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Provides techniques for evaluating armor resistance to attack by HE projectile fragments. Includes static detonations of shell against armor plate and armored vehicles and firing tests using projectile fragments, fragment simulators, and simulated fragments in a canister. Includes index of test data from static detonations of 105-mm and 155-mm projectile fragments against armor, fragment characteristics tables, and technique for calculating fragment perforation probability using Poisson distribution.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101
*Test Operations Procedure 2-2-722 — 15 March 1983
AD No.

FRAGMENT PENETRATION TESTS OF ARMOR

1. SCOPE. This TOP describes the available techniques for testing armor for resistance to attack by projectile fragments. It includes the following: a) static detonation of high-explosive (HE) projectiles against armor plates; b) gun firing of projectile fragments; c) gun firing of fragment simulators; d) gun firing of simulated fragments in a canister; and e) static detonation of HE projectiles against armored vehicles. The basic methods applicable to each test may be modified to suit specific test requirements.

While methods a) through d) are applicable to body armor as well as to vehicle and aircraft armor, additional instructions on testing body armor with fragment simulators (method c)) are contained in TOP 10-2-506.[1]** Test techniques for testing armor with projectiles are contained in TOP 2-2-710.[2]

*This TOP supersedes TOP 2-2-722 dated 25 October 1974.

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

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Because of the extensive use of HE projectiles in combat, armored vehicles of all types are required to provide a high degree of protection against shell fragments. Also, since fragmenting munitions have been responsible for a high percentage of combat casualties, protection through body armor is a matter of continuing concern. Thus, tests to determine the protection afforded by vehicle and body armor against shell fragments have been given considerable attention.

Some indication of the ballistic protection afforded by armor against a fragmentation threat may be determined by laboratory and mathematical techniques based upon established empirical relationships. It is necessary, however, to rely upon ballistic testing, incorporating all of the factors important to a fragment/plate interaction, for an accurate measure of the protection against a given threat, and for establishing baseline data.

Fragment penetration testing of armor is conducted to fulfill a variety of requirements such as:

a. Determining and comparing the fragment penetration resistance of various thicknesses and types of experimental materials.
b. Evaluating vehicle overhead, frontal, and flank protection based on design (or threat) requirements stipulated in requirements documents.
c. Checking ballistic quality of production armor against minimum acceptable requirements (acceptance testing).
d. Determining the lethality of fragments that pass through the armor.

Many parameters are involved in fragment attack on armor, including:

a. Projectile parameters: caliber, velocity, angle of fall, direction from target, distance from target, explosive type, type of casing, type of fuzing
b. Armor parameters: type, thickness, obliquity to attacking fragments, mechanical properties, areal density; body armor usually falls in the range of 1 to 20 kg/m^2 (0.2 to 4.0 lb/ft^2), while vehicle armor for fragment consideration falls within the range of 34 to 244 kg/m^2 (7 to 50 lb/ft^2).

This TOP is an outgrowth of reference 9c, Appendix D, which contains additional details on fragment penetration tests of armor.

2. <u>FACILITIES AND INSTRUMENTATION</u>. These are indicated in the individual subtests below. In addition to velocity-measuring equipment, the following facilities are required for gun firing of projectile fragments (see 4.2):

a. Smooth bore weapon. The caliber is determined by the size and weight of the fragment and velocity range to be explored. Calibers to 37-mm are employed.

b. Sabot. The sabot material is usually a type of plastic (linenbase phenolic, lexan, etc.), with the design, diameter, and length determined by the weight and shape of the projectile fragment. The fragment is held in position on the sabot with paste or a nonhardening adhesive. Reference 9h describes firing with a sabot. Teflon pushers are placed behind the sabots to act as obturators.

c. Sabot stripper or tipping device. The standard cal .22 or cal .30 stripper screwed to the gun muzzle or the NRL (Naval Research Lab) tipper device is necessary to separate the fragment from the sabot (see also ref 9c, App. D). A sabot-discarding aid is also used. This is a steel deflector plate, .6-cm

(1/4-in) minimum thickness, with a 2.5- to 3.2-cm-diameter (1- to 1-1/4-in) hole aligned with the center of the gun bore, between the gun muzzle and the first break screen.

d. Velocity break screen. A 10-by 15.9-cm (4-by 6-1/4-in) (minimum) manifold paper with silver circuit grid, line space and width determined by fragment size, may be located both in front of and behind the target to initiate velocity-measuring instrumentation.

e. Yaw cards. These consist of double-weight, color-print photographic paper located within 2.5 cm in front of the target to show the presented area of fragments at impact.

f. Witness material. Building board, 1.3 cm (1/2 in) thick is used to catch residual fragments which are recovered for analytical purposes.

g. Target holder. A rigid structure made of nonmetallic material is used to hold the target in a fixed position when the flash X-ray method is used.

Facilities for Subtest 4.4. The parallelepipeds, cubes, or other shaped simulated fragments in various weight ranges are packed in layers in a standard canister or a specially designed sabot. In a typical test program, artificial fragments made from SAE 4140 steel are heat-treated to a hardness of Rockwell C 30 $\pm$ 1, placed in a modified 90-mm M366 canister projectile, and fired from a 90-mm gun. Two 1.8-by 1.8-m (6-by 6-ft) target plates are mounted side by side 15 m (50 ft) from the muzzle. A 0.3 m space is left between the plates to enable the base of the canister projectile to pass between without damaging the plates. Other details are contained in reference 9c (App. D).

3. REQUIRED TEST CONDITIONS. Armor plates are given a laboratory check if there is a question about their mechanical properties. Other preliminary activities are described in the applicable sections below.

4. TEST PROCEDURES.

4.1 Static Detonation of HE Projectiles Against Armor Plates ("Yankee Stadium" Test).

4.1.1 Objective. The objective is to determine the resistance to penetration of various armor materials, thicknesses, and composites against actual fragmenting munitions, and to use the data to build up a data bank. This procedure deals with flat plates only; similar procedures may be used, however, on the few occasions when fabricated assemblies are tested.

NOTE: An index to the data bank of HE projectile detonations that have been conducted against armor is included in Appendix A.

4.1.2 Method. Position the plates to be tested in a circular array at a specified distance and orientation from a given HE projectile to represent a given attack condition. Most often, you should mount the projectile vertically so that the targets will receive the main spray of the bursting shell. The main spray, characterized by high-velocity and high fragment spatial density, consists of those fragments that fly off to the side of the projectile over the approximate range of 80° to 105° from the nose of the projectile (see Figure 1).

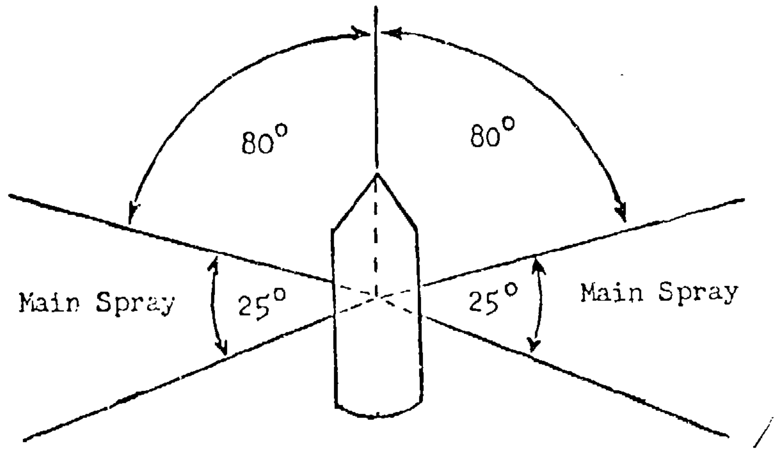


Figure 1. Main spray region of 105-mm and 155-mm projectiles.

The fragment density, from nose to tail of projectiles, 105-mm, HE, M1 and 155-mm, HE, M107, both TNT-loaded, and the velocity distributions are included in Tables B-1 and B-2 of Appendix B. These projectiles produce consistent fragmentation patterns from round to round. As a consequence, the detonation of five rounds of each is usually adequate to assess penetration resistance provided that approximately 18.6 sq m (200 sq ft) of target area are provided. When several types or thicknesses of material are to be tested under like conditions, it is best to increase the number of projectiles and reduce the square feet of each target. The number of perforations will depend on the target material, thickness, obliquity, and distance.

When individual plates are tested, they are best supported by being positioned on a wooden frame braced at intervals as required. The targets normally are placed tangent to the circumference of a circle of prescribed radius, and tilted back 8° from the vertical to provide for perpendicularity of fragment impacts. If oblique targets are intended, the desired obliquity is added to the 8°. Figures 2 and 3 show a typical test setup.

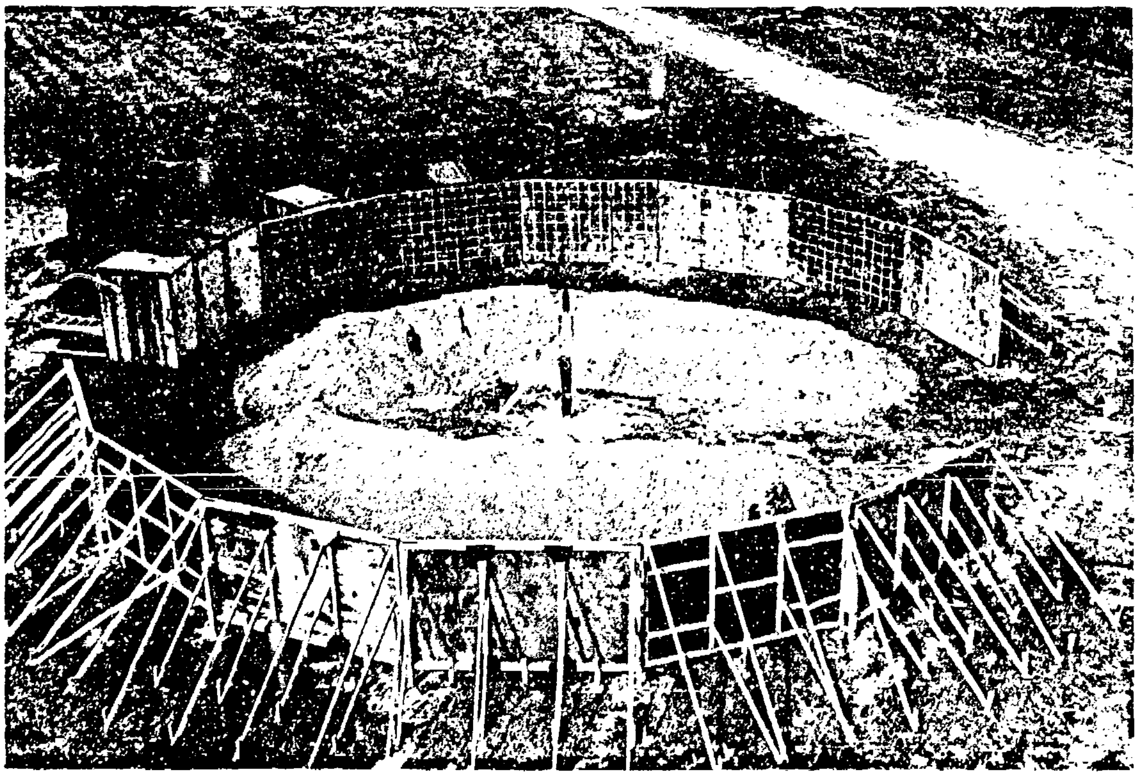
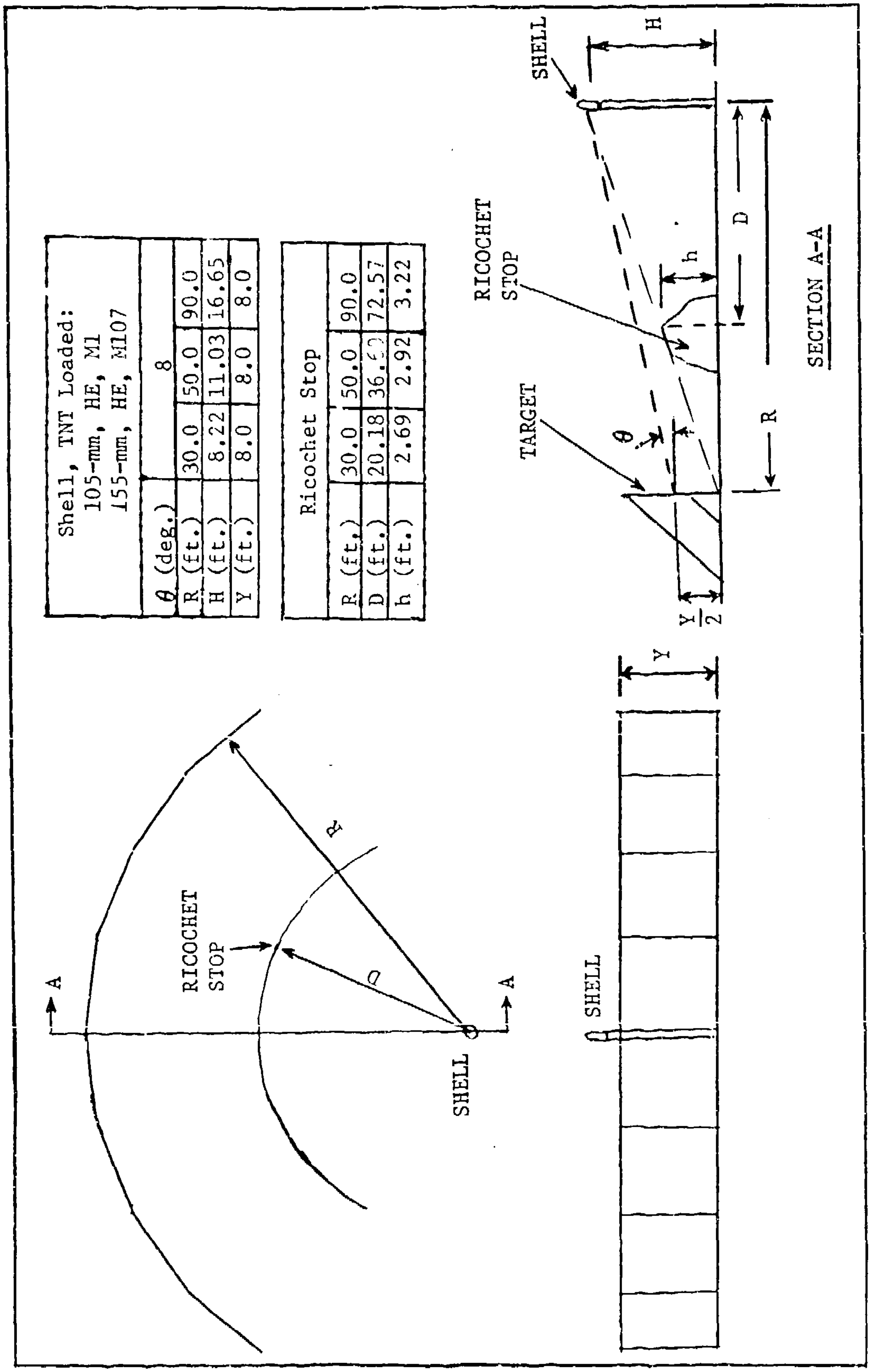


Figure 2. Setup for fragmentation test of armor.



Shell, TNT Loaded: 105-mm, HE, M1; 155-mm, HE, M107			
θ (deg.)	8		
R (ft.)	30.0	50.0	90.0
H (ft.)	8.22	11.03	16.65
Y (ft.)	8.0	8.0	8.0

Ricochet Stop			
R (ft.)	30.0	50.0	90.0
D (ft.)	20.18	36.[illegible]	72.57
h (ft.)	2.69	2.92	3.22

Figure 3. Schematic diagram of typical HE projectile fragmentation test setup.

Position the projectiles vertically on a pedestal at the center of this circle at a height that will cause the densest part of the main spray (98° angle from nose) to strike the vertical center of the targets. Unless special test conditions are specified, mount the projectile nose up. Check the vertical alignment in two directions 90° apart using a plumb line. Since a deviation of 1° displaces the main spray 0.5 m (1-1/2 ft) at a distance of 27 m (90 ft), take care to make the projectile absolutely plumb.

The fragmenting projectiles are generally provided with modified fuzes to allow ready acceptance of electrical firing detonators. After positioning the projectile, insert the firing device, and detonate from some remote and protected area. It is important that the modification of the fuze does not modify the fragmentation pattern of the projectile.

To assure proper orientation of the projectile and to separate results into angular zones, the targets are provided with horizontal lines, one through the center and the others spaced 1° apart, centered on the projectile. Fragment penetrations from individual projectile bursts are identified by painting hits with distinguishing colors.

4.1.3 Data Required. Record the following test data:

a. Projectile - full nomenclature, including type of fuze
b. Distance from center of arena to the target
c. Target obliquity in degrees
d. Fragment spray zone covered by targets, in degrees (e.g., 95.6° to 100.4° from nose)
e. Target material, thickness and alloy temper, mechanical properties, and military specification as appropriate, and manufacturer's name
f. Target area (including length and width of individual plates)
g. Number of fragment perforations for each round fired, their dimensions and locations
h. Number and definition of significant hits, and their locations with respect to 1° zones

4.1.4 Analytical Plan.

a. To analyze the fragmentation effects on the target plates, you must establish criteria for hits and perforations. The following definitions apply:

(1) Significant hit (sometimes called valid hit or effective hit) - any penetration equal to or greater than 0.3 cm (1/8 in) deep for steel targets and equal to or greater than 1 cm (3/8 in) deep for aluminum targets. (Other definitions, such as the ability to perforate a 16-gage mild steel plate placed in front of the target, have been used in the past but are discouraged.)

(2) Perforation - any penetration wherein some target material is displaced from the rear of the plate or the fragment passes completely through the plate. (This definition closely resembles the definition of a complete penetration under the "protection" criterion (TOP 2-2-710), but for this application, a thin-gage aluminum witness material is not really necessary.)

b. Determine the number of significant hits per square meter and the perforations per square meter for each round. (Separation into 1° zones is usually desirable.) Additionally, calculate the percent protection for each round, and for the total of all rounds, using the following formula:

$$\text{Percent protection} = 100 \left(1 - \frac{\text{perforations}}{\text{significant hits}} \right)$$

c. Also determine the probability of perforation (for a given zone of the spray - see 4.1.3d above), using the Poisson distribution. In this case, the number of hits (which is really arbitrarily defined) is not considered; only the perforations from each round on a given area at a given distance are considered. If a confidence coefficient is not given, it is assumed to be .95. Make the following determinations, as a minimum, following testing under each condition, with plates positioned X meters from the projectile.

Probability of no perforations per round per sq m at distance X.

Probability of 2 or more perforations per round per sq m at distance X.

Probability of _____ perforations per _____ rounds per _____ sq m at distance X (as specified in directive).

The details for making these determinations are contained in Appendix C.

d. In each case when plates are at an 8° tilt, the actual angle of obliquity of the plate with respect to incoming fragments may be in the range of 0° to 6° which includes the effect of gravity on the trajectory of fragments. For all practical purposes, however, this is considered to be normal attack condition, i.e., 0° obliquity.

e. The only fragments of consequence against vehicular armor are those that are heavy and originate with high velocities. Aside from negligible exceptions, these fragments are found in the 80° to 105° main spray. Important in this regard is the fact that the velocities of large fragments do not decrease with distance as rapidly as velocities of small fragments, as shown in Table B-3, Appendix B. If, for some reason, there is a requirement to interpret results in terms of other angular zones in addition to those covered by the targets, the perforations to be expected in the various zones of the main spray will be in proportion to the number (after data smoothing) of fragments over 400 grains from 105-mm shell, and over 750 grains from 155-mm shell (Tables B-1 and B-2, App. B).

f. To interpret data from 0° obliquity attack in terms of attacks at other obliquities, it is desirable to use a computer model such as that developed by Army Materiel Systems Analysis Agency (AMSAA). A simplification, which is less accurate, is to assume that the plate resistance will be constant for the same straight line distance through the plate - the so-called cosine relationship wherein, for example, 5.0 cm at 0° is considered equal to 2.5 cm at 60°, or:

$$\text{Thickness at } \theta = (\text{Thickness at } 0°)(\cos \theta).$$

The AMSAA computer model, using the data from tests such as these, can develop curves such as those of Figure 4.

NOTE: The test engineer should be aware that this test provides data on the penetration resistance of armor against statically detonated HE projectiles only. The test does not produce the velocity of a projectile detonating in flight. This velocity contributes a forward component to the velocity and direction of the fragments, relative to the projectile.

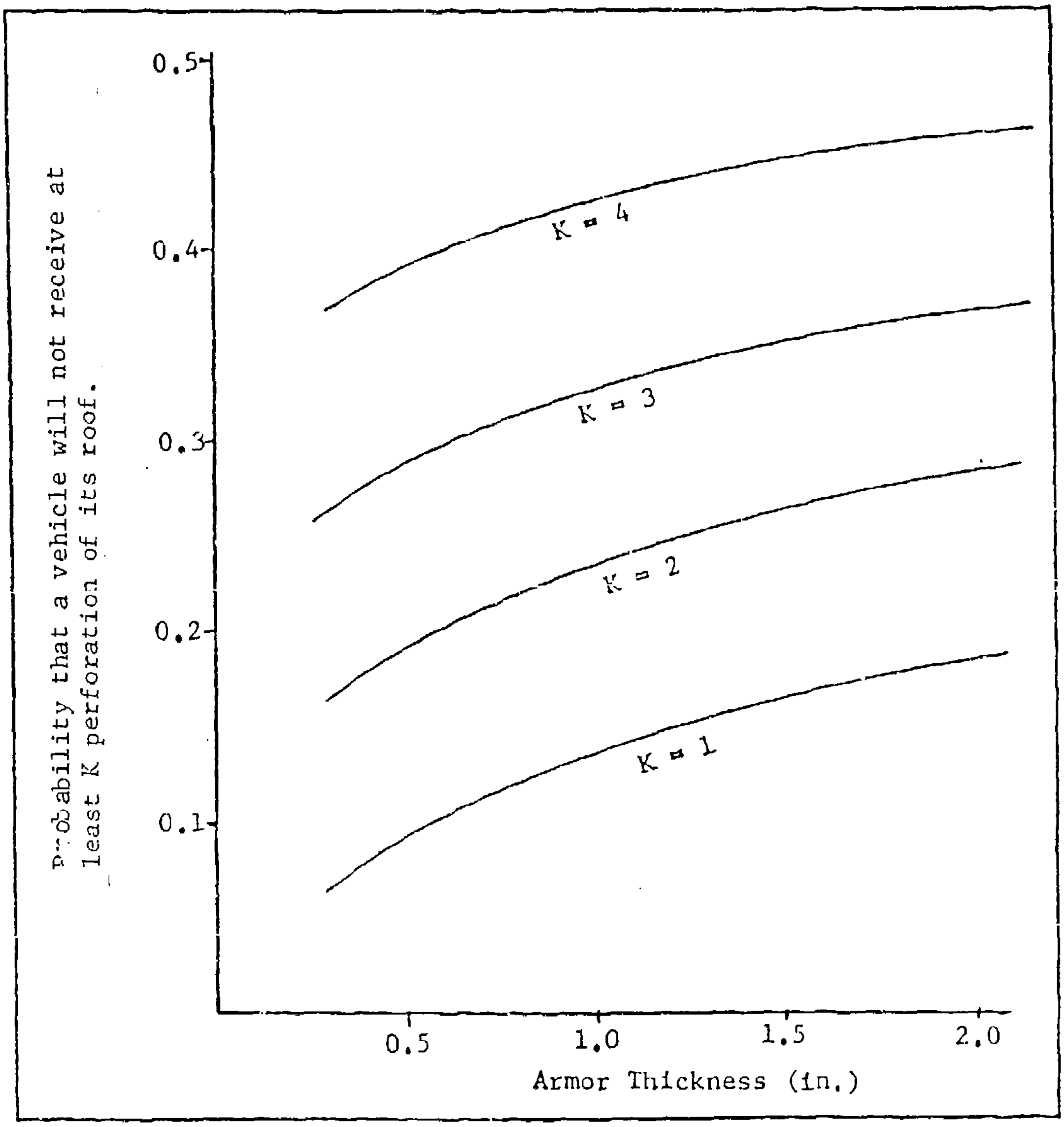


Figure 4. Probability of perforations in roof of XYZ vehicle from a volley of 40 105-mm projectiles against a tactical array of 8 vehicles.

4.2 Gun Firing of Projectile Fragments.

a. Objective. To obtain precise penetration data using actual fragments when static detonations (para 5) are considered lacking sufficient control and simulated fragments (para 7) are not considered adequate. These tests often include the measurement of residual velocity (fragment velocity remaining after a complete penetration of the armor) to assess the lethality of the fragments that penetrate, particularly in connection with body armor. This section deals primarily with vehicular armor. For tests of body armor, see TOP 10-2-506.

b. Method. In this test, use actual shell fragments recovered from static detonations of HE projectiles. (For tests of vehicular armor, fragments from 105-mm and 155-mm shell are frequently used. For tests of body armor, fragments from mortar shell and foreign ammunition are more appropriate.) Use a soft recovery technique, generally employing wallboard which will not damage the fragments. TOP 4-2-813[3] describes a method for recovering a small portion of the main spray. To recover all of the main spray would require that wallboard be stacked all around the sides of the projectile at an appropriate standoff. Mount, in a sabot, each recovered fragment to be fired. If residual velocity (behind the target) is to be obtained, the technique used to measure residual velocity is also used to measure velocity before impact.

4.2.1 Velocity Measurement Techniques. The two methods that may be employed to measure fragment velocities are (a) the flash X-ray method which should be used when the target may break up, such as during testing of metallic or hard-faced composites; and (b) the chronograph, break screen (or lumiline screen) method which is generally used when nonmetallic or fabric-type targets are to be tested. The break screens are used to trigger the X-ray tubes and chronograph. Flash X-ray (radiographic) techniques are generally covered in TOP 4-2-825[4], with specific information on velocity measurements in TOP 2-2-710. Chronographic techniques are described in TOP 4-2-805.[5] The setups used in testing body armor (which are also applicable for vehicular armor) are shown in TOP 10-2-506. Velocity measurements of fragments require that special drag coefficients be obtained from appropriate sources. Gun-to-target distances will vary. They may be as little as 132 cm (52 in) for very small fragments fired at body armor, although 3 to 4.9 m (10 to 16 ft) is more common. Vehicular armor may require distances as great as 12 m (40 ft).

4.2.2 Determining a V50 Ballistic Limit. Select fragments to be fired that are as close to the prescribed weight as possible, and choose fragments with characteristic shapes. For vehicular armor, this is preferably within (±) 5%, but not beyond (±) 10%; for body armor where fragments of 2 to 70 grains may be used, this is preferably (±) 2% to 3% but not beyond (±) 5%. The range of fragment weights that must realistically be tolerated within a given weight category is a factor that tends to promote a large zone of mixed results during the determination of a V50 ballistic limit (see TOP 2-2-710). An even more significant factor in this regard is that the wide variety of shapes, hardness patterns, and impact orientations that are possible with randomly selected fragments within the same weight category will result in great variations in the penetrating efficiency of the different fragments. Thus, within the constraints of a typical test program, the V50 ballistic limit determination can, at best, only be considered a fair approximation. The wide variations in the attacking missile cause a considerable amount of data scatter. (This is the primary reason that the methodologies of paragraphs 4.3 and 4.4 are often preferred to shooting actual fragments.)

To determine the V50 ballistic limits, the up-and-down firing technique is usually employed (TOP 2-2-710), with the ballistic limit being based, when practical, upon the average of 10 striking velocities: the five highest partial penetrations and the five lowest complete penetrations occurring within a velocity spread of 46 m/sec (150 ft/sec). Six or eight striking velocities have also been used as a base but are less desirable. A complete penetration is defined by the "protection" criterion; that is, an impact that results in either a portion of the plate or fragment moving behind the plate with sufficient energy to perforate a witness sheet of 0.051 cm (0.020-in) aluminum. Fragment velocities are controlled as usual by varying the weight of propellant. In doing so, however, the varying weights of the combined weight of sabot plus fragment must be considered. A suitable approach when testing vehicular armor is to fire one of the medium-weight fragments and use the following empirically derived relationship to determine propellant weights for subsequent fragments:

$$C_2 = C_1 \, [1 \pm 1/2 \, (P_2 - P_1)]^*$$

C_1 = weight of propellant charge of initial firing

P_1 = combined weight of sabot and fragment of initial firing

C_2 = weight of propellant charge, second firing

P_2 = combined weight of sabot and fragment of second firing

*Use + if initial firing results in a partial penetration; use - if initial firing results in a complete penetration.

4.2.3 Determining the Critical Fragment Weight, W50, to Defeat A Target. This test has the potential of eliminating the need for the static detonation test (para 4.5) while producing more explicit data in a simpler manner, using far less target area. The test attempts to simulate the static detonation test by assuming that the target is located at a certain distance from the shell and firing individual fragments (from guns) to impact the target at the same velocity that would have occurred had they been launched by the static detonation of the shell.

a. Objective. To determine, for a target at a given distance from a shell, what weight of fragment from the shell's main spray (at a known initial velocity) would be required to defeat the target. This test (as with all tests of armor) can produce a zone of mixed results; this leads to the concept of the W50 critical weight, or the weight of fragment that will cause complete penetrations (perforations) of the target 50% of the time and partial penetrations 50% of the time. Since data are already available on the distribution of fragment weights and velocities (Tables B-1 and B-2, App. B), it will be possible to determine how many fragments from the main spray of a particular shell have the potential of defeating the target.

b. Method. It is necessary first to select actual fragments to cover the appropriate range of weights. Use available velocity data (e.g., Table B-4, App. B) to establish the velocity for each weight of fragment. (Drag varies with weight; the heavier the fragment, the higher the velocity at a given distance.) Fire the fragment whose weight is estimated to be closest to the W50, first. Place it in a sabot and fire from a gun to impact at the prescribed velocity. If a partial penetration occurs, the next fragment should be heavier; if a complete penetration, the next fragment should be lighter. Weight changes should not be under 10%. Once both a complete and partial penetration have been obtained, confirming firings are desirable. The W50 is the average of an equal number (usually two) of the lowest complete and highest partial penetrations occurring within a 35% weight range. A typical example, assuming a target 27.4 m (90 ft) (Tables B-3 and B-4, App. B) from a 155-mm shell, is shown in Table 1.

For all practical purposes, the W50 may be considered the absolute dividing point between 100% complete penetrations and 0% complete penetrations. While the actual situation is probabilistic, it may be considered deterministic. Actually, variations in the W50 by a few percentage points are insignificant in the total picture. (This test method was first proposed in ref 9m and tried in the study reported in ref 9c, App. D.)

TABLE 1 - Example of Firing to Determine W50

Round No.	Fragment Weight, grains	Impact Velocity, fps	Result
1	1048	2430	PP
2	1191	2478	PP
3	1340	2504	CP
4	1172	2575	CP

W50 = 1188 grains

4.2.4 Determining Residual Velocities. Conduct test programs for determining residual velocities to determine the ability of armor to reduce the velocity, and therefore lethality, of fragments that can perforate the armor. Since this procedure is almost exclusively used in connection with the testing of body armor, it is covered in TOP 10-2-506 which deals with body armor testing.

4.3 Gun Firing of Fragment Simulators.

4.3.1 Objective. To evaluate the fragment resistance of lightweight armor by attacking with hardened steel configurations designed to simulate fragments.

Advantages. This test method has the following advantages over other fragment tests:

a. Missiles of consistent weight, shape, and properties are used, permitting consistency of test conditions.
b. Missiles can be mass-produced and are relatively inexpensive.
c. Precise velocity control is easily achieved.
d. Small targets and modest range facilities are possible.

Disadvantages. For some purposes, the fragment simulators do not simulate fragments adequately. While they can screen materials, fragment simulators cannot show what the performance of a target will be against actual fragments launched by projectile detonations.

4.3.2 Types of Fragment Simulators. There are basically two types of fragment simulators:

a. A standard fragment-simulating (FS) projectile that is a widely used, specific type of solid steel projectile available in different weights.
b. Various other geometric shapes most of which require sabots for launching.

Standard FS projectiles, described in TOP 10-2-506, are homologous in shape; produced in sizes of cal .22 (17 grains), cal .30 (44 grains), cal .50 (207 grains), and 20-mm (830 grains); and procured under MIL-P-46593A (ORD)and Amendment 1 thereto (ref 2, App. D). The FS projectile is an attempt to produce fragments that are standardized and do not require a sabot for firing. It was expressly developed for evaluating the fragment resistance of development body armor and lightweight aircraft and vehicle armor. FS projectiles are also employed in the acceptance testing of body armor. Cubes, suitable for mounting in sabots, have also been standardized and are procurable under MIL-P-46125 (MR) (ref 1, App. D). Cylinders, parallelepipeds, darts, and spheres have also been used. Some of these are shown in Figure 5.

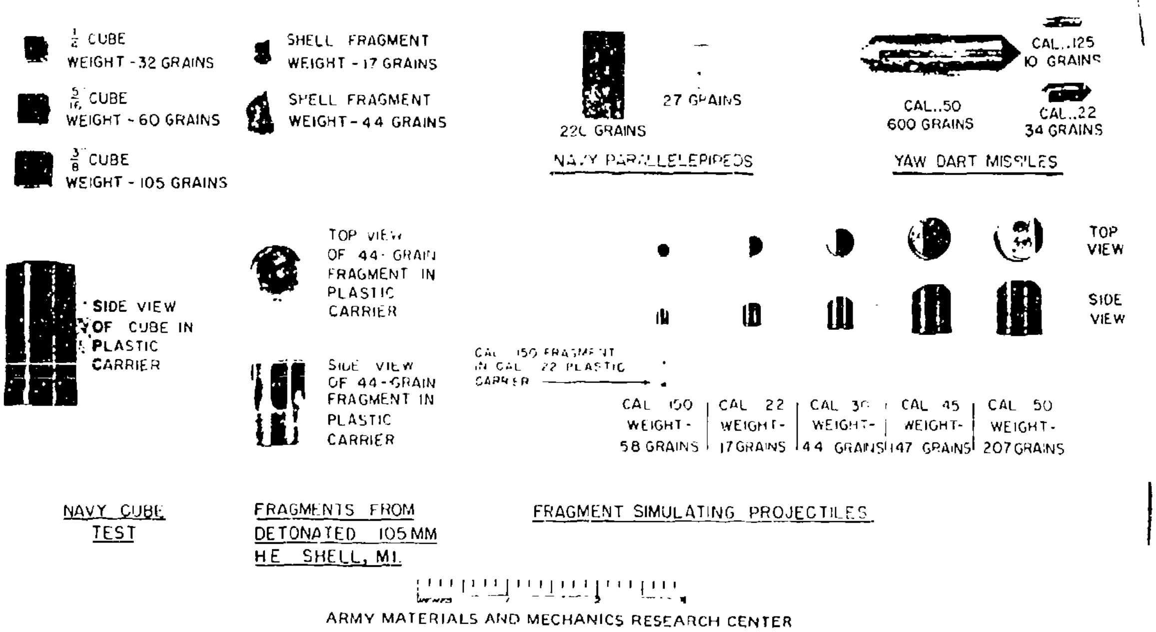


Figure 5. Typical fragment simulators used to evaluate armor.

4.3.3 Characteristics of Fragment Simulators. The orientation of the fragment simulator upon impact with a plate has a considerable effect upon the efficiency of penetration and is a factor in the scatter of data. A cube, for example, hitting on a corner will penetrate more easily than if it hits on one of its flat sides. This is not a problem with FS projectiles when fired at a 0° obliquity target, but does become a factor with oblique targets because penetration is less efficient if the projectile strikes on a tapered portion of its nose rather than on an untapered portion. Right circular cylinders do not have this disadvantage at obliquities while retaining the advantage of not requiring sabots. A major disadvantage of cylinders is the sparsity of data concerning them for use in comparison with materials tested in the past. Spheres, of course, provide perfect consistency of impact orientation, but their use is not recommended because of their marked dissimilarity to fragments.

The vast majority of tests with fragment simulators employ the standard FS projectile for several reasons: a large amount of past data involving them are available; they are readily available in several weights, relatively inexpensive to fire, and they reasonably simulate fragments. Thus, nearly all body armor testing (TOP 10-2-506) and much vehicle armor testing is performed with FS projectiles.

4.3.4 Method.

4.3.4.1 Types of Tests. The type of test conducted depends on the resources (funds and target area) available and the objective of the test program.

a. The simplest test program involves obtaining a 6-round, V50 protection ballistic limit, using the up-and-down firing technique (TOP 2-2-710). Pertinent velocities are limited to a spread of 46 m/sec. This type of ballistic limit is considered marginal since it is not accurate enough for most applications. Acceptance testing of body armor (ref 3, App. D) upgrades this test method somewhat by requiring a 10-round, V50 ballistic limit with pertinent velocities limited to a velocity spread of 38 m/sec (125 ft/sec). If a ballistic limit is not reached within a spread of 38 m/sec, a 14-shot ballistic limit with a spread of 46 m/sec is acceptable.

b. A second testing method that employs the Langlie firing technique (TOP 2-2-710) which generally involves 12 to 16 firings, may produce a standard deviation as well as a V50 ballistic limit, and is suitable for comparing types of materials with regard to V50. This is the minimum test that should be used for comparing materials.

c. Occasionally, another method is employed when there is a need to obtain a very precise measurement of the ballistic limit and its standard deviation. In this case, the Probit method (see TOP 2-2-710) is preferred, with perhaps 50 to 200 fragment simulators fired, composed of groups of 8 or 15 fired at each of 6 to 15 velocities that cover the range from V-0 to V-100.

In firing, a gun-to-target distance of 4.9 m (16 ft) is considered standard for body armor, with two lumiline screens spaced about 1 m (3 ft) apart for velocity measurements. (Special tests may have shorter distances as illustrated in TOP 10-2-506.) For heavy materials requiring medium-sized guns, gun-to-target distances to 12 m (40 ft) may be necessary. Witness material of 0.051-cm (0.020-in) aluminum is placed behind the target to register complete and partial penetrations. When applicable, a yaw card is placed just in front of the target to indicate impact orientations. If residual velocities are required, they are obtained as specified in TOP 10-2-506.

4.3.5 Data Required. Record all data pertinent to the armor material, including type, weight per square foot, and, when applicable, thickness, hardness, impact toughness, yield strength, tensile strength, and chemical composition. Record the exact obliquity of the armor and the striking velocity of each partial and complete penetration. As required by the directive, residual velocity of the fragment after it passes through the armor, and velocity, size, and distribution of the fragments displaced from the target may be recorded as in paragraph 4.2.b. Describe impact orientations when pertinent.

4.3.6 Analytical Plan. Use striking velocities and the corresponding penetration results to estimate the mean and standard deviation parameters of a normal distribution. It is assumed that the probability of penetration versus striking velocity is described by a cumulative normal distribution. If a zone of mixed results does not occur, an estimate of standard deviation is not obtainable from the data. The zone of mixed results is the difference in striking velocity of the partial penetration with the highest velocity and the complete penetration with the lowest velocity. This difference must be positive to have a zone of mixed results.

An hypothesis test for equality of ballistic limits of two materials can be performed, provided both samples had a zone of mixed results. A computer program is available at Aberdeen Proving Ground to calculate the estimates necessary (ref 9d, App. D). The statistic used is as follows:

$$Z = \frac{\hat{\mu}_1 - \hat{\mu}_2}{\sqrt{\left(\hat{\sigma}_{\hat{\mu}_1}\right)^2 + \left(\hat{\sigma}_{\hat{\mu}_2}\right)^2}}$$

(Z is asymptotically distributed as a normal variate with mean zero and standard deviation equal to 1.)

= ballistic limit estimate

$\hat{\sigma}_{\hat{\mu}}^{\,2}$ = variance of ballistic limit estimate

(Subscripts 1 and 2 denote the items being compared.)

If the Probit method (at least 50 rounds) is used, determine the V50 ballistic limit and standard deviation either by use of reference 9d (App. D) or by plotting data on a curve and picking off the desired measures of performance.

4.4. Gun Firing of Simulated Fragments in a Canister.

4.4.1 Objective. To acquire large amounts of data with simulated fragments impacting in many orientations. This method has been used in the past when it was desired to fire large quantities of geometric shapes, such as cubes, parallelepipeds, etc., but to do so at less cost than would be required if each missile were mounted separately in a sabot and fired as discussed in paragraph 4.3 This method has the disadvantages of requiring a large weapon and a large target.

4.4.2 Method.

4.4.2.1 Velocity Measurements. Two techniques can be used to measure initial and striking velocities of the fragments.

a. The first method uses high-speed photography and is capable of measuring the velocity of each fragment. An 8-mm motion picture camera operating at 10,000 frames per second is focused on the target. The camera photographs the firing of the gun by means of a mirror placed in its field of view. The fragments that impact the target are recorded as flashes of light on the film. Fragment flight times are determined through the use of a millisecond time-base on the film. Muzzle and striking velocities are computed with suitable drag coefficients.

b. The second method measures the velocity of the fastest moving fragment that strikes each of two targets. Three printed silver circuit screens are used, one positioned on each target plate acting as the stop, and the third, or start screen, located 6 m (20 ft) from the muzzle. The muzzle velocity and striking velocity are computed for the first fragment that arrives at each target.

4.4.2.2 Duplicating Specific Attack Conditions. The explanation behind this type of testing is contained in paragraph 4.2.3. Using the canister approach, fire all fragments to strike at a given velocity at one time, at a velocity that represents the actual velocity expected of fragments from a particular projectile. (Fragment velocities have some spread, but within acceptable limits.) The targets need not be only armor plates since vehicles are also appropriate targets for this type of firing.

4.4.2.3 Determination of V50 Levels. Fire canisters loaded with fragments of the desired weight at the target plates at several velocities, and the percent of partial penetrations is obtained for each velocity by dividing the number of partials by the total number of hits. Vary propellant weights either up or down until a curve of velocity versus percent of partial penetrations is obtained.

4.4.3 Data Required. Record the following:

a. Number of fragments fired in each weight class
b. Shape, weight, and hardness of the fragments in each weight category
c. Striking velocity of the fragments
d. Test plate material, alloy, thickness, mechanical properties, chemical composition, and heat treatment
e. Number of partial penetrations for each fragment weight class

4.4.4 Analytical Plan. If target materials are to be compared using the technique of paragraph 4.4.2.2, use a statistical approach which tests the hypothesis that each of the plates is equal when performance is judged on the basis of number of complete penetrations or compared to number of impacts. Unless otherwise specified, a risk at both ends of 10% is assumed and the t-test used.

If a V50 ballistic limit is to be estimated (para 4.4.2.3), plot a curve of percent complete penetrations (ordinate) versus striking velocity (abscissa) and pick the V50 point off the curve. If several thicknesses of the same material have been tested, also plot ballistic limit versus areal density.

If a vehicle is being fired upon, record the impact location and the damage caused by each impacting fragment, and evaluate the implications of this damage.

4.5. Static Detonation of HE Projectiles Against Armored Vehicles.

4.5.1 Objective. To evaluate the effectiveness of a vehicle including its roof, hatch covers, doors, front, rear and side armor, etc., in protecting against blast and shell fragments. This basic objective may or may not be related to providing data to validate or improve a mathematical model concerned with protection afforded by vehicles in realistic battlefield scenarios.

4.5.2 Standards. Protection requirements in ROC's/DP's are now being stated in terms of a specified probability of no perforations from a specified projectile bursting at random locations around a formation of specific vehicles in a realistic tactical battlefield scenario. For example, the requirement might state that when forty 105-mm projectiles are detonated in the air above a formation of eight XYZ vehicles, the probability of a complete perforation should not exceed 0.3 per round. Two computerized mathematical models have been developed for determining the perforation probability from given input conditions. Reference 12 (App. D) describes one model developed by Littleton Research and Engineering Corp. for TACOM and includes an explanation for determining the single-shot perforation probability. AMSAA has developed a different model. Periodic validation of the mathematical models requires the detonation of shell at specified locations from a test vehicle.

4.5.3 Method. The test procedures generally follow those performed on a test reported in reference 9h (App. D). The number of shell and location of burst points depends upon the computer program that is chosen and the resources available. The test plan prepared by AMSAA or Littleton will specify the number of shells to be detonated, their height and location above the ground or above the vehicle, and the shell orientations. Constraints will be imposed upon the number of firings by funding and time available. To reduce costs, it is advisable to use more than one target vehicle or to supplement target vehicle(s) with armor plate of the same type, thickness, and obliquity as that of the vehicle. Paint targets with grid lines to help identify locations of perforations. Position shells, one at a time, at a specific location and orientation, and electrically detonated. Paint vehicles with grid lines to help identify locations of fragments.

4.5.4 Data Required. For each detonation, record the following information:

a. Projectile type, location, and orientation with respect to each target

b. Location of each target vehicle; type, thickness, obliquity, and area of pertinent armor areas

c. Location and orientation of target plates, if used; also thickness, area, and types of target plates

d. Locations, number, and definition of significant impacts (para 4.1.4)

e. Locations, number, and definition of perforations (para 4.1.4)

f. Damage to components of vehicles, e.g., periscopes

g. Blast effects

4.5.5 Analytical Plan. If repeated shots under identical conditions are fired, develop data as described in paragraph 4.1.4. If the detonation occurs at a multitude of locations in accordance with a test plan to validate a mathematical model, the results are tabulated and forwarded to the appropriate agency (AMSAA or TACOM) for analysis. The results can be used to improve curves such as those of Figure 4. The roof armor often is the only area of concern because projectiles detonating overhead will usually strike side and end armor at high obliquities, and the armor is usually fairly thick to protect against small arms projectiles.

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APPENDIX A
INDEX OF TEST DATA ON HE PROJECTILE FRAGMENTS VERSUS ARMOR

Tables A-1 and A-2 list the tests that have been conducted by APG on various types and thicknesses of armor by statically detonating 105-mm and 155-mm shell at various distances.

TABLE A-1
TESTS USING PROJECTILE, 105-MM, HE, M1, TNT-LOADED

Material	Thickness (in.) and Report Source
5083 aluminum alloy	1/4, 1/2, 3/4, 1, 1-1/4, 1-1/2, 1-3/4, 2 (DPS-653)
5456 aluminum alloy	1/4, 1/2, 3/4, 1, 1-1/4, 1-1/2, 1-3/4, 2 (DPS-67); 2 (DPS-110)
RRH steel, specification hardness and a modified hardness, BHN 293	3/8, 5/8, 3/4 (DPS-653); 1/2, 5/8, 3/4 (DPS-110); 3/8, 1/2 (DPS-67)
1/4-in steel, XAR-30, BHN 500; XAR-15, BHN 300	1/4 (Firing record No. Ar 30468)
16-gage cold rolled steel	1/16 (Firing record Nos. Ar 30468 and 30651)
Aluminum composite: 7178 alloy face 0.323 in thick; 5456 alloy back, 0.493 in thick	0.323, 0.493 (Ar 30651)
Titanium 6AL-4V	0.514, 0.773, 1.037 (DPS-392)
Doron and nylon (spot bonded)	Doron, 0.25, 0.48, 0.72, 0.91. Nylon spot-bonded), 12-ply, 18-ply, 24-ply (DPS-407)

TABLE A-2
TESTS USING PROJECTILE, 155-MM, HE, M107, TNT-LOADED

Material	Thickness (in.) and Report Source
5083 aluminum alloy	1/2, 3/4, 1, 1-1/4, 1-1/2, 1-3/4, 2 (DPS-67); 1-1/4, 1-1/2, 1-3/4, 2 (DPS-110); 1-1/2, 1-3/4, 2, 2-1/2 (DPS-653); 1-3/4 (APG-MT-3778)
5456 aluminum	1/2, 3/4, 1, 1-1/4, 1-1/2, 1-3/4, 2 (DPS-67)
RH steel, specification hardness and a modified hardness, BHN 293 (same data for each)	3/8, 1/2, 3/4, (DPS-67); 1/2, 5/8, 3/4 (DPS-653); 1/2, 5/8, 3/4 (DPS-110)
Titanium 6AL-4V	0.514, 0.773, 1.037 (DPS-110)
7039-T63 aluminum alloy	1-1/4, 1-3/4, 2-1/4 (APG-MT-3778); 1 to 1.30 (Firing record No. Ar-30650)
Steel, XAR-30 and XAR-15, BHN 500	1/4 (Ar-30650)
Aluminum 7178 face, 0.323 in thick; 5456 back, 0.493 in thick. HH steel face, 0.124 in thick; aluminum 7039 back, 0.731 in thick	0.323, 0.493, 0.124, 0.731 (Firing record Nos. Ar-30651, Ar-30650)
Cold rolled steel	1/16 (Ar-30650 and 30651)

APPENDIX B
FRAGMENT CHARACTERISICS OF 105-MM AND 155-MM SHELL[a]

TABLE B-1
INITIAL VELOCITY AND DENSITY OF FRAGMENTS FROM SHELL, 105-MM, HE, M1, TNT-LOADED

	V_o	Scaled Density Frags/Steradian				V_o	Scaled Density Frags/Steradian		
θ deg	Initial Velocity, fps	Body	Over 400 Grains	Fuze	θ deg	Initial Velocity, fps	Body	Over 400 Grains	Fuze
0	1000	67	–	3841	95	3300	785	12	–
5	–	–	–	787	100	3000	1104	89	–
10	1300	25	–	526	105	2450	314	12	–
15	1200	31	–	265	110	2150	174	6	–
20	1350	11	–	127	115	2050	271	32	12
25	1450	104	–	171	120	2000	241	–	–
30	1600	26	–	71	125	2400	1071	–	–
35	1700	14	–	48	130	2600	1042	8	–
40	1850	7	–	52	135	2850	560	–	–
45	1950	54	–	–	140	2400	385	–	–
50	2100	121	–	37	145	2400	262	–	–
55	2400	134	7	36	150	2350	253	–	–
60	2250	107	20	–	155	2300	355	–	–
65	2850	129	6	7	160	2200	414	–	–
70	3300	117	19	6	165	2600	749	–	–
75	3050	181	–	12	170	3050	769	–	–
80	3500	225	–	6	175	3400	600	–	–
85	3650	422	12	6	180	3800	1304	–	–
90	3900	649	–	–	–	–	–	–	–

[a]Extracted from reference 14 (App. D).

TABLE B-2

INITIAL VELOCITY AND DENSITY OF FRAGMENTS FROM SHELL, 155-MM, HE, M107,TNT-LOADED

θ deg	V_o Initial Velocity, fps	Scaled Density Frags/Steradian Body	Scaled Density Frags/Steradian Over 750 Grains	θ deg	V_o Initial Velocity, fps	Scaled Density Frags/Steradian Body	Scaled Density Frags/Steradian Over 750 Grains
0-50	-	-	-	115-120	1930	156	-
50-55	3270	58	-	120-125	1970	137	-
55-60	2700	82	-	125-130	2020	160	-
60-65	2540	78	-	130-135	2670	423	-
65-70	3050	175	25	135-140	2450	170	-
70-75	3220	218	-	140-145	2720	322	-
75-80	3400	344	36	145-150	2560	94	-
80-85	3450	397	23	150-155	2320	241	-
85-90	4070	475	-	155-160	2330	493	-
90-95	4000	996	46	160-165	2020	114	-
95-100	3440	1225	58	165-170	2380	357	-
100-105	2830	1138	71	170-175	2480	1278	85
105-110	2470	340	12	175-180	2710	3083	111
110-115	1890	275	25	-	-	-	-

APPENDIX C
CALCULATION OF THE PROBABILITY OF FRAGMENT PERFORATION USING THE POISSON DISTRIBUTION

The Poisson distribution is used on the assumption that testing will continue until a large number of hits, including some complete penetrations, are experienced over a large area. Then the probability of ΣX_i or fewer penetrations per A square units of area after N rounds have been detonated is given as

$$p = \sum_{k=0}^{\Sigma X_i} e^{-\lambda N} (\lambda N)^k / k!$$

where X_i = number of fragments penetrating area A for the ith round.

(λN) = the Poisson parameter in units of number of penetrations in N rounds per A square meters.

This probability is set equal to $1-\gamma$ when γ is the confidence coefficient. The upper 100γ-% confidence limit on the number of penetrations per N rounds per A square meters is obtained by solving the equation for λN. This is accomplished by using cumulative Poisson probability tables such as those given in reference 13 (App. D).

To determine the probability P_L of m or fewer penetrations per round per S square units of area,

let $$\lambda_u = \frac{\lambda N}{N} \times \frac{S}{A}$$

where λ_u = number of penetrations per round per S square meters (upper 100γ-% confidence limit)

then $$P_L = \sum_{k=0}^{m} e^{-\lambda_u} (\lambda_u)^k / k!$$

when P_L is the lower 100γ-% confidence limit on the true probability of m or fewer penetration occurrences per round per S square meters.

Round No.	No. of Penetrations (χ_i)
1	2
2	1
N = 3	5

$$\sum_{i=1}^{N} \chi_i = 8 = m$$

Fired on area of 8.9 square meters = A

Probability (8 or few penetrations per 3 rounds on area A):

$$= \sum_{k=0}^{8} e^{-(\lambda N)} (\lambda N)^k / k!$$

$$= 1-\gamma = 0.05 \text{ (confidence coefficient = .95)}$$

Therefore, the problem is to solve $\sum_{k=0}^{8} e^{-\lambda N} (\lambda N)^k/k! = .05$ for λN.

This is done by entering Poisson tables with probability = .05 and C-1 = 8 and interpolating to obtain the value of the Poisson parameter. These tables give λN = 14.43 penetrations/3 rounds/8.9 square meters.

Suppose we wanted to find the probability of no penetrations per round per 9.3 square meters; i.e.,

$$P_L = \sum_{k=0}^{0} e^{-\lambda_u} (\lambda_u)^k / k!$$

Now $$\lambda_u = \lambda N \left(\frac{1}{N}\right)\left(\frac{S}{A}\right) = 14.43 \left(\frac{1}{3}\right)\left(\frac{9.3}{8.9}\right) = 5.010$$

$$P_L = e^{-5.010} (5.010)^0/0! = .0067$$

λ_u is an upper 95% confidence limit on the true Poisson parameter λ ; P_L is the lower 95% confidence limit on the true p = probability of no penetrations per round per 9.3 square meters.

APPENDIX D
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