Designation: E3110/E3110M – 22

Standard Test Method for Collection of Ballistic Limit Data for Ballistic-resistant Torso Body Armor and Shoot Packs[1]

This standard is issued under the fixed designation E3110/E3110M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method addresses the collection of ballistic limit data for ballistic-resistant torso body armor and shoot packs.

1.2 This test method is intended for testing of soft body armor, hard armor plates, and shoot packs. This test method does not apply to ballistic helmets.

1.3 This test method describes procedures for collecting data and does not specify computation or performance criteria for the ballistic limit. Instructions for computation and performance criteria are specified in other standards and specifications.

1.4 Several commonly used test item mounting procedures and ballistic limit procedures are included in this test method; certifiers, purchasers, and other users will specify the procedures to be used.

1.5 This test method does not address conditioning of test items.

1.6 It is anticipated that this test method will be referenced by certifiers, purchasers, or other users to meet their specific needs.

1.6.1 Certifier, purchasers, and other users will specify and describe the ballistic test threats to be used. Within this test method, the reference will be called the "test threats document."

1.6.2 Certifiers, purchasers, and other users will provide specific instructions for the determination of complete penetrations or partial penetrations.

1.6.3 In this test method, "other standards and specifications" and "unless specified elsewhere" refer to documents (for example, military standards, purchase specifications) that require the use of this test method. Certifiers, purchasers, and other users are responsible for the "other standards and specifications" and for specifying any requirements that supersede those of this test method.

1.7 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.7.1 The user of this standard will identify the system of units to be used, and it is critical to ensure that any cross-referenced standards maintain consistency of units between standards.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B209/B209M Specification for Aluminum and Aluminum-Alloy Sheet and Plate

E3004 Specification for Preparation and Verification of Clay Blocks Used in Ballistic-Resistance Testing of Torso Body Armor

E3005 Terminology for Body Armor

E3062/E3062M Specification for Indoor Ballistic Test Ranges for Small Arms and Fragmentation Testing of Ballistic-resistant Items

E3086 Practice for Creating Appliques for Use in Testing of Nonplanar Soft Body Armor Designed for Females

[1] This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.04 on Public Safety Equipment.

Current edition approved Oct. 1, 2022. Published November 2022. Originally approved in 2018. Last previous edition approved in 2020 as E3110/E3110M – 20. DOI: 10.1520/E3110_E3110M-22.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 *U.S. Army Research Laboratory:*[3]
ARL-TN-437 LangMod Users Manual

2.3 *Department of Defense Standards:*[4]
MIL-STD-662F V_{50} Ballistic Test for Armor

2.4 *Department of Justice Standards:*[5]
NIJ Standard–0101.06 Ballistic Resistance of Personal Body Armor

2.5 *ISO Standards:*[6]
ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories

3. Terminology

3.1 For terms not defined in this test method, the following definitions of Terminology E3005 apply: *angle of incidence, applique, backing assembly, backing material, backing fixture, ballistic limit, body armor, complete penetration, fair hit, gate, hard armor, obliquity, partial penetration, plates, shoot pack, shot-to-edge distance, shot-to-shot distance, soft body armor, stop, strike face, test item, test series, unfair hit,* V_x, V_{50}, *warmer round, yaw,* and *zone of mixed results (ZMR)*.

4. Summary of Test Method

4.1 This test method specifies multiple methods for ballistic limit testing, which are designed to estimate the penetration resistance of soft body armor, hard armor, or shoot packs.

4.2 The test method also specifies multiple methods for mounting test items. A test item is either mounted on a backing assembly with clay backing material or mounted in a frame with a separate witness panel.

4.3 Projectiles are fired at the test item starting at a specified velocity, with subsequent projectiles incrementally increasing or decreasing in velocity based on each shot outcome (complete penetration or partial penetration). This information is subsequently used to calculate the ballistic limit.

5. Significance and Use

5.1 U.S. Department of Defense and U.S. Department of Justice standards require ballistic limit determination for assessing the performance of ballistic-resistant body armor.

5.2 This test method may be used by private-sector and government laboratories, manufacturers, research and development organizations, and others assessing the ballistic resistance of body armor or performing research and development of new materials.

5.3 It is intended that this test method be referenced by other standards, specifications, and test methods.

6. Test Equipment and Apparatus

6.1 Test threats shall be specified in a separate test threats document.

6.2 The ballistic test range shall meet the requirements of Specification E3062/E3062M.

6.2.1 The method of measuring yaw may be with a yaw card, flash radiography, high speed video, or photography and shall be capable of determining, at the point of measurement, whether the angle of yaw was greater or less than 5°.

6.3 When clay blocks are required to be used as backing assemblies behind test items, they shall meet the requirements of Specification E3004.

6.4 For test procedures requiring the test item to be mounted in a frame, the frame shall consist of two layers of metal between which the test item is secured.

6.4.1 The frame shall be of sufficient size to allow restraint of the test item during ballistic impact. The frame, supports, clamps, and mounting fixtures shall be capable of securely retaining the test item and withstanding shock resulting from ballistic impact by the test projectiles.

6.4.2 Additional frame details, such as frame size and clamping force, are provided in other standards and specifications.

6.5 When required by some test procedures, a witness panel shall be used to determine whether a complete penetration has occurred.

6.5.1 The witness panel shall be at least 305 mm by 305 mm [12 in. by 12 in.].

NOTE 1—The witness panel may be larger to allow for impact by all fragments resulting from projectile penetration.

6.5.2 For opaque test items, the witness panel shall be a 0.50 mm ± 0.08 mm [0.020 in. ± 0.003 in.] thick sheet of 2024-T3, 2024-T4, or 5052 aluminum alloy.[7]

7. Hazards

7.1 The ballistic tests described in this test method have inherent hazards. Adequate safeguards for personnel and property shall be employed when conducting these tests.

8. Sampling and Test Items

8.1 The test items shall be individual soft armor panels, hard armor plates, or shoot packs.

8.2 Test item details, including quantity, size, and conditioning, shall be specified in other standards and specifications.

NOTE 2—It is recommended that spare test items be provided.

9. Test Requirements

9.1 Unless otherwise specified, each ballistic impact shall meet the requirements listed below to be considered a fair hit.

9.1.1 The test threat shall impact the test item at an angle ≤5° from the intended angle.

[3] Available from U.S. Army Research Laboratory, 2800 Powder Mill Rd., Adelphi, MD 20783-1138, https://www.arl.army.mil.

[4] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

[5] Available from National Institute of Justice (NIJ), 810 7th St., NW, Washington, DC 20531, http://nij.gov.

[6] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[7] Specifications for these alloys may be found in Specification B209/B209M or equivalent international specifications.

9.1.2 The test threat shall have yaw verified using a yaw card, flash radiography, high speed video, or photography. Yaw shall be checked for every test threat shot and shall be ≤3° for rifle threats or ≤5° for fragment and handgun threats.

9.1.2.1 The yaw measurement equipment shall be positioned perpendicular to the projectile line of flight. The yaw measurement equipment shall be securely mounted and anchored to maintain its required position and alignment.

9.1.2.2 When photographic means are used to assess the projectile yaw angle, the assessment shall be made as close as practical to the strike face of the test item but not more than 305 mm [12 in.] from the front of the strike face.

9.1.2.3 When yaw cards are used to assess the projectile yaw angle, unless specified elsewhere, the cards shall be positioned between 91 cm and 152 cm [3 ft to 5 ft] from the front of the strike face of the test item.

9.1.3 The test threat shall impact the test item no closer to the edge of the test item than the minimum shot-to-edge distance. The measurement for shot-to-edge distance shall be taken from the center of the projectile impact to the nearest edge of the ballistic material in the test item. Other standards and specifications shall specify the minimum shot-to-edge distance.

NOTE 3—Procedures for determining the edge of the test item should be specified in other standards or specifications.

9.1.4 For intended edge shots, the test threat shall impact the test item no further from the edge than the maximum shot-to-edge distance.

9.1.5 The test threat shall impact the test item no closer to a prior impact than the minimum shot-to-shot distance. The measurement for shot-to-shot distance shall be taken from the center of one projectile impact to the center of another. When the minimum shot-to-shot distance is not specified elsewhere, the minimum shot-to-shot distance shall be 51 mm [2 in.].

NOTE 4—For test items designed to defeat a single shot only, the minimum shot-to-shot distances discussed in this test method do not apply.

9.1.6 When assessing whether a particular impact location meets the minimum shot-to-shot distance requirements, the shot-to-shot distances shall be measured from that impact location to the nearest impact locations.

9.2 When warmer rounds are necessary, a test threat shall be fired through the projectile firing system to determine the exact point of impact. Additional test threats shall be fired as required until the proper alignment and a stable velocity have been achieved.

10. Mounting and Positioning of Soft Armor Test Items on a Clay Block

10.1 The test item shall be positioned on a clay block such that the entire test item is supported. When the test item exceeds the size of the clay block, backing fixture extensions shall be installed coplanar with the backing material surface to allow the test item to be fully supported.

10.1.1 Appliques needed for testing nonplanar soft armor test items shall be specified in other standards and specifications as necessary.

10.2 The test item shall be held in contact with the clay block (and appliques if present) and secured using approximately 51 mm to 76 mm [2 in. to 3 in.] wide elastic straps, held closed by hook-and-loop fasteners. Unless otherwise specified, two vertical and three horizontal straps shall be positioned such that they do not interfere with the impact points on the test item. Fig. 1 shows examples of strapping arrangements.

10.3 The clay block shall be positioned to achieve proper projectile impact location and angle (for example, angle of incidence, obliquity) of the test threat. For any shots requiring a nonzero angle of incidence, the clay block shall be rotated to achieve the appropriate angle.

10.4 Between test threat impacts, the test item shall be manipulated by hand so that any wrinkles or bunching in the test item (caused by a previous shot) are smoothed out.

10.4.1 No effort shall be made to recover any projectiles trapped in the test item until the test series is complete.

NOTE 5—Slight manipulation of a projectile is allowed if the projectile will interfere with subsequent shots.

10.4.2 The test item shall be repositioned on the backing material such that the test item is supported by smooth backing material for a distance of no less than 76 mm [3 in.] in all directions around the next shot location.

10.4.3 Instructions related to striking the backing material between shots shall be specified by other standards and specifications.

11. Mounting and Positioning of Hard Armor Test Items on a Clay Block

11.1 The test item shall be positioned on a clay block such that the entire test item is supported.

11.2 Testing of nonplanar hard armor test items on a clay block requires the use of appliques between the test item and the clay block.

NOTE 6—Testing of planar hard armor test items does not require the use of appliques. The applique details of this section may also apply for nonplanar soft armor that requires the use of appliques between the test item and the clay block.

11.2.1 The applique shall conform to the wear face of the test item and create a planar surface for the test item to contact the surface of the clay block.

NOTE 7—Practice E3086 specifies how to create appliques for nonplanar armor intended for females.

11.2.2 The applique shall be formed such that it completely fills the space between the test item and the clay block surface. The applique shall be the minimum thickness required to completely fill the space without preventing contact between the test item edges (or corners) and the surface of the clay block (for example, a multi-curve plate should have at least four points of contact between its edges and the surface of the clay block). See Fig. 2 for an example of a test item with an applique installed.

NOTE 8—A mold is necessary to create an appropriate applique sized for a specific test item, and it is possible that the hard armor could serve as the mold. Other standards and specifications may provide guidance for creating the mold and the applique and for conditioning the applique prior

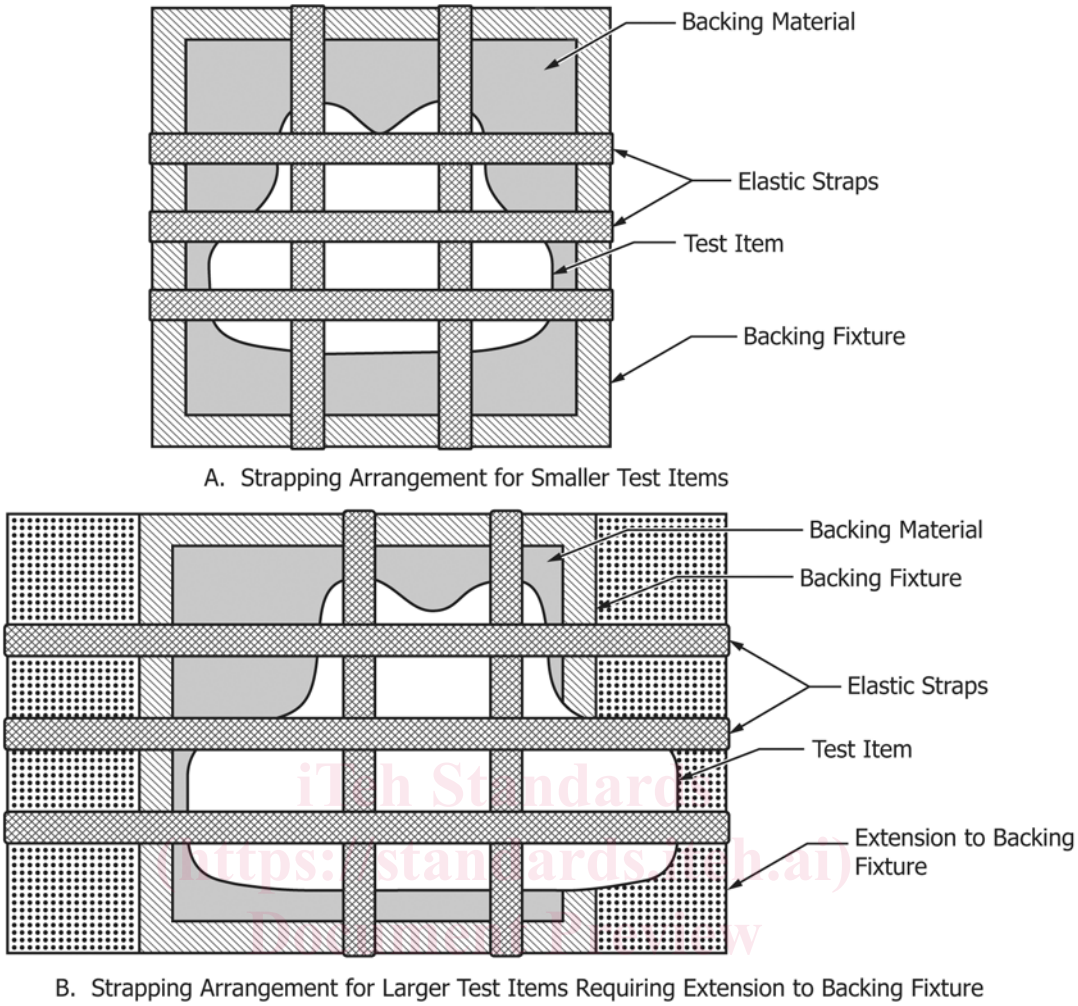

FIG. 1 Examples of Strapping Arrangements

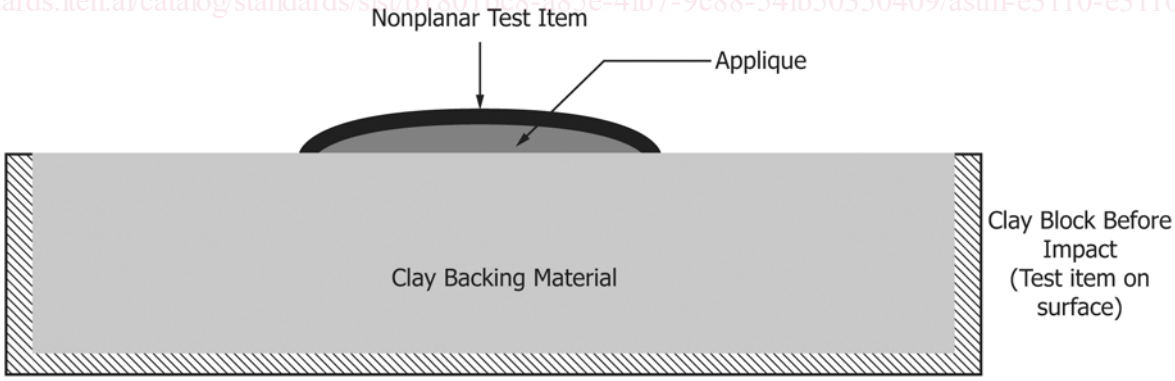

FIG. 2 Example of Test Item with Applique Installed

to use. Some testing requires that the hard armor be tested with soft armor or a shoot pack (that is, in conjunction with armor). In those cases, the hard armor shall be placed appropriately in contact with the soft armor or a shoot pack (placed on the front or inserted).

11.2.3 The applique shall be placed in intimate contact with the clay block prior to testing, and a modicum of force shall be applied to hold the applique in position.

11.2.3.1 When necessary to further secure the applique to the clay block, hand form conditioned clay into a long, thin strip. Place the strip around portions of the perimeter of the applique at the interface with the clay block, and press the clay strip into the interface to ensure that the applique remains adhered to the clay block during testing.

11.2.3.2 Care is required to ensure that the shape of the applique is not significantly changed during affixing it to the clay block.

11.3 The test item shall be positioned on a clay block (with or without an applique installed, as appropriate) such that the entire test item is supported, as shown in Fig. 2.

11.4 The test item shall be held in contact with the clay block and secured using approximately 51 mm to 76 mm [2 in. to 3 in.] wide elastic straps, held closed by hook-and-loop fasteners. Vertical and horizontal straps shall be positioned such that they do not interfere with the impact points on the test item.

11.5 The clay block shall be positioned to achieve proper projectile impact location and angle of incidence of the test threat. For any shots requiring a nonzero angle of incidence, the clay block shall be rotated to achieve the appropriate angle.

11.6 Between test threat impacts, any soft armor backing shall be manipulated by hand so that any wrinkles or bunching in the test item (caused by a previous shot) are smoothed out. No effort shall be made to recover any projectiles trapped in the test item until the test series is complete.

NOTE 9—Slight manipulation of a projectile is permitted if the projectile will interfere with subsequent shots.

12. Mounting of Test Items in a Frame

12.1 The test item shall be sandwiched in a frame and restrained with mechanical or pneumatic clamping devices either at the center of each side of the frame or at each corner of the frame.

12.2 The witness panel shall be positioned behind and parallel to the test item. The witness panel distance to the test item shall be specified in other standards and specifications. If no specification is listed, securely mount the witness panel 150 mm ± 25 mm [6.0 in. ± 1.0 in.] behind the area of impact.

12.3 Between test threat impacts on soft armor, the test item shall be removed from the frame and manipulated by hand so that any wrinkles or bunching in the test item (caused by a previous shot) are smoothed out. No effort shall be made to recover any projectiles trapped in the test item until the test series is complete unless the projectile or fragment interferes with the clamping mechanism in such a way that would result in unequal pressure applied to all sides of the test item.

NOTE 10—Slight manipulation of a projectile is allowed if the projectile will interfere with subsequent shots.

13. V_{50} Ballistic Limit Procedure: Up-Down Method Based on MIL-STD-662F

13.1 This method is intended for determining the V_{50} ballistic limit and is not appropriate for determining other ballistic limit values.

13.2 *Test Procedure Requirements:*

13.2.1 A complete V_{50} ballistic limit test series consists of successful individual ballistic tests being conducted on a number of test items.

13.2.2 The test procedure shall result in an equal number of the highest partial penetration velocities and the lowest complete penetration velocities, which occur within a specified velocity range.

13.2.2.1 The required number of highest partial penetrations and lowest complete penetrations shall be specified by other standards and specifications, and typical numbers and the maximum allowable velocity range are listed in Table 1.

13.2.2.2 The number of test items to be provided for the above shots shall be specified by other standards and specifications.

13.2.3 Unless specified elsewhere, the starting velocity shall be 23 m⁄s to 30 m⁄s [75 ft⁄s to 100 ft⁄s] above the minimum required V_{50} as specified in other standards and specifications.

13.2.4 The intended angle of incidence for all shots shall be specified in other standards and specifications.

13.2.5 Firing shall be done using a random pattern of impact sites, unless specified otherwise in other standards and specifications.

13.2.6 For every shot, verify that the shot was a fair hit (per Section 9 of this test method), taking the following steps:

13.2.6.1 The velocity shall be checked to determine whether it was within the specified range.

13.2.6.2 The difference between the velocity readings from each independent instrument shall be compared as specified in Specification E3062/E3062M.

13.2.6.3 The shot spacing shall be assessed to determine if shot-to-edge, shot-to-shot, and shot-to-clay block edge or shot-to-frame/clamp edge distances meet specified requirements.

13.2.6.4 If the shot is determined to be unfair, another shot shall be taken on that test item in a location that meets shot spacing requirements. If there is not sufficient room to take the required shots, then other standards or specifications shall specify the appropriate course of action.

13.3 *Steps:*

13.3.1 Mount the test item in a frame as specified in Section 12.

13.3.2 Fire the first test threat at the test item.

13.3.3 When the first shot is a fair hit and results in a complete penetration, subsequent shots shall be taken in accordance with the sequence described below, and the flowchart in Annex A1, Fig. A1.1.

13.3.3.1 The next shot velocity shall be equal to the measured velocity of the previous shot *minus* 15 m/s or 30 m/s [50 ft⁄s or 100 ft⁄s].

13.3.3.2 Continue firing the test threat at incrementally decreasing velocities, as given in 13.3.3.1, until a partial penetration is obtained.

TABLE 1 Typical Numbers and Maximum Allowable Velocity Ranges

Label	Number of Highest Partial Penetrations	Number of Lowest Complete Penetrations	Maximum Allowable Velocity Range
2 × 2	2	2	18 m/s [60 ft/s]
3 × 3	3	3	38 m/s [125 ft/s]
5 × 5	5	5	46 m/s [150 ft/s]

13.3.3.3 Once a partial penetration is obtained, continue with the sequence given in 13.3.5.

13.3.4 When the first shot is a fair hit and results in a partial penetration, subsequent shots shall be taken in accordance with the sequence described below, and the flowchart in Annex A1, Fig. A1.2.

13.3.4.1 The next shot velocity shall be equal to the measured velocity of the previous shot *plus* 15 m/s [50 ft/s].

13.3.4.2 Continue firing the test threat at incrementally increasing velocities, as given in 13.3.4.1, until a complete penetration is obtained.

13.3.4.3 Once a complete penetration is obtained, continue with the sequence given in 13.3.5.

13.3.5 Continue firing the test threat at the incrementally increasing velocities (for partial penetrations) or at decreasing velocities (for complete penetrations). Each velocity should change at approximately 15 m/s [50 ft/s] increments until an equal number of partial penetrations and complete penetrations is obtained within the allowable range.

NOTE 11—The V_{50} is calculated by taking the arithmetic mean of an equal number of the highest partial and the lowest complete penetration impact velocities that fall within the allowable velocity range as listed in Table 1 or as specified in other standards and specifications. Other standards and specifications should provide guidance for the path forward when the highest partial penetration and lowest complete penetration are outside the allowable velocity range.

13.4 If the test progresses to velocities beyond the capabilities of the test range, then the test laboratory shall document that this situation has occurred.

14. Ballistic Limit Procedure: NIJ Method Based on NIJ Standard-0101.06

14.1 This method is intended to generate experimental results that can be used, with an appropriate numerical model, to estimate ballistic response over a range of impact velocities. An appropriate model will allow the V_x values to be calculated for a range of penetration probabilities (x) and provide an estimate of the confidence associated with that V_x.

14.2 *Test Procedure Requirements:*

14.2.1 A complete test series for the ballistic limit consists of individual ballistic tests being conducted on a number of individual test items. The conditions that constitute the dividing line between a partial penetration and a complete penetration shall be specified in other standards and specifications.

14.2.2 The velocity of the first shot and subsequent velocity increments shall be specified in other standards and specifications.

14.2.3 The angles of incidence for all shots shall be 0°.

14.2.4 For every shot, verify that the shot was a fair hit (per Section 9 of this test method), taking the following steps:

14.2.4.1 The difference between the velocity readings from each independent instrument shall be compared as specified in Specification E3062/E3062M.

14.2.4.2 The shot spacing shall be assessed to determine if shot-to-edge, shot-to-shot, and shot-to-clay block edge distances meet specified requirements.

14.2.4.3 If the shot is determined to be unfair, another shot shall be taken on that test item in a location that meets shot spacing requirements. If there is not sufficient room to take the required shots, then other standards or specifications shall specify the appropriate course of action.

14.3 *Steps:*

14.3.1 Mount the test item on a clay block as described in either Section 10 or Section 11 (as appropriate).

14.3.2 Fire the first test threat at the test item.

14.3.3 When the first shot results in a complete penetration, subsequent shots shall be taken as described below. A graphical explanation of these requirements is provided in the flowchart in Annex A2, Fig. A2.1.

14.3.3.1 The velocity of the next shot shall be decreased by a nominal 30 m/s [100 ft/s]. Continue this decrease of subsequent velocities until a partial penetration occurs.

14.3.3.2 Once a partial penetration occurs, the velocity of each shot shall be increased by a nominal 23 m/s [75 ft/s] until a complete penetration occurs.

14.3.3.3 Continue shooting until the required number of shots has been placed on the test item. For each shot the velocity shall be decreased by a nominal 15 m/s [50 ft/s] after a complete penetration occurs or increased by a nominal 15 m/s [50 ft/s] after a partial penetration occurs.

14.3.4 When the first shot results in a partial penetration, subsequent shots shall be taken as described below. A graphical explanation of these requirements is provided in the flowchart in Annex A2, Fig. A2.2.

14.3.4.1 The velocity of the next shot shall be increased by a nominal 30 m/s [100 ft/s]. Continue this increase of subsequent velocities until a complete penetration occurs.

14.3.4.2 Once a complete penetration occurs, the velocity of each shot shall be decreased by a nominal 23 m/s [75 ft/s] until a partial penetration occurs.

14.3.4.3 Continue shooting until the required number of shots has been placed on the test item. For each shot the velocity shall be decreased by a nominal 15 m/s [50 ft/s] after a complete penetration occurs, or increased by a nominal 15 m/s [50 ft/s] after a partial penetration occurs.

14.3.5 Repeat the above steps until either the required number of shots or the maximum number of shots that can be placed on the test item has been reached. For a test item of size that does not allow the required number of shots, the firing sequence shall be continued on additional test items until the required number of shots is reached. The number of shots required depends on the protection capability claimed for the test item, and unless specified elsewhere, the requirements in Table 2 shall be followed.

14.3.6 After each sequence of required shots, a new sequence shall be performed until the total required number of shots for the test series has been reached.

14.3.7 When the ballistic limit is sufficiently high that achieving the velocity necessary to perforate the test item is

TABLE 2 Requirements for Number of Test Items and Shots

Protection Capability	Required Number of Test Items Per Threat	Minimum Number of Shots Required
Handgun	10	120
Rifle	8	24
Armor-Piercing Rifle	4 to 12	12

difficult or impossible, the test laboratory shall document this situation has occurred.

14.3.7.1 In such cases, the test series will be considered acceptable even if the minimum number of complete penetrations is not achieved, unless specified elsewhere.

15. Ballistic Limit Procedure: Modified Langlie Method[8]

15.1 This method is intended to generate experimental results that can be used to estimate the ballistic response to include V_x for a range of penetration probabilities.

15.2 *Test Procedure Requirements:*

15.2.1 A complete test series for the ballistic limit consists of individual ballistic tests being conducted on a number of individual test items. The number of test items to be provided shall be specified by other standards and specifications.

15.2.2 The lower and upper gates for the threat shall be selected prior to testing.

NOTE 12—The gates may be specified in other standards and specifications.

15.2.2.1 The lower gate shall be set at a velocity where partial penetrations are expected to be consistently observed.

15.2.2.2 The upper gate shall be set at a velocity where complete penetrations are expected to be consistently observed.

15.2.2.3 The gates shall be set so that the lower gate is at least 20 m/s [65 ft/s] below the lower limit of the expected zone of mixed results (ZMR) and the upper gate is at least 20 m/s [65 ft/s] above the upper limit of the expected ZMR.

NOTE 13—A gate radius of 30 m⁄s to 76 m⁄s [100 ft⁄s to 250 ft⁄s] from the expected V_{50} is reasonable (for example, $V_{50} \pm 76$ m/s [250 ft/s]). For testing of materials that do not have an expected V_{50}, the gate radius should be expanded to 30 m⁄s to 122 m⁄s [100 ft⁄s to 400 ft⁄s].

15.2.3 The intended angle of incidence for all shots shall be specified in other standards and specifications.

15.2.4 For every shot, verify that the shot was a fair hit (per Section 9 of this test method), taking the following steps:

15.2.4.1 The velocity shall be checked to determine whether it was within the specified range.

15.2.4.2 The difference between the velocity readings from each independent instrument shall be compared as specified in Specification E3062/E3062M.

15.2.4.3 The shot spacing shall be assessed to determine if shot-to-edge, shot-to-shot, and shot-to-clay block edge or shot-to-frame/clamp edge distances meet specified requirements.

15.2.4.4 If the shot is determined to be unfair, another shot shall be taken on that test item in a location that meets shot spacing requirements. If there is not sufficient room to take an additional shot, then other standards or specifications shall specify the appropriate course of action.

15.3 *Steps:*

15.3.1 Fire the test threat at a velocity midway between the gates.

15.3.1.1 If the first shot results in a complete penetration, decrease the velocity of the second round halfway between the first round velocity and the lower gate velocity. If the first round results in a partial penetration, increase the velocity of the second round to halfway between the first round velocity and the upper gate velocity.

15.3.1.2 If the first two rounds results in a reversal (that is, one partial penetration and one complete penetration), fire the third round midway between the velocity of the first two rounds. If the first two rounds result in two partials, fire the third round at a velocity halfway between the second round velocity and the upper gate. If the first two rounds result in two complete penetrations, fire the third round at a velocity halfway between the velocity of the second round and the lower gate.

15.3.1.3 If a reversal does not occur in three rounds, adjust the lower and upper gates as follows. If all rounds result in partial penetrations, raise the lower and upper gates by 20 m/s [65 ft/s]. If all rounds result in complete penetrations, decrease the lower and upper gates by 20 m/s [65 ft/s]. Fire the next round half way between the last round and, in case of three partial penetrations, the upper gate or, in the case of three complete penetrations, the lower gate.

15.3.2 Fire the succeeding rounds as follows:

15.3.2.1 If the preceding pair of rounds resulted in a reversal, fire the next round at the velocity midway between the two velocities.

15.3.2.2 If the last two rounds did not produce a reversal, examine the results of the last four rounds. If the number of complete penetrations and partial penetrations is equal, fire the next round at the velocity midway between the velocity of the first and last rounds of the group. If the last four did not produce equal numbers of partial penetrations and complete penetrations, look at the last six, eight, etc., until the number of partial penetrations and complete penetrations is equal. Always fire at a velocity that is halfway between the first and the last round of the group examined.

15.3.2.3 If the conditions in 15.3.2.2 cannot be satisfied and the last round resulted in a complete penetration, fire the next round at a velocity midway between the last round and the lower velocity limit, or if the last round resulted in a partial penetration, fire at a velocity midway between the last round and the upper velocity limit.

15.3.2.4 Repeat the above steps of 15.3.2.1 – 15.3.2.3 until a minimum of twelve impacts has been recorded, and the test stopping requirements of 15.4 can be applied.

15.4 *Test Stopping Requirements:*

15.4.1 Obtain a ZMR. The size of the ZMR is the difference in velocity between the highest partial penetration and the lowest complete penetration, and

15.4.1.1 The average of the complete penetrations is larger than the average of the partial penetrations, and

15.4.1.2 Unless otherwise specified in the test threats document, the range of at least three partial penetrations and an equal number of complete penetrations is within 38 m⁄s [125 ft⁄s], and

15.4.1.3 Using the V_{50} that is estimated from the three highest partial penetrations and three lowest complete penetrations, ensure that the data set contains results at velocities approximately $V_{50} \pm \Delta$. Set Δ to 20 m/s [65 ft/s] unless specified elsewhere.

[8] This procedure is based on ARL-TN-437, *LangMod Users Manual.*