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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Provides procedures for testing small arms ammunition. Includes dispersion, drift, maximum range, ballistic coefficient, and stability factor.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP-702-103
*Test Operations Procedure 4-2-604 12 August 1986
AD No.

RANGE FIRINGS OF SMALL ARMS AMMUNITION

1. SCOPE. This TOP provides procedures for tests of small arms ammunition necessary to provide data for exterior ballistic computations in order to prepare complete firing tables. Tests include dispersion, drift, maximum range, ballistic coefficient, and stability factor, as well as obtaining spin decay data for use in designing fuze mechanisms.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENT
Targets	Vertical, paper or other material suitable for easy marking/replacing; target size about 3 times expected extreme spread of 10-shot groups. Horizontal targets of size to observe width and length of expected group size for all ranges; water or dry sand are the preferred impact media. Grid of piling or other durable material is required for visual/photographic determination of bullet impacts.
Indoor steel rail	91 m (300 ft) long to serve as a base for yaw card mounts

*This TOP supersedes MTP 4-2-604 dated 8 February 1971.

ITEM (Cont'd)	REQUIREMENT (Cont'd)
Pigmented paint	
Mounts: tripods, bipods, bench rests, V-block or slide V-rest, etc.	
Mann barrels, rifles, machine guns, and hand guns	Conform to drawings and specifications with regard to bore dimensions and direction and rate of twist Two Mann barrels, identical except that one must have right-twist rifling and the other left-twist rifling of the same lead angle, are required for drift firings.
Tower	Overlooking grid area to house camera or observer to determine range distance of shot impact on horizontal targets.

2.2 Instrumentation.

DEVICE FOR MEASURING	PERMISSIBLE ERROR OF MEASUREMENT*
Wind velocity and direction at surface and aloft	Velocity ±1.5 knots Direction ±3°
Relative atmospheric density	±1%
Temperature	±0.3° C
Time of flight	±0.1%
To observe shot impact horizontal deviation on horizontal targets	

3. REQUIRED TEST CONDITIONS. Conduct a pre-test inspection to avoid unnecessary delays. Check ammunition, test weapons, instrumentation, supporting facilities, and special equipment for availability and proper condition.

4. TEST PROCEDURES.

4.1 Accuracy-Dispersion Tests (vertical and horizontal targets). This is a firing study designed to measure dispersion of small arms projectiles under controlled conditions against both vertical and horizontal targets at specified ranges.

*The permissible error of measurement (instrumentation) is the two-sigma value for normal distribution; thus, the stated errors should not be exceeded in more than 1 measurement of 20.

a. Test ammunition and control ammunition at specified temperature. NOTE: Most range firing tests determine weapon-ammunition performance under standard meteorological conditions. To ensure that the test ammunition is at or near standard temperature conditions, it may be necessary to use temperature-controlled ammunition storage near the test weapon. Test ammunition should be at 21° C ±6° (70° F ±10°). It should be stored near the weapon on days when the ambient temperature varies widely from 21° C to minimize temperature changes in each cartridge before firing. The time that the cartridge is in the gun chamber should also be minimized to reduce temperature changes of cartridges.

b. Maintain Mann barrels within proper wear tolerance, specified barrel rest and mounts, rifles, machineguns, hand guns within specified wear condition.

4.1.1 Firing Procedure (vertical targets).

a. Position mount (or bench rest if an expert rifleman is to shoulder-fire) at the firing position, and install the proper Mann barrel or weapon on suitable mount.

b. Position the target at the proper range, near a bombproof with means of communication to the gun position. (Target pits are preferable if available.)

c. Position an anemometer and other meteorological equipment as near to the midpoint of range as practical. Do not fire if the cross-range component of wind exceeds 16 km/hr (10 mi/hr).

d. Fire at least three shots to warm and foul the barrel and to adjust the bullet impact to the target center.

e. Fire the 10 (or other specified number) shots for each target in as rapid a sequence as practical to avoid unnecessary exposure to wind changes.

f. Change the target after each group of shots or mark each shot in each group, whichever is more economical.

g. In case of any occurrence that could cause improper bullet performance, note the event. Either mark the impact and replace the shot or re-fire the group. NOTE: Extreme care in communicating between target and gun positions is required to ensure that guns are not loaded while the target crew is exposed.

h. Record wind velocity and direction once during the firing at each target.

i. Compute atmospheric density when the test begins and at 30-minute intervals during firing.

j. Measure to the nearest 0.3 cm (0.1 in.) the cartesian coordinates of each shot. Measure the x coordinates horizontally from a vertical line through the left-most shot in the group, and measure the y coordinates vertically from a horizontal line through the lowest shot in a group. With small targets, it is most convenient to work from a paper containing the bullet prints. In any case, the target can be replotted to scale or to full size for further measuring. Further measurements and computations are as follow:

(1) **Extreme** spread (ES): the diagonal distance between two shots of greatest separation; it is measured directly.

(2) **Extreme** vertical (EV): the vertical distance between the lowest and highest shots; it is measured directly.

(3) Extreme Horizontal (EH): the horizontal distance between the extreme left shot and extreme right shot; it is measured directly.

(4) Mean Vertical (MV): the average displacement of shots above the lowest shot; it is obtained by adding the vertical displacement of each shot and dividing by the number of shots in the group.

(5) Mean Horizontal (MH): the average displacement of shots measured horizontally to the right of the left-most shot; it is obtained by adding the horizontal displacement of each shot and dividing by the number of shots in the group.

(6) Center of Impact (CI) of a shot group: the intersection of a horizontal line through the (already computed) MV (plotted on the target) and a vertical line through the (already computed) MH.

(7) Mean Radius (MR): sum of the radial distances of each shot from the CI divided by the number of shots; each impact is measured directly.

(8) Vertical Standard Deviation (VSD): the standard deviation of the distance in a vertical direction of the individual impacts from the center of impact. A denominator of one less than the number of observations (N-1) is used.

(9) Horizontal Standard Deviation (HSD): the standard deviation of the distance in a horizontal direction of the individual impacts from the center of impact. A denominator of one less than the number of of observations (N-1) is used.

k. Establish point of aim when required. The center of impact of vertical targets is routinely determined so that mean radius can be measured directly. In some cases, however, it is also necessary to find the relationship between the center of impact and the aiming point. The aiming point is established on a vertical target by using a specially designed boresight scope, or by using a muzzle crosswire and an unprimed cartridge case for alignment. Because of bullet drop and wind drift, it might be necessary to use a spotting target off the regular target and relate the position of the spotting target to the impact target.

4.1.2 Firing Procedure (horizontal targets).

a. The procedures listed in paragraph 4.1.1.a through e, g, and i are the same for horizontal target firing.

b. Additional meteorological data are required when horizontal target ranges cause the maximum projectile ordinate to exceed about 60 m (200 ft). With most small arms projectiles, this occurs at ranges beyond 2000 m, but with some low-velocity ammunition, it can occur at shorter ranges. Wind velocity, wind direction, and relative atmospheric density should be determined every half hour during firing to an altitude corresponding to the maximum ordinate of the projectiles at that range. Readings should be taken at enough intervals during ascension of the meteorological balloon to ensure a proper atmospheric information profile from ground level to the maximum ordinate.

c. In single-shot firing on horizontal targets, the range is determined by observer or camera noting bullet impact relative to a range stake in the grid impact area. Deflection is noted by an observer or camera stationed in a bullet-proof shelter directly in the line of fire up range from the impact area and facing the lateral grid stakes of the target grid. Deflection of each shot can be determined by telescopic or camera view of angular displacement on a stadia. Direct estimates of deflection (in meters) are made by associating the bullet impact with the grid stakes.

d. Targets are reconstructed by using the range and deflection data for each shot. Observations are normally estimated to the nearest 10 m (33 ft) in range and 5 m (16 ft) in deflection.

4.1.3 Burst Fire. Burst fire data on both vertical and horizontal targets are obtained in the same manner as single-shot fire. Dispersion measurement of vertical targets requires the same technique for burst fire as for single-shot fire. Data recorded for burst fire on a horizontal target consist of observing the longest and shortest shots in range and the right- and left-most shots in deflection. An estimate of center of impact and mean radius is sometimes required.

4.2 Drift Firings. This is a firing study designed to determine the deviation of spin-stabilized projectiles from the bore-axis vertical-trajectory plane due to the dynamics of projectile rotation.

Test barrels for condition of wear by firing 10 rounds of standard ammunition to obtain mean velocity. Velocity level must be within 30 m/s (100 ft/s) of the assessed velocity for that round.

4.2.1 Firing Procedure.

a. Position the rigid mount at the firing position and sight in on the vertical target (usually at 549 m and 1097 m (600 and 1200 yd)) by alternating the two barrels. Crosswind at time of firing must be less than 5 km/hr (3 mph). Place an anemometer near the midpoint of range to verify the wind velocity.

b. Station down-range observers near the target in a bullet-proof shelter positioned to observe each impact from cover. NOTE: As indicated previously, extreme care in communicating between target and gun positions is required to ensure that guns are not loaded while the target crew is exposed.

c. Using a right-twist barrel and a left-twist barrel both marked at 90° intervals and indexed to a mark on the mount, proceed as follows:

(1) Starting with the right-twist barrel, fire five rounds at zero orientation.

(2) Replace it with the left-twist barrel, firing five rounds at zero orientation. Rotate the left-twist barrel 90°, firing five rounds.

(3) Remount the right-twist barrel in the 90° orientation, firing five rounds. Rotate the right-twist barrel to 180°, firing five rounds.

(4) Continue this process until both barrels have been fired 10 rounds at each 0°, 90°, 180°, and 270° orientation.

d. For analysis, report the data in the form of cartesian coordinates, vertical and horizontal, of each impact on the target. The target pattern (Fig. 1) should show four 10-shot groups from each barrel, these groups having their respective centers of impact approximately at the corners of a square, the vertices of which are associated with the four barrel orientations in the same respective order. The length of the diagonal of each square represents twice the projected angle of deviation between the line of departure and the ceterline of the V-blocks; the line joining the centers of the squares should be essentially horizontal, and its length represents twice the magnitude of drift.

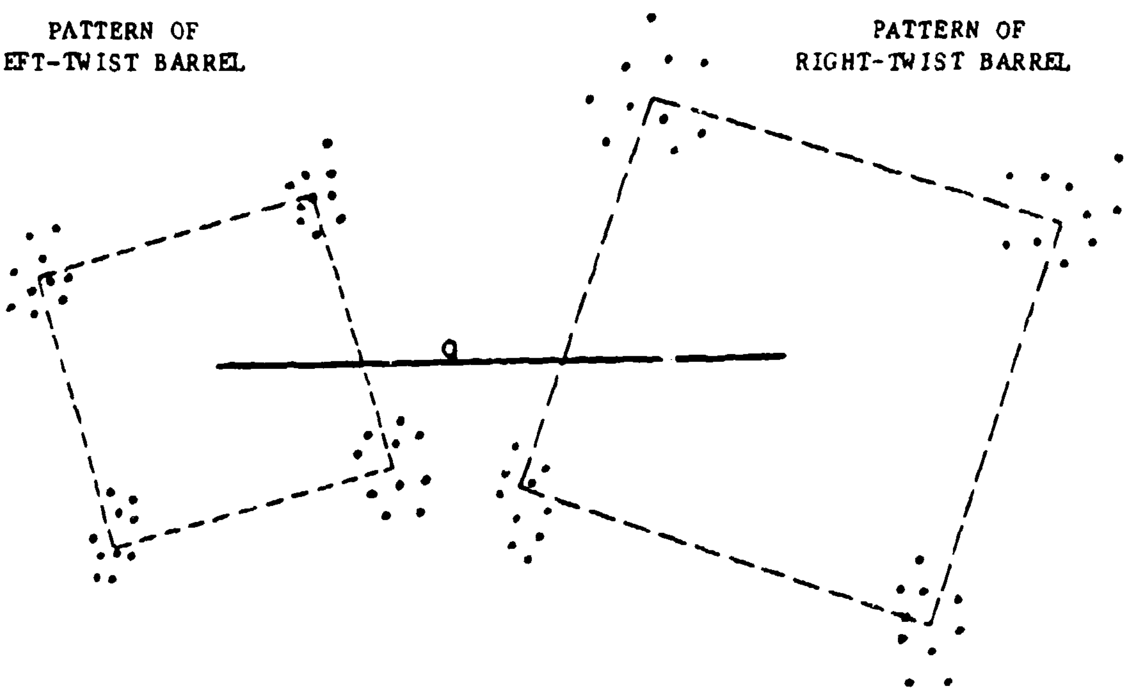


Figure 1. Impact patterns formed by drift firing of two barrels. Line a represents twice the magnitude of drift.

4.3. Maximum-Range Firings. These are to determine the maximum range of small arms ammunition.

4.3.1 Firing Procedure. Firing for determination of maximum range is usually conducted from a Mann barrel to minimize dispersion.

a. Beginning at an estimated or calculated maximum range, and a quadrant elevation of 30°, fire several rounds at a gridded water-impact area. If no impact is observed, reduce elevation in 3° increments until an impact is observed or it becomes evident that all impacts are short. Move the gun position forward or rearward, depending on results, until a location is found that permits observation of impacts when firing at a quadrant elevation of 30°. From this location, fire at elevations near 30° until an elevation is found that gives maximum range. The region investigated for a small arms maximum ranges is between about 27° and 35°. Observe and record range and elevation for each shot when possible.

b. Obtain sensing data by placing observers in or near the impact area in the same manner as that described for horizontal target dispersion tests (para 4.1.3) except that sensings for deflection are not required. Determine elevation of the bore axis by means of any suitable clinometer, usually seated on the V-block slide of the machine rest or at such other position as the construction of the weapon requires. Because range does not change rapidly as a function of elevation at points near maximum range, there may be apparent inconsistencies in the record as a result of round-to-round variations and changes in atmospheric conditions during firing. The number of rounds to be fired depends upon the consistency of results, but at least five impacts should be recorded at each elevation near that for maximum range.

c. Record wind aloft as well as surface wind, temperature, and relative atmospheric density, as described for horizontal target dispersion tests. It is necessary that very calm conditions prevail, both to obtain satisfactory data and to permit observation of impacts on the water surface. Tests can rarely be conducted when surface wind is greater than 5 km/hr (3 mph). The most satisfactory time for conducting such tests is during the summer months, immediately after dawn.

4.4 Ballistic Coefficient Firings. These tests include time-of-flight and velocimeter methods: Firings to determine ballistic coefficients and form factors of various small arms projectiles. The time-of-flight method of obtaining ballistic coefficient data is simple to use and requires little data reduction and computation. The velocimeter technique is more complex and expensive but gives more complete information about each bullet tested. The velocimeter gives a continuous time/velocity reading for each bullet from supersonic through transonic and into the subsonic range, and these data are used to compute many factors beside the ballistic coefficient. When large quantities of ballistic coefficient data are needed, such as for production lots of ammunition (to learn the effect of die wear on bullet shape deterioration and the subsequent effect of flight ballistics), the time-of-flight method is used. If range tables are required, the velocimeter method is more economical.

4.4.1 Firing Procedure (time-of-flight-test).

a. Install the Mann barrel and its mount as described under paragraph 4.1.2.

b. Position the meteorological equipment. Meteorological data required include temperature, relative density of the atmosphere, and the wind vector relative to the line of fire. Wind vectors are determined for each round (e, below). Temperatures are measured at the range site at approximately half-hour intervals. The relative atmospheric density at the range site can be determined at a meteorological station in the general vicinity of the firing station. (Difference in temperature at the two sites can be used to convert the relative atmospheric density as measured at the station to that at the range site.)

c. Place velocity initiators at 16 m (53 ft) and 31 m (103 ft) from the gun muzzle to record the instrumental velocity of the projectile. Place the time-of-flight screen at the end of the range over which the measurement is to be made. (As described in App. A, the time-of-flight screen consists of two conducting layers separated by an insulating layer. Shorting the conducting layers terminates the time-of-flight count.) NOTE: Measure all distances to an accuracy of 0.3 cm (0.01 ft) (TOP 4-2-805): muzzle to first initiator, first to second, and first to time-of-flight screen.

d. Connect the chronographs - one to record the bullet's time of passage between initiators, the other to measure the time interval of the bullet's flight between the first initiator and the time-of-flight screen.

e. To determine the range component of the wind vector, mount the sensing elements of the anemometer and the anemoscope approximately 3 m (10 ft) from the ground, near the trajectory, about 20 m from the gun, and place the recording meters of each at the firing position. The anemometer wind-speed record is in feet per second. Two scales are provided for the anemoscope record, one to read clockwise azimuth of the wind vector in degrees (least count, 5°) from the line of fire, the other to read simultaneously the value of the cosine of the wind vector to one decimal place (with appropriate sign). In practice, either the azimuth of the wind vector or the cosine is read, as required. In time-of-flight tests, the range component only is required. The wind speed and the cosine of the wind vector are recorded in adjacent columns. The product gives the range component of the wind vector in usable form without requiring conversion of units or reference to tables of trigonometric functions.

f. Station observers in a bullet-proof shelter to observe bullet impact on the time-of-flight screen. The observer must have direct communication with the firing position to get proper safety clearance when he approaches the screen to clear short circuits caused by bullets or debris from ricochets.

g. Determine weapon boresight as described under paragraph 4.1.2.

h. Determine weapon superelevation by use of a clinometer that is calibrated to the specific test barrel.

i. Disassemble five rounds and determine the average projectile weight.

j. Fire at least three shots to locate the center of the target. Velocity and time of flight should be measured on these locating shots to determine whether the chronographs, velocity initiators, and time-of-flight screen are functioning properly.

k. Fire five to 20 data rounds at each range as required in the test plan.

l. Record results of each shot on a sheet similar to the sample form, Figure 2.

BALLISTIC FIRING REPORT - Time of Flight Velocity		Date Fired:
Caliber	Gun No.	Barrel No.
Cartridge Type and Lot		
SCREEN DISTANCES:	Muzzle to First 53 Ft.	First to Second 53 Ft. First to Time-of-Flight Screen Ft.
Temperature °F	Rel. Density	Direction of Fire Toward

Time Fired	Rd. No.	Time 1st-2d Sec x 10^{-6}	Velocity 1st-2d fps		Wind Vel. fps	Cos Wind Vector	Range Comp. Wind fps	Remarks

Figure 2. Sample ballistic firing report.

m. Give firing data to ballisticians who use the information to compute the ballistic coefficient of the test projectile. Appendix B shows one accepted approach to this computation.

4.4.2 Firing Procedure (velocimeter test). NOTE: Small arms bullets with tracer or non-flat bases sometimes are difficult to track because of poor reflectivity. If only ballistic coefficient is required, it might be a better choice to use the time-of-flight method. If the ballistic coefficient of a tracer round is desired beyond tracer burnout, the velocimeter technique must be used.

a. Set up the equipment. Use a doppler velocimeter as described in MTP 4-1-005. Figure 3 shows the small-caliber Mann barrel mounted to give proper tracking near the muzzle. For larger calibers, such as cal .50 and 20-mm, the barrel must be well above the radar to avoid blast damage. In emergencies, a large forklift can be used to support the barrel and mount in proper relationship with the velocimeter during firing. If the weapon cannot be mounted near the velocimeters as show in Figure 3, the following conditions must be met:

(1) The intercept angle of the velocimeter to the line of fire should not exceed 6° for muzzle velocities to 610 m/sec (2000 ft/sec).

(2) At velocities above 610 m/sec, the intercept angle should not exceed 3°.

(3) Since elevations for small arms tests are 10° or less, the velocimeter should be positioned 30 to 46 m (100 to 150 ft) to the rear of the weapon and as close to the line of fire as the bulk, which comprises the weapon and its mount, will permit.

(4) The position of the velocimeter relative to the weapon must be surveyed accurately and recorded.

b. To avoid exposure of personnel, keep the velocimeter antennae elevated when personnel must work within 55 m (180 ft).

c. It is desirable to measure velocity with a counter chronograph at the same time velocimeter data are recorded. To do this, use narrow-beam sky screens or lumiline screens specially built to reduce radar reflectivity.

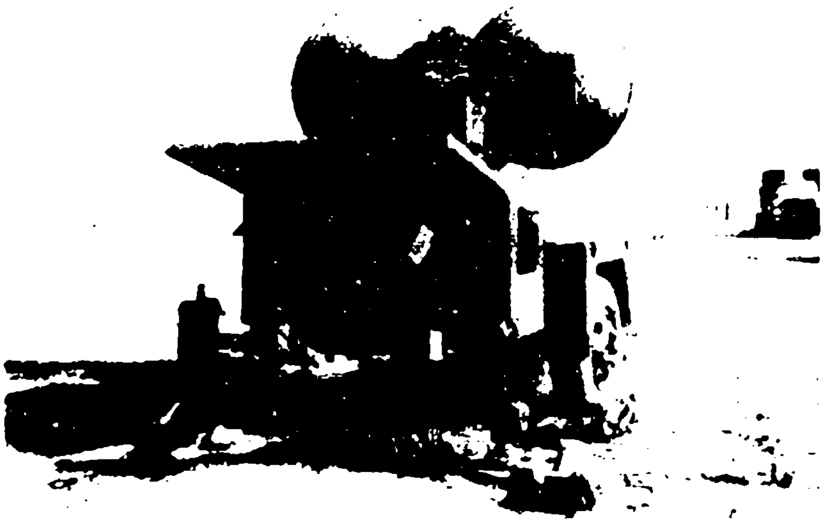
d. If simultaneous velocity readings cannot be obtained, fire 10 rounds separately with the test ammunition in the test barrel under standards conditions. The average velocity figure is needed by the ballistician to index the velocimeter data.

e. Obtain meteorological data as described under time-of-flight tests, paragraph 4.4.1.b an e.

f. Determine boresight and superelevation as described under paragraph 4.4.1.

g. Disassemble five rounds and determine the average bullet weight.

(a)



(b)

Figure 3. Gun mount (a) and velocimeter (b).

h. After the velocity initiators and the velocimeter are properly aligned to the bullet trajectory, fire as many rounds as required to ensure that all instruments are functioning properly.

i. Figure 4 shows a sample of a velocimeter data sheet which is furnished by the operator. Be sure that it agrees with each round on the test director's firing record so that wind data, atmospheric density, and bullet velocity will correspond. Figures 5 and 6 show typical data available from velocimeter testing.

VELOCIMETER DATA SHEET

Test Director:

Date of Test:

Weapon or Mann Barrel: 5.56-mm Mann barrel

Ammunition Type: 68-grain boat-tail bullet

Transmitting Frequency: to ±52

Playback Record/Tape Speed Ratio: 1:4

Time Source: Field tape

Readout Interval: 5 milliseconds

Record Length: 3000 words

Tracking Filter: Was used

Acquisition Frequency: 15000 Hz

Bandwidth: 100 Hz

Zero Time Pulse, initiated by microphone located 6 inches from muzzle.

Round Fired	Data Round	Remarks
1	-	Instrument checkout round
2	-	Instrument checkout round
3	-	Instrument checkout round
4	1	All data satisfactory
5	2	All data satisfactory
6	3	All data satisfactory
7	-	Velocimeter failed
8	4	All data satisfactory

Figure 4. Sample velocimeter data sheet.

Weapon: Cal 5.56-mm Accuracy Barrel
Cartridge: Cal 5.56-mm Ball, BT, 66 gr
Muzzle Velocity, 3013 fps

Range meters	Elevation mil	TOF sec	Max Ord ft	Term Vel fps
0	0.0	0.0	0.0	3013
50	0.3	0.06	0.0	2871
100	0.6	0.11	0.1	2733
200	1.3	0.24	0.2	2465
300	2.2	0.38	0.6	2207
400	3.2	0.54	1.2	1964
500	4.4	0.72	2.1	1737
600	5.7	0.92	3.4	1531
700	7.3	1.14	5.3	1338
800	9.2	1.39	8.0	1161
900	11.4	1.67	11.6	1059
1000	14.0	1.97	16.2	1004
1100	16.9	2.29	22.1	965
1200	20.2	2.62	29.8	927
1300	24.0	2.97	39.4	890
1400	28.3	3.35	51.0	854
1500	33.1	3.75	64.5	820

Figure 5. Typical data obtained from velocimeter testing.

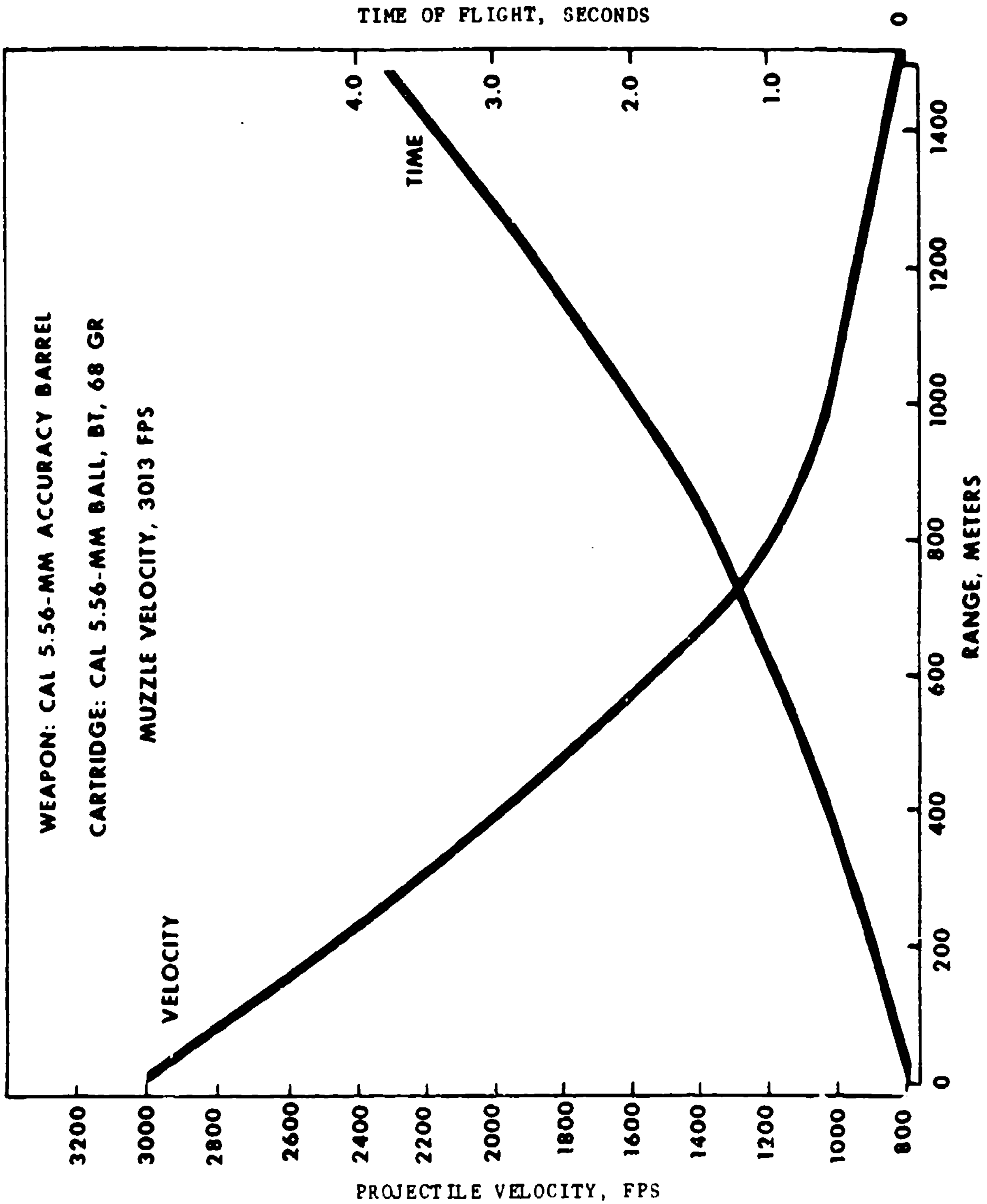


Figure 6. Plot of typical data obtained from velocimeter testing.

j. When presenting the data to the ballistician, include specific instructions about the type of information required. In some cases, only ballistic coefficient and form factor are required. In other cases, limited range tables are needed. These can be computed from velocimeter data, above, because continuous velocity/time information is available through the supersonic, transonic, and at least a part of the subsonic range on each shot. Separate drift data and maximum-range information may be needed for complete range tables.

4.5 Spin Decay Tests. These are firing tests to determine the rate of spin loss, by tests at various trajectory points.

4.5.1 Firing Procedure.

a. Immediately before firing, mark each projectile with diametrically opposite lines, extending from the nose to the cartridge-case mouth, with pigmented paint. Different colors should be used for the diametrically opposite lines.

b. Position three bullet-recording kraft paper screens near the gun, with the nearest one about 9 m (30 ft) from the muzzle to avoid screen damage from blast. Place the second screen behind the first at a distance less than one revolution of the projectiles between screens. A spacing slightly less than the lead of the barrel rifling is required. Place the third screen behind the second a distance to permit approximately five complete projectile revolutions. This can be estimated very closely by firing one painted round through the first two screens and correcting the distance for one complete revolution.

c. Similarly arrange three more kraft paper screens near the end of the range over which spin decay is to be measured. These screens must be large enough to contain a high percentage of hits. Previous ballistic coefficient data on the test projectile will permit an accurate determination of striking velocity on the fourth screen. This striking velocity is corrected from the instrumental velocity of each round, which is measured near the muzzle (see TOP 4-2-805). Final screen spacing is determined from the best estimate of remaining spin and from the calculated striking velocity on the fourth screen.

d. Once final spacing is adjusted to all six screens, fire the painted rounds as rapidly as possible to minimize meteorological variations. New screens will be erected when it becomes difficult to mark properly the shots on each screen.

4.5.2 Computation of Spin Rate.

a. The purpose of the closely spaced screens is to indicate, at each location, the rotation of the projectile with respect to distance along the trajectory with sufficient accuracy to ascertain the integral number of revolutions between the more widely spaced screens. The manner in which this measurement is then refined by measurement of the more widely spaced screen will be evident.

b. A fair determination of spin rates (with respect to time) at the beginning and end of the range can be obtained by multiplying the applicable velocity (ft/s) by the change in orientation (revolutions per foot), the product being the spin rate (rps) at each respective position. The accuracy and applicability of such a determination is limited in that it is not corrected to standard meteorological conditions and results cannot be applied to other ranges without more extensive analysis.

c. For fairly flat trajectories at low angles of elevation (wherein atmospheric density can be considered constant without serious error), a satisfactory application of these empirical data to other points on the trajectory can be made through determination of the axial couple coefficient for the projectile. This requires, in addition to the usual meteorological measurements at the time of the experiment, a knowledge of the diameter and axial moment of inertia of the projectile. (The former can easily be obtained by direct measurement, the latter by established laboratory procedure involving the use of a suitably calibrated torsion pendulum.) When these are known (ref 4 and 7), the axial couple coefficient can be determined from the expression:

$$K_A = \frac{-A}{\rho d^4 X} \ln \frac{N}{N_o}$$

in which K_A = axial couple coefficient

A = axial moment of inertia of projectile

ρ = atmospheric density (absolute, not relative)

d = diameter of projectile

ln = natural or Napierian logarithm

N = spin rate at end of range X

N_o = spin rate at beginning of range X

X = range

Consistent units must be employed. It is obvious that a suitable rearrangement of terms will yield from the expression above, the form:

$$\ln N = \ln N_o - \frac{K_A d^4 \rho X}{A}$$

so that spin rate at any range, X, can be determined when the value of K_A is known. Information about the form of the above expression can be found in references 3, 4, and 7.

4.6 <u>Stability Factor (Yaw-Card Firing)</u>. This is a firing program to obtain data for determining the stability factor of small arms projectiles a factor that indicates the relative stability (ability to maintain a fixed attitude in flight) of a projectile under given conditions.

4.6.1 Projectile Measurements. At some time before the stability computation, projectiles must be carefully pulled from their cartridge cases (to avoid physical damage to the projectiles) and the following data obtained for use in ballistic computations:

a. Dimensions (length and diameters)

b. Weight to an accuracy of 1 part in 1000

c. Distance from base to center of gravity

d. Axial moment of inertia

e. Transverse moment of inertia

4.6.2 Firing Procedure.

a. Install the notched barrel in the rigid mount with the notch in a horizontal position. The horizontal bore axis of the barrel should be about 15 cm (6 in.) above the level surface of the yaw rail to center the bullets on the yaw cards.

b. Place the card mounts along the rail in the dense distribution pattern recommended by the ballistician in charge of data reduction.

c. Level the mounts and cards, mark a horizontal line across each card, and mark a vertical line by projecting the bore axis to each card, beginning at the last card to avoid card interference. One aiming technique is to use a vertical muzzle wire across the bore center and a fired case with its primer removed in the barrel chamber.

d. Mount the lumiline velocity initiators at any convenient location, using at least 7.6 m (25 ft) between screens. The screens connected to the counter chronograph will provide instrumental velocity at screen midpoint.

e. Fire at least five record shots through dense distribution, moving all cards horizontally between shots to avoid double impacts.

f. Rearrange cards to sparse distribution, as recommended by the ballistician, and fire five record rounds.

4.6.3 Computation of Stability Factor.

a. Computation of the stability factor involves (in addition to the projectile measurements described in para 4.6.1) the pitch of the rifling, the caliber of the weapon, the length of the yaw period, the maximum and minimum yaw, and the air density. Firing through dense card distribution and then through sparse distribution permits the ballistician to extrapolate the card effect on the yaw period to the free-flight (no card) period.

b. Enough firing data must be written on each card to ensure that each shot can be identified on all cards and correlated with the firing data record of the test director.

c. Yaw data on each shot are measured by drawing a line through the longest section of the yaw print, determining orientation from the vertical line with a protractor, and finding the magnitude of yaw by equating print length to a yaw, in degrees, with a special table made from the projectile drawing profile.

d. The yaw of a spinning projectile varies in both magnitude and orientation. Because this magnitude varies periodically, it is necessary to determine the maximum and minimum values and the length of the period which is defined as the distance between two successive minima. To determine the period, the projectile is fired through a length of cards estimated to encompass several periods. Yaw can then be plotted as a function of distance.

e. Precession of the yawing projectile can be determined from the plot of successive yaw orientation. Each yaw is measured clockwise from a vertical line segment above the yaw print on the card.

f. A projectile is stable if its stability factor is greater than 1. If the factor is only slightly above 1, however, the yaw becomes quite large. The stability might be satisfactory at normal air density, but too low when air temperature drops or pressure rises to increase air density. A stability factor of about 1.7 is needed for most small arms ground weapons to ensure proper stability to -46° C (-50° F). A factor of 2, 3, or higher might be required for forward fire from high-speed aircraft. The reason for this is that the overturning moment of the projectile is aggravated by the added air speed imposed on the projectile without any stabilizing influence of added spin velocity which would occur if its velocity in the barrel were increased to match the above stated air speed.

g. Information on data reduction is in reference 8.

h. A more sophisticated technique for determining stability factor is the two-plane, spark-photography method. This is used by Ballistic Research Laboratories (BRL) personnel when the cost of test projectiles (fewer are required) is enough to offset the savings of the yaw-card method.

5. DATA REQUIRED. Data to be recorded are described in 4.1 through 4.6.

6. DATA PRESENTATION. The test report should include appropriate data reduction, data consolidation, sketches, tables, and graphs in accordance with guidance contained in the paragraphs above.

Recommended changes of this publication should be forwarded to Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-TC-M, Aberdeen Proving Ground, MD 21005-5055. Technical information can be obtained from the preparing activity: Commander, U.S. Army Combat Systems Test Activity ATTN: STECS-AD, Aberdeen Proving Ground, MD 21005-5059. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22304-6145. This document is identified by the accession number (AD No.) printed on the first page.

APPENDIX A

TIME-OF-FLIGHT SCREEN

The time-of-flight screen consists of two conducting layers separated by an insulating layer. Shorting of the conducting layers by the projectile terminates the time-of-flight count. It is not economical to provide and all-purpose time-of-flight screen. A larger screen, used on a longer range, requires more rugged construction. It may be desirable on an extensive test that a screen as large as 6 by 9 m (20 by 30 ft) be constructed to remain erect and withstand strong wind gusts in periods of nonuse. Often, a 1.2- by 1.9-m (4- by 5-ft) screen is large enough. Generally, a frame of suitable size and mechanical strength is constructed of two-by-four lumber, covered on one side with 1/4- or 3/8-in. plywood. This is covered by strips of aluminum foil, 0.007 cm (0.003 in.) thick, stretched tightly and attached by stapling at the strip edges and by strips of adhesive tape around the target edges. This is next covered with corrugated cardboard and another layer of aluminum foil stretched tightly and attached in the same manner as the first layer. To provide for stapling so that the two conducting layers are not shorted, small patches about 1 inch square must be cut out of the first layer, baring the plywood at the points of attachment. The screen should be stored inside overnight. If the screen sags after repeated use so that the conducting layers are too far apart to be shorted by the bullet, it may be restored to service by drilling 1/4-in. holes and "sewing" the three layers, where necessary, close to plywood with waxed cord. For a high-velocity bullet smaller than caliber .30, screen wire is sewed on the front and back of chipboard and mounted on a suitable frame.

APPENDIX B

COMPUTATION OF BALLISTIC COEFFICIENTS

The following are symbols used in the discussion that follows. Different symbols are used in some of the references cited, but their correspondence with the symbols below will be obvious upon comparison.

S = Primary Siacci functions, space

V = Velocity of bullet relative to gun at muzzle (or some instrumental point near muzzle)

X = Horizontal range from gun (or from instrumental point)

u = Velocity of bullet relative to gun at horizontal range

C = Ballistic coefficient

ρ = Relative atmospheric density

$1/a$ = Ratio of velocity of sound under standard atmospheric conditions to velocity of sound under ambient conditions at time of firing

W_x = Range component of wind vector (range wind)

t = Time of flight to horizontal range X

Messrs. Hitchcock and Kent have shown (ref. 9) that the solution for the primary Siacci space function

$$S = \int_V^u \frac{du}{G} \text{ is } X = \frac{C}{\rho}\left(S_u - S_V\right)$$

They also derived the effect of wind on range (op. cit., pp. 9, 10), and Bliss (ref. 10) has described the manner in which the velocity of sound enters into determination of the drag function, G(u). No attempt will be made here to derive by rigorous methods an expression combining these effects in a restatement of the solution of the Siacci space function given above, but a qualitative explanation follows of a form convenient for use with Siacci space function tables using bullet velocity in feet per second as the argument.

It is apparent that, for the condition of zero range wind, the horizontal range traversed by the bullet relative to the gun and that relative to the air are identical. For a range wind of velocity W_x, however, the displacement of the air relative to the gun during the time of flight is $W_x t$, while the displacement of the bullet relative to the gun during the time of flight is X by definition. The displacement of the bullet relative to the air is therefore the vector difference between these two displacements, or $X - W_x t$.

Similarly, of the bullet velocities at two points are v and u, respectively, relative to the gun, and the velocity of the air relative to the gun is W_x, then the velocities of the bullet relative to the air at these two points are the vector differences $v - W_x$ and $u - W_x$, respectively. Since, upon launching, the bullet evidently becomes "unaware" of the further motion of the gun that launched it and is "aware" only of its motion relative to the medium through which it moves, it seems most reasonable that the equation

$$X = \frac{C}{\rho}\left(S_u - S_v\right) \quad \text{becomes}$$

$$X - W_x t = \frac{C}{\rho}\left[S_{(u-Wx)} - S_{(v-Wx)}\right]$$

As Bliss notes (op. cit., p. 19), the retardation of the bullet (at supersonic velocities) is largely due to energy lost in generation of shock waves, the formation of which is influenced by the ratio of bullet velocity to the velocity of sound. It is "natural" therefore that drag at a given bullet velocity should vary with the velocity of sound. The nature of the function is, as Bliss further notes, "justified by experience." Including this, the complete restatement of the solution for use with space function tables constructed for standard atmospheric conditions is

$$X - W_x t = \frac{C}{\rho}\left(\frac{S_u - W_x}{a} - \frac{S_v - W_x}{a}\right)$$

Of this equation, all quantities are measurable except C. The equation is used in the following form for computation of ballistic coefficients.

$$C = \frac{\rho(X - W_x t)}{\left(\frac{S_u - W_x}{a} - \frac{S_v - W_x}{a}\right)}$$

APPENDIX C

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