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An American National Standard

Standard Specification for Impact Attenuation of Surfacing Materials Within the Use Zone of Playground Equipment[1]

This standard is issued under the fixed designation F1292; 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.

INTRODUCTION

Surveys by the United States Consumer Product Safety Commission (CPSC)[2] and others have shown that falls from playground equipment onto the underlying surface are a significant cause of injuries to children. Severe head injuries are the most frequently implicated cause of death in playground equipment-related falls. Use of appropriate impact-attenuating surfacing materials in the use zone of playground equipment can reduce the risk of fall-related injury. In particular, it is believed that the risk of life-threatening head injuries is reduced when appropriate surfacing materials are installed.

This specification specifies impact attenuation performance requirements for playground surfaces and surfacing materials and provides a means of determining impact attenuation performance using a test method that simulates the impact of a child's head with the surface. The test method quantifies impact in terms of *g*-max and Head Injury Criterion (HIC) scores. ~~*G*~~*g*-max is the measure of the maximum acceleration (shock) produced by an impact. The Head Injury Criterion or HIC score is an empirical measure of impact severity based on published research describing the relationship between the magnitude and duration of impact accelerations and the risk of head trauma. ~~The standard includes procedures allowing surfacing materials to be performance-rated before installation and for installed surfacing materials to be tested for conformance with the specification.~~

The purpose of this specification is to reduce the frequency and severity of fall-related head injuries to children by establishing a uniform and reliable means of comparing and specifying the impact attenuation of playground surfaces. Its use will give designers, manufacturers, installers, prospective purchasers, owners, and operators of playgrounds a means of objectively assessing the performance of surfacing materials under and around playground equipment and hence of evaluating the associated injury risk.

This specification determines the critical fall height for the surface material or surfacing system at each of three temperatures.

1. Scope

1.1 This specification establishes minimum performance requirements for the impact attenuation of playground surfacing materials installed within the use zone of playground equipment.

1.2 This specification is specific to surfacing used in conjunction with playground equipment, such as that described in Specifications F1148, F1487, F1918, ~~F1951,~~ CSAZ614 (Canada), and ~~F2075.~~SS457 (Singapore).

1.3 This specification establishes an impact attenuation performance criterion for playground surfacing materials; expressed as a critical fall height.

1.4 This specification establishes procedures for determining the critical fall height of playground surfacing materials under laboratory conditions. The laboratory test is mandatory for surfaces to conform to the requirements of this specification.

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[1] This specification is under the jurisdiction of ASTM Committee F08 on Sports Equipment, Playing Surfaces, and Facilities and is the direct responsibility of Subcommittee F08.63 on Playground Surfacing Systems.

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[2] U.S. CPSC Special Study. Injuries and Deaths Associated with Children's Playground Equipment, April 2001. ~~US~~U.S. Consumer Product Safety Commission, Washington, DC.

1.5 The laboratory test required by this specification addresses the performance of dry surfacing materials.

1.6 This specification also provides optional procedures to determine the critical fall height under wet or frozen test conditions, or both.

1.7 The critical fall height of a playground surfacing material determined under laboratory conditions does not account for important factors that have the potential to influence the actual performance of installed surfacing materials. Factors that are known to affect surfacing material performance include but are not limited to aging, moisture, maintenance, exposure to temperature extremes (for example, freezing), exposure to ultraviolet light, contamination with other materials, compaction, loss of thickness, shrinkage, submersion in water, and so forth.

~~1.7 This specification also establishes a procedure for testing installed playground surfaces in order to determine whether an installed playground surface meets the specified performance criterion.~~

~~1.8 The results of a field test determine conformance of installed playground surfacing materials with the criterion of this specification and are specific to the ambient conditions under which the test was performed.~~

1.8 The impact attenuation specification and test methods established in this specification are specific to the risk of head injury. There is only limited evidence that conformance with the requirements of this specification reduces the risk of other kinds of serious injury (for example, long bone fractures).

NOTE 1—The relative risk of fatality and of different degrees of head injury may be estimated using the information in Appendix X1, which shows the relationships between the Head Injury Criterion (HIC) scores of an impact and the probability of head injury.

1.9 This specification relates only to the impact attenuation properties of playground surfacing materials and does not address other factors that contribute to fall-related injuries. While it is believed that conformance with the requirements of this specification will reduce the risk of serious injury and death from falls, adherence to this specification will not prevent all injuries and deaths.

1.10 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.11 *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.*

1.12 *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:*[3]

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

F355 Test Method for Impact Attenuation of Playing Surface Systems, Other Protective Sport Systems, and Materials Used for Athletics, Recreation and Play

~~F429 Test Method for Shock-Attenuation Characteristics of Protective Headgear for Football (Withdrawn 2017)[4]~~

F1148 Consumer Safety Performance Specification for Home Playground Equipment

F1487 Consumer Safety Performance Specification for Playground Equipment for Public Use

F1918 Safety Performance Specification for Soft Contained Play Equipment

~~F1951 Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment~~

F2075 Specification for Engineered Wood Fiber for Use as a Playground Safety Surface Under and Around Playground Equipment

F3313 Test Method for Determining Impact Attenuation of Playground Surfaces Within the Use Zone of Playground Equipment as Tested in the Field

~~2.2 *SAE Standard:*~~

~~SAE J211 Recommended Practice for Instrumentation for Impact Tests[5]~~

2.2 *Federal Documents:*[4]

U.S. Consumer Product Safety Commission, Publication ~~325,~~325 Handbook for Public Playground Safety

U.S. Consumer Product Safety ~~Commission,~~Commission Special Study: Injuries and Deaths Associated with Children's Playground Equipment. April 2002

U.S. Department of Justice 2010 Standard for Accessible Design

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[3] 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.

~~[4] The last approved version of this historical standard is referenced on www.astm.org.~~

[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.~~Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.~~

2.3 *ISO Document:*[5]
ISO/TR 20183 Sports and other recreational facilities and equipment – Injury and safety definitions and thresholds – Guidelines for their inclusion in standards

3. Terminology

3.1 *Definitions of Terms Related to Playground Installations:*

3.1.1 *critical fall height (CFH)*—a measure of the impact attenuation performance of a playground surface or surfacing materials; defined as the highest theoretical drop height from which a surface meets the impact attenuation performance criterion specified by this specification. The critical fall height approximates the maximum fall height from which a life-threatening head injury would not be expected to occur.

3.1.2 *designated play surface*—any elevated surface for standing, walking, sitting, or climbing, or a flat surface larger than 2.0 in. (51 mm) wide by 2.0 in. (51 mm) long having less than 30° angle from horizontal.

3.1.3 *fall height*—the vertical distance between a designated play surface and the playground surface beneath it.

3.1.3.1 *Discussion*—

Fall heights for specific types of play structure are defined in Specifications F1148, F1487, F1918~~and~~, ~~F1918.~~CSAZ614, and SS457.

3.1.4 *playground equipment*—any fixed physical structure installed in a designated play area that is accessible to children for activities such as climbing, swinging, sliding, rocking, spinning, crawling, creeping, or combinations thereof.

3.1.5 *playground surface*—a manufactured or natural material used to cover the ground below playground equipment, including foundations, substrates, and any compliant surfacing materials intended to attenuate impact.

3.1.6 *play structure*—a free-standing structure with one or more components and their supporting members.

3.1.7 *public use playground equipment*—a play structure anchored to the ground or not intended to be moved, for use in play areas of schools, parks, child-care facilities, institutions, multiple-family dwellings, private resorts and recreation developments, restaurants, and other areas of public use.

3.1.8 *specifier*—person or entity responsible for specifying the performance requirements of a playground surface (for example, an architect or the prospective purchaser, owner, or operator of a playground).

3.1.9 *surfacing materials*—materials used to cover the surface of the playground use zone.

3.1.9.1 *loose-fill surface*—a compliant top layer of small, independently, movable components; for example, wood fiber, bark mulch, wood chips, shredded foam, shredded rubber, sand, gravel, and so forth.

3.1.9.2 *aggregate surface*—a ~~loose fill~~ loose-fill surface in which the compliant top layer is made of particulate materials (for example, sand, gravel, crushed marble, slag, cinders, calcined materials).

3.1.9.3 *unitary surface*—a compliant top layer of one or more material components bound together to form a continuous surface; for example, urethane and rubber composites, ~~moulded~~molded foam, ~~moulded~~molded rubber mats.

3.1.10 *use zone*—the area beneath and immediately adjacent to a play structure or playground equipment that is designated for unrestricted circulation around the equipment and on whose surface it is predicted that a user would land when falling from or exiting the equipment.

~~3.1.10 *specifier*—person or entity responsible for specifying the performance requirements of a playground surface. (For example an architect, or the prospective purchaser, owner, or operator of a playground.)~~

3.2 *Definitions of Terms Related to Impact Testing:*

3.2.1 *acceleration*—the rate of change of velocity with time, expressed in units of m s^{-2} (ft s^{-2}).

3.2.2 *drop height*—height from which the missile is dropped during an impact test, measured as the vertical distance between the lowest point of the elevated missile and surface under test.

3.2.3 *g*—common notation for accelerations expressed in units of *standard gravity*, where 1 g = 1 standard gravity.

3.2.4 *g-max*—the maximum acceleration of a missile during an impact, expressed in g units.

3.2.5 *head injury criterion (HIC)*—a specific integral of the acceleration-time history of an impact, used to determine relative risk of head injury. See Appendix X1.

3.2.6 *HIC interval*—the time interval within the acceleration-time history of an impact over which the HIC integral is evaluated.

3.2.7 *impact*—contact caused by a moving object (for example, an impact test missile) striking another object (for example, a surface) and during which one or both bodies are subject to high accelerations.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.2.8 *impact attenuation*—property of a playground surface that, through localized deformation or displacement, absorbs the energy of an impact in a way that reduces the magnitudes of peak impact force and peak acceleration.

3.2.9 *impact test*—a procedure in which the impact attenuation of a playground surface or surfacing materials is determined by measuring the acceleration of a missile dropped onto the surface.

3.2.9.1 *free-fall impact test*—an impact test in which the trajectory of the missile is not restrained by rails, wires, or mechanisms or structures of any type.

3.2.9.2 *guided impact test*—an impact test in which the trajectory of the missile is restrained by rails, wires, or other mechanism or structure.

3.2.9.3 *impact test results*—one or more measured or calculated values from one or more impact tests used to define the impact attenuation of a playground surface or surfacing materials.

3.2.10 *impact test site*—point on the surface of an installed playground surface that is selected as the target of an impact test.

3.2.11 *impact velocity*—the velocity (V_0) of a falling body (for example, a missile) at the instant of impact.

3.2.12 *missile*—a rigid object of specified mass having a hemispherical surface of specified radius; used to impart an impact to a ~~surface (see~~ surface.~~Fig. 1).~~

~~3.2.13 *missile reference plane*—the plane of the flat circular face of the hemispherical missile.~~

3.2.13 *performance criterion*—limiting values of one or more impact test results used to specify minimum impact attenuation performance.

3.2.14 *qualified personnel*—those with current knowledge, training, skill, education and experience who have successfully demonstrated the ability to solve or resolve problems relating to the subject matter and work through the application of professional judgement.

3.2.15 *reference drop height*—a specification of the theoretical drop height of an impact test.

3.2.16 *reference MEP pad*—a modular elastomer programmer pad with consistent and known impact attenuation properties that is used to verify proper functioning of the impact test equipment.

3.2.17 *reference temperature*—a specification of the temperature conditioning of a surfacing materials on which an impact test is performed.

3.2.18 *sample test point*—point on the surface of a sample selected as the target of an impact test.

3.2.19 *standard gravity*—the nominal value of the acceleration due to gravity at sea level having an international standard value of exactly 9.806 65 m s^{-2} (approximately 32.174 ft s^{-2}).

3.2.19.1 *Discussion*—

Accelerations may be expressed in units of standard gravity.

3.2.20 *theoretical drop height*—the drop height (*h*) that, under standard conditions, would result in an impact velocity equal to a missile's measured impact velocity (V_0). ~~The standard conditions assume that friction and air resistance do not affect the acceleration of the missile and that the acceleration due to gravity is equal to the standard value of g at sea level. In a free-fall impact test, the actual drop height will approximate the theoretical drop height. In a guided impact test, the theoretical drop height will be less than the actual drop height, due to the effects of friction in the guidance mechanism.~~

3.2.20.1 *Discussion*—

The standard conditions assume that friction and air resistance do not affect the acceleration of the missile and that the acceleration due to gravity is equal to the standard value of *g* at sea level. In a free-fall impact test, the actual drop height will approximate the theoretical drop height. In a guided impact test, the theoretical drop height will be less than the actual drop height, due to the effects of friction in the guidance mechanism.

~~3.3 *Definitions of Terms Related to the Measurement of Acceleration:*~~

~~3.3.1 *accelerometer*—a transducer for measuring acceleration.~~

~~3.3.1.1 *transducer*—the first device in data channel, used to convert a physical quantity to be measured into a second quantity (such as an electrical voltage) which can be processed by the remainder of the channel.~~

~~3.3.1.2 *triaxial accelerometer*—a transducer or combination of transducers used for measuring the three vector components of acceleration in three dimensions, relative to three orthogonal spatial axes.~~

~~3.3.1.3 *uniaxial accelerometer*—a transducer used to measure the component of acceleration relative to a single spatial axis.~~

~~3.3.2 *accelerometer data channel*—all of the instrumentation and procedures used to communicate information about the physical quantity of acceleration from its origin to the point of presentation. The data channel includes all transducers, signal conditioners, amplifiers, filters, digitizers, recording devices, cables and interconnectors through which the information passes and also includes the analytical software or procedures that may change the frequency, amplitude, or timing of the data.~~

4. Performance Requirements

4.1 *Surface Performance Parameters*—The average *g*-max and average Head Injury Criterion (HIC) scores calculated from the last two of a series of three impact tests shall be used as measures of surface performance.

4.2 *Performance Criterion*—The performance criterion used to determine conformance with the requirements of this specification shall be: a *g*-max score not exceeding 200 *g* and a HIC score not exceeding 1000.

4.3 *Critical Fall* ~~*Height of Installed Playground Surfaces:*~~ *Height:*

~~4.3.1 The critical fall height of surfaces installed in the use zone of a play structure shall not be less than the fall height of the equipment. The fall height shall be determined as defined by Specifications F1148, F1487, or F1918 for play structures of specific types or in accordance with 3.1.4 of this specification for play structures of unspecified type, unless a higher height is specified.~~

4.3.1 The critical fall height of the playground surface shall have been determined in accordance with the requirements of Section ~~13~~15 of this specification, using reference temperatures of 25, 72, and 120°F (–6, 23, and 49°C), surface performance parameters, and the performance criterion.

Note 2—The specified temperatures span the range experienced by most playgrounds. If higher or lower surface material temperatures prevail when the playground is used, additional tests at higher or lower temperatures may be specified.

Note 3—*Wet/Frozen Test*—The specifier may require that surfacing materials be tested to determine critical fall height under wet or frozen surface conditions, or both. Procedures for wet/frozen conditioning are described in ~~Appendix X5~~Annex A1.

4.3.2 The laboratory test used to determine critical fall height shall have been conducted on surfacing material samples identical in design, materials, components, thickness, and manufacture as the installed playground surface.

4.3.3 The laboratory test used to determine critical fall height of materials specified for use in a playground shall have been conducted no more than five years prior to the date of installation of the playground surface.

4.3.4 Test Method F3313 is a test method for conducting *g*-max and HIC testing on an installed playground surface to ensure quality control of surfaces as they are installed.

~~4.4 *Performance of Installed Playground Surfaces:*~~

~~4.4.1 When an installed playground surface is tested in accordance with the requirements of Sections 16 – 19 at the reference drop height, the surface performance parameters at every tested location in the use zone shall meet the performance criteria of this specification. The reference drop height shall be the greater of (*1*) the height specified by the owner/operator prior to purchase, (*2*) the critical fall height specified when the playground surface was installed, (*3*) the equipment fall height, or (*4*) the critical height of the surface at the time of installation.~~

~~4.4.2 When an installed playground surface is tested in accordance with this section, if the impact test scores at any tested location in the use zone of a play structure do not meet the performance criterion, bring the surface into compliance with the requirements of this specification or the play structure shall not be permitted to be used until the playground surface complies.~~

~~4.4.3 *More Stringent Specifications*—The specifier is permitted to specify additional impact attenuation performance requirements, providing that such additional performance requirements are more stringent than the performance requirements of this specification.~~

5. Summary of Test Method

5.1 *Critical Fall Height Test*—The impact attenuation of ~~a playground surface or~~ surfacing materials is measured using an impact test in which a missile is dropped onto the playground surface from a predetermined drop height. The acceleration of the missile during the impact is measured using an accelerometer and associated data recording equipment. The acceleration time history is analyzed to determine *g*-max and HIC scores. For each playground surface sample at each reference temperature and drop height, scores from the second and third of three consecutive drops are averaged to give average scores. No modification of the playground surface sample shall be permitted between the three impacts.

5.2 The critical fall height of surfacing materials is determined by impact testing representative samples at a range of drop heights. The surfacing material is tested at temperatures of 25, 72, and 120°F ~~(–6,~~(–4, 23, and 49°C). The critical fall height is determined as the highest theoretical drop height from which the surface performance parameters meet the performance criterion.

~~5.3 *Installed Surface Performance Test*—To test whether a playground surface installed within the use zone of a play structure meets the performance criterion of this specification, an impact test is performed in accordance with Sections 16 – 19 using a theoretical drop height equal to or greater than the equipment fall height of the structure. The test is performed under ambient conditions and the results reported.~~

6. Significance and Use

6.1 The purpose of this specification is to establish minimum impact attenuation requirements for playground ~~surfaces~~ surfacing materials in order to reduce the risk of severe head injury from falls.

6.2 This specification provides a uniform means of quantifying the impact attenuation performance of playground ~~surfaces~~ surfacing materials and is appropriately used to compare the relative performance of different playground surfacing materials.

6.3 This specification is to be used as a reference for specifying the impact attenuation performance of playground ~~surfaces.~~surfacing materials.

~~6.4 This specification provides a uniform means of comparing the impact attenuation performance of installed playground surfaces with the performance requirements of this specification and with other performance requirements expressed in terms of drop height. Consequently, the specification is appropriately used to determine the actual impact attenuation performance of installed playground surfaces under ambient conditions of use.~~

6.4 In combination with data relating impact test scores to head injury, the information generated by application of this specification is suitable to estimate the relative risk of a severe head injury due to a fall.

7. Equipment Operator Qualifications

7.1 ~~The equipment operator shall be trained in the proper operation of the test equipment by a competent agency.~~Impact tests shall be conducted by qualified personnel.

8. Test Apparatus

8.1 *Temperature Measuring Device*—The thermometer, digital temperature gage, or other sensor used to measure surface temperature shall have a functional range of at least from ~~–20~~20 to +130°F (–7 to +54°C), a resolution of 1.0°F (0.6°C), and an accuracy of ±1.0°F (0.6°C). The temperature sensor shall be capable of penetrating the playground surface to a depth of at least ~~one inch.~~1 in. (2.5 cm).

8.2 *Impact Test System*—A device or system for performing an impact test in which an instrumented missile is dropped onto a playground surface or surfacing ~~material from a predetermined drop height.~~material.

8.2.1 ~~*Missile:*~~ *Missile—*

~~8.2.1.1 The body of the missile shall be made of Aluminum Alloy 6061-T6, finished with a surface roughness of 1000 µin. (25 µm).~~The test will be conducted using Missile E as specified in Test Method F355.

~~8.2.1.2 The missile shall have a hemispherical impacting surface with an external diameter of 6.3 ± 0.1 in. (160 ± 2 mm). The missile is defined as being in a level position when the missile reference plane is uppermost and lies in a horizontal plane.~~

~~8.2.1.3 It is possible that the missile will include cavities and additional components required to accommodate the attachment of sensors or to attach a supporting assembly. The form of any cavities or additional components shall be generally symmetrical about the *Z*-axis of the level missile such that center of mass lies within 0.08 in. (2 mm) of the *Z*-axis and the moments of inertia about any two horizontal axes do not differ by more than 5 %.~~

~~8.2.1.4 It is acceptable to rigidly attach a supporting assembly (for example, a handle or ball arm) to the missile as a means of connecting it to an external guidance system. The total mass of the drop assembly, which is the combined mass of the missile, accelerometer, and supporting assembly shall be 10.1 ± 0.05 lb (4.6 ± 0.02 kg). The mass of the supporting assembly alone shall not exceed 3.0 lb (1.4 kg).~~

~~8.2.1.5 *Missile Axes*—An axis normal to the missile's reference plane, passing through the missile's center of mass, and having its positive direction pointing upwards shall be designated the *Z*-axis. This axis is nominally perpendicular to the surface being tested. Two mutually orthogonal axes lying parallel to the missile reference plane and passing through the missile's center of mass shall be designated the *X*- and *Y*-axes (Fig. 1).~~

~~NOTE 4—In this reference frame, the acceleration due to gravity has a negative magnitude and the acceleration of the headform during an impact has a positive magnitude.~~

8.2.2 *~~Guidance Mechanism for~~ Guided Impact Tests—*~~For guided impact tests, it is acceptable for the missile to be connected to low-friction guides (such as monorail, dual rails, or guide wires) using a follower or other mechanism in order to constrain the fall trajectory of the missile to a vertically downward path. The guidance system must allow the missile to be leveled prior to a drop and must maintain the missile in a level (±5°) attitude during the drop. The guidance mechanism shall be constructed in a manner that does not impede the trajectory of the missile during its fall or during its contact with the surface being tested; other than necessary impedance caused by friction in the guidance mechanism.~~It is acceptable to rigidly attach a supporting assembly (for example, a handle or ball arm) to the missile as a means of connecting it to an external guidance system. The total mass of the drop assembly, which is the combined mass of the missile, accelerometer, and supporting assembly shall be 10.1 ± 0.05 lb (4.6 ± 0.02 kg). The mass of the supporting assembly alone shall not exceed 3.0 lb (1.4 kg).

8.2.2.1 For guided impact tests, it is acceptable for the missile to be connected to low-friction guides (such as monorail, dual rails, or guide wires) using a follower or other mechanism in order to constrain the fall trajectory of the missile to a vertically downward path. The guidance system must allow the missile to be leveled prior to a drop and must maintain the missile in a level

(±5°) attitude during the drop. The guidance mechanism shall be constructed in a manner that does not impede the trajectory of the missile during its fall or during its contact with the surface being tested; other than necessary impedance caused by friction in the guidance mechanism.

8.2.3 *Support Structure for Free-Fall Impact Tests*—For free-fall impact tests, a support structure (for example, a tripod) shall be used to ensure repeatable drop height and location. The support structure shall be sufficiently rigid to support the weight of the missile without visible deformation. The support structure shall be erected in a manner that does not impede the trajectory of the missile during its fall or during its contact with the surface being tested.

8.2.4 *Drop Height Control Mechanism*—The guidance mechanism of 8.2.28.2.2.1 or the support structure of 8.2.3 shall incorporate a means of repeatedly positioning the missile at a predetermined drop height.

8.2.5 *Release Mechanism*—A manual or electronically operated quick-release mechanism shall be provided as a means of initiating a drop of the missile. The operation of the release mechanism shall not influence the fall trajectory of the missile following release.

8.3 *Acceleration Measurement System*—A transducer or transducers and associated equipment for measuring and recording the acceleration of the missile during an impact with an accuracy of within ±1 % of the true value.

8.3.1 *Accelerometers*—An accelerometer shall be rigidly attached at the center of mass of the missile. The sensing axis or axes of the accelerometer shall pass through the center of mass of the missile.

8.3.1.1 For a free-fall test, a triaxial accelerometer is required. The three axes of the triaxial accelerometer shall be aligned (±5°) with the missile's *Z*-, *X*-, and *Y*-axes.

8.3.1.2 For a guided test, it is acceptable to use a single uniaxial accelerometer. The accelerometer shall be rigidly attached at the center of mass of the missile with its axis of sensitivity aligned (±5°) with the missile's *Z*-axis and passing through the center of mass of the missile.

8.3.2 Accelerometers shall have a minimum sensitive range from ±500 g and be capable of tolerating accelerations of at least 1000 g along any axis.

8.3.3 *Accelerometer Calibration*—Accelerometers shall be calibrated by reference to a National Institute of Standards and Technology (NIST) traceable standard using a shaker table to excite a range of frequencies and amplitudes determined suitable by the accelerometer manufacturer. The calibration procedure shall include, as a minimum, the range of frequencies from 20 to 2000 Hz.

8.3.4 Accelerometers shall be recalibrated at a time interval recommended by the equipment manufacturer or every two years, whichever is the lesser time interval.

8.3.5 *Accelerometer Connections*—The means of providing power and signal connections to the accelerometer (for example, a cable) shall be constructed in a manner such that the connecting devices do not influence the trajectory of the missile before or during the impact test.

8.3.6 *Accelerometer Signal Conditioning*—Any signal conditioning of amplifying electronies required for proper operation of accelerometers shall be of a type recommended by the accelerometer manufacturer and shall have impedance and frequency response characteristics that are compatible with the accelerometer. Additional signal conditioning requirements are specified in Annex A1.

8.3.7 *Accelerometer Signal Filtering:*

8.3.7.1 *Anti-aliasing Filter*—To prevent aliasing in the digitized acceleration data, the acceleration signals shall be filtered with an analog low pass filter prior to digitization. The anti-aliasing filter shall have a corner frequency of 5000 ± 500 Hz or a maximum of 0.25 times the single channel sampling rate.

8.3.7.2 *Data Channel Filter*—Digitized data shall be filtered using a 4th order Butterworth Filter appropriate for the data channel specification described in 8.3.14.2 and Annex A1. It is acceptable for an analog filter to be substituted provided it has 4-pole characteristics and conforms to the data channel specification.

NOTE 5—A computer algorithm for the 4-pole digital Butterworth Filter is provided in Appendix X4.

8.3.8 *Recording Device*—A digital recording device such as a digital storage oscilloscope, a dedicated waveform analyzer of a computer equipped with an analog to digital converter shall be used to capture the acceleration time signal produced during an impact. Analog oscilloscopes and other analog recording devices shall not be used.

8.3.9 *Resolution*—The conversion from analog accelerometer signal to digital data shall be accomplished with a digitizer having a resolution of no less that twelve bits spanning the range ±500 g.

8.3.10 *Sample Rate*—Minimum sampling rate of the recording device shall be 20.0 kHz per accelerometer channel. When a triaxial accelerometer is used, three individual digitizers (one per accelerometer axis), each with a minimum sampling rate of 20 kHz is recommended. Alternatively, it is acceptable to use a single digitizer with a minimum sampling rate of 60.0 kHz if simultaneous track and hold amplifiers are provided for each accelerometer axis.

8.3.11 *Capacity*—The digitizer shall be capable of recording and storing data continuously for a minimum of 50 ms, beginning at least 5 ms before onset of the impact and ending no earlier than 5 ms after the cessation of the impact.

8.3.12 *Display*—The recording system shall have the capability of displaying the recorded acceleration-time data in order to allow inspection by the operator. A graphical display is recommended, but a tabular printout or other form of display is acceptable.

The display shall allow inspection of all the data points recorded from at least 5 ms before the onset of impact until no less than 5 ms after cessation of the impact. The display shall show acceleration data in a manner that allows inspection of all data points lying in the acceleration range from -10 g to a value that exceeds the maximum recorded acceleration value.

8.3.13 *Accelerometer Data Channels:*

8.3.14 *Accuracy*—The accuracy of each data channel shall be such that the maximum acceleration recorded during an impact is within ±1 % of the true value.

8.3.14.1 *Frequency Response*—All acceleration data channels, before signal filtering, shall have a flat frequency response ±0.1 dB in a range extending from below a maximum of 1.0 Hz to above a minimum of 2000 Hz.

8.3.14.2 *Channel Frequency Class*—All acceleration data channels, including signal filtering, shall conform to the requirements of a Channel Frequency Class 1000 data channel, as specified by SAE Recommended Practice J211, with the additional requirement of increased accuracy in the range from 1 to 1000 Hz, as defined in Annex A1.

8.4 *Drop Height Measurement*—A means of repeatably determining the missile's drop height with a resolution of 1 in (25 mm) and to an accuracy of ±1 % of the true value is required.

8.4.1 For a free-fall impact test, the drop height shall be measured directly, prior to release of the missile, using a measuring stick, a steel tape, or other appropriate means where possible. An indirect means of determining the theoretical drop height shall also be used. It is acceptable for such indirect means to comprise the velocity measuring system described in 8.4.2, or a means of measuring the time interval between release of the missile and the onset of impact (the fall time), in which case the time interval shall be determined with a resolution and accuracy of 1.0 ms. Both the measured drop height and the theoretical drop height shall be reported.

8.4.2 For a guided impact test, the theoretical drop height must be determined by measuring the velocity of the missile immediately prior to the onset of an impact; at a point in the missile's trajectory no more than 2.0 in. (51 mm.) above the first point of contact between the missile and the surface under test. The velocity measuring system shall be permitted to consist of a light gate device to measure the time an opaque flag interrupts a light sensor or other appropriate means. The velocity measuring device shall not interfere with or impede the trajectory of the missile and shall be capable of recording impact velocity with a resolution of 0.1 ft s^{-1} (0.03 m s^{-1}) and an accuracy of ±1 % of the true value.

NOTE 6—Since theoretical drop height is proportional to the square of impact velocity, the ±2 % tolerance on drop height measurement and the ±1 % tolerance on velocity measurement are equivalent. For a typical flag and light gate velocimeter to achieve ±1 % accuracy, the flag width must be known to an accuracy of ±0.5 % and the transit time measured with an accuracy of ±20 ms (that is, a timing device with a clock rate of at least 50 kHz is required).

8.5 *Battery-Operated Equipment*—Battery-operated equipment shall have a means of monitoring battery voltage (for example, a voltage gage or indicator).

8.6 *System Integrity Check*—Prior to and following each use, the test apparatus shall be checked for proper operation. The system integrity check shall include, as a minimum, the following steps:

8.6.1 The battery status of each piece of battery-operated equipment shall be checked to ensure adequate power availability and voltage level.

8.6.2 Test the proper operation of the equipment by performing the instrumentation check described in Section 10.

8.7 *Equipment Performance Verification*—In order to conform to the requirement of this specification, testing agencies shall acquire and maintain for inspection the following documentation:

8.7.1 *For Each Accelerometer:*

8.7.1.1 A manufacturer's certificate showing that the accelerometer's frequency response conforms to the requirements of 8.3.5.

8.7.1.2 A calibration certificate from a competent agency showing the accelerometer's sensitive range and the calibration factor to a precision of three significant figures.

8.7.2 *For Each Signal-Conditioning Device*—A manufacturer's certificate showing that the device's frequency response conforms to the requirements of 8.3.14.

8.7.3 *For the Acceleration Measurement System*—Documentation from the manufacturer of the acceleration measurement system certifying that each acceleration data channel conforms to the requirements of this specification. Alternatively, if a testing agency has assembled or manufactured its own acceleration testing system, one method to verify conformance with the requirement of this section is by performing and documenting the results of the tests described in Annex A1.

8.7.4 *For the Drop Height Measurement System*—Documentation from the manufacturer of the drop height or impact velocity measurement system certifying that it conforms to the requirements of this specification. Alternatively, if a testing agency has assembled or manufactured its system, one method to verify conformance with the requirement of this section is by performing and documenting the results of the tests described in Annex A1.

9. Calculation

9.1 *Theoretical Drop Height:*

9.1.1 The theoretical drop height, h, shall be calculated from a measurement of impact velocity, v, using the formula $h = v^2 / 2g$, where g is the acceleration due to gravity.

9.1.2 Alternatively, in a free-fall test, one method to calculate the theoretical drop height, *h*, s is by a measurement of fall time, *t*, using the formula $h = ½ gt^2$.

9.1.3 *Resultant Acceleration*—If a triaxial accelerometer is used, the resultant acceleration at each point in the time history of the impact shall be calculated as $A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$ where A_R is the resultant acceleration and A_x,A_y, and A_z are the accelerations recorded by accelerometers aligned with the *X*,*Y*, and *Z* missile axes.

9.2 *g-max*—The *g*-max of score is determined as the maximum value of acceleration recorded during an impact. If a triaxial accelerometer is used, *g*-max shall be determined as the maximum value of the resultant acceleration.

9.3 *Average g-max*—Determine the average *g*-max score by averaging the *g*-max score of the second and third of a series of three impact tests.

9.4 *Determination of Missile Angle*—In a free-fall impact test, the angle of the missile at the onset of impact and at the instant of maximum acceleration shall be calculated. For the purposes of this calculation, the onset of impact shall be the data sample at which the resultant acceleration first meets or exceeds a threshold value of 5 g. The angle shall be calculated from the component accelerations. The cosine of the missile angle shall be calculated as:

$$\cos(\theta_{headform}) = \frac{A_z}{A_R}$$

9.5 *Head Injury Criterion*[6]—The HIC score of an impact shall be computed as follows:

9.5.1 In the acceleration-time history of the impact, locate the time point T_0 at a point immediately preceding the onset of the impact and the time point T_1 at a point immediately following the cessation of the impact.

9.5.2 For each time interval (t_1, t_2) for which $t_1 \geq T_0$, $t_2 > t_1$ and $t_2 \leq T_1$ evaluate and record the trial HIC integral:

$$\text{Trial HIC}(t_1, t_2) = (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t=t_1}^{t_2} a_t \; dt\right]^{2.5}$$

where:

a_t = acceleration at time *t*, defined as the resultant acceleration if a triaxial accelerometer is used.

9.5.3 For each time interval (t_1, t_2) calculate and record the trial HIC interval, $t_2 - t_1$.

9.5.4 The HIC score for an impact is determined as the maximum value of all the Trial HIC(t_1, *t*2) scores.

9.5.5 The numerical procedures used to calculate HIC shall provide results that are within ±1 % of the true value.

NOTE 7—A computer algorithm for calculating HIC is provided in Appendix X3.

9. Calculations

9.1 *Theoretical Drop Height:*

9.1.1 The theoretical drop height, *h*, shall be calculated from a measurement of impact velocity, *v*, using the formula $h = v^2 / 2g$, where *g* is the acceleration due to gravity.

9.1.2 Alternatively, in a free-fall test, one method to calculate the theoretical drop height, *h*, is by a measurement of fall time, *t*, using the formula $h = ½g\, t^2$.

9.1.3 *Resultant Acceleration*—If a triaxial accelerometer is used, the resultant acceleration at each point in the time history of the impact shall be calculated as $A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$ where A_R is the resultant acceleration and A_x,A_y, and A_z are the accelerations recorded by accelerometers aligned with the *X*,*Y*, and *Z* missile axes.

9.2 *g-max*—The *g*-max of score is determined as the maximum value of acceleration recorded during an impact. If a triaxial accelerometer is used, *g*-max shall be determined as the maximum value of the resultant acceleration.

9.3 *Average g-max*—Determine the average *g*-max score by averaging the *g*-max score of the second and third of a series of three impact tests.

9.4 *Determination of Missile Angle*—In a free-fall impact test, the angle of the missile at the onset of impact and at the instant of maximum acceleration shall be calculated. For the purposes of this calculation, the onset of impact shall be the data sample at which the resultant acceleration first meets or exceeds a threshold value of 5 *g*. The angle shall be calculated from the component accelerations. The cosine of the missile angle shall be calculated as:

$$\cos(\theta_{headform}) = \frac{A_z}{A_R}$$

9.5 *Head Injury Criterion*[6]—The HIC score of an impact shall be computed as follows:

9.5.1 In the acceleration-time history of the impact, locate the time point T_0 at a point immediately preceding the onset of the impact and the time point T_1 at a point immediately following the cessation of the impact.

9.5.2 For each time interval (t_1, t_2) for which $t_1 \geq T_0$, $t_2 > t_1$ and $t_2 \leq T_1$ evaluate and record the trial HIC integral:

[6] Chou, C., and Nyquist, G., "Analytical Studies of the Head Injury Criterion," *SAE Paper No. 740082*, Society of Automotive Engineers, 1974.

$$\text{Trial HIC}(t_1, t_2) = (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t=t_1}^{t_2} a_t \; dt\right]^{2.5}$$

where:

a_t = acceleration at time t, defined as the resultant acceleration if a triaxial accelerometer is used.

9.5.3 For each time interval (t_1, t_2) calculate and record the trial HIC interval, $t_2 - t_1$.

9.5.4 The HIC score for an impact is determined as the maximum value of all the Trial HIC (t_1, t_2) scores.

9.5.5 The numerical procedures used to calculate HIC shall provide results that are within ±1 % of the true value.

10. Instrumentation Check

10.1 Check the proper operation of the test apparatus by performing a series of impact tests on a reference MEP ~~pad.~~pad immediately prior to the start of testing and within 24 h of completion of the tests.

10.2 The reference MEP pad shall be provided by the equipment manufacturer or by another agency capable of ensuring reproducible reference pads and shall have been assigned a reference drop height and a nominal *g*-max score.

10.3 Perform three impact tests on the reference MEP pad from the reference drop height with an interval of 1.5 ± 0.5 min between impacts.

10.4 Determine the average *g*-max score by averaging the *g*-max scores from the second and third drops.

10.5 Compare the average *g*-max score to the nominal *g*-max score provided with the reference MEP pad.

10.6 If the difference between the recorded *g*-max score and the nominal *g*-max score exceeds either the manufacturer's specified tolerance or 5 % of the nominal *g*-max score, the equipment does not conform to the requirements of this specification and shall not be used.

11. Impact Test Procedure

11.1 *Data Recording:*

11.1.1 Determine the test point of the conditioned sample.

11.1.1.1 If the sample has nonuniform properties (due to uneven thickness, seams, fasteners, or other factors) the sample test point shall be the point on the surface of the specimen expected to show the least favorable impact attenuation properties that lies within an area no closer than 3.0 in. (75 mm) to the edge of the sample.

11.1.1.2 *Procedure for Determining Least Favorable Impact Location:*

(1) Least favorable impact location shall be determined using the average of the last two of three impacts, from impacts performed at 23°C, at all applicable locations.

(2) Once the average is calculated, divide the *g* value by 200, and divide the HIC value by 1000. The resulting calculations are percentages of the maximum allowable value for both *g* and HIC.

(3) Determine the highest percentage of maximum allowable value, either *g*'s or HIC, for all locations tested. This calculated highest percentage of the maximum allowable value(s), shall be considered the least favorable impact location.

(4) Subsequent to determining the least favorable impact location remaining temperature testing (–6°C and 49°C) shall be performed at the determined least favorable impact location only.

(5) Exemptions to 11.1.1.1—Poured-in-place (for example, SBR with EPDM, TPV or turf top cap) and bonded safety surfaces are exempt from least favorable impact location. Laboratory testing has been provided demonstrating that the maximum values obtained among locations for these types of surface are minimal/insignificant.

11.1.1.3 If the sample has uniform properties, the sample test point shall be the center of the sample's top surface.

11.1.2 Mount the sample to be tested on a flat, rigid anvil or floor beneath the impact test system.

11.1.3 Align the sample test point with the point of impact of the missile and fix the sample to the anvil or floor using an appropriate means that does not alter the sample's impact attenuation properties (for example, with double-sided adhesive tape).

NOTE 4—Tests with unitary surface samples show that the variability of *g*-max and HIC scores is increased by a factor of four or more if the sample is not fixed to the underlying surface.

11.1.4 Before the first drop in any series, elevate the missile to the reference drop height. For subsequent drops in a series, the missile shall be elevated to the same point, notwithstanding the formation of cavities of other elevation changes in the surface being tested.

11.1.5 Before the first drop in any series, measure and record the drop height.

11.1.6 Release the missile and record the outputs of the acceleration measuring system and the drop height measuring system. If the trajectory of the missile prior to and during impact is impeded by any fixtures, human intervention, or other means, data from the trial shall be discarded.

11.1.7 Record the depth of any cavity in the surface formed by the impact.

NOTE 5—The depth is conveniently determined by measuring the distance between the lowest point of the elevated missile and the surface under test. The cavity depth is the difference between this measurement and the originally measured drop height.