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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-103

*Test Operations Procedure 4-2-805

AD No. A119554

21 September 1982

PROJECTILE VELOCITY MEASUREMENTS

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1. SCOPE. This TOP describes the techniques and equipment employed to measure instrumental velocity of projectiles and to translate it into muzzle or striking velocity. This is limited to projectile velocity measurements associated with muzzle and striking velocities. The assumption is made that drag coefficients, form factors, and ballistic coefficients have already been determined. When velocity measurements along the trajectory and at the target are required for time of flight and ballistic coefficient determinations, the instrumentation of this TOP is used in conjunction with the procedures of TOP/MTP 4-2-827.^{1**}

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

<u>ITEM</u>	<u>REQUIREMENT</u>
Test site	An area for firing that provides adequate safety shelters for test personnel and instrumentation and range and emplacement space appropriate for the weapon system involved

*This TOP supersedes TOP 4-2-805 dated 23 April 1979.

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**Footnote numbers correspond to reference numbers in Appendix G.

<u>ITEM (cont'd)</u>	<u>REQUIREMENT (cont'd)</u>
Magnetizing device	As needed to magnetize projectiles when the coil technique is used
Pulse simulator	A device for inducing polarized pulses to the velocity coils to check system response
Doppler velocity simulator	To check muzzle velocity radar operation

2.2 Instrumentation.

<u>ITEM</u>	<u>MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT*</u>
Doppler velocimeters:	
Modified HAWK CW illuminator	60 to 3000 m/s $\pm 0.15\%$
Muzzle velocity radar	150 to 1200 m/s $\pm 0.25\%$ or 0.5 m/s, whichever is greater
Velocity coils with shaping adapter and chronographs	
Sky screens and chronographs	velocity to 3000 m/s $\pm 0.1\%$
Lumiline screens and chronographs	
Make or break screens and chronographs	
Photographic equipment	see TOP/MTP 4-2-816 ²
Flash radiography	velocity to 6000 m/s $\pm 0.3\%$
Calibrated steel measuring tape or	distance to within ± 3 mm (0.01 ft)
Electronic distance-measuring devices	
Meteorological equipment:	
Thermograph	temperature -35° to $+50^{\circ}$ C $\pm 0.2^{\circ}$
Hygrothermograph	relative humidity 5% to 100% $\pm 1\%$
Barograph	pressure 965 to 1050 mbar ± 0.3
Anemograph	wind speed 0 to 9 m/s ± 0.8
Vane	wind direction (360°) $\pm 3^{\circ}$

3. REQUIRED TEST CONDITIONS.

3.1 Planning. Select the technique to be used for velocity measurement from the table below, unless there is a specific customer or test requirement. Consider and use muzzle velocity radar (MVR) before other techniques whenever its known limitations permit; then use velocity coils, sky screens, etc., as listed in descending order of preference. Weigh the advantages and limitations of each technique given in Appendix B to decide which technique will yield the required data accurately, economically, and with the most reliability. Consider using the MVR as a backup system when another measurement technique is selected.

*Values may be assumed to represent ± 2 standard deviations; thus, the stated tolerances should not be exceeded in more than 1 measurement of 20.

TABLE 1
RECOMMENDED TECHNIQUES FOR VELOCITY MEASUREMENT

Measurement Technique	Projectiles above 40 mm		Projectiles 40 mm and below	Fragments
	Direct Fire	Indirect Fire		
muzzle velocity radar	X	X	X	X ^a
velocity coils	X	X	-	-
sky screens	X	X	-	-
Hawk CW illuminator	X	X	X	X ^a
lumiline screens	-	-	X	X
make or break screens	X	-	X	X
smear cameras	X	-	-	-
high-speed cameras	X	-	-	X
flash radiography	X	-	-	X

^apotential application

3.2 Test Item.

a. Record projectile model number.

b. If the velocity coil technique is to be used, magnetize the projectile. To preclude possible damage, do not assemble electrically actuated fuzes to the projectile until after magnetization. For projectiles made of nonmagnetic material, consider mounting a small permanent magnet in the round on the longitudinal axis. Make sure that the magnet is securely mounted and that it does not disturb projectile balance (TOP 4-2-801³). Verify that the magnet is of the correct polarity and of sufficient magnetic strength to deflect a compass 45° from the earth's field when held at a distance of about 9 centimeters (4 inches) from the nose of the projectile (see Figure 1). This step is important since the lack of proper magnetization will result in loss of the records.

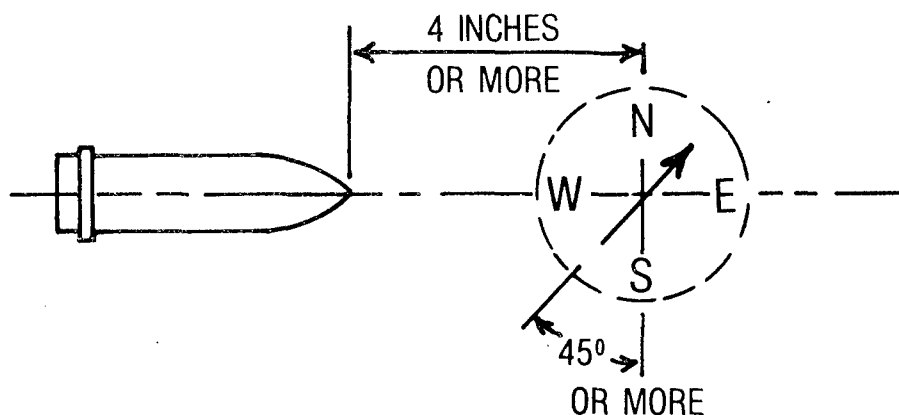


Figure 1. A correctly magnetized projectile.

3.3 Instrumentation.

3.3.1 Muzzle Velocity Radar.

a. The use of two independent MVRs is preferred if mutual interference can be eliminated through the use of different RF frequencies. Mount a radar

microwave head(s) near the trunnion of the weapon (either on the weapon or on a nearby tripod) with the head(s) oriented to optimize the microwave beam for the particular trajectory at which firing occurs. Mounting on the weapon will ensure measurements of medium- to high-angle firings, whereas mounting on the tripod can result in a poor position for the radar(s) and will require resighting of the radar(s) for elevation changes.

b. Prepare a sketch or describe the test setup showing the location of the radar relative to the weapon.

c. Verify that the system is operational, using a Doppler velocity simulator. This is a solid-state battery-operated hand-held device that modulates and reflects a portion of the MVR output to simulate the signal produced by a moving object. This check ensures that the MVR is radiating and that the processor is functioning.

3.3.2 Solenoid or Velocity Coils.

a. Support the coils by standards or, for high elevation firings, a tower and cage, in the line of fire at the distances recommended in Appendix C for muzzle to first sensor and between-sensor spacing.

b. Connect the coils to pulse shaper and time interval measuring equipment.

c. Verify that the coils are properly polarized to obtain pulses for starting and stopping the time interval measuring equipment. A simulator is commonly used for this purpose. This is a solid-state battery-operated hand-held device that magnetically induces polarized pulses to the coils when placed inside the coils. By using an oscilloscope for pulse display, the entire system installation is checked, including transmission lines and polarity of coil connections.

3.3.3 Sky Screens.

a. Position three (five when possible) sky screens on the ground projection of the trajectory at the distances recommended in Appendix C for muzzle to first sensor and between-sensor spacing. Level and orient the sky screens so that their optical axes intersect the trajectory at right angles as shown in Figure B-6 of Appendix B. Variations between individual sensor response at high angles of elevation can be reduced by mounting the sky screens in a plane parallel to the line of fire so that the distance from each sky screen to the line of fire (sensing area) is the same. One method is to mount the sky screens a fixed distance apart on a missile launcher rail for elevation in the line of fire.

b. Connect the sky screens to appropriate time interval measuring equipment (see Appendix D).

3.3.4 Hawk CW Illuminator. Position the velocimeter for measurements following the guidance of TOP/MTP 4-1-005.⁴

3.3.5 Lumiline Screens.

a. Position two lumiline screens in the line of fire at the distances recommended in Appendix C for muzzle to first sensor and between-sensor spacing.

- b. Connect the screens to appropriate time interval measuring equipment.

3.3.6 Make or Break Screens.

a. Support two screens by standards in the line of fire at the distances recommended in Appendix C for muzzle-to-first-sensor and between-sensor spacing.

- b. Connect the screens to appropriate time-interval-measuring equipment.

3.3.7 Cameras. Set up cameras for measurements following the guidance of TOP/MTP 4-2-816.

3.3.8 Flash Radiography. Set up flash radiography equipment in accordance with TOP 4-2-825.

3.3.9 Test Controls.

- a. Observe all safety SOP's throughout testing.
- b. Remeasure distances each day that testing continues and whenever sensors are disturbed for any reason.
- c. Record meteorological data for all periods of test firing.
- d. Make sure the instrumentation used is calibrated in accordance with AR 750-25.⁶
- e. When possible, use two instruments for measurement (e.g., two velocimeters MVR of different RF frequency, a velocimeter (MVR) with velocity coils as a backup, velocity coils with sky screens as backup, two chronographs, etc.). When inconsistencies exceed acceptable precision tolerances for the instrumentation system, determine the source of error before making additional measurements.

4. MEASUREMENTS.

4.1 Method.

- a. Fire two conditioning rounds, and verify that the velocity-measuring instrumentation produces the nominal velocity for the round.
- b. Fire the weapon as prescribed by the particular firing program, and obtain projectile velocities as required.

4.2 Data Required. Record the following data, using data-collection sheets as applicable (see Appendix A):

- a. Weapon caliber and model number
- b. Projectile model number and free flight weight
- c. Round number
- d. Time of day
- e. Firing elevation
- f. Air density (computed by meteorological station)
- g. Distance (specify horizontal or slant): from muzzle to first sensor; between sensors; and from last sensor to target, when appropriate
- h. Time required for the projectile to travel between sensors
- i. Doppler velocimeter (MVR) readings and delay settings

5. DATA REQUIRED AND PRESENTATION.

a. Compute the instrumental velocity ($V = d/t$) of the projectile from recorded time and distance measurements.

b. Convert MVR velocimeter readings, if required, to instrumental velocity in accordance with the velocimeter operating manual. When the MVR velocimeter is located to the side of the weapon tube and its measurement is the radial component of velocity, apply a geometric correction to the measurement in accordance with Appendix E.

c. Translate instrumental velocity to muzzle or striking velocity as described in Appendix F. For MVR velocimeters with the capability of obtaining multiple velocity measurements of the same in-flight projectile, muzzle velocity is determined by the best straight-line fit through the measured velocities, using the method of least squares.

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APPENDIX B

MEASUREMENT TECHNIQUES AND INSTRUMENTATION

The various techniques and instrumentation used to measure projectile velocity and the advantages/disadvantages of each are described herein.

1. Doppler Radar Velocimeters. In the Doppler radar technique, a continuous radio frequency wave is transmitted through space, reflected from the moving projectile, and received by the receiver of the velocimeter. If the range of the projectile is changing with respect to the receiving unit, the transmitted and reflected frequencies will not be equal. The difference in these two frequencies is known as the "Doppler shift" and is directly proportional to the range rate or radial velocity of the projectile with respect to the receiving unit.

Two different types of Doppler velocimeters are used to measure projectile velocity: small muzzle velocity radars such as General Electric MV203, the Nera-Bergen NM87 (Norwegian), and the Lear Siegler DR-810 used with the terminal 700 (see Figure B-1), which measure velocity at one or more fixed points near the muzzle; and the modified Hawk CW illuminator (see Figure B-2) which has the capability of continuously measuring the velocity of the projectile versus time nearly all the way from the weapon to the impact points. Velocimeters and their advantages/disadvantages are described in TOP/MTP 4-1-005.

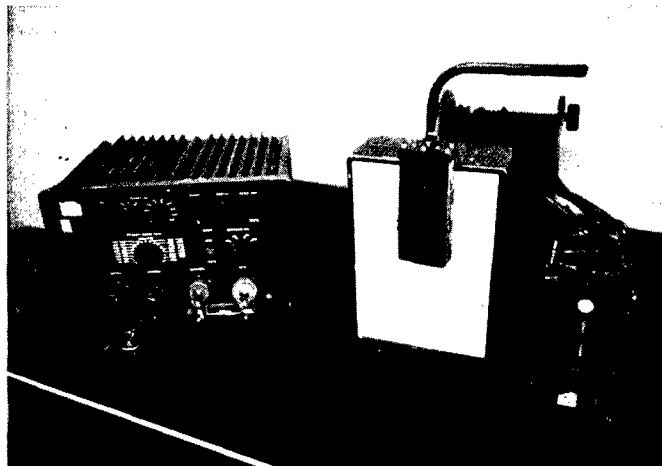


Figure B-1. Lear Siegler DR-810 radar.

2. Paired Sensing Devices. These sense the projectile passage, establish the measurement reference planes, and control the starting and stopping of the chronographs. Many types of sensors exist, each designed for specific applications or a particular operational mode. Several of the more conventional devices are described below.

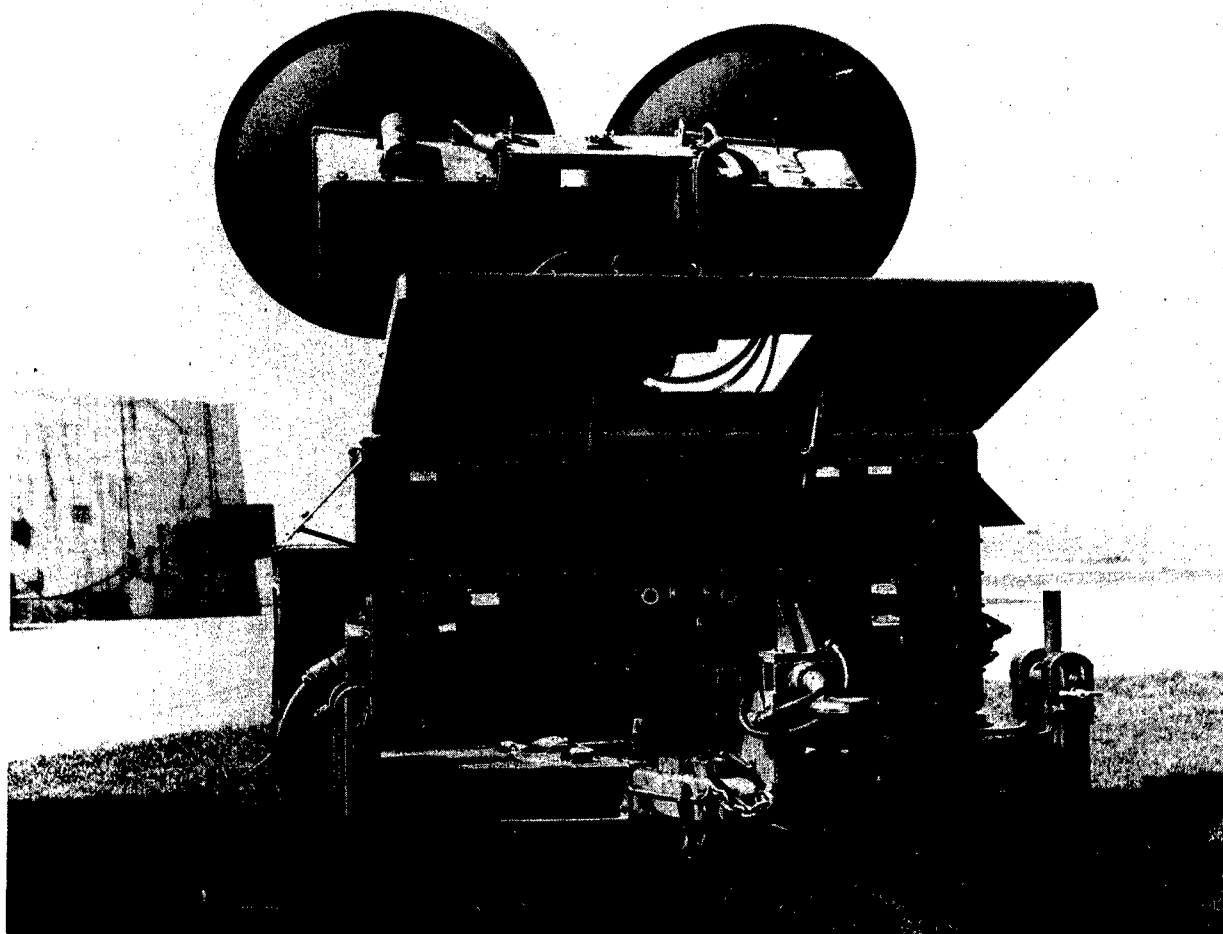


Figure B-2. Doppler radar velocimeter (modified Hawk CW illuminator).

2.1 Solenoid or Velocity Coils. The coil technique measures projectile velocity by sensing the electromotive force induced in a coil of wire by the passage of a magnetized projectile. The coil consists of an octagonal wooden frame (Figure B-3) with 60-110 turns of wire wound around the periphery. An inside coil diameter of 51 cm (20 in) is recommended for projectile calibers of 37 to 57 mm; 76 cm (30 in) for 75 to 155 mm; and 1 meter (40 in) for 175 to 280 mm. For velocity determination, the time of flight of the projectile is measured between a minimum of two coils separated by a fixed base length (Figure B-4). The electromotive force induced in the first coil is transmitted to a shaping adaptor that amplifies and shapes the signal to a precise start pulse for a counter chronograph. The shaping adaptor also contains coils for purposes of setting gain and observing polarity. The signal from the second coil is processed in the same manner and is used to stop the counter. Two counters are usually paralleled to provide a consistency check for the counting interval.

The coil technique should not be used near large masses of iron or steel since such masses distort the magnetic field of the projectile and cause errors in

timing. For other test situations, the coil technique is simple, reliable, and not restricted by weather or day/night conditions. Large support structures are required for the coils, however, when used for indirect firing at large angles of elevation. Structures of the proper size usually are not readily available, and a compromise of the muzzle-to-first-coil distance is made. In these instances, damage from muzzle blast can occur.

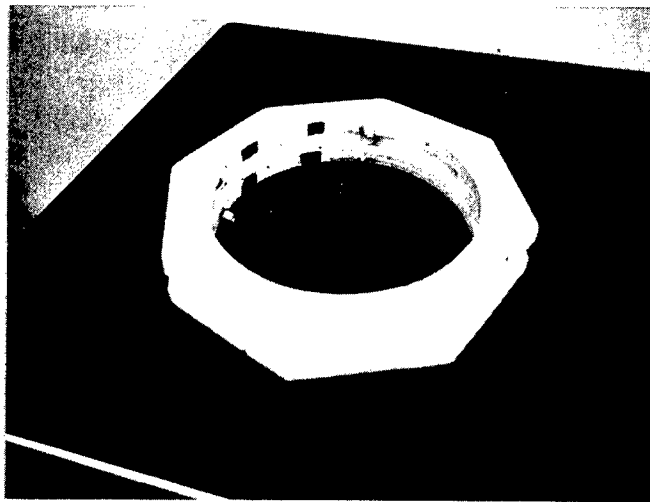


Figure B-3. Solenoid coil frame.

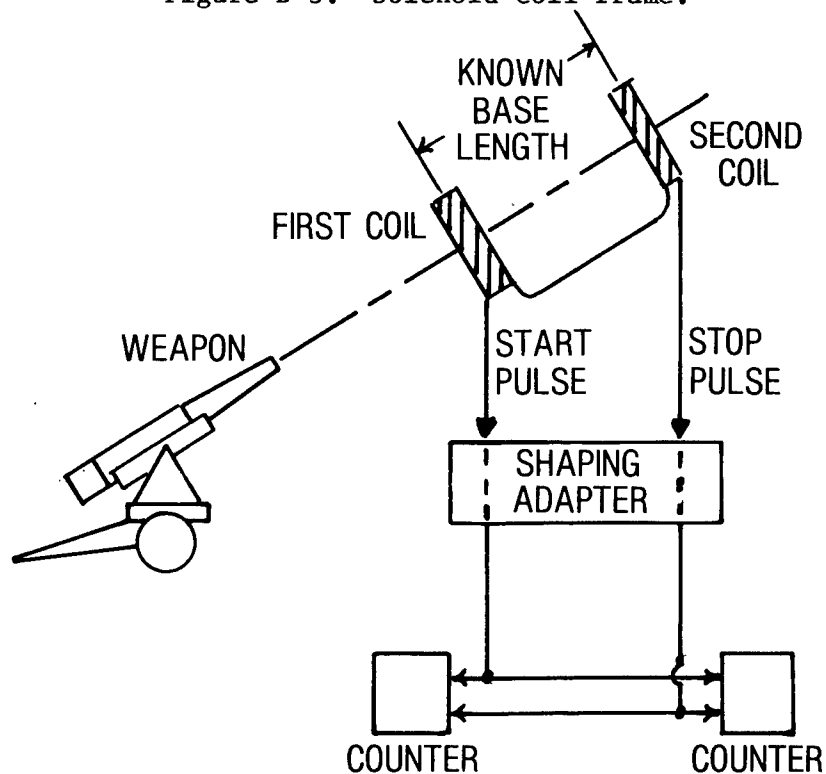


Figure B-4. Measurement of projectile velocity, using coils.

2.2 Break Screens. A break screen consists of conductive paint deposited on paper to form a conducting grid. The paint is applied as a continuous line running back and forth across the paper with each end of the line connected to a timing circuit. When the grid is penetrated, the circuit is broken and the timing instruments start or stop. This screen is used mainly in connection with tests of small arms and fragment simulators. The principal disadvantage of the break screen is that it must be replaced after each round, thus limiting the productivity of the particular firing range.

2.3 Make Screens or Panels. A "make" screen or panel generally consists of two sheets of a thin conductive material separated by a thin sheet of dielectric material. One type is made of two sheets of aluminum foil separated by styrofoam; another type consists of a thin sheet of dielectric material (usually Mylar) coated on both sides with 0.05-mil layers of aluminum. Still another type consists of two wire mesh screens separated by a thin layer of paper or some other dielectric material. Regardless of the type of construction, the conductive material is connected to a timing circuit. When the screen or panel is penetrated by a projectile, the circuit is temporarily completed through the projectile and the timing cycle is started or stopped.

The main advantage of the make screen over the break screen is that rounds can be fired through it repeatedly as long as the panel does not become short-circuited. Panels constructed of aluminum-coated Mylar are preferable to those constructed of aluminum foil because they are more dependable and less susceptible to short-circuiting. They are available in widths up to 1.4 meters (54 in). The wire mesh screen construction is most often used in time-of-flight measurements when a large panel area is required.

2.4 Lumiline Screens. This screen (see Figure B-5) measures velocity by sensing the change in intensity of a light beam. A sensitive area, roughly triangular in shape, is formed by a beam of artificial light that focuses on a phototube in the screen. As a projectile passes through the sensitive area, the amount of light falling on the phototube is reduced. This reduction in light causes a signal to be produced that starts or stops a chronograph. When used outdoors, a means of preventing too much natural light from falling on the photosensitive element must be provided. For lumiline screens, the error caused by lack of spatial repeatability is estimated at 9 mm (0.03 ft). This can result in a random error of 0.3 to 0.6 meter per second (1-2 fps) at velocity levels of 762 m/s (2,500 fps).

2.5 Sky Screens. Like the lumiline screen, the sky screen (see Figure B-6) measures velocity by sensing the change in intensity of a light beam. This screen, however, uses an optical system and natural light. Because of a slotted diaphragm in the optical system lens barrel, the light falling on the phototube can come only from a restricted area of space. The passage of a projectile through this restricted area reduces the light falling on the phototube. This reduction in light causes a signal to be produced which starts or stops a chronograph. Usually, three sky screens are oriented on the ground projection of the trajectory so that their optical axes intersect the trajectory at right angles as in Figure B-7. The passage of a projectile through these optical planes produces three electrical pulses that are used to start and stop counters 1, 2, and 3. Three velocities can be measured in this manner: the velocity between screens 1 and 2, 1 and 3, and 2 and 3. Also, as a timing check, the times

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between detectors 1 and 2 and between 2 and 3 totaled should equal the time between 1 and 3.

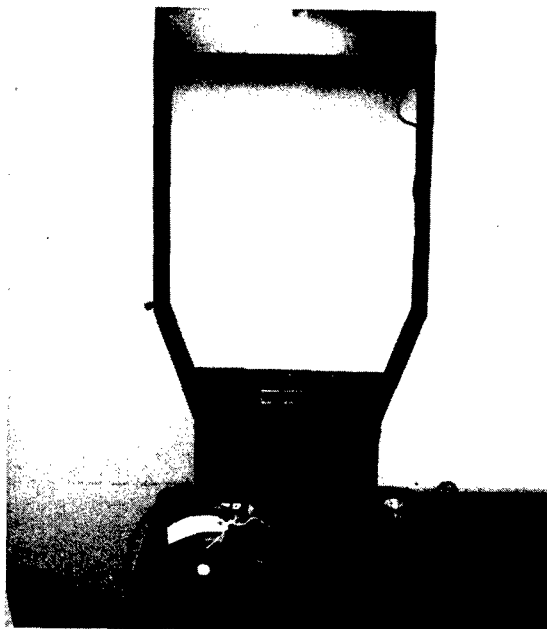


Figure B-5. Lumiline screen.

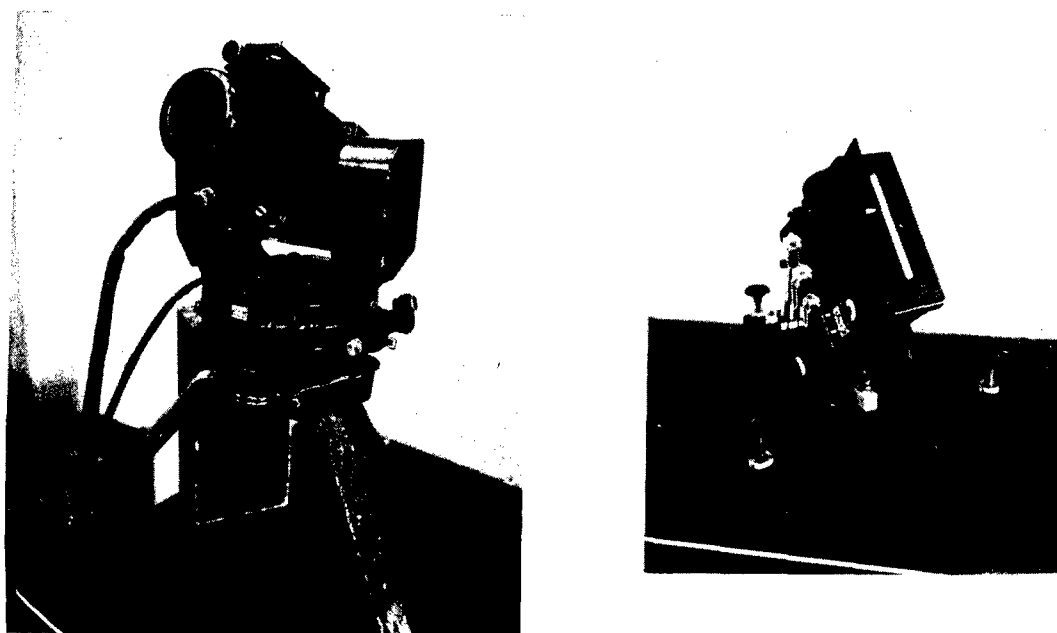


Figure B-6. Sky screens.

Sky screens are useful for firings conducted at high elevation angles since they eliminate the need for complicated structures to support the sensing devices. Their use is somewhat restricted, however, by their general lack of spatial repeatability. Systematic errors of 1.8 to 2.4 m/s (6-8 fps) and random errors of 0.9 to 1.2 m/s (3-4 fps) can be expected at velocity levels of 762 m/s. The sky screen is not generally used for night firings, during rain or snow, or when the line of sight of the screen falls on or near the sun. When the sky screen elevation is low, however, these sensors can be used in rain or snow with special covers built for this purpose. They have also been used for tracer type rounds at night firings, but their accuracy is not consistent under these conditions.

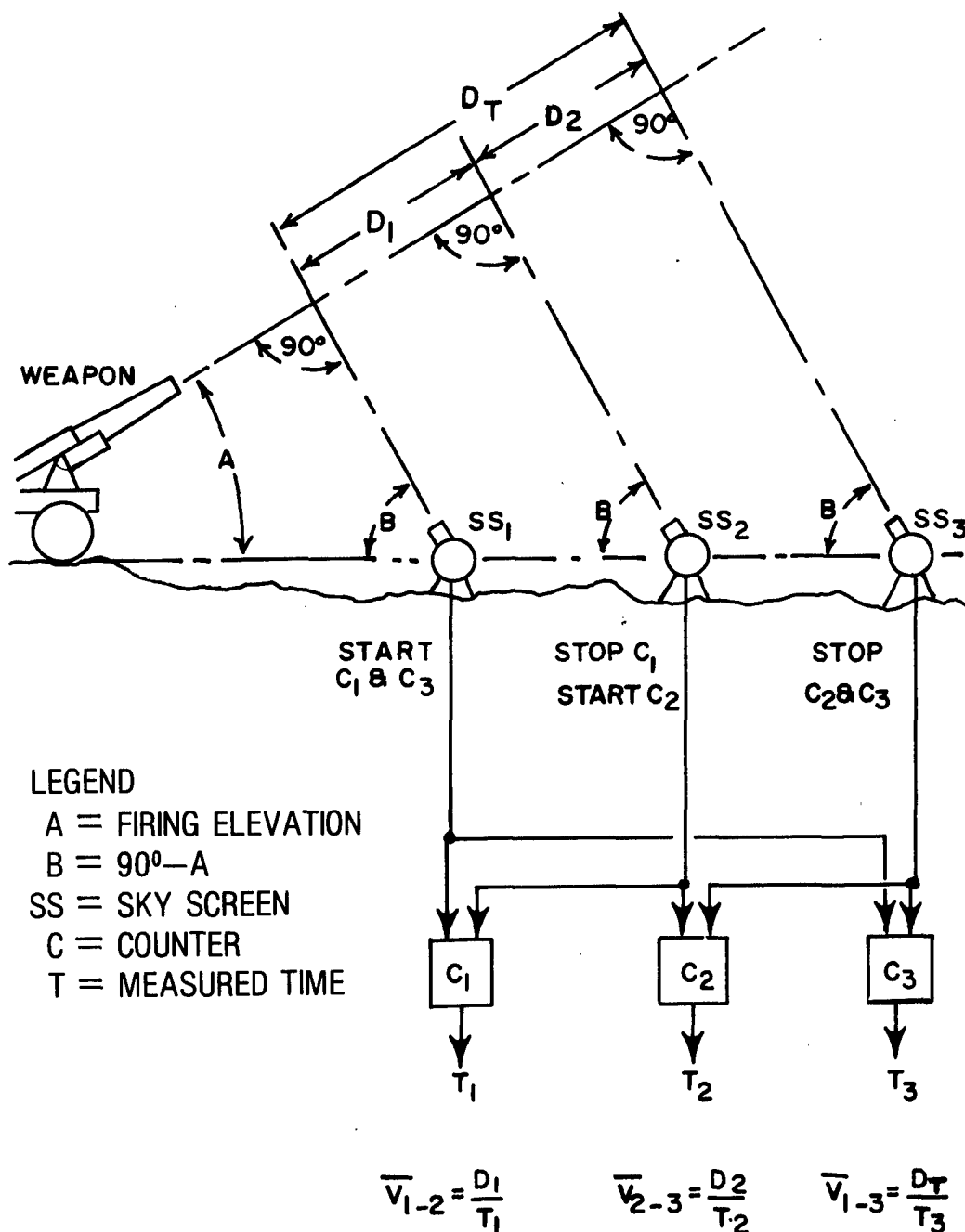


Figure B-7. Measurement of projectile velocity, using sky screens.

3. Smear Camera. This is a modified high-speed camera (see Figure B-8) with no shutter or prism, therefore, no blind time. A continuous film transport moves the film past a narrow slit aperture that limits the space to be photographed. As the projectile passes through this area, its image is recorded on the film, along with timing marks from a timing system. The instrumental velocity of the projectile is the length of the projectile expressed in meters divided by the length of the projectile image measured in seconds on the film. A disadvantage of this technique, as with all photographic techniques, is that the velocity measurement is not immediately available in the field because of the time required to process the film. Additional information pertaining to the use of this technique is contained in TOP/MTP 4-2-816.

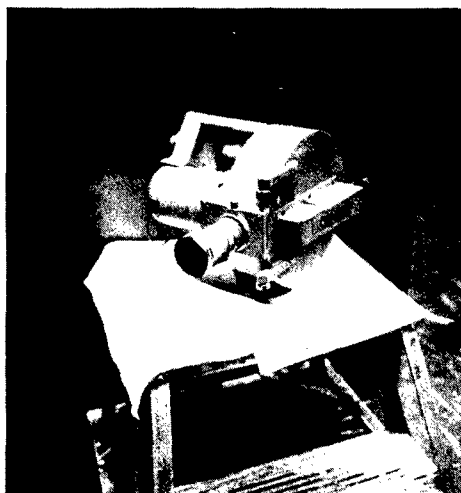


Figure B-8. Smear camera.

4. Ultra High-Speed Cameras. These cameras have framing rates of thousands of frames per second. The two main ones are the Fastax camera, normally 8-mm with rates up to 8,000 frames per second (but up to 14,000 with stepped up voltage) as described in TOP/MTP 4-2-816, and the High-Cam camera which uses 16-mm film at rates up to 32,000 frames per second. Although it is possible to use ultra high speed cameras for measuring projectile velocity, the smear camera is preferable because of its greater accuracy. The Fastax camera does play an important role, however, in connection with measuring fragment velocities from exploding shells as described in TOP 4-2-813.⁷

5. Flash Radiography. Flash radiography equipment, using two X-ray tubes or orthogonal pairs of X-ray tubes a known distance apart with a known interval between flashes, can be used for measuring the velocity of projectiles, fragments, etc. Because of cost and complexity, however, flash radiography is used for this purpose only under circumstances in which other methods cannot be used; e.g., when excessive obscuration is expected from flash and a large number of flying

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objects are expected. Such is the case when behind-the-plate fragments are to be observed for velocity and direction. Application of this technique in testing body armor can be obtained from TOP 10-2-506.⁸ An explanation of flash radiography techniques is given in TOP 4-2-825.

APPENDIX C

DISTANCE MEASUREMENTS

Distances must be measured accurately and precisely since errors in distance measuring result in inaccurate velocity figures even if the time interval is measured accurately. This appendix covers distance measurements including the placement of sensing devices and the accuracies of measurement that are generally required for coil and screen sensors.

1. Muzzle to Sensor Distance. The spacing from the weapon muzzle to the first sensor should be sufficient to prevent damage from muzzle blast and obscuration from smoke in the case of optical devices. The minimum permissible distances are shown below. These should be exceeded when possible; otherwise, rugged supports must be employed for the sensors. When possible, use the recommended spacing as listed below.

Caliber	Minimum Distances		Recommended		Maximum	
	Meters	Feet	Meters	Feet	Meters	Feet
Under 20 mm	2.7	9	3.1	10	3.1	10
20- to 40-mm guns	7.0	23	7.6	25	7.6	25
75-mm howitzer						
75- to 90-mm guns	13.7	45	15.2	50	15.2	50
105-mm howitzer						
105-mm gun	45.7	150	67.1	220	67.1	220
155-mm howitzer	21.3	70	22.9	75	22.9	75
120- to 280-mm guns	32.0	105	38.1	125	38.1	125
8-inch howitzer	29.0	95	30.5	100	30.5	100
Over 280-mm guns	44.2	145	45.7	150	45.7	150

If the sensors are supported by standards at a considerable distance above ground, it is inconvenient to measure the distance directly by use of measuring tapes. In such cases, the horizontal projection is measured by dropping the points to a plane by means of two or three transits. In reporting sensor distances, careful distinction should be made between the true (inclined) distance and the horizontal projected distance (see Figure C-1). Knowing the angles of elevation and the horizontal projected distances, the true (inclined) distance can be calculated.

When the program calls for firing through a velocity cage at different elevations on the same day, much time can be saved by first measuring the projected distance from the trunnion center of the weapon to the midpoint of the cage when the cage is still close to the ground. Since velocity cages move up and down along a vertical line, the inclined distance (muzzle to first coil) for any elevation can be determined by dividing the projected value just obtained by the cosine of the elevation angle, then subtracting the distance from the trunnion center to the muzzle and one-half the coil separation in the cage. Obtaining this projected distance eliminates dropping the point from the first coil every time the weapon elevation is changed. The measurement of the selected distance should be made with an accuracy to the nearest 3 mm (0.01 ft).

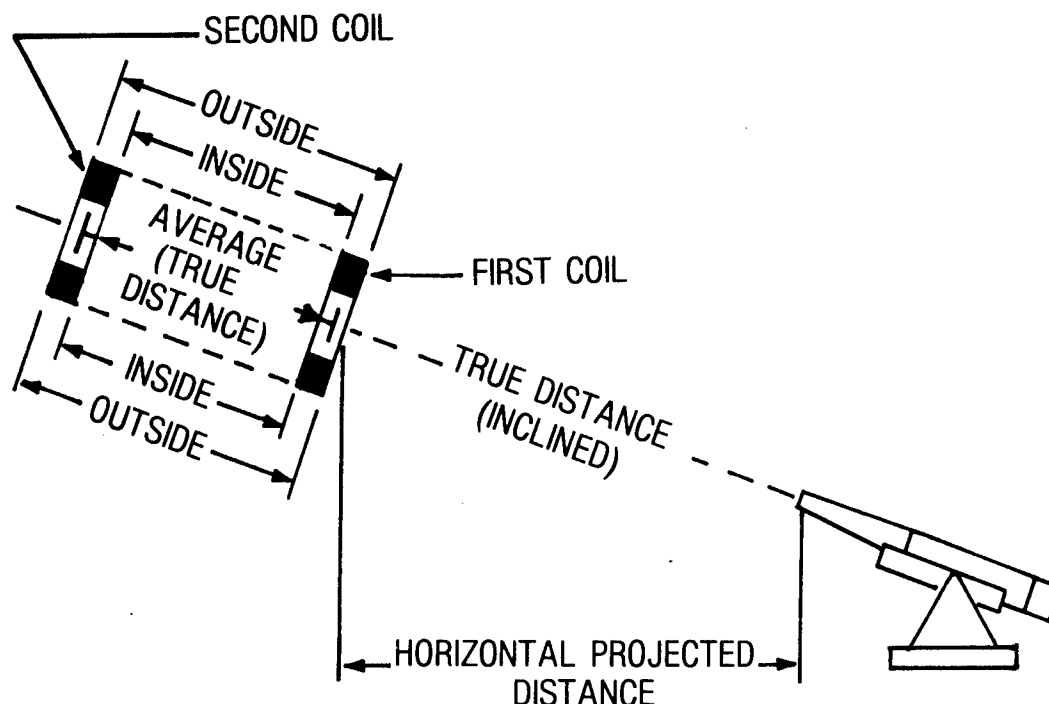


Figure C-1. Method for measuring distance between weapon and first coil and between coils.

2. Distance Between Sensors. Spacing between sensors is a function of the expected velocity of the projectiles being fired. The spacing guideline for maintaining chronograph system accuracy and reducing the physical error in distance measurement is one-sixtieth of the expected velocity for all calibers of ammunition for velocities from 180 m/s (600 fps) to 1830 m/s (6,000 fps). The minimum spacing for velocities below 180 m/s is 3 m (10 ft). For separate-loading ammunition, use the expected velocity for the top zone propellant charge weight.

It must be understood that certain programs have physical restrictions such as sensors mounted in cages for high-angle firing, short overall distances from muzzle to plate, or other test limitations that require the use of specific techniques to satisfy customer needs. The longest permissible spacings should be maintained when these restrictions occur. The distance between coil sensors, either the cage type or those supported by standards, is the average of four measurements as illustrated in Figure C-1: from inside first coil to inside second, top and bottom, and from outside first to outside second, top and bottom. All of these distances should be measured to an accuracy of 3 mm.

3. Measuring Devices.

a. Steel tapes. Most steel tapes that are used for measuring distances between sensors are "surveyor" tapes that are calibrated to take into account the droop of the tape when it is suspended between two points and a certain horizontal pull (i.e., force) is applied. Persons using these tapes should be familiar with the pull requirements specified by the manufacturer. A tape that does not

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have a droop correction is suitable for short measurements, but for long distances, it can measure accurately only if resting on a flat surface.

b. Electronic distance-measuring devices. These can measure distances very accurately and are available from several manufacturers.

c. Surveys. Some ranges have fixed locations for skyscreens, that have been very carefully surveyed in advance.

APPENDIX D

TIME INTERVAL MEASURING EQUIPMENT

1. Counter Chronograph. This is an electronic timer consisting of a series of counting circuits having a time resolution of ± 1 microsecond (see Figure D-1). Protective circuits have been incorporated in the counter chronograph to prevent against false operation when random interference is present on the signal lines. Under certain conditions, such as high velocity small arms firing, protective circuits may not be sufficient to prevent false operation. In such cases, an auxiliary chronograph should be used as backup.

The main advantage of the counter chronograph is the speed with which a velocity can be reported. The usual time required to record the flight time and report the velocity of a fired round is 1 minute. The disadvantages of the counter chronograph are a lack of permanent record and an inability to operate routinely over noisy lines.

2. Computing Chronograph. This has the same input characteristics as the counter chronograph with the addition of being able to indicate instrumental velocity directly instead of time. The between-coil distance is set into the instrument by means of digital switches, and the velocity computation is performed within the instrument. The display is a visual and printed record of the velocity.

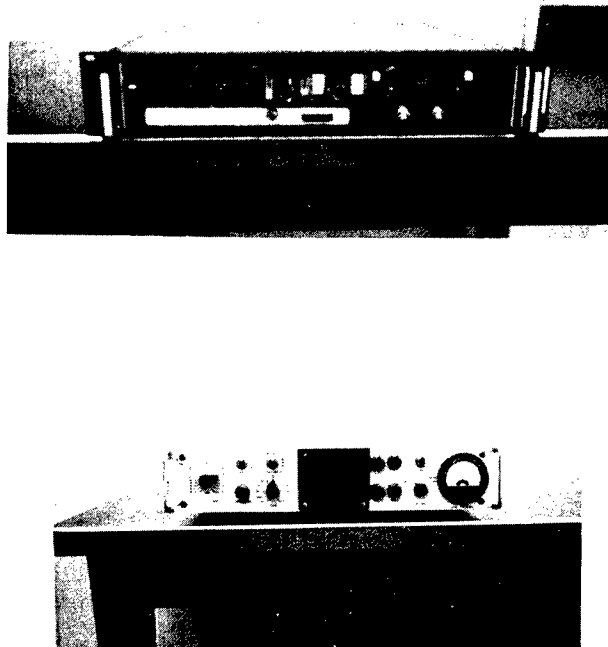


Figure D-1. Transitorized counter chronograph (top) and shaping adapter (bottom)

APPENDIX E

GEOMETRIC CORRECTION

When the radar head is located to the side of the tube, the radar measures the radial component of the projectile velocity. To obtain the projectile velocity, a geometric correction must be applied to the instrumental velocity as given by the following equation:

$$V_{\text{PROJ}} = V_{\text{INSTR}} \left[\frac{\sqrt{R^2 + (X + L)^2}}{X + L} \right]$$

in which: V_{PROJ} = projectile velocity

V_{INSTR} = instrumental velocity

X = distance from weapon muzzle to measurement point

L = distance parallel to weapon axis from weapon muzzle to center of test item antenna

R = distance perpendicular to weapon axis from centerline of tube to test item antenna

These distances are shown below in Figure E-1.

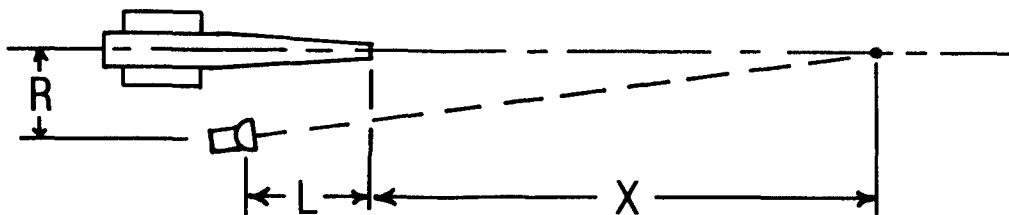


Figure E-1. Distances used in calculating geometric correction.

APPENDIX F

TRANSLATION OF INSTRUMENTAL VELOCITY
TO MUZZLE OR STRIKING VELOCITY

1. Computing Muzzle or Striking Velocity. To translate instrumental projectile velocity to either muzzle velocity or striking velocity, the following relationship is used:

$$V_2 = V_1 + V$$

$$V_3 = V_1 - V$$

in which: V_1 = instrumental velocity
 V_2 = muzzle velocity
 V_3 = striking velocity
 V = velocity correction, calculated as follows:

$$\Delta V = \frac{\rho i d^2 X G}{W} = \frac{\rho X G}{C}$$

in which: ρ = relative air density (ratio of actual density in kg/m^3 to standard air density at sea level (1.225 kg/m^3))
 i = projectile form factor (see Note c)
 d = projectile diameter in centimeters
 X = distance in meters from muzzle or target to midpoint between the two sensors
 G = drag function, $G = K_D \rho_{\text{std}} V$ (see Note b)
 W = projectile weight in kg
 C = ballistic coefficient (see Note c)

NOTES:

a. The above method for determining striking velocity should not be used for distances greater than approximately 122 meters (400 ft). For distances greater than this, the appropriate space and time function should be used.

b. Drag coefficient (G) is a function of the shape of the projectile. Coefficients for standard shapes and for many particular projectiles are tabulated for a range of projectile velocities by Cantey.⁹ The characteristics of the standard projectile shapes, identified as G_1 , G_5 , etc., are diagrammed by Heppner.¹⁰ Experimental data and computer programs (for IBM 360) for computing drag coefficients for standard shapes and for most current projectiles are available from the Commander, US Army Aberdeen Proving Ground, ATTN: STEAP-MT-G, Aberdeen Proving Ground, Maryland 21005.

c. Projectile form factor and ballistic coefficient for many standard and developmental projectiles can be obtained from Hitchcock.¹¹ For specific projectiles not covered in that report, form factors can be computed from measured trajectory velocities or times of flight to known ranges by the procedures described in TOP/MTP 4-2-827.

2. Gravity Correction Due to High-Angle Fire. The instrumental velocity should be given an additional correction due to gravity when h is greater than $V/64$,

in which: h = height of midpoint of screens above the level of the weapon muzzle in meters

V = instrumental velocity in meters per second

The formula for this correction is:

$$\Delta V_g = 32 h/V$$

in which: ΔV_g = correction for drop in velocity due to gravity in meters per second. This correction is to be added to the instrumental velocity, as is the correction due to drag.

3. Correction Due to Wind. In the event of strong winds or firing a projectile with a low velocity, it may be desirable to correct the velocity for the effect of the wind. The total velocity correction to the weapon or to the target can be found as follows:

$$\Delta V' = \Delta V \left(1 - \frac{2W_X}{V} \right)$$

in which: $\Delta V'$ = correction for drag and wind to obtain muzzle velocity
 W_X = range component of wind velocity in meters per second between muzzle and sensor midpoint. The range component of the wind is positive when blowing in the direction of fire.
 V = projectile instrumental velocity
 ΔV = velocity correction for drag over distance X (muzzle to sensor midpoint)

APPENDIX G

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