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BULLET PENETRATION IN SNOW

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The purpose of this work was to investigate the behavior of small arms ammunition in snow under laboratory conditions. Knowledge of this behavior will lead to more efficient design of expedient field fortifications using snow as the primary construction material. Three types of ammunition, the M193, M80, and M43, were tested. Rounds were fired into snow targets of various thicknesses up to that thickness required to fully stop the projectiles. The maximum penetrations for the three rounds tested were 0.70m, 1.26m and 1.06m respectively. Velocity loss as a function of target thickness was determined by measuring projectile velocity before and after impact of the projectile with the target. The velocity-loss-versus-thickness data showed a sigmoid shape common to the three types of rounds. The impact and exit yaw angles of the M193 rounds were estimated. Scatter in the test data was attributed, in part, to random

20. Abstract (cont'd)

variations in the impact yaw angle. The penetration required for a 90° yaw was determined by the exit yaw measurements. This was shown to correspond to the inflection point on the velocity-loss-versus-penetration curve. This point is potentially significant in the design of composite fortifications. Discussions deal with basic concepts and definitions, the occurrence and significance of projectile tumbling and the use of laboratory tests for small arms evaluation in snow targets. The validity of the methodology used was established by testing M193 rounds in gelatin targets. These results compared favorably with similar test results in the literature.

PREFACE

This report was prepared by David M. Cole, Research Civil Engineer, Applied Research Branch, and by Dennis R. Farrell, Mechanical Engineer, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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The authors express appreciation to Gregory A. Simonds, who performed much of the experimental work in this study.

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BULLET PENETRATION IN SNOW

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INTRODUCTION

The work described in this report is a part of the overall investigation of terminal ballistics in snow, ice and frozen ground being conducted for the Office, Chief of Engineers, under the Military Research and Development, Test and Evaluation Program. The tests reported here were performed to investigate, under laboratory conditions, the behavior of projectiles penetrating snow targets. The knowledge gained will add to the understanding of the ballistic properties of snow and thus facilitate its use in field fortifications in cold regions.

BACKGROUND

The potential of snow as a construction material for expedient field fortifications has been recognized for some time. Guidelines for its use in military operations are included in pertinent U.S. Army field manuals (e.g., Field Fortifications, Basic Cold Weather Manual, Northern Operations).

The recommended thicknesses for defense against small arms fire are usually given as 4.00 m and 2.00 m for loose snow and packed snow, respectively (HQAMC, FM 31-70, 1968). These values are generally accepted and appear in literature dating back several decades (Chekotillo 1943).

Field tests have been the primary source of data regarding the ballistic properties of snow. They have provided the necessary information on total penetration of a given round under a specific set of conditions but have allowed little latitude to control, or at least monitor, all the test parameters.

Scant attention has been paid, beyond the determination of total penetration, to understanding the projectile's behavior as it passes through the snow. Johnson (1977), while reporting the results of field total penetration tests, observed the occurrence of tumbling of small arms ammunition in snow. However, due to the nature of the tests, quantitative information regarding the path length required for tumbling was impossible to obtain. Similar observations were made by Farrell (1978a) in reporting field tests with small arms ammunition. But again, only qualitative observations could be made beyond the recording of total penetration for a given round, snow temperature and snow density.

The gap in knowledge concerning projectile behavior during snow penetration can be bridged by the use of laboratory testing techniques which permit closer control of test parameters and more detailed observation of projectile behavior. Laboratory test results will aid in the design of more efficient snow fortifications as well as yield information which will be more useful in the design of composite fortifications (i.e., those consisting of layers of two or more materials).

The total penetration of projectiles in snow has been examined in the laboratory by Swinzow

(1975) and more recently by Aitken (1978). In both cases, fragment-simulating metal cubes or spheres were fired into mechanically processed snow at various impact velocities to determine total penetration. This type of test, however, yields no information pertaining to velocity loss as a function of projectile penetration. Also, most analytical techniques applied to small projectile penetration, as show by Aitken, are valid only for stable projectiles (i.e., those which maintain their original orientation during penetration). As will be seen, the small arms ammunition studied here is unstable during penetration and thus its performance cannot be analyzed adequately by most existing methods. The analytical problem could be addressed by finite element methods, but the complexity of the solution would result in extremely high computer costs; therefore, these methods are not considered a realistic approach.

Given the scarcity of directly applicable laboratory data on snow, test data on other relatively soft target materials were sought which would give some insight pertinent to the question of projectile behavior during penetration. Work done at the U.S. Army Ballistics Research Laboratory (BRL) reported by Roecker et al. (1977) provided some valuable information in this connection. In that study, velocity loss characteristics and projectile orientation of M193 and XM732 ammunition in gelatin targets were determined using an X-ray measurement system. A cursory comparison between the velocity loss data reported here and the data reported by Roecker et al. showed some distinct similarities, so the comparison was pursued in more detail.

Roecker et al. showed impact yaw to be a major variable affecting the penetration observed before the round became unstable and tumbled, which then led to a rapid velocity loss. (Yaw is defined as the angle between the direction of motion of the center of gravity of the projectile and its longitudinal axis.) Roecker et al. also monitored the variations in the yaw angle with increased penetration, called yaw growth. Similarities in the projectile velocity loss patterns in snow and gelatin suggested that the yaw growth in snow roughly parallels that in gelatin. This assumption was verified by the tests reported here.

The data of Roecker et al. were also used as a means of verifying the methodology used at CRREL for determining velocity loss. The X-ray technique used by these workers is widely accepted, but rather costly and geared to relatively low volume testing. The CRREL methodology, on the other hand, is considerably less complex and geared to relatively high volume testing, but yields less information per round. By testing the gelatin targets at the CRREL facility, and comparing results with those of Roecker et al., a reasonable verification was achieved.

TEST FACILITY AND EQUIPMENT

All tests were performed in the Ballistics Testing Facility at CRREL. The basic layout of the facility is shown in Figure 1. A description of this test facility has been given by Farrell (1978b).

Projectile velocity is measured before and after projectile impact by means of two pairs of Oehler Research Model 55 chronograph screens in conjunction with two TSI Model 361 Universal counters to within ± 2 m/s. The counters are set to start and stop on triggering commands sent by the chronograph screens when they sense the passage of a projectile. Thus, the time required for the projectile to traverse the known distance between the screens is recorded.

Paper witness screens were placed behind the last chronograph screen to indicate the direction of each round after impact with the target.

The sample preparation procedures for both snow and gelatin targets are given in Appendix A.

The significant characteristics for the rounds tested are given in Table 1.

EXPERIMENTAL PROGRAM

The experimental program consisted of several types of tests, each performed to determine a specific aspect of projectile behavior. This was necessary because the test methodology did not allow for the simultaneous determination of the variables. Placement of a witness screen to determine impact yaw, for example, would seriously affect the validity of the residual velocity measurements. Therefore, separate tests were performed to evaluate both the impact and exit yaw angles under the conditions described. Another set of tests was performed to determine the velocity loss characteristics in snow of the three rounds under

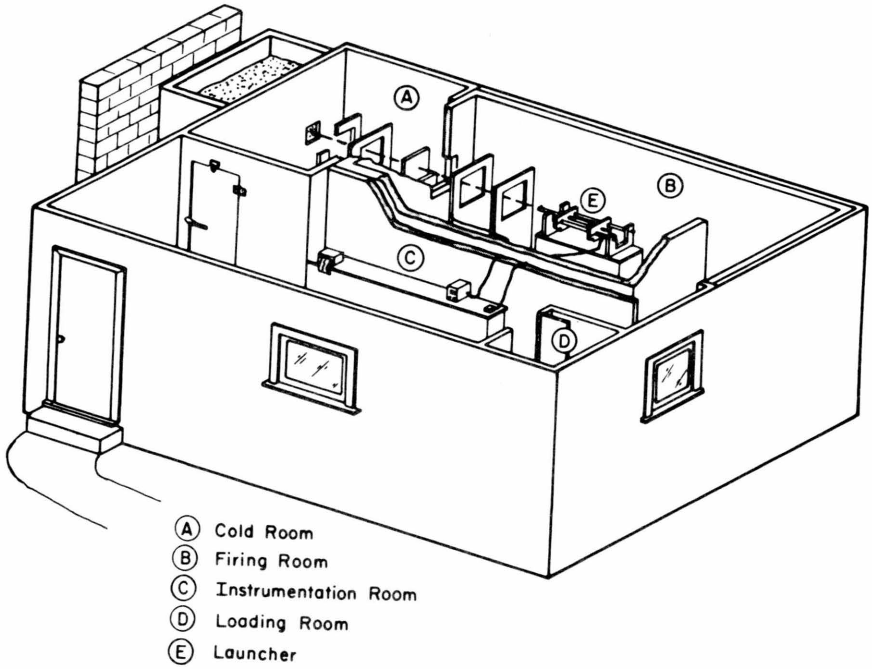

Figure 1. Terminal ballistics facility.

Table 1. Rounds tested.

Round	Diameter (mm)	Weight (g)	Length (mm)	Muzzle velocity (m/s)	Projectile spin (rev/s)
M193	5.56	3.57	19.56	990	3250/2780*
M80	7.62	9.73	32.25	850	2390
M43	7.62	7.81	26.50	740	3100

* Dependent on barrel twist.

consideration. Only the velocity loss characteristics of the M193 round were determined in the gelatin target material.

Impact yaw

Procedures

The impact yaw angle for a given round was determined by firing directly into a witness screen of photographic paper placed 3 m from the rifle muzzle. The resulting hole was then measured, and the largest dimension was recorded. A graphical technique was used to determine projectile yaw from the witness screen information. A round of each type was photographed in profile and enlarged by a factor of five. A grid was then superimposed and the round was oriented at several angles to the horizontal. The maximum dimension of the round projected on a line perpendicular to the horizontal was then determined for each angle. This dimension corresponds to the maximum dimension of a hole formed by a round passing

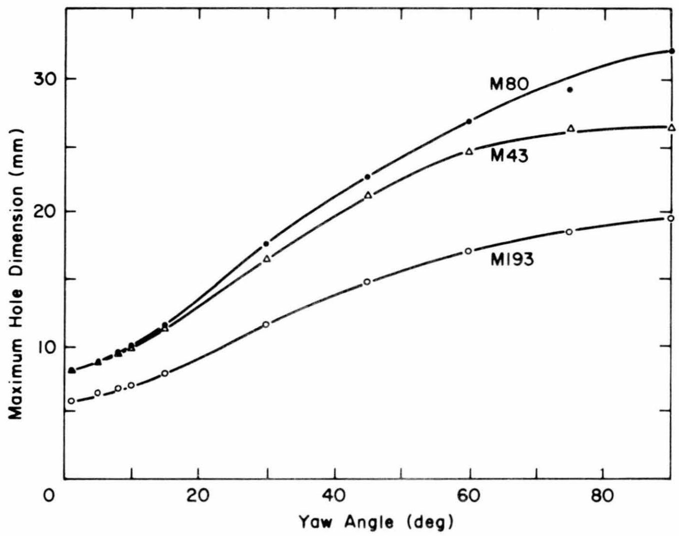

Figure 2. Yaw angle as a function of maximum bullet hole diameter.

through a witness screen at that yaw angle. The results of this operation are seen in Figure 2. This method was also used to estimate the exit yaw angles.

Results

The results of the tests to characterize the impact yaw of the M193 rounds are given in Table B1, Appendix B. Two rifle barrels which produced projectile spin rates of 2780 rev/s and 3250 rev/s were used for these tests. Rounds fired at full muzzle velocity at the 2780-rev/s spin rate averaged 6° of yaw, while those fired at the 3250-rev/s spin rate averaged 5° of yaw. Rounds fired at 600 m/s at a correspondingly reduced spin rate of 1970 rev/s did not have a detectable yaw angle. Attempts were made to estimate the impact yaw for the M80 and M43 rounds as well, but the resulting holes in the witness screen were not distinct, so reasonably accurate measurements could not be made.

Discussion

Yaw is defined as the angle between the direction of motion of the center of gravity of a projectile and the longitudinal axis of the projectile (Fig. 3). When a spin-stabilized projectile is fired in air, the angle of yaw varies rapidly at first, then decreases to a minimum value. As the round nears the end of its range, the yaw gradually increases (Sturdivan et al. 1969, Fig. 4).

The angle of yaw is primarily a function of the rifle design, the projectile's stability and velocity, the air density, and the projectile's location along its trajectory. Manufacturing inconsistencies in either the rifle or the projectiles further affect yaw characteristics.

Although projectile velocity at a given range can be duplicated by decreasing the powder load an appropriate amount, the actual yaw corresponding to that range cannot be duplicated in short-range tests.

Roecker et al. (1977) showed that the projectile yaw at the moment of impact is a critical factor influencing the behavior of a round passing from air into a denser medium. The same workers indicated that, in a gelatin sample, the rounds undergo a common yaw growth pattern up to about 135°, and then the yaw oscillates in an arbitrary fashion. The rate of yaw growth appears to increase until a 90° yaw is reached. For a given round and target medium, the depth to which a bullet penetrates before rapid yaw growth, called tumbling, begins varies with impact yaw. As the impact yaw increases, the depth of penetration required for the initiation of rapid yaw growth within the target decreases. Since the projectile velocity decay is a function of the yaw growth, as will be discussed below, the round's velocity loss characteristics also vary as the impact yaw varies.

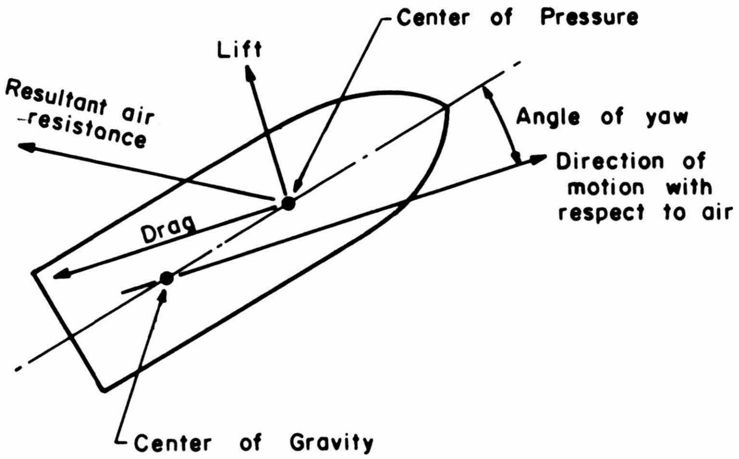

Figure 3. Forces on a projectile (from AMCP 706-242).

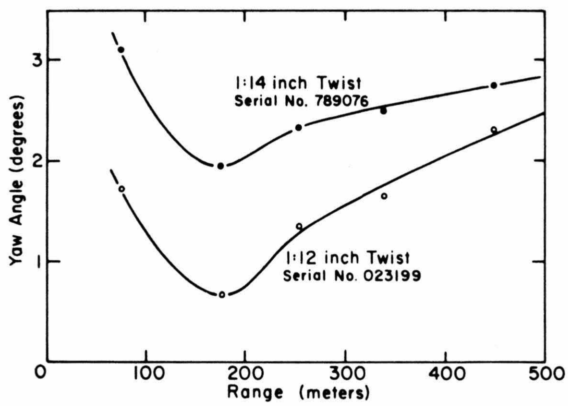

Figure 4. Mean yaw angle versus range (from Sturdivan et al. 1969).

Yaw as a function of range for two projectile spin rates is shown in Figure 4 (Sturdivan et al. 1969). Barrels producing both these spin rates were used for the M193 tests on snow. The 1:14 twist ratio produced a spin rate of 2780 rev/s and the 1:12 twist ratio produced a spin rate of 3250 rev/s. That the lower impact yaw may be associated with the 3250-rev/s spin rate is significant because of its effect on the velocity loss characteristics of the projectile during target penetration. This is discussed in the next section.

On rare occasions a round impacts with effectively a zero yaw angle. Although this did not appear to occur here, it has been noted in testing conducted at Ballistics Research Laboratory (BRL) (MacAllister, 1977) that M193 rounds passed entirely through a 0.300-m gelatin block with no detectable yaw growth, and correspondingly, a relatively small velocity loss. This is also a likely explanation for excessive penetration noted in certain instances by Johnson (1977), in which 7.62-mm machine gun ammunition passed through 1.80 m of snow, which, based on previous tests, should have stopped the rounds at 1.25 m. This is an interesting and important phenomenon, but unfortunately, due to the limited information available, no probabilities can be attached to its occurrence.

Velocity loss in snow

Procedures

The projectile velocity loss as a function of snow target thickness was determined by measuring the residual velocity of rounds fired through targets of varying thicknesses up to and including the thickness required for 100% velocity loss. The fronts of the targets were located 3 m from the muzzle of the rifle for the relatively thin targets (i.e., $\leq$ 0.300 m). However, it was necessary to vary this distance somewhat to accommodate the larger targets. The rounds struck the center of the targets with a trajectory perpendicular to the target surface.

Projectile impressions on the witness screens placed behind the final set of chronograph screens allowed the determination of the change in trajectory resulting from impact with the target.

Results

The results of the tests to determine velocity loss characteristics for the M193, M80 and M43 rounds are given in Tables B2, B3 and B4. Snow density, target thickness, initial and final velocities, normalized exit velocity loss, percentage of velocity loss, and deviation from original trajectory are given for each round. Snow densities ranged from 0.36 Mg/m^3 to 0.50 Mg/m^3. Target thicknesses ranged from 0.025 m to 0.700 m for the M193, from 0.045 m to 1.26 m for the M80, and from 0.150 m to 1.060 m for the M43.

Discussion

The velocity loss versus target thickness data for each type of round are shown in Figures 5-7. The results for all three types of rounds have a markedly similar sigmoid shape.

The rounds undergo only a slight velocity loss up to a penetration of about 0.075 m for the M193 and 0.150 m for the M80 and M43. This corresponds to a gradual increase in the angle of yaw. Then, the velocity decreases more rapidly, corresponding to an accelerated rate of yaw growth. A point of inflection occurs between 30 and 40% velocity loss for each type of round which, as will be seen in the discussion on exit yaw, roughly corresponds to the point at which 90° yaw occurs. This seems reasonable, since the greatest velocity loss per unit of target thickness would be expected when the maximum possible area of the round is facing the direction of motion.

After the inflection point, the velocity loss becomes more gradual until the round finally stops. The yaw is varying rapidly in this region, but apparently the projectile maintains a more or less straight path.

Effect of spin rate

As noted above, two spin rates were used in the M193 tests. The rounds in Table B2 (App. B) having a spin rate of 3250 rev/s are marked with an asterisk. All others had the 2780-rev/s spin rate.

The barrel producing the 3250-rev/s spin rate was used in tests on the 0.300-m to 0.700-m-thick targets, while the barrel producing the 2780 rev/s spin rate was used for the 0.025-m to 0.300-m thick targets. Data scatter was somewhat less in the tests employing the higher spin rate.

For the 0.300-m target thickness tested with both barrels, velocity losses obtained using the higher spin rate tended to be slightly lower on the average than those obtained using the lower spin rate. This trend is most probably a result of the lower average impact yaw associated with the higher spin rate.

Bullet deformation and break-up in snow

Since a "soft catch" technique (to stop the rounds without causing additional deformation) was not used, quantitative assessment of bullet deformation is not possible. However, the witness screens give some information pertaining to the extent of projectile break-up. In most tests using the M193 round where the target thickness was 0.100 m or greater, one or more fragments would pass through the witness screen along with the main portion of the round.

It is assumed that the time interval recorded by the rear chronograph screens was triggered by the main body of the round, and not by one of the bullet fragments or target material.

It is not strictly correct to consider data from broken and unbroken rounds, as well as from rounds in varying states of deformation, as homogeneous, since the projectile mass and geometry, and therefore the velocity loss characteristics, are not uniform. However, in arriving at an empirical model for the ballistic properties of snow, it was decided to include all data indicative of actual projectile behavior.

Bullet fragmentation was not a significant problem with the M80 and M43 rounds.

Deviation from original trajectory

As a round passes through a target, it is usually deflected from its original trajectory. The angle between final and original trajectories were determined from the witness screen information. As expected, the less stable M193 rounds tended to veer after considerably less penetration than the M80 or M43 rounds.

It appears that most of the deflection occurred during the period of yaw growth up to about 90°. Once the yaw exceeded that point and the round began to tumble, the path became approximately straight through the remainder of the target.

The deviation from the original trajectory for the M193 rounds reached a maximum of about 20°. Several rounds hit the rear chronograph screen frame, indicating deviation angles slightly greater than 20°, but these data were not considered in the analysis. Both the M80 and M43 rounds reached a maximum of about 10°. However, these maxima were not necessarily

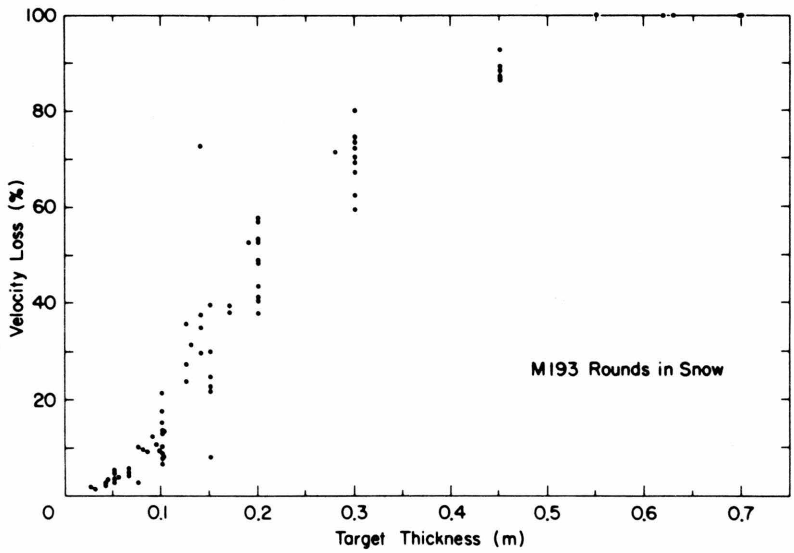

Figure 5. Test results for 5.56-mm, 3.57-g M193 rounds in snow.

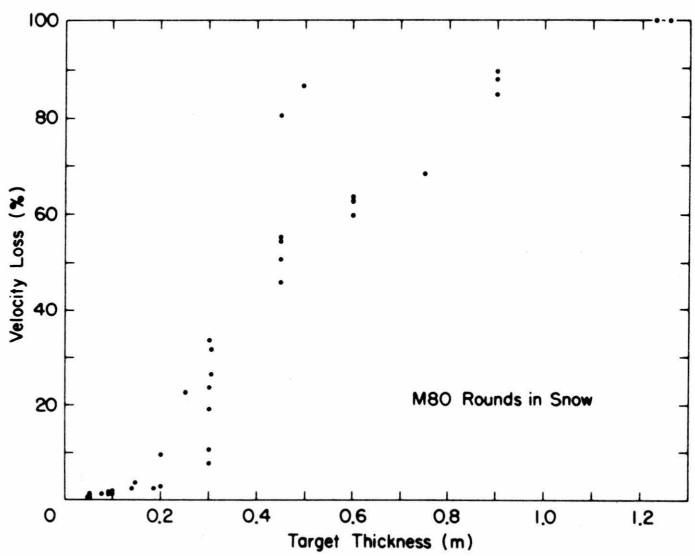

Figure 6. Test results for 7.62-mm, 9.73-g M80 rounds in snow.

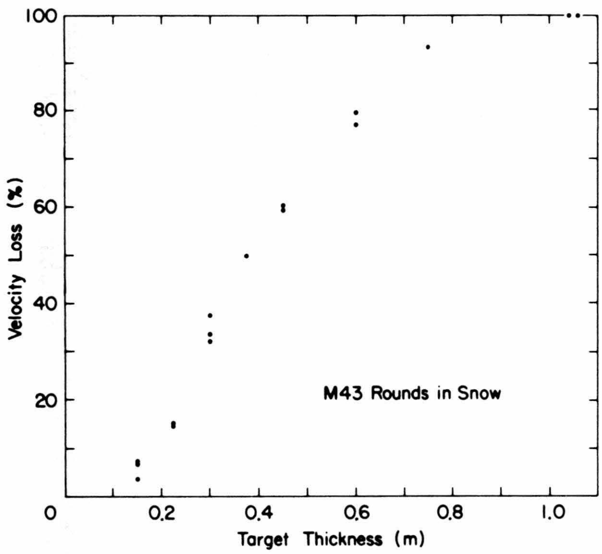

Figure 7. Test results for 7.62-mm, 7.91-g M43 rounds in snow.

reached at the greatest target thicknesses. Also, for a given target thickness, the deviation angle varied considerably. The reason for this is unclear at present. If this behavior were a function of impact yaw, a correlation between deviation angle and velocity loss would be expected. However, this is not verified by the results.

Snow density and sample age

The density of most of the targets tested was from 0.39 to 0.49 Mg/m^3. This is a rather narrow band, but it is representative of snow that has been disturbed, and thus realistic with respect to field fortifications.

Snow density variations, over the range considered here, did not appear to exert a discernible influence on the velocity loss characteristics. Johnson (1977) presented data that indicate the variations in total penetration are minimal over the density range of 0.40 to 0.50 Mg/m^3. It is most likely that the scatter resulting from random impact yaw variations overshadowed the more subtle influence of density variations.

Target age, over the range considered, did not appear to influence the test results either. Sample age was from 1 to 15 days. Considering a 0.100-m-thick target, the velocity loss for M193 rounds in 1 to 3-day old snow ranged from 7.8% to 13.5% with a mean of 11.1% and a standard deviation of 2.8. For 15-day old targets of the same thickness, the range was 6.3% to 21.1%, with a mean of 15.0% and a standard deviation of 6.3. Thus, although the average velocity loss for the older targets was somewhat higher, the spread in the data prevents any firm conclusions from being drawn.

Target damage

Photographs of some snow targets after testing are shown in Figures 8-13. Targets thick enough to cause tumbling generally sustained much more damage than the relatively thin targets. But this is to be expected since the amount of energy imparted by a round per unit of path length increases after tunbling is initiated. Figure 13 shows a 0.250-m-thick target which has not been cut to expose the cavity caused by an M80 round. The round was not fully tumbling over this target length, but the yaw was increasing rapidly when the round exited.

Exit yaw

Procedures

Exit yaw, the yaw of the projectile as it left the target, was measured by means of a witness screen placed directly behind and in contact with the snow target. The witness screen material used was painted fiberboard. The rounds left a fairly distinct impression. The holes were measured and analyzed according to the graphical method described earlier.

Results

The results of tests to characterize exit yaw for the M193 and M80 rounds are given in Table B5. For the M193, target thickness ranged from 0.030 to 0.200 m; exit yaw ranged from approximately 17° to 90°. For the M80 rounds, target thickness ranged from 0.050 m to 0.200 m; exit yaw ranged from 0° to about 29°. It must be noted that the minimum and maximum exit yaws did not necessarily correspond to the minimum and maximum target thicknesses. The effects of bullet deformation on these measurements were neglected. The test results are shown in Figure 14.

Discussion

The exit yaw angle versus target thickness plot gives an indication of the manner in which projectile yaw increases with penetration. It is suggested that variations in impact yaw are a primary cause of scatter in these data.

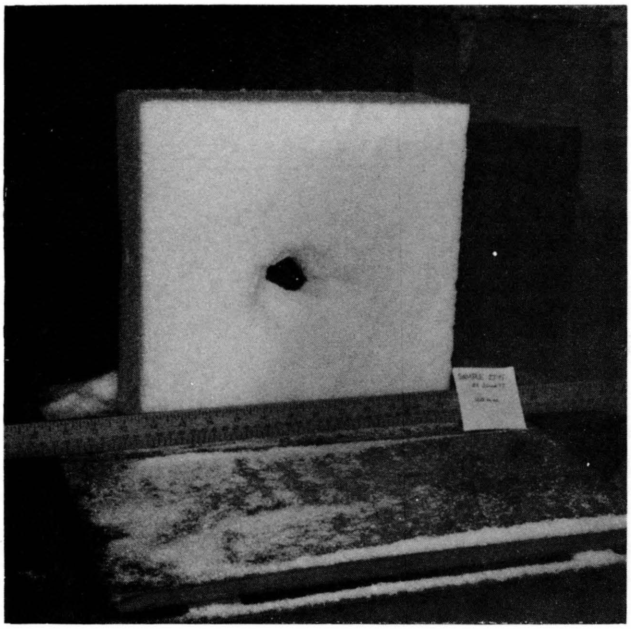

Figure 8. 0.100-m-thick snow target after impact by an M193 round.

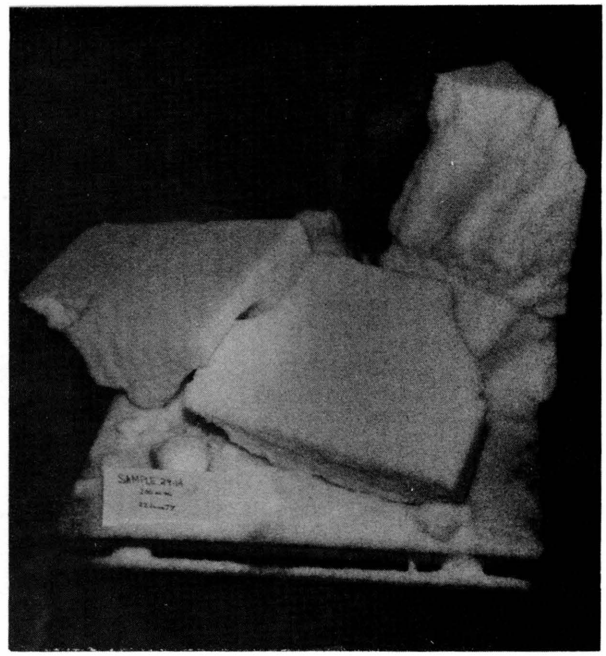

Figure 9. 0.200-m-thick snow target after impact by an M193 round.

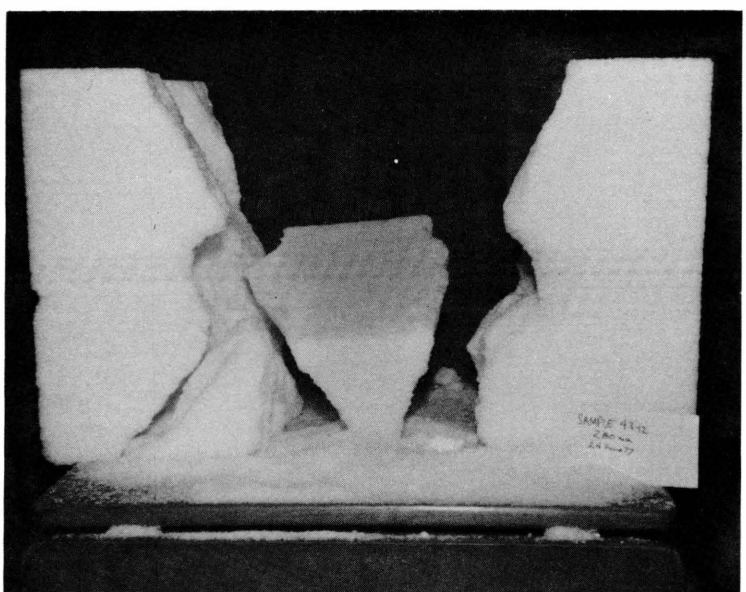

Figure 10. 0.280-m-thick snow target after impact by an M193 round.

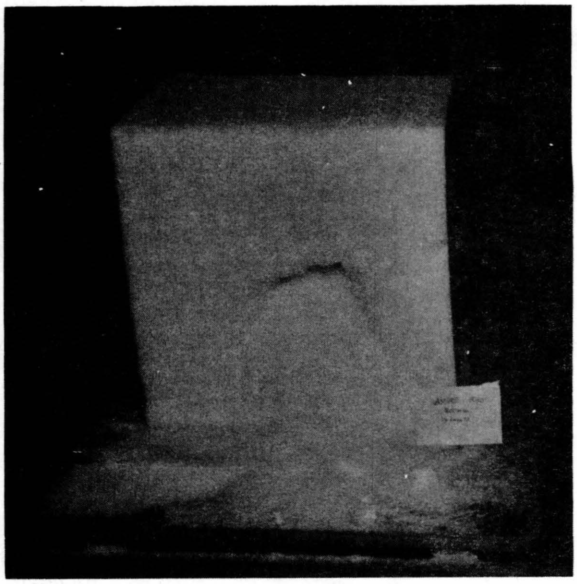

Figure 11. 0.200-m-thick snow target after impact by an M80 round.

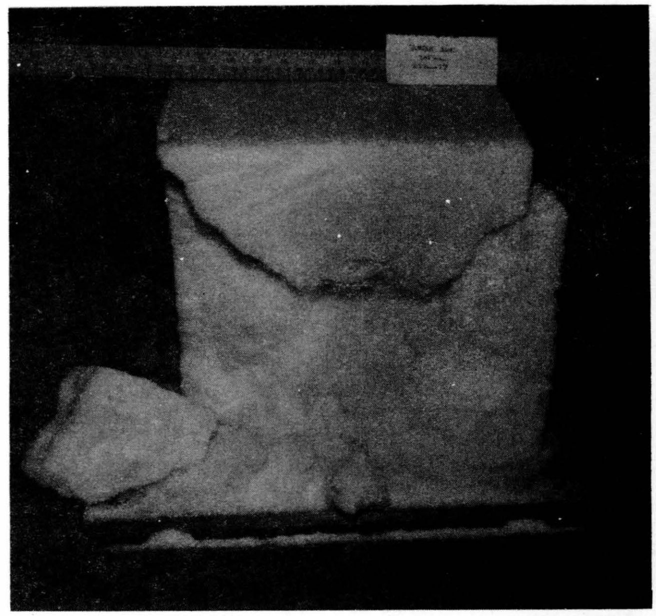

Figure 12. 0.305-m-thick snow target after impact by an M80 round.

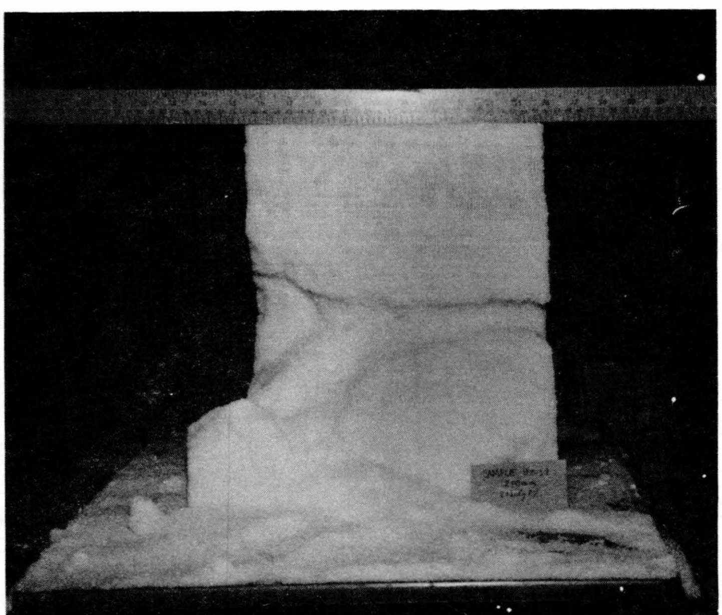

Figure 13. Cross section of a 0.250-m-thick snow target after impact by an M80 round.

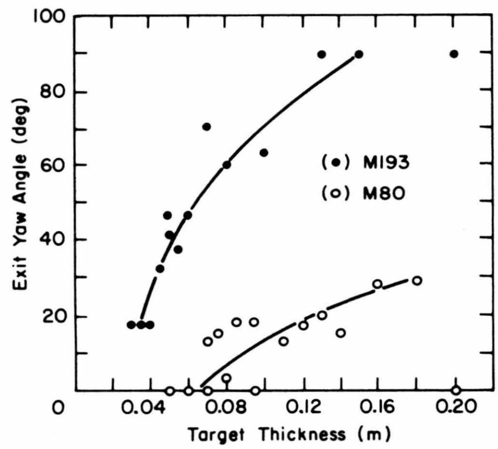

Figure 14. Exit yaw angle versus snow target thickness for the M193 and M80 rounds.

The general trend of yaw growth correlates reasonably well with the velocity loss characteristics in that 90° of yaw occurs roughly at the sample thickness corresponding to the point of inflection on the M193 velocity loss curve (Fig. 5). Exit yaw measurements indicate an increasing yaw angle for target thicknesses up to 0.130 m. Approximately 90° yaw angles were found for target thicknesses of 0.130 m, 0.150 m and 0.200 m. These values, although somewhat scattered, coincide with the steepest part of the velocity loss curve and tend to bracket the inflection point.

Since the velocity loss characteristic graphs of all the rounds tested are very similar in shape, it is assumed on the basis of the M193 tests that the rounds all reach 90° of yaw and begin to tumble at or near the inflection point.

Velocity loss in gelatin

Procedures

The test procedure was the same as that used to determine the velocity loss of projectiles in snow.

Results

The results of tests to characterize the velocity loss of the M193 rounds in gelatin are given in Tables B6 and B7. The nominal muzzle velocities were 600 m/s and 1000 m/s. Target thicknesses up to 0.302 m were tested and velocity losses up to 87% were recorded.

Discussion

A comparison between the results of this test series and some similar data from Ballistics Research Laboratory (Roecker et al. 1977) is shown in Figure 15. The average residual velocity of the CRREL rounds is roughly 80 m/s greater than the average for several representative BRL rounds over the target thickness range of 0.100 m to 0.300 m. However, the velocity appears to decay at very nearly the same rate for both sets of data.

This implies that the CRREL rounds penetrated further into the target before the onset of rapid yaw growth; but once tumbling was initiated, the rounds lost velocity in the same manner as the BRL rounds. The negligible impact yaw angles, as measured for the CRREL rounds fired at 600 m/s, undoubtedly contributed to the increased penetration.

It would be expected that the basic difference between the two methods of velocity loss measurement would cause discrepancies among the results as well. The BRL data for the rounds shown in Figure 15 are a result of measurements taken using X-ray photography at several locations as the projectiles pass through a 0.300 m target. As noted earlier, the velocity losses presented here result from a residual velocity measurement after the projectile has passed through a target of a given thickness, between 0.100 m and 0.400 m. Thus, especially for the thinner targets, some inherent variations would be expected due to the difference in boundary conditions between the two methods.

However, if this were the case, it would also be expected that, as the target thicknesses for the CRREL rounds approach those of the BRL tests (0.300 m), the measured velocity losses would converge. This does not occur. The velocity loss of the CRREL rounds remains less than that of the BRL rounds throughout the entire target. It appears, then, that the above mentioned boundary conditions do not have a significant effect on the results under these test conditions. The tentative conclusion can thus be drawn that the two methods of measurement yield similar results in gelatin. However, this must be treated with some reservation when making the necessary inferences concerning snow, since differences in the mechanical properties of the two materials could affect the validity of the conclusion. Tests on snow, using the BRL techniques, would have to be performed to completely clarify this validation process.

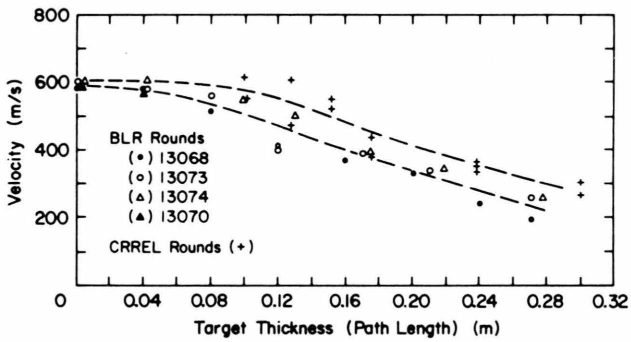

Figure 15. Comparison of CRREL and BRL (Roecker et al. 1977) test results for the M193 rounds in gelatin.

It is interesting to note that, in these tests conducted on gelatin targets, the rounds impacting at a normal 600 m/s underwent far lower velocity loss for a given target thickness than did the rounds impacting at a nominal 1000 m/s. The rounds impacting at 1000 m/s generally broke up after a small amount of penetration (approximately 0.080 mm). The resulting fragments would rapidly lose velocity and the total penetration of any given fragment would not exceed 0.160 m. Rounds impacting at 600 m/s, however, would usually remain intact and lose only 50% of impact velocity at penetrations as high as 0.300 m.

The fact that the residual velocity was much greater and bullet deformation was much less in the slower projectile is significant. As the impact velocity increased, the rate of energy dissipation in the target also increased. At some velocity (i.e., between 600 m/s and 1000 m/s), a transition occurred at which the forces resulting from the deceleration became great enough to cause significant fragmentation of the projectile, and the penetration was then reduced. The effect of variation in impact velocity and the resulting projectile fragmentation was not examined in the tests on snow, but it should be recognized as a potentially significant parameter.

MATHEMATICAL MODEL

For purposes of analysis, the exit velocity data have been normalized with respect to the muzzle velocity and the target thickness has been normalized with respect to total penetration. The results of this operation are seen in Figures 16 and 17.

Attempts were made to analyze the data using various curve fitting techniques, but it was finally decided to formulate a mathematical model based on a trigonometric function which would satisfy the boundary conditions. A shaping factor, in the form of an exponent, could then be used to contour the resulting curve to fit each data set as well as possible.

The following equation was developed for this purpose:

$$v_N = \tfrac{1}{2}\,[1-\cos[\pi(1-t_N)^n]] \qquad (1)$$

Where v_N = Normalized exit velocity
t_N = Normalized target thickness
n = Shaping factor

The shaping factor provides the versatility needed to adapt the equation to the M193, M80 or M43 test data.

For a given value of n, theorectical values of v_N exit can be calculated for the target thicknesses used in the tests. These values can then be plotted versus the actual exit velocities to examine the linearity of the relationship. This is shown in Figure 16 for the M193 data, with $n = 1.8$. Perfect correlation is indicated by a line passing through the origin with a slope of +1. It can be seen that the points are reasonably well distributed about this line. The correlation coefficient for the experimental versus theoretical exit velocity data is 0.960. A value of $n = 1.4$ was found to characterize both the M80 and

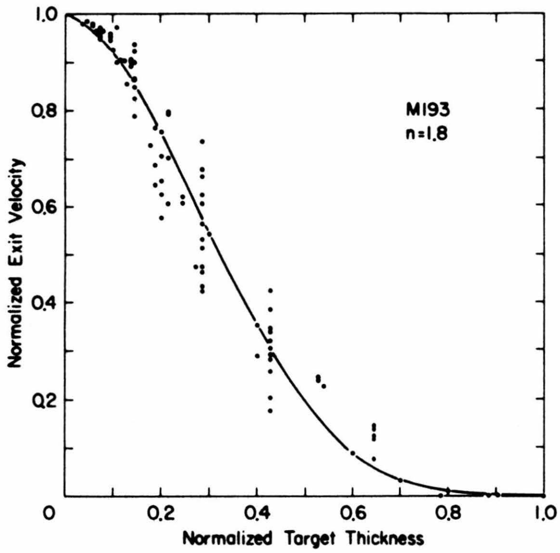

Figure 16. Normalized M195 data. Curve results from eq 1, n=1.8.

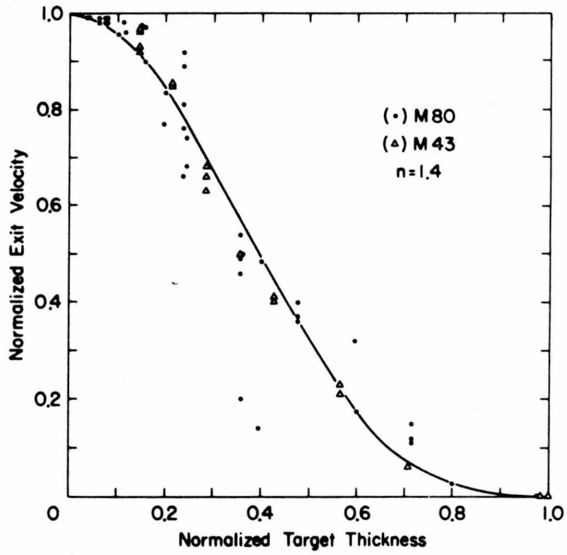

Figure 17. Normalized M80 data. Curve results from eq 1, n=1.4.

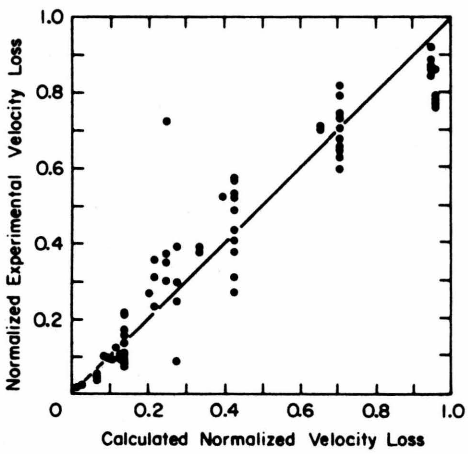

Figure 18. Experimental versus calculated velocity loss for the M193 data.

M43 data as seen in Figure 17. The correlation coefficents for these are 0.957 and 0.995 respectively.

It is interesting to note (refer to Fig. 16 and 17) that the curves all begin their steepest slope (i.e., the rounds reach 90° of yaw) at approximately 25% of total penetration.

COMMENTS

The basic trends of projectile behavior in snow were determined from the results presented here. Impact yaw was a major factor in the onset of tumbling, which causes rapid dissipation of the projectile's kinetic energy, and thus reduces its penetration.

The point was brought out that the yaw of a bullet in flight varies considerably and that simulating a long range firing in the laboratory by merely decreasing the powder charge does not necessarily result in the appropriate impact yaw angle. This indicates the need for field verification of laboratory data thus obtained. However, if a correspondence between laboratory and field test results could be established for several types of ammunition at varying velocities, it would be possible to evaluate other existing or newly developed types of ammunition primarily with laboratory tests and only a minimum of field tests.

It was originally intended that these tests be indicative of the worst-case field conditions, that is, a round fired at full muzzle velocity at short range (4.0 m). However, this may not actually be the worst case since a round fired at a somewhat greater distance is likely to have a considerably smaller angle of yaw (refer to Fig. 4) while losing only a small percentage of its original velocity. The net result would be greater penetration before tumbling and a subsequently greater total penetration. This point should be clarified by appropriate field tests.

The importance of impact yaw and subsequent yaw growth should also be viewed in the light of fortification efficiency. If rapid growth could be induced early in the penetration of the projectile, its energy would be dissipated more readily. The total penetration, and thus the necessary snow thickness, could then be reduced. Mechanisms by which yaw growth could be induced are not within the scope of this report. However, they are a potentially significant area of study.

CONCLUSIONS

Based on the work reported here, the following conclusions may be drawn:

1. The maximum penetrations in snow, under the conditions described for the M193, M80 and M43 rounds, were 0.70 m, 1.26 m, and 1.06 m, respectively.

2. The impact yaw of a round is a critical factor influencing the onset of tumbling, and consequently, velocity loss.

3. A change in snow density over the range of 0.36 Mg/m^3 to 0.50 Mg/m^3 did not exert a discernible influence on the velocity loss characteristics of the projectile studied. It is likely, however, that variations in impact yaw overshadowed the effects of target density.

4. The rounds tested began to tumble at approximately 25% of their total penetration.

5. Test results obtained using CRREL methodology are in reasonable agreement with test results reported by the Ballistics Research Laboratory.

RECOMMENDATIONS

1. Additional laboratory tests should be performed to evaluate the effect of variations in muzzle velocity on the velocity loss characteristics and total snow penetration of the rounds tested here. This information is required to establish a correspondence between laboratory tests conducted at short ranges and field tests conducted at realistic ranges.

2. Field tests should be conducted to establish total snow penetration values for several types of small arms ammunition, to include those used here, at actual ranges.

3. Two types of rounds should be evaluated by BRL, using X-ray techinques, to determine impact yaw, yaw growth and velocity decay in snow targets to further validate the CRREL methodology and to better define projectile behavior during penetration.

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APPENDIX A. SAMPLE PREPARATION

Snow

Samples were prepared by sieving snow through a no. 4 sieve into 305-mm cubic plywood molds. The molds were then sealed in plastic bags and allowed to age in a -6.7°C (20°F) cold room

Just before testing, the plywood was removed and a target of the desired thickness was cut from the snow block. Targets were oriented so that the direction of firing coincided with the vertical axis of the snow sample as it was formed.

Resulting snow densities ranged from 0.36 Mg/m^3 to 0.50 Mg/m^3. This density range corresponds to a variety of possible field conditions for mechanically processed snow.

Gelatin

1. Sixty-six kg (30 lb) of tap water was heated in a large flat pan to 85°C (185°F).
2. A 7.71-kg (3.5-lb) quantity of dry gelatin powder was spread in a thin layer over the surface of the water and stirred slowly with a spoon until the powder dissolved.
3. An additional 8.14 kg (3.7 lb) of gelatin powder was then added and stirred until no lumps of undissolved gelatin larger than about 5 mm (0.2 in.) remained.
4. The mixture was allowed to stand for 2 to 4 hours at room temperature, and any foam formed was skimmed from the surface.
5. The mixture was then poured into two forming pans 457 mm long x 127 mm wide x 127 mm deep (18 in. x 5 in. x 5 in.). Again, any foam formed was skimmed from the surface of the mixture.
6. The forming pans were then placed in a 5°C (41°F) environment for 14 to 18 hours.
7. The solidified mixture was removed by placing the forming pans in 50°C (122°F) water until the gelatin block could be easily removed.
8. The blocks were sealed in plastic bags and stored at the test temperature of 10°C (50°F).
9. Just prior to the test, the desired target thickness was cut from the block by pushing a saw blade through the gelatin.

APPENDIX B: VELOCITY LOSS CHARACTERISTICS AND IMPACT AND EXIT YAW ANGLES

Table Bl. Impact yaw angles for the M193 round.

Round no.	Rifle spin rate (rev/s)	Muzzle velocity (m/s)	Maximum bullet hole dimension (mm)	Impact yaw (°)	Average yaw (°)
1	22-0.250	990	6.6	8	
2	(2780)		7.0	11	
3			7.1	11	
4			5.8	1	
5			6.6	8	
6			6.8	9.5	
7			5.8	1	
8			6.6	8	
9			6.7	8	
10			6.8	9.5	
11			6.2	4	
12			6.2	4	
13			5.9	1	
14			6.4	6	
15			5.7	1	
16			6.5	8	
17			6.9	9.5	
18			6.3	6	
19			6.6	8	
20			6.4	6	6
21	0.223	1040	5.6	0	
22	(3250)		6.2	4	
23			6.7	8	
24			6.0	4	
25			6.3	6	
26			6.1	4	
27			6.8	9.5	
28			6.0	4	
29			6.7	8	
30			6.4	6	
31			6.4	6	
32			6.2	4	
33			6.1	4	
34			6.1	4	
35			6.7	8	
36			6.4	6	
37			6.8	9.5	
38			5.8	1	5
39	0.223	600	5.6	0	
40	(1970)		5.6	0	
41			5.6	0	
42			5.6	0	
43			5.6	0	0

Table B2. Velocity loss characteristics of the M193 round in snow.

Round no.	Snow density (Mg/m^3)	Target thickness T(m)	Normalized target thickness T_N	Muzzle velocity V_o(m/s)	Exit velocity V_e(m/s)	Normalized exit velocity $V_{EN} = V_e/V_o$	Velocity loss V_L (%)	Deviation from original trajectory (°)
1	0.42	0.025	0.036	990	971	0.980	2.0	0.8
2	0.41	0.030	0.043	990	975	0.985	1.5	0.5
3	0.48	0.040	0.057	980	960	0.980	2.0	1.1
4	0.48	0.040	0.057	965	942	0.976	2.4	1.1
5	0.44	0.045	0.064	990	956	0.966	3.4	1.9
6	0.41	0.050	0.071	994	965	0.971	2.9	1.5
7	0.46	0.050	0.071	979	928	0.948	5.2	2.3
8	0.49	0.050	0.071	981	945	0.963	3.7	2.0
9	0.44	0.050	0.071	980	943	0.952	4.8	2.0
10	0.48	0.055	0.079	978	942	0.963	3.7	1.5
11	0.49	0.065	0.093	998	951	0.953	4.7	2.9
12	0.48	0.065	0.093	994	954	0.960	4.0	1.7
13	0.48	0.065	0.093	968	914	0.944	5.6	3.2
14	0.42	0.075	0.107	993	894	0.900	10.0	5.1
15	0.49	0.075	0.107	984	956	0.972	2.8	0.6
16	0.49	0.080	0.114	977	885	0.906	9.4	4.5
17	0.44	0.085	0.121	1024	928	0.906	9.4	4.7
18	0.48	0.090	0.129	984	942	0.856	14.4	6.7
19	0.42	0.095	0.136	972	867	0.892	10.8	5.6
20	0.48	0.095	0.136	957	870	0.909	9.1	5.1
21	0.46	0.095	0.136	983	890	0.905	9.5	5.2
22	0.44	0.100	0.143	993	894	0.900	10.0	5.0
23	0.41	0.100	0.143	997	865	0.868	13.2	6.9
24	0.46	0.100	0.143	974	898	0.922	7.8	5.5
25	0.49	0.100	0.143	983	850	0.865	13.5	7.9
26	0.47	0.100	0.143	987	779	0.789	21.1	7.3
27	0.47	0.100	0.143	990	928	0.937	6.3	5.6
28	0.47	0.100	0.143	999	848	0.849	15.1	6.6
29	0.48	0.100	0.143	964	795	0.825	17.5	6.9
30	0.46	0.100	0.143	993	859	0.865	13.5	6.3
31*	0.43	0.100	0.143	998	913	0.922	8.5	-
32	0.46	0.125	0.179	978	713	0.729	27.1	10.0
33	0.46	0.130	0.186	960	659	0.686	31.4	9.1
34	0.45	0.130	0.186	965	736	0.763	23.7	9.2
35	0.48	0.130	0.186	971	624	0.643	35.7	9.0
36	0.44	0.140	0.200	989	645	0.652	34.8	10.4
37	0.46	0.140	0.200	971	607	0.625	37.5	8.6
38	0.49	0.140	0.200	991	573	0.578	42.2	9.4
39	0.44	0.140	0.200	1017	716	0.704	29.6	10.9
40	0.46	0.150	0.214	968	679	0.701	29.8	8.7
41	0.46	0.150	0.214	968	586	0.605	39.5	10.7
42*	0.39	0.150	0.214	1054	969	0.979	8.0	-

Table B2. (cont'd).

Round no.	Snow density (Mg/m^3)	Target thickness T(m)	Normalized target thickness T_N	Muzzle velocity V_o(m/s)	Exit velocity V_e(m/s)	Normalized exit velocity $V_{EN} = V_e/V_o$	Velocity loss V_L (%)	Deviation from original trajectory (°)
43*	0.40	0.150	0.214	1040	785	0.793	24.5	-
44*	0.40	0.150	0.214	1048	791	0.799	24.5	7.0
45	0.45	0.170	0.243	962	597	0.620	37.9	9.1
46	0.48	0.170	0.243	963	586	0.608	39.1	6.7
47	0.50	0.190	0.271	982	466	0.474	52.5	7.3
48	0.42	0.200	0.286	989	420	0.425	57.5	7.5
49	0.41	0.200	0.286	985	506	0.514	48.6	8.9
50	0.46	0.200	0.286	968	419	0.433	56.7	10.1
51	0.46	0.200	0.286	981	459	0.468	53.2	7.5
52	0.42	0.200	0.286	993	473	0.476	52.4	8.7
53*	0.43	0.200	0.286	1008	600	0.606	40.5	-
54*	0.43	0.200	0.286	996	730	0.737	26.7	-
55*	0.43	0.200	0.286	1017	526	0.531	48.3	-
56*	0.43	0.200	0.286	987	558	0.563	43.5	-
57*	0.43	0.200	0.286	969	672	0.678	30.7	-
58*	0.44	0.200	0.286	1053	657	0.663	37.6	8.2
59*	0.44	0.200	0.286	1040	616	0.623	40.7	8.9
60	0.42	0.280	0.400	975	283	0.290	71.0	11.6
61	0.44	0.300	0.429	992	253	0.255	74.4	11.0
62	0.48	0.300	0.429	965	194	0.201	79.9	-
63*	0.36	0.300	0.429	1000	345	0.348	65.6	-
64*	0.37	0.300	0.429	1000	300	0.303	70.0	-
65*	0.39	0.300	0.429	978	176	0.178	82.0	-
66*	0.39	0.300	0.429	1016	383	0.387	62.3	-
67*	0.43	0.300	0.429	1041	420	0.425	59.6	8.3
68*	0.38	0.300	0.429	1042	289	0.292	72.2	11.0
69*	0.38	0.300	0.429	1043	279	0.281	73.3	12.9
70*	0.39	0.300	0.429	1048	336	0.340	67.9	5.0
71*	0.39	0.300	0.429	1042	318	0.321	69.5	3.1
72*	0.42	0.370	0.529	1049	244	0.247	76.7	15.4
73*	0.44	0.370	0.529	1057	237	0.239	77.6	16.7
74*	0.44	0.370	0.529	1053	244	0.247	76.8	16.7
75*	0.44	0.370	0.54	1050	224	0.226	78.7	16.4
76*	0.39	0.450	0.643	1059	78	0.079	92.6	15.2
77*	0.40	0.450	0.643	1038	138	0.139	86.7	5.4
78*	0.37	0.450	0.643	1064	118	0.119	88.9	6.0
79*	0.40	0.450	0.643	1064	147	0.148	86.2	8.1
80*	0.41	0.450	0.643	1049	121	0.123	88.4	9.6
81*	0.39	0.450	0.643	1047	144	0.146	86.2	11.0
82*	0.41	0.550	0.786	1052	0	1.0	100.	-
83*	0.41	0.620	0.886	1048	0	1.0	100.	-
84*	0.40	0.630	0.900	1051	0	1.0	100.	-
85*	0.41	0.700	1.000	1052	0	1.0	100.	-
86*	0.41	0.700	1.000	1050	0	1.0	100.	-

NOTE: * Indicates round fired from the 1:12 twist barrel; all others fired from the 1:14 twist barrel. (see Fig. 4)

Table B3. Velocity loss characteristics of the M80 round in snow.

Round no.	Snow density (Mg/m^3)	Target thickness T(m)	Normalized target thickness T_N	Muzzle velocity V_o(m/s)	Exit velocity V_e(m/s)	Normalized exit velocity $V_{EN} = V_e/V_o$	Velocity loss V_L (%)	Deviation from original trajectory (°)
1	0.38	0.045	0.036	829	824	0.99	0.6	0.2
2	0.44	0.050	0.040	840	836	0.99	0.4	-
3	0.44	0.050	0.040	845	839	0.99	0.7	1.5
4	0.44	0.050	0.040	837	826	0.99	1.3	1.2
5	0.48	0.050	0.040	839	833	0.99	0.7	0.3
6	0.41	0.050	0.040	848	843	0.99	0.5	0.2
7	0.44	0.075	0.060	828	816	0.98	1.4	0.5
8	0.48	0.075	0.060	842	832	0.99	1.2	0.5
9	0.48	0.090	0.071	848	838	0.99	1.2	0.9
10	0.41	0.090	0.071	830	816	0.98	1.7	0.6
11	0.44	0.100	0.079	820	806	0.98	1.7	0.5
12	0.50	0.100	0.079	849	839	0.99	1.2	1.4
13	0.41	0.140	0.111	825	805	0.98	2.4	0.9
14	0.48	0.145	0.115	840	809	0.96	3.7	2.0
15	0.44	0.185	0.147	850	828	0.97	2.6	0.6
16	0.48	0.200	0.159	845	763	0.90	9.7	5.1
17	0.41	0.200	0.159	828	803	0.97	3.0	0.9
18	0.44	0.250	0.198	853	660	0.77	22.6	7.1
19	0.45	0.300	0.238	850	562	0.66	33.9	5.5
20	0.43	0.300	0.238	835	745	0.89	10.8	4.1
21	0.42	0.300	0.238	845	684	0.81	19.1	5.8
22	0.44	0.300	0.238	848	785	0.92	7.5	2.9
23	0.44	0.300	0.238	838	640	0.76	23.6	6.4
24	0.42	0.305	0.242	841	620	0.74	26.3	6.7
25	0.48	0.305	0.242	837	572	0.68	31.7	5.3
26	0.44	0.450	0.357	846	457	0.54	46.0	6.4
27	0.44	0.450	0.357	851	169	0.20	80.2	6.5
28	0.44	0.450	0.357	846	387	0.46	54.3	7.0
29	0.43	0.450	0.357	858	421	0.49	50.9	6.1
30	0.44	0.450	0.357	839	412	0.49	50.9	5.8
31	0.44	0.450	0.357	833	372	0.50	55.4	9.8
32	0.42	0.495	0.393	832	115	0.14	86.2	8.7
33	0.43	0.600	0.476	827	333	0.40	59.8	5.8
34	0.42	0.600	0.476	820	298	0.36	63.7	5.6
35	0.42	0.600	0.476	840	314	0.37	62.7	6.1
36	0.43	0.750	0.595	843	267	0.32	68.4	5.9
37	0.43	0.900	0.714	847	89	0.11	89.5	8.7
38	0.44	0.900	0.714	845	103	0.12	87.8	10.3
39	0.43	0.900	0.714	845	129	0.15	84.8	10.00
40	0.43	1.230	0.976	841	0	0	100.	-
41	0.43	1.260	1.0	831	0	0	100.	-

Table B4. Velocity loss characteristics of the M43 round in snow.

Round No.	Snow density (Mg/m^3)	Target thickness T(m)	Normalized target thickness T_N	Muzzle velocity V_o(m/s)	Exit velocity V_e(m/s)	Normalized exit velocity $V_{EN} = V_e/V_o$	Velocity loss V_L (%)
1	0.45	0.150	0.142	747	719	0.96	3.7
2	0.45	0.150	0.142	734	679	0.92	7.4
3	0.45	0.150	0.142	741	691	0.93	6.8
4	0.45	0.150	0.142	734	707	0.96	3.6
5	0.45	0.225	0.212	745	636	0.85	14.6
6	0.45	0.225	0.212	743	630	0.85	15.2
7	0.45	0.300	0.283	729	458	0.63	37.2
8	0.45	0.300	0.283	749	496	0.66	33.8
9	0.45	0.300	0.283	746	507	0.68	32.1
10	0.45	0.375	0.354	749	376	0.50	49.9
11	0.45	0.450	0.425	746	305	0.41	59.1
12	0.45	0.450	0.425	743	296	0.40	60.2
13	0.45	0.600	0.566	745	172	0.23	77.0
14	0.45	0.600	0.566	744	155	0.21	79.2
15	0.45	0.750	0.708	739	47	0.06	93.6
16	0.45	1.040	0.981	744	0	0	100.
17	0.45	1.060	1.0	746	0	0	100.

Table B5. Exit yaw angles for the M193 and M80 rounds in snow.

Round no.	Type of round	Rifle spin rate (rev/s)	Snow density (Mg/m^3)	Target thickness (m)	Maximum bullet hole dimension (mm)	Exit yaw angle (°)
1	M 193	220-0.250	0.48	0.030	8.4	17
2		(2780)	0.46	0.035	8.5	17
3			0.48	0.040	8.3	17
4			0.48	0.045	12.3	32
5			0.46	0.050	14.1	41
6			0.48	0.050	14.9	46
7			0.46	0.055	13.4	37
8			0.46	0.060	14.9	46
9			0.46	0.070	17.9	70
10			0.48	0.080	17.0	60
11			0.48	0.100	17.4	63
12		0.223	0.43	0.130	19.6	90
13		(3250)	0.43	0.150	19.6	90
14			0.43	0.150	19.6	90
15			0.43	0.200	19.6	90
16	M 80	0.62	0.44	0.050	7.8	0
17		(2390)	0.44	0.060	7.8	0
18			0.44	0.070	11.2	13
19			0.44	0.070	7.8	0
20			0.44	0.075	11.6	15
21			0.44	0.080	8.6	3
22			0.44	0.085	12.7	18
23			0.44	0.095	8.0	0
24			0.44	0.095	12.5	18
25			0.44	0.110	11.0	13
26			0.44	0.120	12.1	17
27			0.44	0.130	13.4	20
28			0.44	0.140	11.7	15
29			0.44	0.160	16.7	28
30			0.44	0.180	17.2	29
31			0.44	0.200	7.8	0

Table B6. Velocity loss characteristics of the M193 rounds in gelatin. $V_o \approx 600$ m/s

Round no.	Gelatin density (Mg/m^3)	Target thickness T(m)	Muzzle velocity V_o(m/s)	Exit velocity V_e(m/s)	Velocity loss V_L(m/s)
1	1.08	0.100	647	610	5.6
2		0.100	597	550	7.9
3		0.128	645	606	6.1
4		0.152	595	522	12.3
5		0.152	626	543	13.3
6		0.176	570	437	23.3
7		0.238	622	369	40.7
8		0.238	635	366	42.4
9		0.238	615	337	45.2
10		0.302	629	272	56.8
11		0.302	597	311	48.0

Table B7. Velocity loss characteristics of the M193 rounds in gelatin. $V_o \approx 1000$ m/s

Round No.	Gelatin density (Mg/m^3)	Target thickness T(m)	Muzzle velocity V_o(m/s)	Exit velocity V_e(m/s)	Velocity loss V_L(%)
1	1.08	0.077	1059	945	10.8
2		0.103	1049	648	38.2
3		0.104	1036	725	30.1
4		0.131	1043	537	48.6
5		0.132	1041	443	57.4
6		0.156	1041	113	89.1
7		0.164	1040	139	86.6
8		0.256	1052	0	100.0