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Change in Muzzle Velocity Due to Freezing and Water Immersion of .22, Long Rifle, K.F. Cartridges

Velocity is probably the single most important factor that determines the wounding power of a bullet. It attains this importance because it is responsible for imparting to a bullet the kinetic energy necessary to produce a casualty. During World War II, a criterion of 58 ft·lb of energy as the minimum to cause a disabling wound was used. Although this criterion was arbitrary, it was found to provide a fairly good yardstick against which to measure the theoretical efficiency of a bullet. Attempts have also been made to correlate the various levels of energy with the probability of causing a disabling wound. At the same time, experimental studies indicate the existence of certain velocity thresholds for the penetration of human skin and bone [*1*]. It appears that only a few missiles with striking velocity less than 200 ft/s are capable of causing more than a trivial injury on a clothed human being.

The general characteristics of wounds caused by various types of firearms are well understood and documented [*2*]. For example, it is well known that with low striking velocities (less than 1200 ft/s), wounds are free from the explosive effect and are on the whole cleaner. For medium velocities (1200 to 2500 ft/s), wounds become more extensive, with considerable tissue destruction, and the explosive effect begins to appear to some degree. High velocities (above 2500 ft/s) result in explosive wounds with enormous destruction of the tissues. Thus, a knowledge of the striking velocity or energy of a bullet may be helpful in gaging whether or not a particular type of injury could be caused by it. Striking velocity or energy of a bullet is to a great extent dependent on its muzzle velocity or energy. For example, the striking velocity of a bullet at some distance away from the muzzle cannot be greater than its muzzle velocity. A bullet which is incapable of being lethal at its muzzle velocity will be all the more so at any distance away from the muzzle. Further, striking velocity at any distance can, in general, be deduced from the muzzle velocity, provided the ballistic coefficient of the bullet is known. Thus, even a knowledge of the muzzle velocity is helpful in gaging the lethal potentiality of a bullet at various ranges of firing.

In criminal trials the wounding ability of a bullet is often a matter of great controversy. These controversies generally arise when the nature of injury as described in the postmortem report is incompatible with the type of firearm suspected to have been involved in the crime. The responsibility of resolving such controversies rests to a great extent on the shoulders of a firearms expert who is often summoned by the courts to face a searching cross-examination

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on the various technical aspects of the matter. Such incompatibilities can arise due to the following reasons:

(1) incorrect observations recorded in the postmortem report,
(2) incorrect identification of the suspect firearm,
(3) mismatching of ammunition.
(4) defective or worn-out firearm, and
(5) deterioration in ammunition.

Assuming that the observations recorded in the postmortem report are correct and that the suspect firearm has been properly identified, one has only to consider the last three reasons outlined above. Mismatching of ammunition may result in considerably lower muzzle velocity. This is especially true when improvised firearms are used. A .303, ball, MK7 cartridge fired through a pipe gun (a common occurrence in India) may cause an injury quite different from that expected from an MK7 bullet at its muzzle velocity when discharged through a service rifle. A defective or worn-out firearm may also discharge a bullet with reduced velocity. A similar situation may arise if the ammunition is defective. In some of the cases the well-known phenomenon of tandem bullets [*3*] is found to occur. Adverse storage conditions or aging can deteriorate the ammunition to such an extent that it may cause misfires or hangfires. Lowering of temperature may result in a reduction in the muzzle velocity. Hatcher [*4*] has listed velocity variations in some cartridges on account of temperature. According to him the velocity will be higher when the firearm and the propellant are warmer, and will be lower when they are cooler. It also appears that this gain or loss of velocity on account of temperature to some extent depends on the type of propellant and the level of pressure generated on firing. The various factors responsible for ballistic variations in a cartridge have been very ably discussed by Munhall [*5*].

In a country like India where there are extreme variations in temperature and humidity, and where the criminals reside in jungles and ravines, the possibility of the cartridge used in the crime being subjected to adverse storage or climatic conditions or both cannot be discounted. The consequences of these adverse conditions, which are generally detrimental to the muzzle velocity developed and hence to the striking velocity at various ranges of firing, cannot, therefore, be underestimated vis-à-vis the phenomenon of wounding. With this in view, it was decided to investigate the change in muzzle velocity due to freezing and water immersion of some Indian-made small arm cartridges since they are every now and then involved in crimes committed in this country. The results of the study of .22, long rifle, Kirkee Factory (K.F.) cartridges are given in the present paper. The paper also deals with the development of a statistical procedure to analyze experimental data in such problems, which can form a basis for further inquiry into similar problems relating to ammunition performance.

Material and Method

The entire series of experiments was directed towards measuring bullet velocity before and after subjecting the cartridges to different treatments. An experimental setup to measure bullet velocity was therefore essential. An electronic timer (ET 452A), manufactured by the Electronics Corporation of India Ltd., was employed for measuring bullet velocity in close proximity to the muzzle. This timer is a versatile, transistorized unit used for time interval measurements as low as 10 microseconds. It uses an accurate and stable crystal-controlled oscillator as the standard clock source for the measurement of time intervals. The measurements are displayed by indicator tubes and the units of measurement, as well as the decimal point, are automatically indicated. The accuracy of the instrument for time interval measurements is ± 1 count ± clock accuracy. The clock frequency is initially set at 1 MHz. There is a frequency change of about 25 ppm over a temperature range from 15 to 45°C. The clock pulses can be selected from 1 microsecond to 10 milliseconds in decade steps.

Screens were prepared by cutting aluminium foil into spiral shapes and pasting them on ordinary target papers. These screens were made part of the two electrical circuits, the breaking of which started and stopped the timer. Two such screens were mounted in a vertical plane parallel to one another on a wheeled carriage made from slotted angles. The horizontal distance between the two screens was 3 ft. The slotted angle carriage carrying the aluminium foil screens was placed between a cotton-filled bullet recovery box and a heavy table on which the firearm was held firmly in a vise. The bullet recovery box served the purpose of a bullet catcher. The distance between the first screen and the muzzle of the firearm was kept as 4 ft. This was done to avoid breaking the screen by the muzzle blast. The time required by the bullet to traverse the distance between the two screens was thus shown by the timer, from which the velocity of the bullet was computed. The velocity so determined was therefore the mean velocity at a distance of 5.5 ft in front of the muzzle and can be taken approximately as the muzzle velocity.

Caliber .22, long rifle cartridges (40-grain lead bullet), manufactured in Indian ordnance factories, were selected for the experiments. The firing was conducted with a .22-caliber rifle, No. 2, Rifle Factory, Ishahore, Serial No. 6278. All the cartridges belonged to the same batch and lot. This was done to minimize round-to-round variations. The cartridges were divided in a random manner into one group of 50 and four groups of five cartridges each. The velocities of the 50-cartridge group were first measured without any pretreatment at an average room temperature of 35°C. The other four groups, each containing five cartridges, were subjected to the following treatments (one treatment accorded to one group):

(1) freezing in the freezer of a refrigerator for three days by enclosing the cartridges in a polythene envelope, thereby preventing them from having any contact with water;

(2) immersion in water for three days;

(3) immersion in water for three weeks; and

(4) immersion in water and freezing in the freezer of a refrigerator for three days.

The velocities of the cartridges were again measured after the treatments outlined above. Velocity measurements of the 50 cartridges without any treatment are given in Table 1. Table 2 gives the velocity measurements after subjecting the cartridges to the various treatments outlined above.

TABLE 1—*Muzzle velocity measurements of 50 .22-caliber, long rifle, K.F. cartridges (without any treatment), arranged in ascending order of magnitude from left to right.*

Muzzle Velocity, ft/s									
774	842	872	900	912	977	987	991	992	994
1001	1001	1005	1009	1012	1012	1016	1018	1020	1022
1023	1023	1025	1029	1032	1033	1034	1037	1045	1051
1053	1053	1057	1066	1066	1067	1068	1076	1081	1090
1101	1106	1111	1116	1150	1196	1201	1206	1221	1239

Statistical Analysis

Having obtained the data on bullet velocity, one can now outline a procedure for analyzing these data in the light of the goal set forth earlier in the paper, that is, measuring

TABLE 2—*Muzzle velocity measurements of .22-caliber, long rifle, K.F. cartridges after the various treatments.*

Serial No.	Type of Treatment	Muzzle Velocity for Five Firings, ft/s				
		1	2	3	4	5
1	freezing for three days without any contact with water	1041 [a]	1028	1040	990 [b]	1004
2	immersion in water for three days	986	1022	1041 [a]	1041	924 [b]
3	immersion in water for three weeks	1016 [a]	*c*	*c*	*c*	*c*
4	immersion in water and freezing for three days	379 [b]	416	518 [a]	*d*	*d*

[a] Maximum velocity in the group.
[b] Minimum velocity in the group.
[c] Cartridges fired but the bullet lodged in the barrel.
[d] In one case the bullet simply came out of the barrel and fell down without breaking the screen. In the other, the bullet lodged in the barrel.

the change in muzzle velocity due to various treatments. A little consideration will show that there is no direct method of ascertaining this change in velocity in respect to a particular cartridge, because the velocity of a cartridge can only be determined once, either before or after a treatment. Although the cartridges belonging to the same batch and lot are similar in all respects, they rarely produce identical results. Considerable variations in velocity are encountered among them. This is also reflected in the velocity figures given in Table 1. The principal cause of these variations is normal factory tolerance in ammunition manufacture. Each component of a cartridge may have small differences from its counterpart in the same batch and lot. These minute differences might sum up to produce extreme ballistic variations. The possible areas of difference are primer, powder, wadding, bullet, and the cartridge case. In addition to this, the firearm itself might lack uniformity. Thus, inferences regarding the change in muzzle velocity can only be drawn on a statistical basis.

When one applies statistical tests, one must generally consider the nature of distribution of the parent population, of which the experimental data constitute a sample. In the present study, one is dealing with muzzle velocity data of cartridges belonging to the same batch and lot before and after certain treatments. As far as the velocity data before any treatment are concerned, the reasons for variations have already been discussed. These variations can reasonably be treated as random. Under such circumstances, the assumption that the muzzle velocity data of the cartridges of a particular type belonging to the same batch and lot may be treated as a random sample from a "normal" population does not seem to be unjustified. However, to be on the safe side, it was considered necessary to check the validity of this assumption with respect to the muzzle velocity data of the 50 .22 cartridges given in Table 1. For this purpose, the velocities given in Table 1 were first grouped into ten class intervals of 50 ft/s ($750 < x \leqslant 800$, $800 < x \leqslant 850$, ..., $1200 < x \leqslant 1250$), and the frequency of each class was enumerated. The frequency distribution is shown in Fig. 1 by a histogram. The mean and the unbiased estimate of the standard deviation of this distribution were found to be 1043 and 91.92 ft/s, respectively. The assumption of normality can now be checked with the help of Kolmogorov-Smirnov test [*6*]. This test requires the calculation of observed and expected relative cumulative frequencies. The expected relative cumulative frequencies, assuming a normal distribution with mean and standard deviation equal to those of the sample of 50 cartridges (namely, 1043 and 91.92

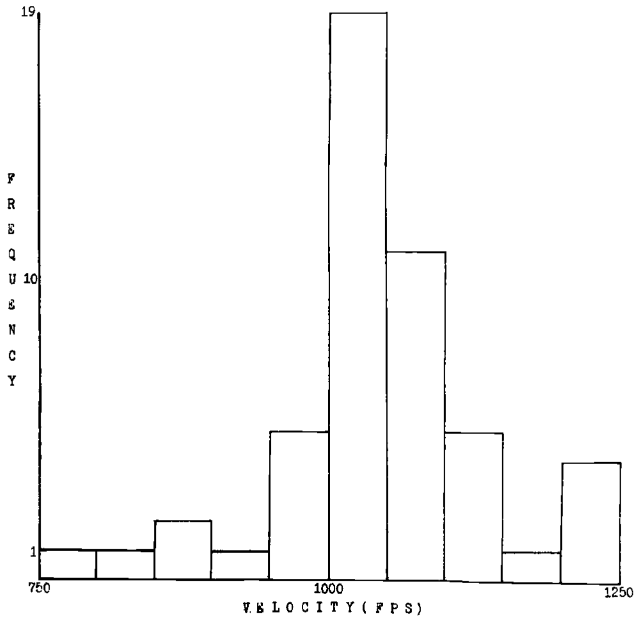

FIG. 1—*Histogram demonstrating frequency distribution of velocities illustrated in Table 1.*

ft/s, respectively), are given in Table 3, together with the observed relative cumulative frequencies. It is seen that the modulus of the maximum deviation between the observed and the expected relative cumulative frequencies (D = 0.11990) is less than the critical value of D at a 5% level of significance.

$$D_{\text{Critical}} = 1.36/50^{1/2} = 0.19236$$

Thus, our hypothesis of a normal distribution is not rejected at a 5% level of significance. One is now justified in assuming that the muzzle velocity data of 50 cartridges given in Table 1 are a random sample from a normal population. The tolerance limits [*6*] within which the velocities of at least a certain percentage of cartridges will fall can now be specified with a known degree of confidence. Thus, if constant K = 3.2, $\bar{X} \pm KS$ (where $\bar{X}$ and S are the sample mean and the unbiased estimate of standard deviation, respectively) denotes the tolerance limits such that one is 95% confident of including at least 99% of the sampled population. For the sample of 50 .22 cartridges, these limits work out to be 749 and 1337 ft/s. Thus, if the muzzle velocity of a .22 cartridge falls outside these limits after treatment, one will have sufficient reason to infer that the particular treatment results in a change in muzzle velocity. This criterion can, therefore, be used to evaluate the effect of the various treatments on the muzzle velocity of a .22, long rifle, K.F. cartridge.

Discussion

When the trigger of a firearm is pulled, the firing pin hits the percussion cap and in so doing crushes the priming mixture, which explodes with hot, piercing flame. The flame reaches the propellant through the flash holes, thereby igniting and converting the

TABLE 3—*Application of the Kolmogorov-Smirnov goodness of fit test to the muzzle velocity data of .22, long rifle, K.F. cartridges given in Table 1.*

Muzzle Velocity X, ft/s	Cartridges with Velocity $\leqslant$ the Specified Value (Cumulative Frequency)	Relative Cumulative Frequency $S_n(X)$	Expected Relative Cumulative Frequency Assuming a Normal Distribution $F(X)$	$\lvert F(X) - S_n(X) \rvert$
750	0	0	0.00072	0.00072
800	1	0.02000	0.00410	0.01590
850	2	0.04000	0.01786	0.02214
900	4	0.08000	0.05856	0.02144
950	5	0.10000	0.15577	0.05577
1000	10	0.20000	0.31990	0.11990[a]
1050	29	0.58000	0.53029	0.04971
1100	40	0.80000	0.73237	0.06763
1150	45	0.90000	0.87739	0.02261
1200	46	0.92000	0.95618	0.03618
1250	50	1.00000	0.98784	0.01216

[a] $D = \max \lvert F(X) - S_n(X) \rvert = 0.11990 < 1.36/\sqrt{50} = 0.19236$.

propellant into a hot mass of gases. The efficiency of ignition depends inter alia on the heat given off by the flame. When the flame plays on a grain of smokeless powder in a cartridge, the powder burns in a manner which is very much akin to wood. The surface of a propellant grain is required to be raised to the ignition point before it starts burning. When the cartridges are subjected to a freezing temperature, the temperature of the surface of the powder grains is at 0°C. Thus, more energy is required from the primer to elevate the temperature of the propellant grains to the ignition point than when they are at a higher temperature. This loss in energy is therefore expected to result in some loss of velocity. The exact loss in velocity is variable and is dependent on the type of propellant, pressure level, etc of the particular cartridge under consideration. In the present investigation, the velocity of the untreated cartridges was measured at an average room temperature of 35°C. The cartridges were then subjected to 0°C for three days without having any contact with water. A reference to Table 2 shows that the velocities of the five rounds at 0°C are within the tolerance limits prescribed for the muzzle velocity of a .22 cartridge at an average room temperature of 35°C. One is therefore unable to infer that the lowering of temperature of the cartridges from 35 to 0°C affects the muzzle velocity of the cartridges.

The other treatments to which the cartridges were subjected involved intimate contact with water for varying periods. It is common knowledge that contact with water can make the propellant, as well as the priming composition, unserviceable. The cartridges used for experiments were of rimfire variety and the cartridge cases were all metallic. Water can enter inside a rimfire metallic cartridge case through the space between the bullet and the mouth of the cartridge case. Thus, immersion of cartridges in water can result in the passage of water into the cartridge case, thereby causing deterioration in the priming composition and the propellant. When a cartridge is manufactured, efforts are made to waterproof it by blocking the various possible water inlets with the help of waterproofing compositions. This waterproofing may not be perfect nor may it be able to withstand an intimate contact with water for prolonged periods. Once the priming composition becomes unserviceable, the cartridge will misfire. If it deteriorates partially, the flash given by the primer may not be strong enough to ignite the propellant or, if it ignites the propellant, the ignition may be quite inadequate for the development of normal pressure. Similarly, if the powder becomes unserviceable even a normal flash from the primer may be ineffective in igniting it. If, however, it is partially affected, the flash may be able to burn a portion of the propellant. In many cases the primer flash may itself be strong enough to push the bullet into the barrel without igniting the propellant to the slightest degree. In such cases the bullet may be either lodged in the barrel or leave the muzzle with a negligible velocity and thus drop in close proximity to the muzzle. A reference to Table 2 shows that the immersion of cartridges in water for three days cannot be deemed to have affected the muzzle velocities of the cartridges on the basis of the criterion formulated earlier. The velocities of all five cartridges fall well within the tolerance limits specified above. When the period of immersion was increased to three weeks, four out of the five cartridges failed to eject their bullets out of the barrel. The primer fired in all the four cases, as was evident from the sound produced on firing, but almost the entire powder charge was left unburnt. The powder was wet to the touch. It appeared that the primer flash drove the bullets down the barrel some distance to where they lodged. The velocity of one cartridge (1016 ft/s) was, however, well within the tolerance limits for the muzzle velocity. Here is a situation which can easily lead to the phenomenon of tandem bullets. For example, if the cartridge which registered a velocity of 1016 ft/s had been fired after the bullet of one of the other four cartridges lodged in the barrel, there is a possibility that the second bullet would have driven the first one along with it as a single projectile, thereby creating a single wound of entry and a single channel in the body. When the cartridges were immersed in water for three days and simultaneously frozen, one cartridge lodged its bullet in the barrel. In another, the bullet came out of the muzzle but dropped in close proximity to the muzzle without even breaking the aluminium foil screen connected to the timer. Again, the powder was largely unburnt and wet to the touch. In the other three instances, the bullets registered a velocity which was less than 50% of the average velocity of the untreated .22 cartridges.

A 40-grain, .22-caliber, lead bullet, with an average muzzle velocity of 1043 ft/s, has a muzzle energy of 97.1 ft·lb, which is higher than the minimum required to cause a disabling wound (58 ft·lb). The average muzzle velocity of 1043 ft/s is also much higher than the minimum velocities required to effect the penetration of human bone (200 ft/s) and skin (125 to 170 ft/s). Although the muzzle velocities of the three cartridges subjected to simultaneous freezing and water immersion for three days are higher than the thresholds prescribed for the penetration of bone and skin, the corresponding energies (12.8, 15.4, and 24 ft·lb) are much below the minimum energy of 58 ft·lb generally considered necessary to cause a disabling wound. It is obvious that the lethal potentiality of a .22 bullet is adversely affected by water immersion for three weeks and also by freezing and water immersion for three days. A .22 bullet leaving the muzzle with less than 50% of its normal average muzzle velocity will have an altogether different trajectory, requiring readjustment of sights. At the same time, the ranges of scorching, powder tattooing, etc, which are intimately related with the internal ballistics of a cartridge, may undergo drastic changes requiring caution on the part of the firearms examiner in interpreting the results of experiments conducted in connection with range estimation.

Summary

A study of change in muzzle velocity due to freezing and water immersion of .22, long rifle, K.F. cartridges has been presented. A statistical criterion has been formulated to ascertain whether or not a cartridge undergoes a change in muzzle velocity due to a particular treatment. The muzzle velocity data of .22, long rifle, K.F. cartridges, obtained by an electronic timer before and after the various treatments, have been analyzed in the light of this criterion. These cartridges have generally been found to suffer considerable loss in muzzle velocity when immersed in water for three weeks and also when immersed in water for three days and simultaneously cooled to 0°C. The forensic significance of this loss in muzzle velocity has been discussed.

References

[1] Beyer, J., Ed., *Wound Ballistics,* Office of the Surgeon General, Department of Army, Washington, D.C., 1962, p. 138.

[2] Gonzales, T. A., Vance, M., Helpern, M., and Umberger, C. J., *Legal Medicine, Pathology and Toxicology,* 2nd ed., Appleton-Century-Crofts, New York, 1954, p. 381.

[3] Lowbeer, L., "An Unusual Gunshot Wound in the Head," *Journal of Forensic Sciences,* JFSCA, Vol. 6, 1961, pp. 88-97.

[4] Hatcher, J. S., *Hatcher's Notebook,* 2nd ed., The Stackpole Co., Harrisburg, Pa., 1957, p. 398.

[5] Munhall, B. D., "Fundamental Ballistics Pertaining to Investigations Involving Firearms," *Journal of Forensic Sciences,* JFSCA, Vol. 6, 1961, pp. 215-217.

[6] Ostle, B., *Statistics in Research,* 2nd ed., Oxford & IBH Publishing Co., Calcutta, 1966, p. 471 and pp. 98-100.

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