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Standard Test Method for Measuring Forces During Dynamic Slicing of a Soft Projectile

RATIONALE

Measurements of forces generated by the dynamic slicing of soft projectiles can be challenging due to the very short duration of the event and the impracticality of producing a pure slicing response. This test provides a standard method for measuring these forces for comparison of one material to another. 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 develop physical simulants for impact and ingestion certification testing for aircraft.

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1. SCOPE

This document describes a method for measuring transient force histories generated by the impact of a soft or frangible projectile on a thin slicer oriented in a plane parallel to the direction of the projectile motion. The slicer is intended to be representative of a typical turbofan engine fan blade. 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 a relatively thin, flat, blade-like device with a sharp leading edge (the "slicer"). The direction of motion of the projectile is parallel to the plane of the slicer. The test is designed to minimize lateral motion in the projectile as a result of the impact. The intended impact velocity range for this test is between approximately 50 and 300 m/sec. The slicer has a width greater than the largest diameter of the projectile and is supported on a fixture instrumented to measure force. The projectile material is expected to be soft compared with the slicer material. Impact stresses are expected to be small compared with the yield strength of the slicer material so that any deformations in the slicer are elastic. 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 F330-21 Standard Test Method for Bird Impact Testing of Aerospace Transparent Enclosures

2.1.2 Other Publications

Bateman, V., Himelblau, H., and Merritt, R. (March 2012). Validation of Pyroshock Data. *Sound & Vibration*, 6-11.

2.2 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 SAE standard symbology for fundamental dimensions, shown within square brackets: [M] for mass, [L] for length, [T] for time, 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 Impact Velocity, V_i [LT⁻¹], n

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

3. UNITS

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.

4. 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 a thin, flat steel structure with a sharp leading edge and specified dimensions, referred to here as the slicer. The plane of the slicer is parallel to the direction of impact, and the leading edge of the slicer is normal to the direction of impact. The goal of the test is for the impact to occur as close as possible to the centerline of the projectile. The slicer has a span that is larger than the lateral dimension of the projectile so that the complete projectile is cut (see Figure 3, Dimension S). It is mounted on force sensors supported on a massive structure to measure the reaction forces. The stiffness and strength of the projectile are small compared to those of the slicer. High-speed cameras record the velocity and orientation of the projectile prior to impact as well as the velocity and path of the resulting debris.

5. 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 cases of bird strike or bird ingestion. To develop accurate simulants it is necessary to demonstrate that the impact response produced by the simulant is similar to that from the real projectile. One parameter that may be important is the force history required to slice a projectile, as occurs when it impacts an aircraft engine inlet guide vane, rotor blade, or fan blade. This device allows the measurement of this slicing 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.

6. EQUIPMENT AND MATERIALS REQUIRED

6.1 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).

6.2 Calipers

Calipers may be required to measure the dimensions of the projectile. If so, the required accuracy of the measuring equipment will be specified by the test requester.

6.3 Force Sensors

Two piezoelectric force rings capable of measuring force to within an accuracy of ± 5 N (± 1 lbf) with a flat frequency response up to a minimum of 35 kHz are required. The force rings must be large enough to accommodate the fixture bolt diameter. Due to geometrical constraints, the recommended force sensors may have a load range much higher than the expected loads from the soft projectile impact. It is recommended that, in addition to the standard force sensor calibration, a special calibration be conducted that spans the range of expected loads. Examples of force sensors that can be used include the PCB Piezotronics model 206C force ring, PCB 216B force ring, and the Kistler 9061C force sensor. The force sensors must be preloaded by the support bolts to the value specified by the manufacturer.

6.4 Data Acquisition

6.4.1 A data acquisition system capable of recording at the rate and resolution specified by the test requester.

The following specifications are recommended (refer to Bateman et al., 2012):

- a. Bandwidth - DC to 100 kHz minimum
- b. Sampling rate - ten times the desired data bandwidth or higher
- c. Analog anti-aliasing filter roll-off - 60 dB/octave or steeper
- d. Analog anti-aliasing filter cutoff frequency - one octave below Nyquist frequency or lower
- e. Slew rate - greater than 20 V/ μ s

6.5 High-Speed Cameras

A minimum of three digital high-speed video cameras are required, capable of recording with a resolution and frame rate specified by the test requester. The minimum frame rate shall be 10,000 frames/second with a resolution of at least 8 px/cm (21 px/in). Figures 1A and 1B show schematics of camera locations for the case where the slicer is oriented in a horizontal plane. One camera (Camera 1) should view the fixture from the side, normal to the path of the projectile, and should have a field of view sufficient to allow the measurement of projectile velocity prior to impact as well as the path and velocity of the projectile debris after impact with the slicer. 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 6.5.1. A second camera (Camera 2) should view the fixture from above, normal to the path of the projectile, with a field of view as specified in 6.5.1. The third camera (Camera 3) should view the impact location from the front, adjacent to the gun barrel, and as close to the gun barrel as is deemed safe by the test conductor. The field of view must be sufficient to show the complete projectile just prior to impact and as it travels through the test fixture.

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

- 6.5.1.1 f_{1a} , f_{2a} : Field of view, Cameras 1 and 2, respectively, at rear of fixture. Must be a minimum of four times the nominal length of the projectile.
- 6.5.1.2 f_{1b} , f_{2b} : Field of view, Cameras 1 and 2 in front of fixture. Minimum length of three times the nominal length of the projectile.
- 6.5.1.3 d_1 , d_2 : Distance from gun Cameras 1 and 2 to axis of the gun. This distance should be greater than the sum of f_{1a} and f_{1b} or f_{2a} and f_{2b} , respectively.
- 6.5.1.4 f_3 : Field of view of Camera 3. The camera should focus on the center of the slicer and have a field of view at least twice its width.