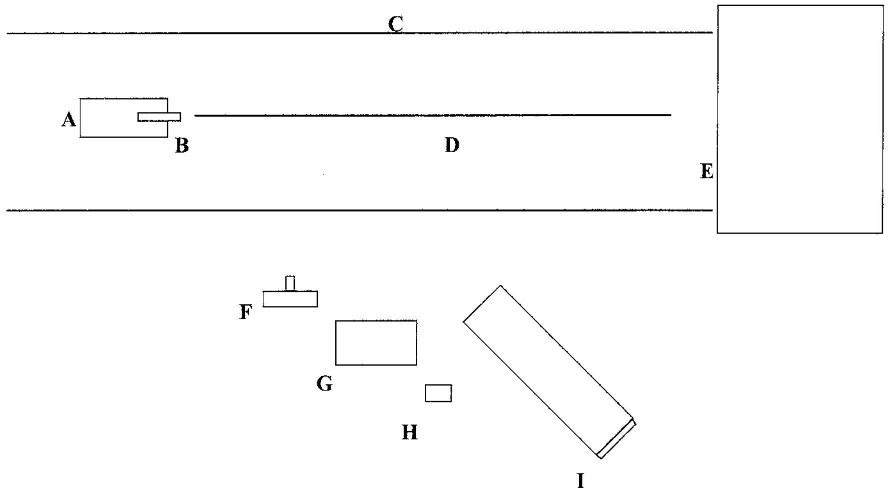

FIG. 1—*Photographic setup in darkroom: a—Ransom Rest®; b—firearm with vibration sensor; c—black velvet background; d—steel measure; e—bullet trap; f—camera on tripod; g—Palseq sequencer; H—Mazof trigger, I—Palflash 500 spark gap light source. The bench was approximately 76 cm in depth. The Ransom Rest® was affixed to the bench with bolts and centered at about 38 cm from the black velvet background. The distance between the muzzle and the bullet trap was approximately 180 cm.*

from the hammer fall, initiated the electronic sequencer. While the lights were on, the hammer was cocked. The room was partially ventilated between discharges and a complete change of room air was made with a fan after six discharges during the course of particle experiments for both photographic and safety purposes. After the hammer was cocked, the lights were turned off. The camera shutter, which was set on the bulb ("B") position, was then opened with a cable release. The lens aperture was set at f/1.8. This lens setting allowed the maximum amount of light to strike the film, and minimized the depth of field to reduce parallax error. The trigger was then gently squeezed. The hammer fell, the gun discharged, the flash pulsed sequentially, and the shutter was then closed.

Particle Experiments

The velocities of 840 particles were determined for eight different sources of ammunition using multiple flash photography. Calculations for the ninth source (PMC 357) could not be made since the number of particles was too great to permit accurate measurements. A summary of the results of the calculations of velocities for the eight sources is shown in Table 2. Deceleration data for four sources of ammunition are presented in Table 3. Figure 2 is an example of a stroboscopic photograph used for the experiments reported here (black and white enlargements were only used for illustration/publication purposes).

The velocity distribution of the measured particles for six of the ammunition sources was plotted in a rectangular coordinate system as profiles (three .38 & three 9 mm caliber bullets (Figs. 3–8). The x-axis represents the distance from the muzzle. The y-axis represents the distance of the particles above and below the line of fire. Points were plotted from approximately twelve inches to beyond 48 in., corresponding to the distance from the muzzle, and a vertical range of about ten inches centered at the line of fire (see Figs. 3–8 for the actual distances involved). It was generally too difficult, and inaccurate, to obtain measurements closer to the muzzle except in the case of Winchester .38 + P (began near 6 in. from the muzzle). At distances closer than 12 in., particles were obscured by the cloud, flames and an over-abundance of other particles. A selected number of particles from each of the ammunition sources listed in Table Three were used to approximate the deceleration.

TABLE 2—*Velocity data of particles from eight different sources (rounded to nearest 100 fps).*

Ammunition	Mean Velocity	No. of Particles Measured	Region Measured
Federal 357 Magnum, 110 Grain, JHP	600 fps	50	19″–28″
CCI 357 Magnum, 158 Grain, JHP	600 fps	40	33″–41″
CCI .38 + P, 125 Grain, JHP	500 fps	178	10″–48″
CCI 9 mm, 115 Grain, TMJ	500 fps	107	18″–52″
Remington 9 mm + P, 115 Grain, JHP	500 fps	69	18″–52″
Megtech 9 mm, 124 Grain, FMC	400 fps	97	26″–46″
Winchester .38 + P, 158 Grain, HP	500 fps	180	6″–44″
Federal .38 + P, 125 Grain, JHP	500 fps	119	18″–42″

Note: JHP = jacketed hollow point; TMJ = total metal jacket; FMC = full metal case; HP = hollow point.

TABLE 3—*Deceleration data from four different sources (rounded to nearest foot per second).*

Ammunition Distance	Change in Velocity from Muzzle	No. of Particles (100 μs Interval)	Measured
Federal 357 Magnum, 110 Grain, JHP	19″–28″	−35 fps	17
CCI 357 Magnum, 158 Grain, JHP	33″–41″	−24 fps	16
CCI .38 + P, 125 Grain, JHP	10″–48″	−21 fps	13
CCI 9 mm, 115 Grain, TMJ	18″–52″	−18 fps	11

Note: JHP = jacketed hollow point; TMJ = total metal jacket.

Velocity calculations were based on the distances traversed by particles during the elapse of 100 μs. Only particles in good focus were used for measurement. A digital caliper was used to measure the distance between particle images to the nearest tenth of a

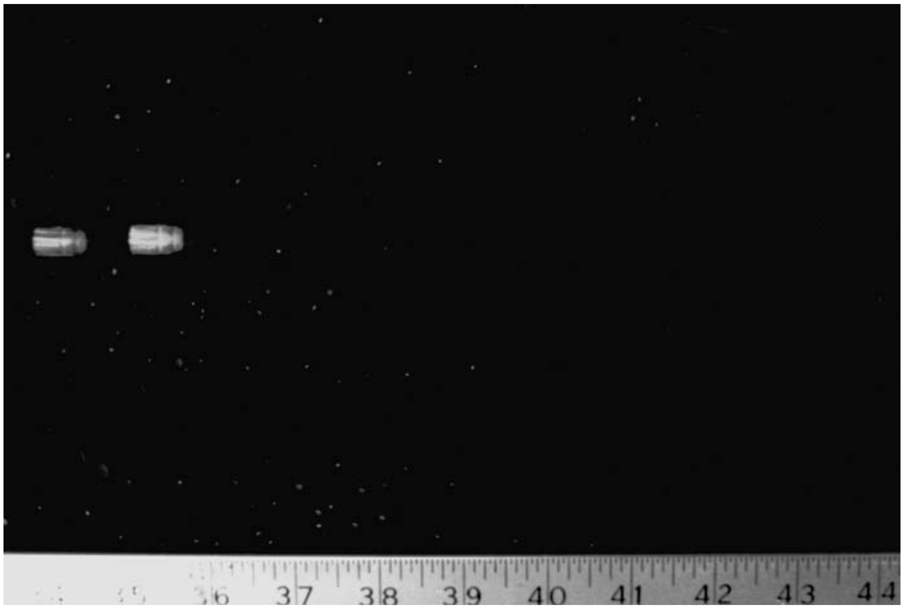

FIG. 2—*High speed multiple flash photograph of bullet & particles in flight from discharge of a CCI cartridge 357 Magnum, 158 grain, jacketed hollow point (100 μs between each of three flashes; first image of bullet not included).*

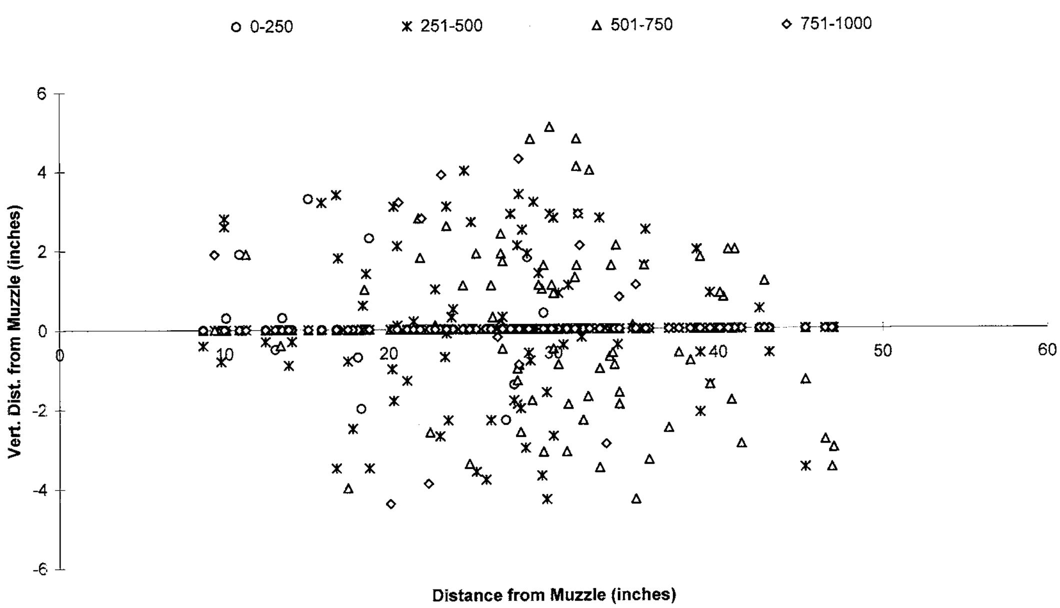

FIG. 3—*Distribution of velocity as ranges of individual propellant particles. X-axis represents the horizontal position in inches along the line of fire. The Y-axis represents the vertical distance (inches) above and below the line of fire. CCI .38 + P 125 grain, jacketed hollow point. Symbols for Figs. 3 through 8 are: 0 = 0 – 250 feet per second (fps) X = 251 – 500 fps; △ = 501 – 750 fps; ◇ = 751 – 1000 fps.*

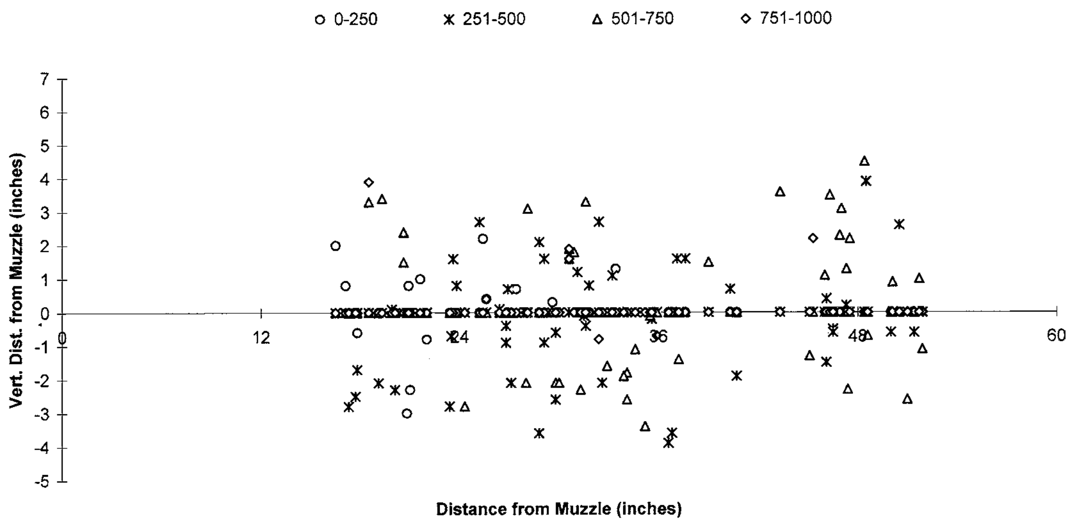

FIG. 4—*Distribution of velocity as ranges of individual propellant particles. X-axis represents the horizontal position in inches along the line of fire. The Y-axis represents the vertical distance (inches) above and below the line of fire. CCI 9 mm Blazer 115 grain, total metal jacket. See legend for Fig. 3 for symbol designations.*

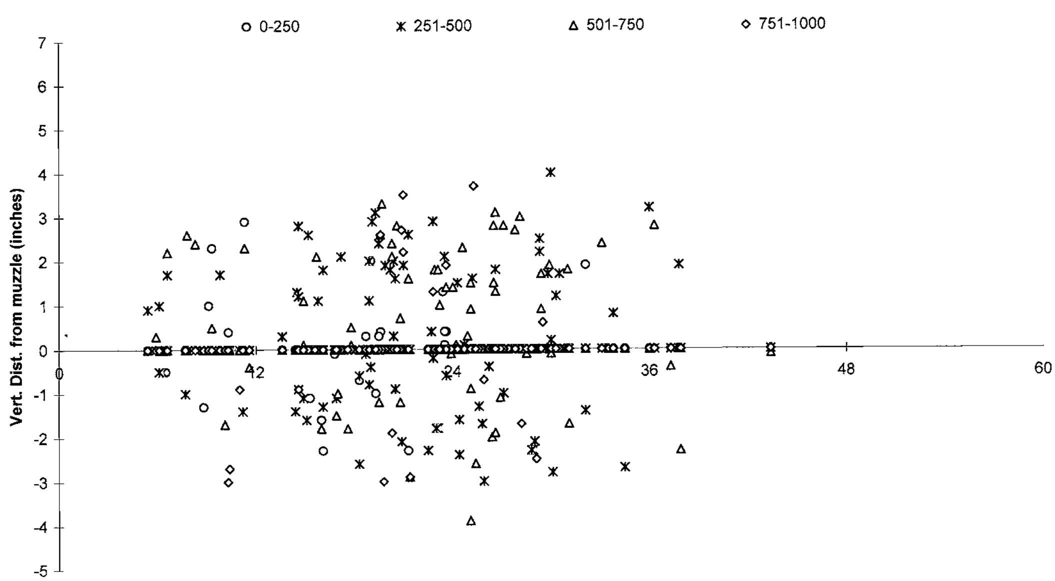

FIG. 5—*Distribution of velocity as ranges of individual propellant particles. X-axis represents the horizontal position in inches along the line of fire. The Y-axis represents the vertical distance (inches) above and below the line of fire. Winchester .38 + P 158 grain, hollow point, lead nose. See legend for Fig. 3 for symbol designations.*

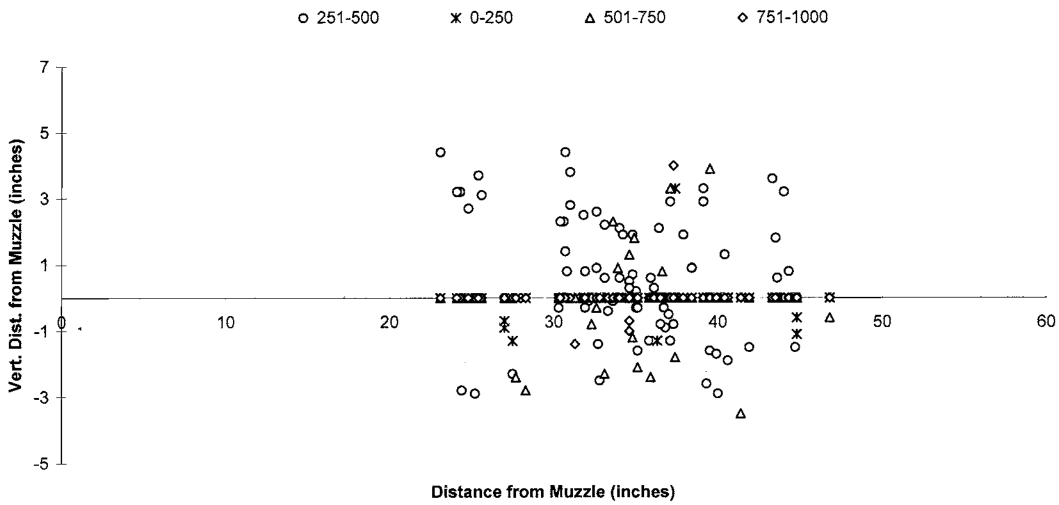

FIG. 6—*Distribution of velocity as ranges of individual propellant particles. X-axis represents the horizontal position in inches along the line of fire. The Y-axis represents the vertical distance (inches) above and below the line of fire. Magtech 9 mm 124 grain, full metal case. See legend for Fig. 3 for symbol designations.*

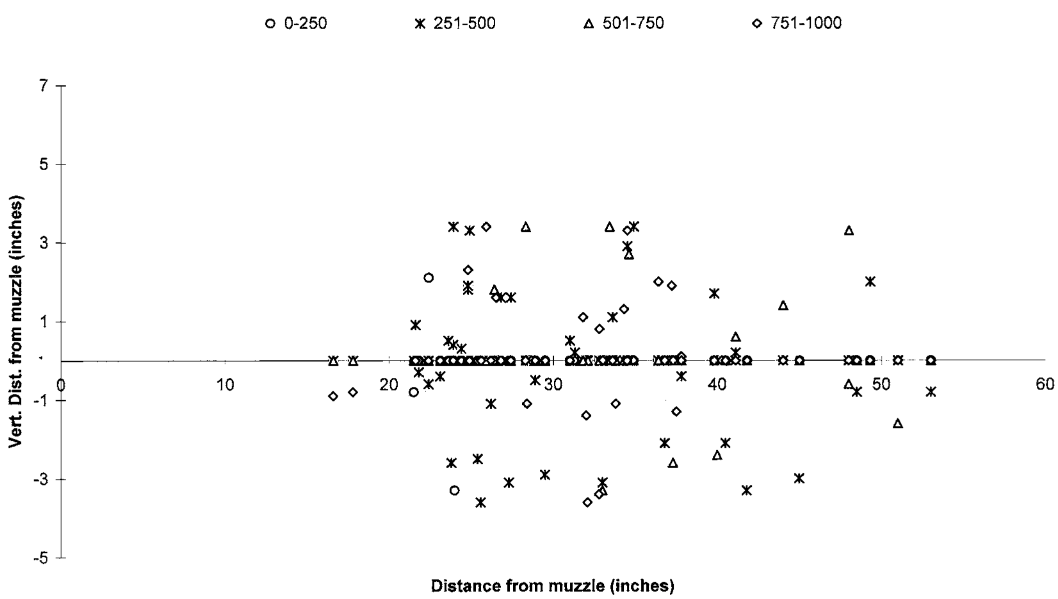

FIG. 7—*Distribution of velocity as ranges of individual propellant particles. X-axis represents the horizontal position in inches along the line of fire. The Y-axis represents the vertical distance (inches) above and below the line of fire. Remington 9 mm + P 115 grain, jacketed hollow point. See legend for Fig. 3 for symbol designations.*

millimeter. A fingerprint magnifier was used, in conjunction with a light box, to facilitate the measurements. For velocity measurements, the distances between images produced by light pulses #1 & #2 (for set 1) and those for pulses #2 and #3 (for set 2) set 2 was measured (see Fig. 9). The interval between sequential images of the same particle corresponded to 100 μs. If deceleration data were required both sets of distances were measured. The set closest the muzzle (produced by pulses 1 and 2), as depicted in Fig. 9, was designated as set 1. Since the pulses of light for set 2 occurred later than for set 1, the separation in the image pair was always somewhat less than that of set 1 (due to a decrease in the velocity of the particle). The length of time between exposures is the same. The same edge (all left or all right) of each image, associated with a particular particle, was measured to determine distances between images. Only those images clearly belonging to the same particle were measured. This was determined in part by an obvious straight trajectory, continuity of path, similar colors, size, and overall general appearance. In those instances when it was not clear if particle images corresponded to a particular particle measurements were not attempted.

Results and Discussion

While particles were found to decelerate rapidly, the velocities that many of them acquired was surprising. A large percentage of the particles photographed had velocities in the range of 750 to 1000 fps (Figs. 4–9). The distribution of velocities as shown in the aforementioned figures is presented to illustrate both an approximate position and corresponding velocity of a particular particle. The absence of data in an area of a particular figure should not be construed to signify that particles will not be found there. However, very few particles were observed beyond the horizontal distances noted in Figs. 4–9. Most of the particles that could be measured

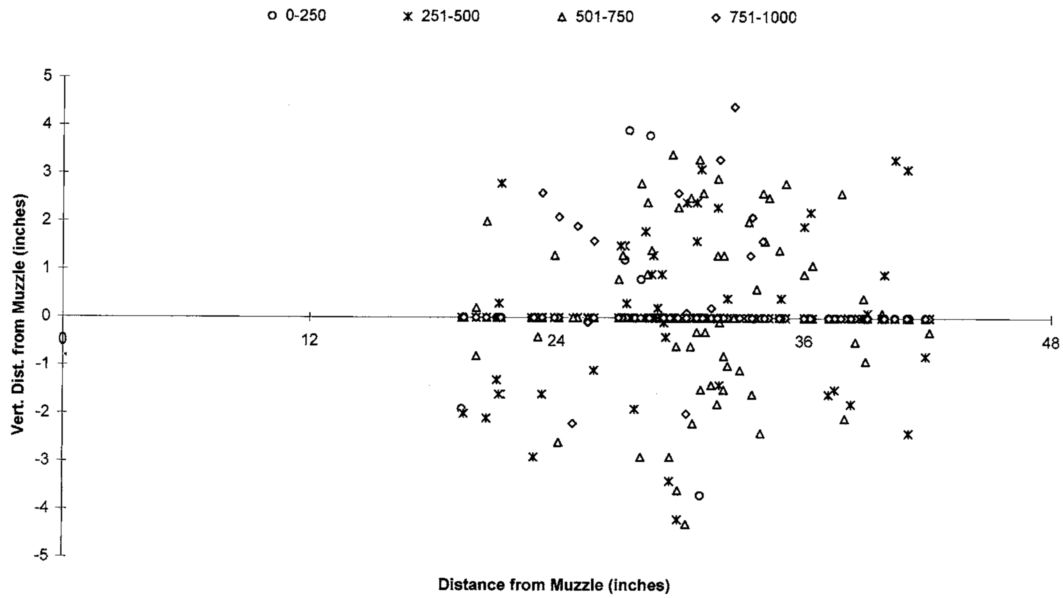

FIG. 8—*Distribution of velocity as ranges of individual propellant particles. X-axis represents the horizontal position in inches along the line of fire. The Y-axis represents the vertical distance (inches) above and below the line of fire. Federal .38 + P 125 grain, jacketed hollow point. See legend for Fig. 3 for symbol designations.*

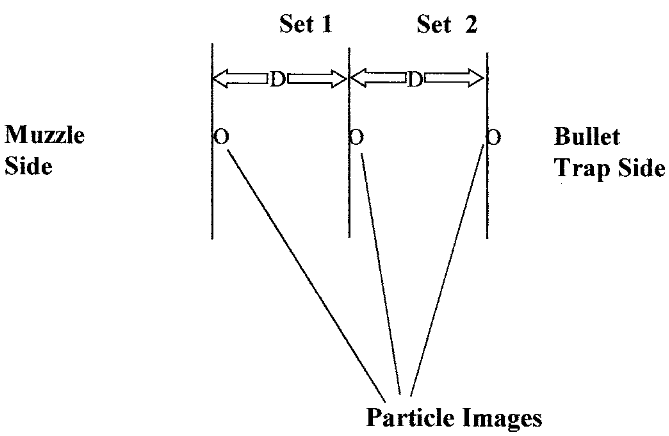

FIG. 9—*Diagram of measurement of particle inter-image distances.*

possessed velocities in the range of 400 to 800 fps (Table 2). While conducting the photography, many particles could be seen surrounding the flight of the bullet as it moved forward. The rapid deceleration of the particles explains why they are generally not found far from the muzzle (Table 3). The deceleration of the particles would not be expected to be linear. The particles are traveling in a non-uniform jet of hot gases rather than in a static medium. Thus, it is likely that the rate of deceleration for some particles change from the time they exit the muzzle.

Because of the high initial velocities many particles acquire from the discharge of the propellant, they can also penetrate or even easily perforate relatively porous materials. Fabric is thus readily penetrated or perforated.

Conclusion

Particles acquire surprisingly high velocities from the propellant ignition (Table 2, Figs. 4–9). Thus, they have sufficient energy to embed themselves within nearby targets like skin or fabric. The velocity that the particles possess when they impact skin would explain the production of punctate wounds associated with stippling (powder tattooing). Although no particles may be apparent on the upper surface of a garment or upholstery fabric it should not be assumed that no GSR is present. While loosely adhering particles may have fallen or transferred to another surface, many others may be anchored quite effectively below the outer surface. Because of their relatively high velocity near the muzzle, normal wind velocity will not significantly influence the motion of propellant particles responsible for stippling.

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