



AEROSPACE STANDARD

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Standard Test Method for Measuring Forces During Normal Impact of a Soft Projectile on a Rigid Flat Surface

RATIONALE

Measurements of forces generated from a soft object impacting a relatively rigid stationary object can be difficult due to the very short time duration of the event and limitations on the dynamic response of standard transducers. This test method overcomes some of these limitations. The method can be used to generate data useful in developing and validating computational material models for soft or frangible objects such as ice, soft polymers, and materials used to simulate birds used for aircraft certification testing. The method can also be used to provide comparison data in the development of physical simulants for impact and ingestion certification testing for aircraft.

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1. SCOPE

This document describes a method for measuring forces during an impact between a soft or frangible projectile and a relatively rigid flat normal surface. The document describes the hardware and instrumentation required, as well as the processing and data reduction required to compute force.

In this test, a projectile impacts one end of a long cylindrical bar with flat ends, called a Hopkinson bar. The impact occurs on the centerline of the bar in the axial direction. The diameter of the cylindrical bar is large compared to the lateral dimension of the projectile so that, during and after the impact, the projectile material moves radially or backward, rather than extruding around the perimeter of the impact surface.

The bar is instrumented with strain gages at some distance from the impacted end to measure the longitudinal strain in the bar. The bar must be sufficiently long so that the duration of the impact is less than the time it takes for the transient stress wave generated by the impact to travel to the end of the bar and back to the location of the strain gages.

This test is intended for measuring the transient force generated by the projectile when it impacts the cylindrical bar. Projectile breakup pattern data may also be captured during this test. The projectile material is expected to be soft compared with the bar material. Impact stresses are expected to be small compared with the yield strength of the bar material so that all deformations in the bar are elastic.

The values stated in either SI units or inch-pound units are considered separate standards. The values stated in each system may not be exactly equivalent; therefore, each system must be considered as independent.

This standard does not address all of the safety concerns associated with its use. It is the responsibility of each user of this standard to ensure that any safety issues are properly addressed.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM F330-16 Standard Test Method for Bird Impact Testing of Aerospace Transparent Enclosures

2.1.2 Other Publications

Bateman, V.I., Himelblau, H., and Merritt, R., "Validation of Pyroshock Data," Sound and Vibration, March, 2012.

Davies, R.M., "A Critical Study of the Hopkinson Pressure Bar," Philosophical Transactions of the Royal Society of London, V240A, January, 1948, pp. 375-457.

Follansbee, P.S. and Frantz, C., "Wave Propagation in the Split Hopkinson Pressure Bar," J. Engineering Materials and Technology, V105, January, 1983, pp. 61-66.

Follansbee, P.S., "The Hopkinson Bar," Metals Handbook, The American Society for Metals, V8, 1985, pp. 198-203.

2.2 Terminology

2.2.1 Definition 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 SAE 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

2.2.1.1 X-DIRECTION, n

The direction parallel to the axis of the gun barrel and Hopkinson bar. The positive direction is in the direction of projectile flight.

2.2.1.2 Y-DIRECTION, n

The direction of a horizontal vector in the plane of the front face of the Hopkinson bar pointed to the right when facing from the gun barrel to the Hopkinson bar.

2.2.1.3 Z-DIRECTION, n

The direction of a vertical vector in the plane of the front face of the Hopkinson bar pointed downward when facing from the gun barrel to the Hopkinson bar.

2.2.1.4 LONG AXIS OF THE PROJECTILE, n

A vector pointing from the center of the rear of the projectile to the center of the front of the projectile. The direction of this vector may change during flight.

2.2.1.5 IMPACT VELOCITY, V_i [LT⁻¹], n

Velocity of the projectile in the direction of projectile travel just before impact.

2.2.1.6 PITCH ANGLE, n

Angle of the long axis of the projectile about the Y-direction.

2.2.1.7 YAW ANGLE, n

Angle of the long axis of the projectile about the Z-direction.

2.2.1.8 IMPACT FORCE, F [MLT⁻²], n

Force generated by the impact of the projectile on the impacted face of the Hopkinson bar.

3. SUMMARY OF TEST METHOD

An impact test is performed by accelerating a soft projectile to a specified velocity, typically with the use of a single-stage gas gun, into the end face of a right circular cylindrical aluminum bar, referred to as a Hopkinson bar. The impact direction is parallel to the axis of the bar and the impact location is at the center of the face of the bar. The stiffness and strength of the projectile are small compared to those of the bar. The diameter of the bar is at least twice the lateral dimension of the projectile so that after impact the projectile material moves either radially or back toward the direction from which it came. Strain gages located at least a length of 1.5 bar diameters from the impacted face record the strain generated from the impact. Strain gages may be located at a number of distances along the bar to assess the validity of a one dimensional wave assumption.

Because the strain values are small, semi-conductor strain gages—which have a higher sensitivity than conventional strain gages—are used. The bar is long enough so that the impact event is fully recorded before stress wave reflections from the non-impacted end of the bar travel back to the strain gage locations. The strain history of the bar at the strain gage locations is recorded for the full impact duration. From this the force history at the impact face is calculated.

If specified by the test requestor, the breakup pattern of the projectile after impact can be measured through high-speed photography. The pattern is defined by a line that traces the perimeter of the debris observed in sequential high speed video images. The coordinates of points on this line can be digitized to allow quantification of variables such as overall area, average diameter, and average velocity of the debris. The number of points defining the curve and the time increment between successive measurements are prescribed by the test requestor.

4. SIGNIFICANCE AND USE

Simulants are used as projectiles in impact and ingestion testing in cases where it is undesirable to use real projectiles, such as in the case of bird strike or ingestion. To develop accurate simulants, it is necessary to demonstrate that the impact response produced by the simulant is similar to that produced by the real projectile. One parameter which must be similar is the impact force. This device allows the measurement of impact force for comparison with that of the real projectile. The test method can also be used to develop and validate dynamic material constitutive models for other soft or frangible materials such as ice and soft polymers.

5. EQUIPMENT AND MATERIALS REQUIRED

5.1 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 ± 1 g (0.035 ounce).

5.2 Signal Conditioning

A signal conditioner capable of providing strain gage bridge excitation up to 10 V, bridge balance and signal amplification with a frequency response, and technical specifications specified by the test requestor. A minimum frequency response of 100 kHz is recommended.

5.3 Data Acquisition

A data acquisition system capable of recording at the rate and resolution specified by the test requestor. The following specifications are recommended (Follansbee, P.S.):

1. Bandwidth: DC to 100 kHz minimum.
2. Sampling rate: Ten times the desired data bandwidth or higher.
3. Analog anti-aliasing filter rolloff: 60 dB/octave or steeper.
4. Analog anti-aliasing filter cutoff frequency: One octave below Nyquist frequency or lower.
5. Slew rate: Greater than 20 V/ μ s.
6. Minimum of 16 bit resolution.

5.4 High-Speed Cameras

A minimum of three digital high-speed video cameras capable of recording with a resolution and frame rate specified by the test requestor are required. One camera (Camera 1) should be pointed normal to the path of the projectile from the side, as specified below. A transparent shield may be required for lens protection from impact debris. A pair of cameras may be used (if using a 3D photogrammetry technique to measure velocity). In that case, the cameras should be offset from one another and have a combined field of view with a minimum length specified in 5.4.2. The second camera (Camera 2) is located as close as possible and directly above, below, or alongside the muzzle of the gun barrel, supported independently of the gun barrel and aimed at the front face of the Hopkinson bar. The third camera (Camera 3) is located directly above the impact location and pointed in a normal direction to the path of the projectile, as specified below.

The camera locations are to be as specified in Figure 1 with the following parameters:

5.4.1 d_1

Distance from Camera 1 to the gun centerline. It is recommended that this distance be at least that of measurement f_1 .

5.4.2 f_1

Field of view of Camera 1. Minimum length must be three times the length of the projectile and allow a minimum of 15 recorded frames prior to impact.

5.4.3 d_2

Distance from gun Camera 2 to the front face of the Hopkinson bar. This distance is governed by the distance from the gun barrel muzzle to the Hopkinson bar.

5.4.4 f_2

Field of view of Camera 2. Minimum length of three times the diameter of the Hopkinson bar.

5.4.5 d_3

Distance from Camera 3 to the gun centerline. It is recommended that this distance be at least that of measurement f_3 .

5.4.6 f_3

Field of view of Camera 3. Minimum length must be three times the length of the projectile and allow a minimum of 15 recorded frames prior to impact.