Designation: D8101/D8101M – 17

Standard Test Method for Measuring the Penetration Resistance of Composite Materials to Impact by a Blunt Projectile[1]

This standard is issued under the fixed designation D8101/D8101M; 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 measures the resistance of flat composite panels in one specific clamping configuration to penetration by a blunt projectile in free flight. In this test method, the term "penetration" is defined as the case in which the projectile travels completely through the composite panel and fully exits the back side. The composite materials may be continuous fiber angle-ply, woven or braided fiber-reinforced polymer matrix composites, or chopped fiber-reinforced composites. The resistance to penetration is quantified by a statistical function that defines the probability of penetration for a given kinetic energy.

1.2 This test method is intended for composite test panels in which the thickness dimension is small compared with the test panel width and length (span to thickness greater than fifty).

1.3 This test method is intended for applications such as jet engine fan containment, open rotor engine blade containment, or other applications in which protection is needed for projectiles at velocities typically lower than seen in ballistic armor applications. The typical impact velocity that this test is intended for is in the range of 100 to 500 m/s [300 to 1500 ft/s], as opposed to higher velocities associated with armor penetration.

1.4 A flat composite panel is fixed between a circular-shaped clamping fixture and a large base fixture each with a large coaxial hole defining a region of the panel that is subjected to impact in the direction normal to the plane of the flat panel by a blunt projectile. Clamping pressure is provided by twenty-eight through bolts that pass through the front clamp, the test specimen and the back plate. The mass, geometry, desired impact kinetic energy, and impact orientation of the projectile with respect to the panel are specified before the test. Equipment and procedures are required for measuring the actual impact velocity and orientation during the test. The impact penetration resistance can be quantified by either the velocity or kinetic energy required for the projectile to penetrate the test panel fully. A number of tests are required to obtain a statistical probability of penetration for given impact conditions.

1.5 This test method measures the penetration resistance for a specific projectile and test configuration and can be used to screen materials for impact penetration resistance, compare the impact penetration resistance of different composite materials under the same test geometry conditions, or assess the effects of in-service or environmental exposure on the impact penetration resistance of materials.

1.6 The impact penetration resistance is highly dependent on the test panel materials and architecture, projectile geometry and mass, and panel boundary conditions. Results are not generally scalable to other configurations but, for the same test configurations, may be used to assess the relative impact penetration resistance of different materials and fiber architectures.

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 may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Within the text, the inch-pound units are shown in brackets.

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 and health 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.*

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[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

A36/A36M Specification for Carbon Structural Steel

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D883 Terminology Relating to Plastics

D3171 Test Methods for Constituent Content of Composite Materials

D3878 Terminology for Composite Materials

D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation

E2533 Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications

2.2 *NIJ Standard*[3]

NIJ Standard 0101.06 Body Amor—Ballistic Resistance

3. Terminology

3.1 *Definitions*—In Terminology D3878, terms are defined relating to composite materials. In Terminology D883, terms are defined related to plastics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other standards.

3.2 *Definitions of Terms Specific to This Standard:* If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: [M] for mass, [L] for length, [T] for time, [θ] for thermodynamic temperature, and [nd] for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the terms may have other definitions when used without the brackets.

3.2.1 *impact velocity, Vi [LT^{-1}], n*—velocity of the projectile in the direction of projectile travel just before impact.

3.2.2 *penetrate, v*—to travel fully through a body and emerge completely on the other side.

3.2.3 *projectile face, n*—front portion of the projectile that first comes into contact with the test panel.

3.2.4 *projectile orientation, n*—angular position of the projectile as determined by a set of measurements relative to the reference coordinate system.

3.2.4.1 *Discussion*—Typically used to define the angular position of the projectile just before impact with the test specimen.

3.2.5 *Impact Penetration Resistance (IPR), n*—the kinetic energy (or associated impact velocity) of a projectile corresponding to the 50% probability of penetration.

3.2.6 *reference coordinate system, n*—coordinate system defined for the purpose of identifying the impact velocity and orientation of the projectile and the orientation of the test specimen.

3.2.6.1 *Discussion*—An example of a reference coordinate system is one in which the X direction is normal to the plane of the flat panel with positive values measured in the direction of the projectile travel, the Y direction is in the plane of the flat test panel and is horizontal with positive values measured to the right when viewing the panel from the impacted side, and the Z direction is vertical with positive values measured downward and the origin is at the center of the panel on the impacted face. The reference coordinate system is defined by the organization conducting the tests.

3.2.7 *residual velocity, Vr [LT^{-1}], n*—absolute velocity of the projectile just after penetration (if penetration occurs).

3.3 *Symbols:*

3.3.1 E_a [ML^2T^{-2}] —Loss in kinetic energy of the projectile as a result of the impact.

3.3.2 E_i [ML^2T^{-2}] —Kinetic energy of the projectile at the time of impact.

3.3.3 E_r [ML^2T^{-2}]—Kinetic energy of the projectile after penetrating the test panel (if penetration occurs).

3.3.4 M[M]—Projectile mass.

4. Summary of Test Method

4.1 An impact test is performed by accelerating a defined projectile to a specified velocity, typically with the use of a single-stage gas gun, into a composite test panel that is supported in a fixture. The test panel is supported in a circular fixture with precision bolts extending through a front clamp and the specimen itself to avoid slipping of the specimen at the boundaries. The location of the holes is remote from the impact site so that damage is not initiated at the holes. Depending on the kinetic energy of the projectile, it may or may not damage or penetrate the test panel. The penetration resistance is quantified by either the velocity or kinetic energy required to penetrate the test panel. The penetration resistance is a function of the geometry and materials of the test panel. Comparisons between materials or material conditions cannot be made unless identical test configurations and test conditions are used.

4.2 Procedures and equipment for measuring the impact velocity and orientation of the projectile just before impact are required. Equipment for measuring the residual velocity of the projectile after penetration, if it occurs, is desirable but not required.

5. Significance and Use

5.1 Advanced composite systems are used in a number of applications as shields to prevent penetration by projectiles. In general, the use of composites is more effective for blunt, rather than sharp, projectiles or in hybrid systems in which an additional shield can be used to blunt a sharp projectile.

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[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.

[3] Available from the National Institute of Justice, Washington, DC, www.jij.gov/publications.

Knowledge of the penetration impact resistance of different material systems or the effects of environmental or in-service load exposure to the penetration resistance of given materials is useful for product development and material selection.

5.2 An impact test used to measure the penetration resistance of a material can serve the following purposes:

5.2.1 To quantify the effect of fiber architecture, stacking sequence, fiber and matrix material selection, and processing parameters on the penetration resistance of different composite materials;

5.2.2 To measure the effects of environmental or in-service load exposure on the penetration impact resistance of a given material system; and

5.2.3 As a tool for quality assurance requirements for materials designed for penetration resistance applications.

5.3 The penetration resistance values obtained with this test method are most commonly used in material specification and selection and research and development activities. The data are not intended for use in establishing design allowables, as the results are specific to the geometry and physical conditions tested and are not generally scalable to other configurations.

5.4 The reporting section requires items that tend to influence the penetration resistance of material systems. These include the following: fiber and matrix materials, fiber architecture, layup sequence, methods of material fabrication, environmental exposure parameters, specimen geometry and overall thickness, void content, specimen conditioning, testing environment and exposure time, specimen fixture and alignment, projectile mass and geometry, and projectile orientation at impact. Additional reporting requirements include size and description of damage, results of any pre- and post-test nondestructive inspection, impact velocity, accuracy of the velocity measurement apparatus, and whether or not the projectile penetrated the panel. Residual velocity is a desirable, but not a necessary, value to be reported.

5.5 The reporting section shall also include the parameters of a statistical function that gives the probability of penetration as a function of impact kinetic energy (see 14.4).

5.6 The relevant measurements that result from the impact test are the kinetic energy and impact velocity of the projectile and whether or not the projectile penetrated the specimen. An optional item to be measured is the loss in kinetic energy of the projectile as a function of impact velocity if measurements of the residual velocity are recorded.

6. Interferences

6.1 The impact penetration resistance is dependent on many factors, such as test specimen thickness, areal density, fiber architecture, fiber and matrix materials, fiber volume ratio, pre-test environmental and load exposure, test environment, boundary conditions, projectile geometry, and projectile mass. Consequently, comparisons cannot be made between materials unless identical test configurations, test conditions, and material thickness are used. Therefore, all deviations from the standard test configuration shall be reported in the results.

6.2 *Materials and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber placement and stacking sequence alignment, and damage induced by improper specimen machining are known causes of high material data scatter in composites in general. Important aspects of panel specimen preparation that contribute to data scatter include thickness variation and out-of-plane curvature.

6.3 *Impact Location and Projectile Orientation*—The location of the projectile impact shall occur at the center of the panel for results to be valid. Lack of control over the impact location will produce scatter in the results and invalidate comparisons between different materials or environmental exposure conditions. The orientation of the projectile shall be such that its center of mass is aligned with the impact direction and the impact direction is normal to the plane of the test specimen. Differences in projectile orientation between tests will lead to data scatter.

6.4 *Support Fixture Characteristics*—Results are affected by the dimensions, as well as the corresponding mass and rigidity of the support fixture. Bolt torque differences will affect the boundary conditions and lead to inconsistent results. The support fixture shall be significantly more rigid than the test specimen for results to be valid.

6.5 *Impact Device Characteristics*—The method of accelerating the projectile will affect the repeatability of the projectile impact velocity and orientation. Lack of control over repeatability will require a greater number of tests to ensure statistically valid results are obtained.

6.6 *Velocity and Orientation Measurement Equipment*—Valid results are directly dependent on the accuracy of the velocity and orientation measurements.

6.7 *Damage Modes*—Damage mode differences between materials will affect the evaluation of results. Widespread damage that extends to the specimen boundaries may invalidate results.

6.8 *Nondestructive Inspection*—Nondestructive testing (NDT) results are affected by a number of factors, including the particular Practice or Test Method used, the inherent variability of the NDT Practice or Test Method, and the experience of the operator.

7. Apparatus

7.1 *Micrometers and Calipers*—A micrometer with a 4 to 7 mm [0.16 to 0.28 in.] nominal diameter ball interface or a flat anvil interface shall be used to measure the specimen thickness. A ball interface is recommended for thickness measurements when at least one surface is irregular (for example, a coarse peel ply surface that is neither smooth nor flat). A micrometer or caliper with a flat anvil interface shall be used for measuring length, width, and other machined surface dimensions. The use of alternative measurement devices is permitted if specified (or agreed to) by the test requestor and reported by the testing laboratory. The accuracy of the instrument(s) shall be suitable for reading to within 1 % of the specimen dimensions. For typical specimen geometries, an instrument with an accuracy of ±0.0025 mm [±0.0001 in.] is adequate for thickness measurements, while an instrument with an accuracy of ±0.025 mm [±0.001 in.] is adequate for measurement of length, width, and other machined surface dimensions.

7.2 *Balance or Weighing Scale*—An analytical balance or weighing scale is required that is capable of measuring the mass of the projectile accurately to within ±0.5 %.

7.3 *Velocity Measurement*—The impact device shall be instrumented to measure the velocity of the impactor at a given point before impact. Several approaches to velocity measurement are available, and the selection of a particular method is dependent upon the desired measurement accuracy. One commonly used approach to velocity measurement uses a pair of laser beams pointed in a direction normal to the path of the projectile and separated by a known distance. The laser beams are directed at detectors that measure the light intensity. As the projectile interrupts the laser beam, the detector signal changes state, indicating an interruption in the light path. The time between the detections and the distance between the beams are used to calculate the projectile velocity. An alternate approach is to use photogrammetry to track targets on the projectile to compute velocity. The required accuracy of the velocity measurement system, and the associated method for verifying the measurement accuracy, shall be specified by the test requestor.

NOTE 1—It is recommended that the test requestor specify the required accuracy of the velocity measurement as a percentage of indicated value.

7.4 *Attitude Measurement*—Equipment shall be used for measuring the orientation of the projectile just before impact. The accuracy of data shall be reported. An example of equipment that may be used is a pair of calibrated high-speed cameras and a digital image correlation system. The required accuracy of the orientation measurement system, and the associated method for verifying the measurement accuracy, shall be specified by the test requestor.

7.5 *Impact Location Measurement*—Impact Location Measurement—Tools shall be used for measuring the impact location relative to the center point of the specimen. The accuracy of the equipment shall be reported. An example of equipment that may be used is a standard machinist scale.

7.6 In general, any device capable of accelerating the projectile in free flight into the test specimen with a repeatable velocity and orientation at sufficient speeds to penetrate the panel is acceptable. The device should be designed in such a way to minimize axial spin in the projectile. A schematic of an example of such a device is shown in Fig. 1. This device is a single-stage compressed gas gun and consists of a pressure vessel, a burst valve, and a gun barrel aimed at the test specimen. For safety, the test specimen should be located inside of a closed containment structure vented to allow pressure in the structure to be released. The device shown in Fig. 1 has a pressure vessel volume of approximately 0.011 m^3 [671 $in.^3$]. The burst valve consists of a pair of thin biaxially oriented polyethylene terephthalate (BoPET) polyester sheets with a thickness of approximately 0.125 mm [0.005 in.] with a nichrome wire sandwiched between them in a circular shape slightly smaller diameter than the gun barrel. The gun barrel has a length of approximately 3.7 m [12 ft] and a machined-smooth bore with a diameter approximately 0.05 mm [0.002 in.] greater than the diameter of the projectile. To operate the device, a projectile is loaded into the breach of the gun, and the pressure vessel is connected to the gun barrel with the polyester sandwiched between the two. Helium or nitrogen is introduced into the pressure vessel to the desired pressure. A voltage is applied to the nichrome wire, which heats up and causes the polyester sheets to rupture. The released gas accelerates the projectile down the gun barrel. Before impact, and after exiting the gun barrel, there is a region of free flight, which shall be long enough for the velocity and the orientation of the projectile to be measured.

7.7 *Support Fixture*—The impact test fixture, shown schematically in Fig. 2, is constructed from structural steel, Specification A36/A36M or equivalent or higher strength, and consists of a heavy back frame with a circular aperture and a circular front frame with through bolts that thread into nuts on the back of the frame. The inner diameter of the front frame and the circular aperture of the back frame is 254 mm [10 in.]. The test specimen is sandwiched between the two components. The test specimen shall extend a minimum of 25.4 mm [1 in.] beyond the circular aperture of the back frame so that it is completely clamped between the two parts of the fixture. The specimen contains machined holes to accommodate the through bolts. To minimize slippage at the specimen boundaries, the bolts are precision shoulder type with a

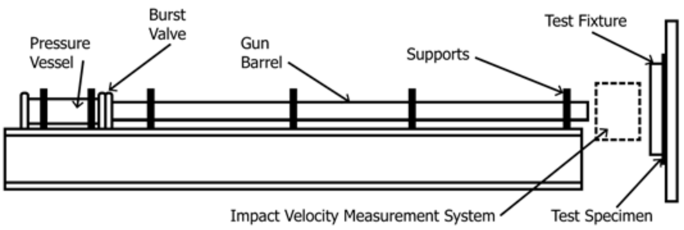


FIG. 1 Schematic of a Gas Gun Used for Accelerating Projectiles into Composite Panels

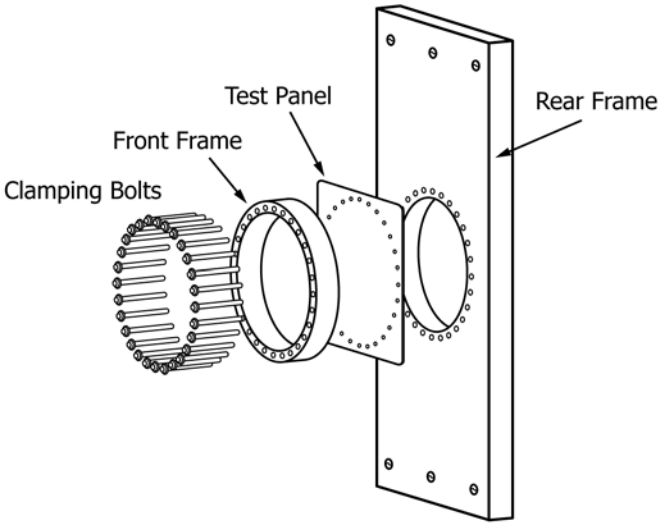


FIG. 2 Exploded View of Impact Test Fixture, including Front Frame, Test Panel, Back Frame, and Clamping Bolts

minimum tensile strength of 965 MPa [140 ksi]. The holes in the front frame and the specimen are precision machined to accommodate a clearance fit. All bolts should be torqued to a minimum value of 25 N-m [220 in.-lb]. Number the bolts sequentially from 1 to 28 around the bolt circle. Using a torque wrench, tighten the nut on each stud in an appropriate sequence to distribute the pressure on the test panel. A recommended order for tightening the bolts is 1, 15, 8, 22, 5, 19, 12, 26, 3, 17, 10, 24, 6, 20, 13, 27, 2, 16, 9, 23, 7, 21, 14, 28, 4, 18, 11, and 25. Tighten the bolts according to the following increments:

7.7.1 Tighten each stud to approximately 40 % of the final torque,

7.7.2 Tighten each stud to approximately 70 % of the final torque, and

7.7.3 Tighten each stud to 100 % of the final torque.

7.7.4 *Support Fixture Details*—Detailed drawings for manufacturing a support fixture that satisfies the requirements of the test method are contained in Figs. 3-8. The supporting frame shall be stiff and heavy compared to the test specimen. Thus, the front and rear frame are specified to be manufactured from steel, both with a thickness of 50 mm [2 in.].

7.8 *Projectile*—The projectile used for this test is shown in Fig. 9 and Fig. 10. It is a 2024-T351 aluminum thin-walled, cup-shaped projectile with a well-defined front face radius. The critical dimensions are the inner and outer radius of the front face, the overall diameter, and the wall thickness. The projectile shown in Fig. 9 and Fig. 10 is the recommended projectile; if it is necessary to alter the mass of the projectile to achieve penetration velocities in the range of interest for a given application, the thickness of the front face can be varied. This shall be done without changing the front face inner or outer radii. However, results are invalidated if the front face thickness is reduced to the point at which the impact test results in visible permanent deformation of the projectile. The mass of the projectile for both the SI and inch-pound versions of the test method is specified to be 50 ± 0.5 g [1.8 ± 0.02 oz]. If the front face thickness is altered, the mass of all projectiles in a given test series shall be within plus or minus 1 % of the stated mass. Typically, a projectile is used only once as it may sustain plastic deformation as a result of either impacting the test panel or secondary impacts after impacting the panel. If a projectile is to be reused, it shall be inspected to ensure that its dimensions are within the required tolerances.

8. Hazards

8.1 The use of compressed gas as a propellant and free-flying projectiles always presents safety issues.

8.2 Ensure that, if used to propel the projectile, the pressure vessel has been safety checked, relief valves are in place and functional, and all hoses and piping are according to applicable safety codes.

8.3 3 Ensure that the test fixture is contained within safety shields so that the projectile cannot rebound and injure laboratory personnel.

8.4 Ensure that the compressed gas, when released, is properly vented so as not to cause an overpressure situation in the test laboratory or the containment structure.

9. Sampling and Test Specimens

9.1 *Sampling*—Test at least six specimens per test condition over a range of impact velocities that spans the velocity

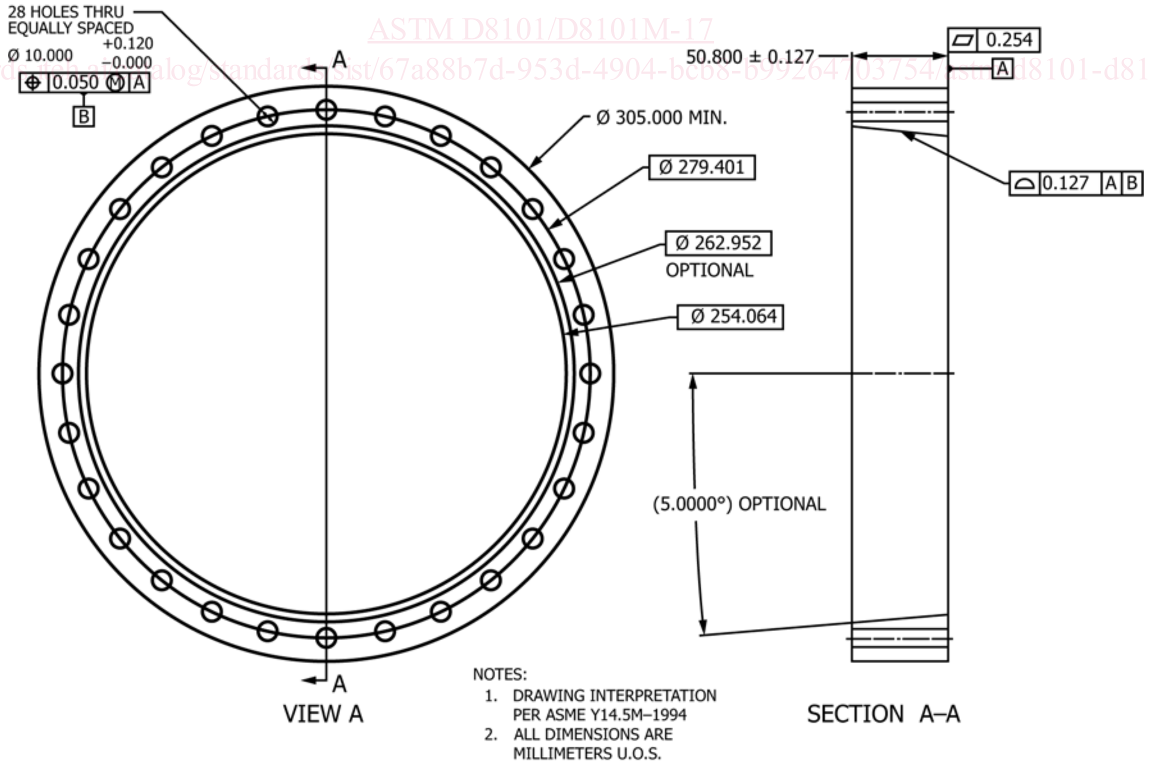
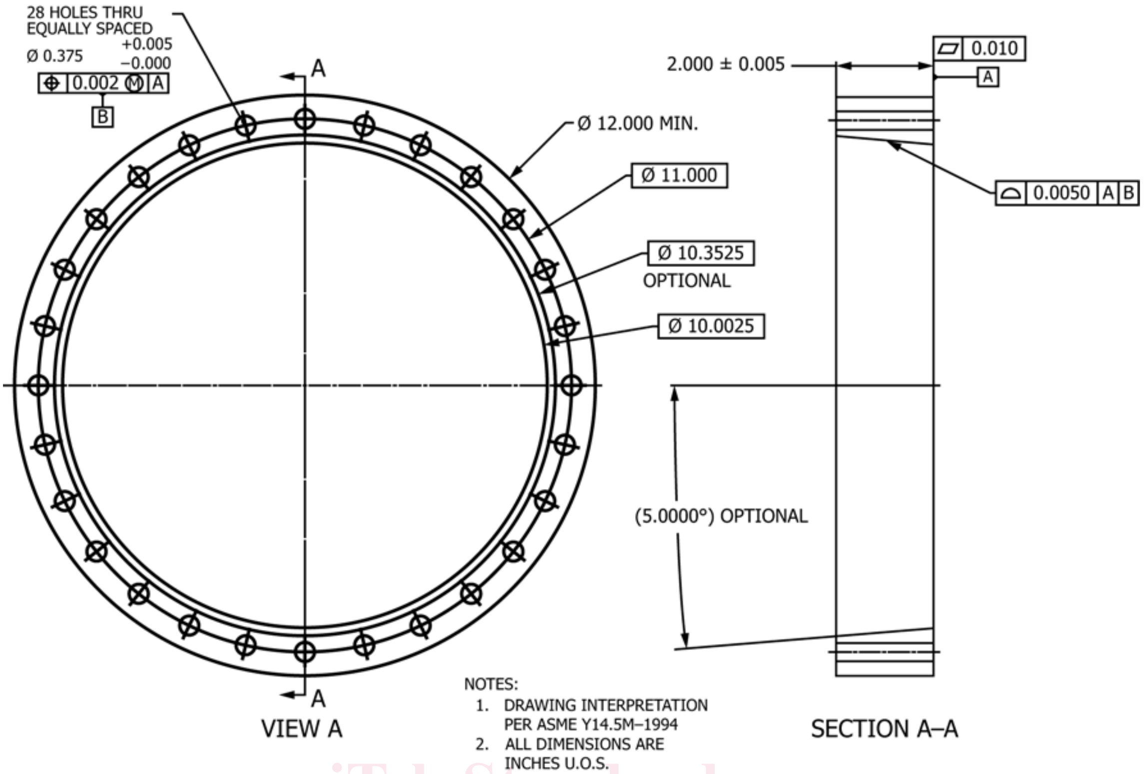
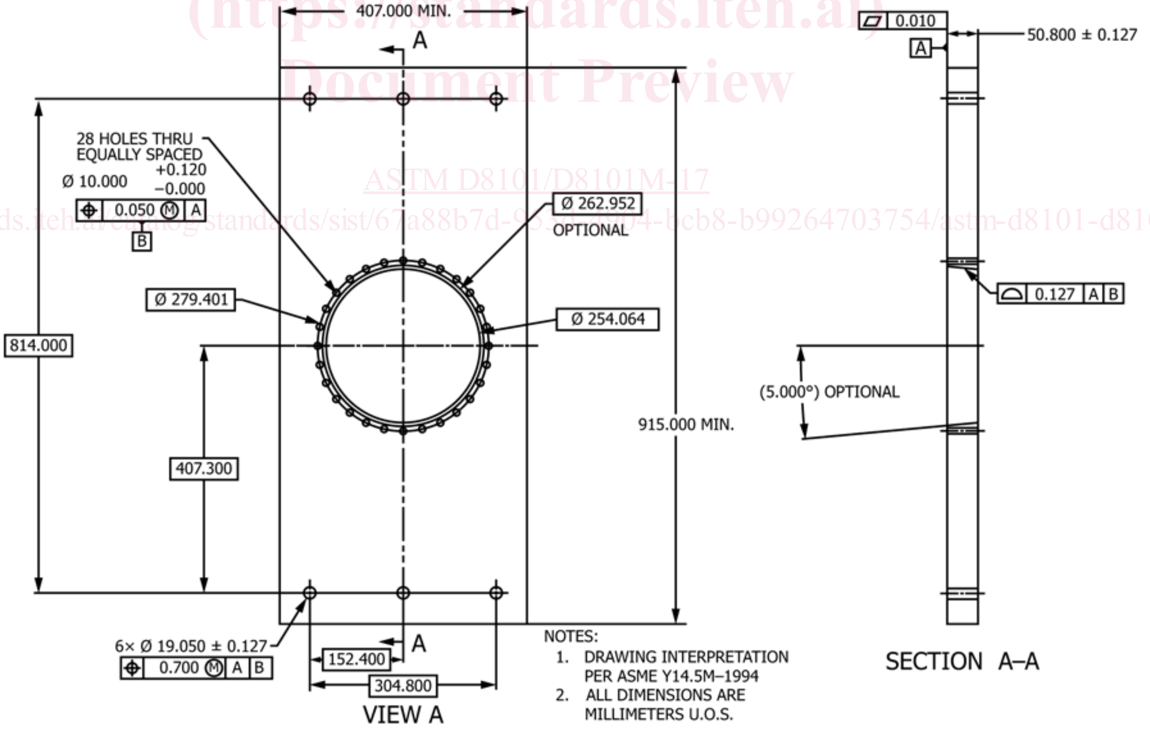


FIG. 3 Front Frame (SI Version)



NOTES:
1. DRAWING INTERPRETATION PER ASME Y14.5M–1994
2. ALL DIMENSIONS ARE INCHES U.O.S.

FIG. 4 Front Frame (Inch-Pound Version)



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2. ALL DIMENSIONS ARE MILLIMETERS U.O.S.

FIG. 5 Rear Frame (SI Version)

required to penetrate the specimen. The projectile shall penetrate the specimen in at least three of the tests and not penetrate in at least three tests. Because of statistical variation in materials and testing procedures, there may be some overlap in results in which the kinetic energy in a penetrated test is lower than the kinetic energy in a non-penetrated test. In either