Designation: F320 − 16

Standard Test Method for Hail Impact Resistance of Aerospace Transparent Enclosures[1]

This standard is issued under the fixed designation F320; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers the determination of the impact resistance of an aerospace transparent enclosure, hereinafter called windshield, during hailstorm conditions using simulated hailstones consisting of ice balls molded under tightly controlled conditions.

1.2 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.

1.3 *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.* For specific hazard statements see Section 7.

2. Terminology

2.1 *Definitions:*

2.1.1 *damage, n*—any modification in visual properties or integrity of a windshield as a result of hail impact including scratches, crazing, delamination, cracks, or shattering.

2.1.2 *ice ball, n*—a frozen mass of water, with filler, that simulates a natural hailstone in weight, size, and toughness.

2.1.3 *impact angle, n*—the angle between the ice ball flight path and the target normal.

2.1.4 *sabot, n*—a plastic device for protecting the ice ball while in the launch tube. One type of sabot (see Fig. 1) consists of a split polycarbonate rod containing a central cavity for holding the ice ball. Each sabot half is designed to assure aerodynamic separation from the ice ball after ejection from the launch tube.

3. Summary of Test Method

3.1 The test method involves launching a series of ice balls of specified sizes at a sample windshield at a designated velocity and angle and in a specified pattern. Requirements are specified for the ice ball, test specimen, procedure, and data acquisition. The ice ball is photographed in flight to verify its integrity.

3.2 Requirements are specified for a particular apparatus and test procedure, but options are permitted for certain areas. However, it must be possible to demonstrate that the options used result in an ice ball impacting the test panel with the same size, consistency, and velocity as with the specified apparatus and procedure. Following are areas where options are allowed:

3.2.1 *Ice Ball Mold Material.*

3.2.2 *Launcher*—Any type of launcher is allowable as long as the iceball reaches the test specimen intact at the correct speed. The use of sabots and sabot material and geometry are optional.

3.2.3 *Method of Determining Ice Ball Integrity.*

3.2.4 *Ice Ball Speed Measurement,* optional as long as accuracy standards are met.

3.2.5 *Test Specimen Sizes*—Those given are minimum.

3.2.6 *Safety*—Safety must satisfy the safety standards of the test facility being used.

4. Significance and Use

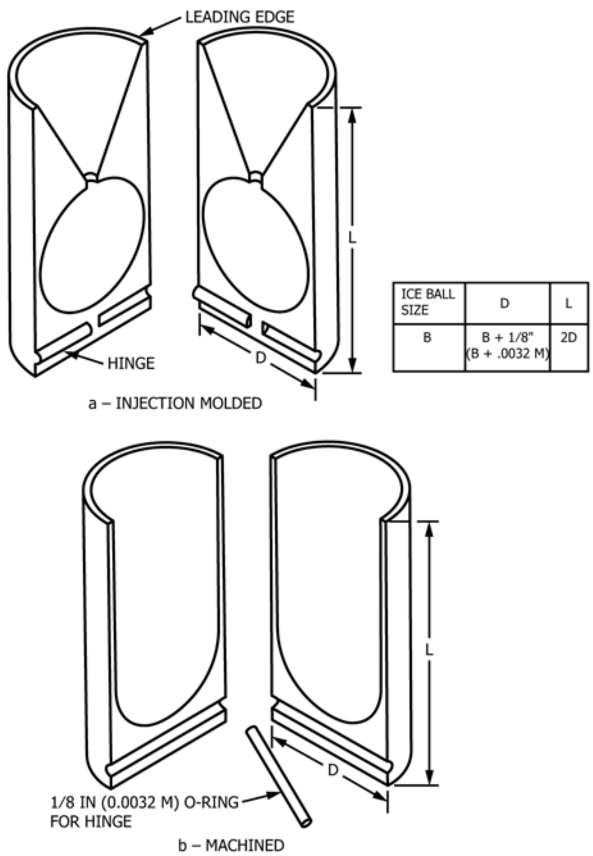
4.1 This test method shall be used to determine the hail impact resistance of windshields for acceptance, design, service, or research purposes. By coupling this method with the installed angle and velocity of a specific aerospace vehicle, design allowables, criteria, and tolerances can be established for that vehicle's windshield.

5. Apparatus

5.1 The facilities and equipment required for the performance of this test procedure include a suitable firing range equipped with an ice ball mold, a launcher, blast deflector, sabot trap, velocity measuring system, test specimen holder, and a camera with strobe lights to verify ice ball integrity. Ancillary equipment required for this test include test

[1] This test method is under the jurisdiction of ASTM Committee F07 on Aerospace and Aircraft and is the direct responsibility of Subcommittee F07.08 on Transparent Enclosures and Materials.

Current edition approved April 1, 2016. Published April 2016. Originally approved in 1978. Last previous edition approved in 2010 as F320 – 10. DOI: 10.1520/F0320-16.



ICE BALL SIZE	D	L
B	B + 1/8" (B + .0032 M)	2D

FIG. 1 Sabot Configuration

specimen, ice balls, sabots, and firing cartridges. An example facility is described below.

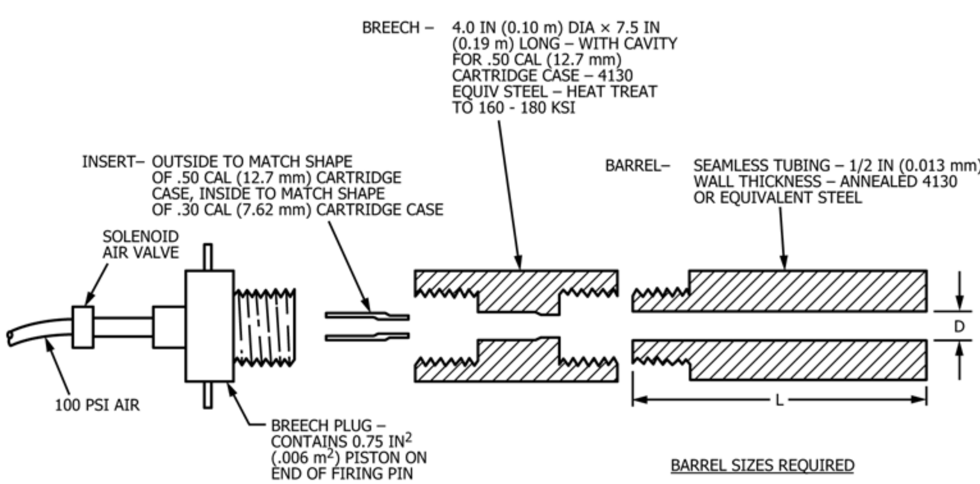
5.2 *Firing Range*—The firing range shall be a minimum of 9 by 18 ft (3 by 6 m) enclosed to contain flying debris and to exclude unauthorized personnel.

5.3 *Ice Ball Mold,* two aluminum blocks with hemispherical cavities and vent holes for filling with water and for water expansion during freezing.

5.4 *Launcher,* a variety of launchers are suitable as noted in 3.2.2. In addition to the powder gun described in this test method, laboratories have also successfully utilized compressed gas gun launchers. An example of a powder gun launcher is shown in Fig. 2, consisting of a barrel, breech, breech plug, and control. The barrel shall be made from high-quality AISI 4130 seamless steel tubing, or equivalent, in the annealed condition. The breech shall be made from AISI 4130 steel rod, or equivalent, heat treated to a 160- to 180-ksi (1104- to 1242-MPa) ultimate tensile strength condition. The size of cavity to be used in the breech depends on the desired test velocity (see Table 1). The breech plug, which locks the cartridge in place and contains the firing pin, shall be made of 4340 steel heat treated to a 160- to 180-ksi ultimate tensile strength condition. The firing pin is actuated by a kinetic impact air piston. Control is accomplished by an electrically actuated air valve. For a 100-psi (0.69-MPa) air source, a 0.75-in.^{2} (4.84-cm^2) piston traveling 0.5 in. (13 mm) is used.

5.5 *Blast Deflector*—Place a plate with a 4-in. (100-mm) diameter hole as shown in Fig. 3 between the sabot trap and the first velocity measuring station. Then place a corrugated cardboard plate over the hole. This deflector is not required for compressed gas gun systems.

5.6 *Sabot Trap* is made by placing two steel plates two to four ice ball diameters apart, centered on the flight path and located a minimum of 6 ft (1.82 m) from the launcher muzzle



BARREL SIZES REQUIRED

VELOCITY RANGE	L
200 - 1000 FPS (60 - 300 MPS)	10 IN (0.25 m)
600 - 3000 FPS (180 - 900 MPS)	60 IN (1.53 m)

HAIL SIZE	D
1/2 IN (0.013 m)	0.75 IN (0.019 m)
1.0 IN (0.025 m)	1.25 IN (0.032 m)
2.0 IN (0.051 m)	2.25 IN (0.058 m)

FIG. 2 Launcher Design

TABLE 1 Power Loads

Desired Velocity, ft/s (m/s)	Barrel Bore, in. (mm)	Barrel Length, in. (m)	Cartridge Size, caliber	Powder Type	Powder Weight, grains (g)
200 (60)	1.25 (32)	10 (0.25)	0.30	Bullseye[A]	6 (0.39)
	2.25 (57)	10 (0.25)	0.30	Bullseye	6 (0.39)
500 (150)	0.75 (19)	10 (0.25)	0.30	Bullseye	5 (0.32)
	1.25 (32)	60 (1.52)	0.50	4227[B]	40 (2.59)
	2.25 (57)	60 (1.52)	0.50	Bullseye	30 (1.94)
	2.25 (57)	10 (0.25)	0.30	Bullseye	12 (0.78)
1000 (300)	0.75 (19)	10 (0.25)	0.30	Bullseye	9 (0.58)
	1.25 (32)	60 (1.52)	0.50	Bullseye	60 (3.89)
	1.25 (32)	10 (0.25)	0.30	Bullseye	20 (1.30)
	2.25 (57)	60 (1.52)	0.50	Bullseye	70 (4.54)
2000 (600)	0.75 (19)	60 (1.52)	0.50	Bullseye	35 (2.27)
	1.25 (32)	60 (1.52)	0.50	Bullseye	70 (4.54)
	2.25 (57)	60 (1.52)	0.50	Bullseye	150 (9.72)

[A] The sole source of supply of the apparatus known to the committee at this time is Hercules, Inc., 1313 North Market Street Wilmington, DE 19894-0001. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee [2], which you may attend.
[B] The sole source of supply of the apparatus known to the committee at this time is duPont, Chestnut Run Plaza 705/GS38 Wilmington, DE 19880-0705. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee [2], which you may attend.

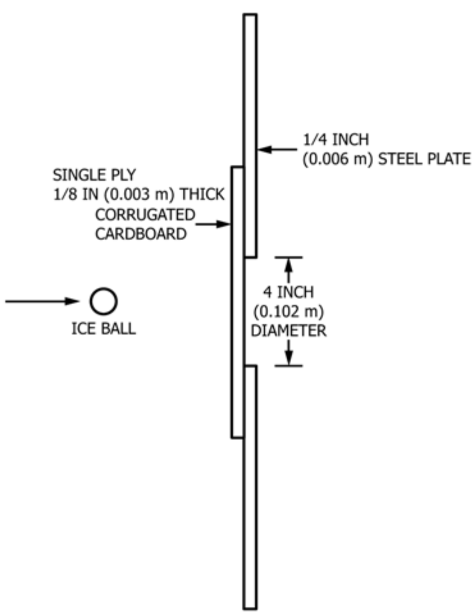


FIG. 3 Blast Deflector

as shown in Fig. 4. This trap is not required for systems that utilize aerodynamic separation of the sabot or other suitable mechanisms to ensure that the sabot does not impact the test article.

5.7 *Velocity Measurement System*—The break-screen velocity measurement consists of a set of screens, power supply, wiring, and counters. Three screens shall be made from a lightweight bond paper with an electrical circuit painted on the paper by the silk screen process. The paint for the circuit shall be electronic grade electrical conducting paint.[2] Do not thin the paint. The break-screen shall be made with lines ⅛ in. (3.2 mm) wide by 18 in. (460 mm) long as shown in Fig. 5 giving a resistance of no more than 300 Ω. Fig. 6 shows the arrangement of components and gives the electronic circuit to be used with the three screens. The system shall be accurate to ±1 % or better. Laser-based photo detector systems and high-speed-film-based systems are also acceptable, provided the accuracy is ±1 %.

5.8 *Test Specimen Holder*—Use one of two types of test specimen holders. The one in Fig. 7 is designed to hold an 18- by 18-in. (0.46- by 0.46-m) test specimen that can be impacted at angles ranging from 0 to 80° as detailed in Section 8. When testing a complete windshield, use edge restraints similar to the actual installation and place the windshield in the proper orientation (see 9.2).

[2] The sole source of supply of the apparatus known to the committee at this time is "Silver Preparation," duPont electronic grade No. 4817. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee [2], which you may attend.

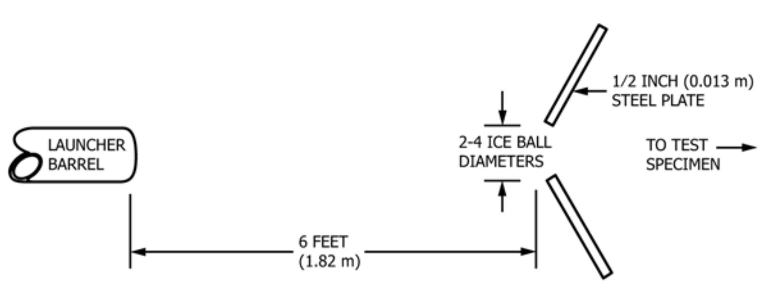


FIG. 4 Sabot Trap

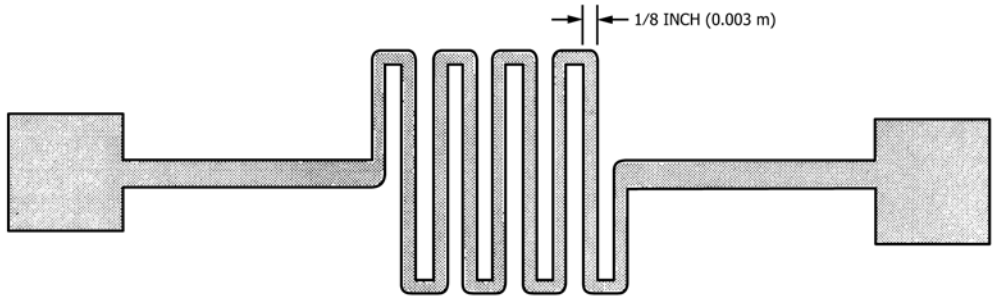
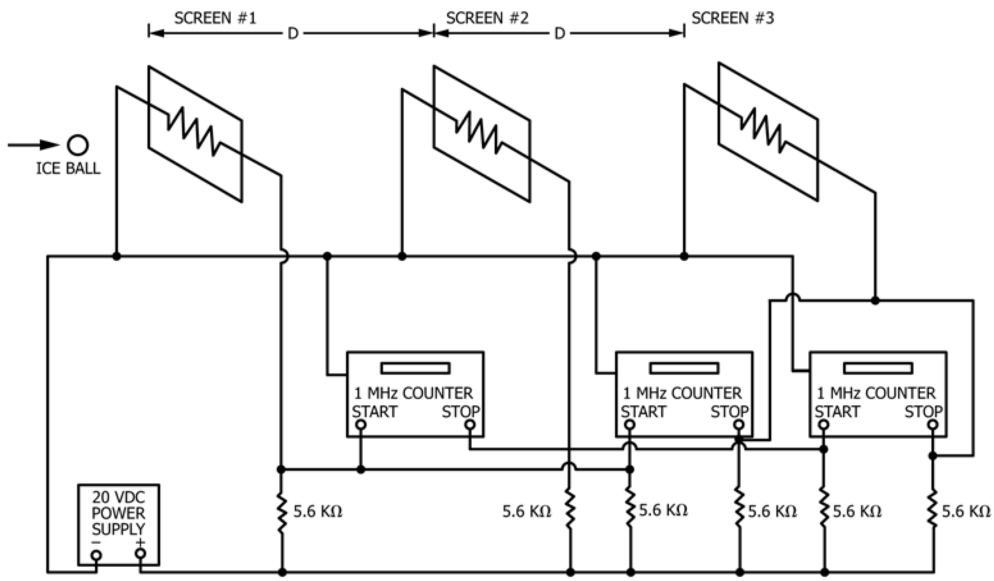


FIG. 5 Velocity Screen



$$V = \frac{D}{t_1} = \frac{2D}{t_2} = \frac{D}{t_3}$$

WHERE V = VELOCITY
D = SCREEN SEPARATION
t = TIME FROM COUNTER #1, #2, OR #3

FIG. 6 Velocity Measuring System

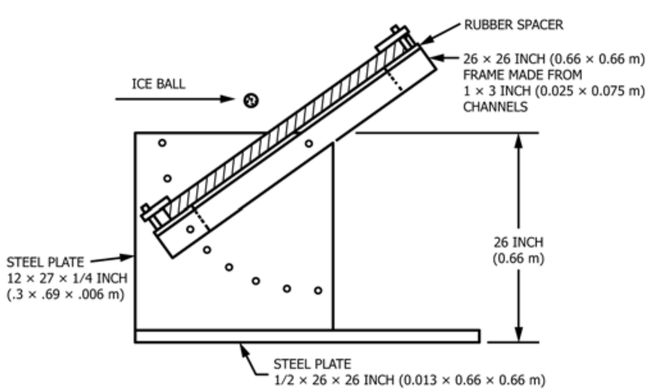


FIG. 7 Test Specimen Holder

5.9 *Ice Ball Integrity Camera*—Verify ice ball integrity before impact by obtaining a photograph of the ice ball in flight before impact. This is accomplished by illuminating the ice ball with a strobe light while the ice ball is in the field of view of a camera lens. This synchronization can be obtained by using an open shutter with the strobe triggered at the second velocity screen. The signal is split with part going to the velocity counters and part to a variable time-delay generator. Using the estimated ice ball velocity, a time delay is selected so the ice ball will be in view of the camera lens when the strobe is triggered.

5.10 *Balance,* for powder and ice balls, capacity 0.2 lb (100 g), accuracy ±1 % (1.0 g).

5.11 *Clinometer or Protractor,* to measure impact angle, accuracy ±¼ °.

5.12 *Syringe,* 100-cm^3, for putting water into the ice ball mold.

6. Materials

6.1 *Sabot*—An effective injection molded sabot configuration is shown in Fig. 1*a*, while a machined configuration is shown in Fig. 1*b*. In either design, polycarbonate material is used to form the two halves of the sabot at a minimum diameter equal to the ice ball diameter plus ⅛ in. (3.2 mm) with a length approximately twice this diameter to assure in-flight separation of the sabot halves. An acceptable tolerance of the sabot diameter has been found to be within 0.005 in. (0.127 mm) of the minimum barrel diameter.

6.2 *Gunpowder*—The brands listed in Table 1 have been found to be satisfactory for powder guns.

6.3 *Cartridge Cases,* with primers, 0.30 and 0.50 caliber, or other sizes used with powder guns.

6.4 *Cotton Fiber*—Standard pharmaceutical cotton balls.

6.5 *Bags, Polyethylene,* commercial grade.

6.6 *Plastic Wrapping*—Poly(vinylidene chloride).

7. Hazards

7.1 *Powder Storage and Handling*—Powder handling and storage shall conform to all Federal and local regulations. The handling facility in which the powder charges are weighed and loaded must be reserved for this purpose alone. Procure primers already mounted in the cartridge cases or special facilities provided for this dangerous operation.

7.2 *Firing Area*—Exclude all personnel from the firing area except the operator.

7.3 *Locked Switch*—There shall be a locked switch on the firing circuit which can be closed only by a key kept in the operator's possession during the entire calibration and test procedure.

8. Test Specimen

8.1 The test specimen shall be a duplicate of the windshield being simulated or a section thereof. If a section is used, it shall measure 18 by 18 in. (0.46 by 0.46 m). Surface condition shall be dry. Temperature shall be ambient unless special temperatures are associated with the particular installation being simulated. In the case of special temperatures, the temperature to use and the method of attainment are to be established by mutual agreement between the user and the testing agency. Use a strong backlight to aid visual inspection of the windshield both before and after the test.

9. Preparation of Apparatus

9.1 *Velocity*—Select the ice ball velocities from one of the standard values in Table 2 unless otherwise specified.

9.2 *Impact Angle*—Select the impact angles from the following standard conditions, unless otherwise specified.

9.2.1 For the 18- by 18-in. (0.46- by 0.46-m) cut section, the impact angle shall be 45° at the center of the section.

9.2.2 For the complete windshield, the impact angle at the center and at the edge shall be the actual minimum angle between the ice ball flight path and the normal to the windshield surface.

TABLE 2 Velocity

Aircraft Type	Velocity, ft/s (m/s)
Low speed	200 (60)
Fixed wing, piston engine, or rotary wing, turbine engine	500 (150)
Fixed wing, turbine engine	1000 (300)
Supersonic	2000 (600)

9.3 *Preparation of Ice Balls:*

9.3.1 Separate and weigh an amount of cotton filler as specified in 10.2.

9.3.2 Dip the above amount of cotton into a container of water, remove, and shape into a sphere.

9.3.3 Place the cotton sphere into the mold.

9.3.4 After securing the mold halves, fill the cavity with water from a syringe. Place the syringe point at the lowest point in the mold cavity so that the rising water will drive the air out.

9.3.5 Place the mold in a 0°F (−18°C) environment until frozen. With experience, complete freezing can be determined from the length of the sprue extruded from the filler hole.

9.3.6 Rapidly bring the mold to above freezing by immersing it in room temperature water until the ice on the mold slips. Remove from water.

9.3.7 Open the mold and remove the ice ball. Seal the ice ball in a polyethylene bag and store in the freezer at 0°F (−18°C). Ice balls shall not be more than four days old before use. Minimize the time out of the mold because of the formation of cracks with time.

9.4 *Ice Ball Size and Impact Pattern:*

9.4.1 If a pass/fail iceball size requirement is not specified, impact nine ½-in. (13-mm) diameter ice balls in the pattern shown in Fig. 8. Likewise, impact nine 1.0-in. (25-mm) diameter and five 2.0-in. (51-mm) diameter ice balls with the respective patterns shown in Fig. 8. An exception is the testing of a windshield edge where only four 2.0-in. (51-mm) ice balls will be tested. If a pass/fail iceball size requirement is specified, impact with the specified iceball size in the Fig. 8 pattern, which is nearest to the specified size.

9.4.2 Orient the edge of the windshield such that the center of the impact pattern is located 2.8 in. (71 mm) laterally from the point on the windshield edge selected in 9.2.2. This orientation is shown in Fig. 9 for a 2.0-in. (51-mm) diameter ice ball impact test. Any impact points that fall outside of the windshield area shall be omitted.

9.5 *Test Specimen*—In addition to the requirements of Section 8, mark the test specimen at the desired location for the first impact points and mount in the test specimen holder at the proper angle (see 9.2).

9.6 *Velocity Screens*—If used, prepare velocity screens as described in 5.6. Use three screens per shot.

9.7 *Cartridge*—For powder guns, load an appropriate number of cartridges with the amounts of gunpowder based on the calibration tests (see 10.1).

10. Calibration and Standardization

10.1 *Calibration of Powder Charges*—For powder guns, calibrate the charge before testing within 10 % of the planned velocity. Accomplish this by test-firing ice balls of the specified size starting with the powder amounts shown in Table 1.

10.2 *Standardization of Ice Balls*—Make five ice balls of each size. Visual inspection must show no air bubbles or cracks. Measurements of density, or diameter measurement of

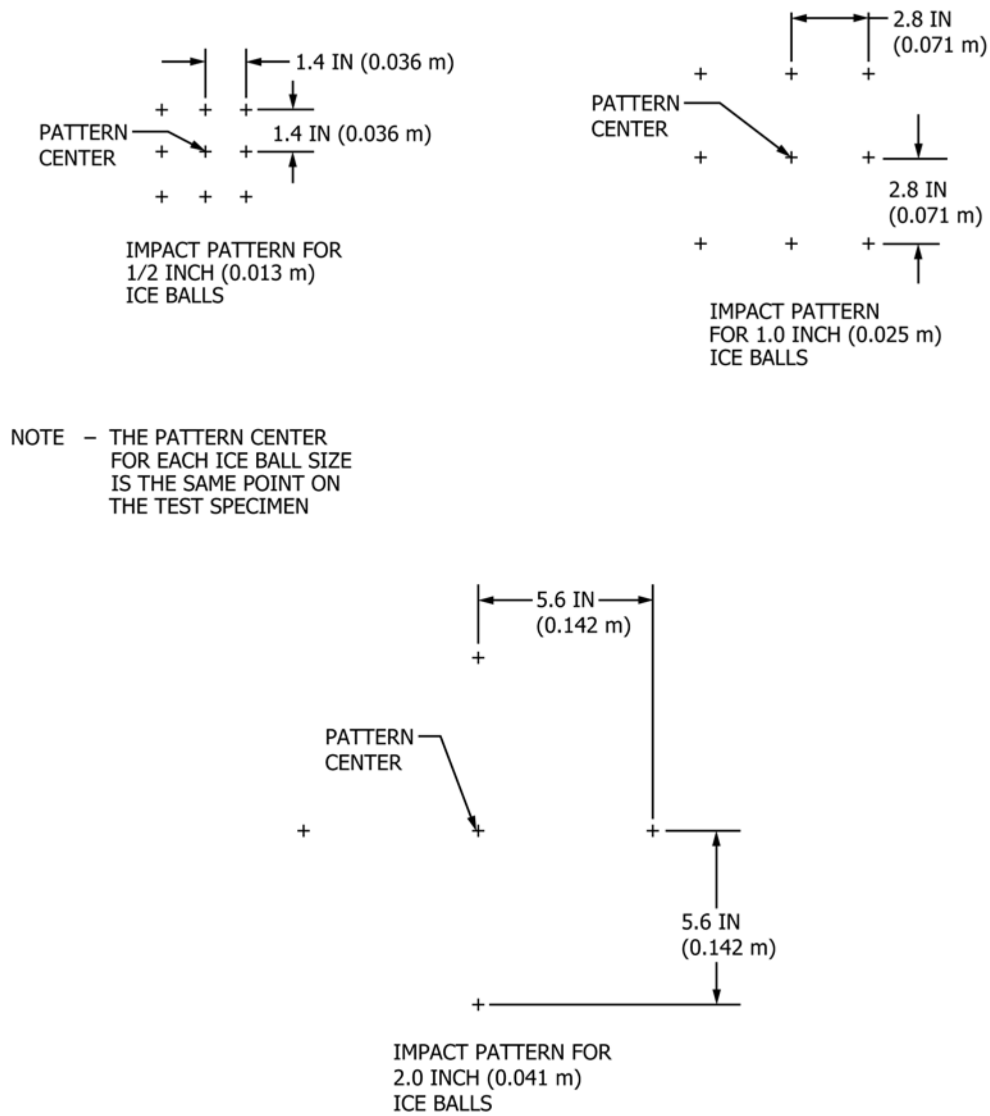


FIG. 8 Impact Patterns

each ice ball, are not practical during testing. However, the following must be verified on the first five balls of each size (see Table 3).

11. Procedure

11.1 *Test Sequence:*

11.1.1 The series of tests involving all three ice ball sizes is called a test set. Accomplish each test set in sequence from small to large ice balls. Launch all ½-in. (13-mm) diameter ice balls in the pattern and at the aiming points detailed in 9.4. Follow with all 1-in. (25-mm) diameter ice balls and all 2-in. (51-mm) diameter ice balls in the respective patterns. After tests with each size have been completed, record the damage imposed on the test specimens.

11.1.2 Locate the test set impact pattern at the center of the test panel for sections of windshields. For complete windshields, locate the main test set pattern at the center (see 9.4). Accomplish a test set at the point along the windshield edge where the impact angle is smallest, unless this angle is within 5° of the minimum impact angle anywhere on the windshield. In this case, only the windshield edge test set need be fired.

11.2 *Procedure for Each Shot:*

11.2.1 Align test specimen for the next impact.

11.2.2 Replace the velocity screens, or arm the velocity measurement system.

11.2.3 Replace the blast plate, if utilized.

11.2.4 Load the film in the camera.

11.2.5 The ice ball and sabot shall be at 0°F (−18°C) at this point. Place two sabot halves on a table and cut two squares of plastic wrapping. The sides of the squares shall be approximately twice the ice ball diameter. Place one square over the cavity in each sabot half.

11.2.6 Roll the ice ball in the palm of the hands until the surface of the ice ball is wet.

11.2.7 Quickly place the ice ball in one of the sabot halves and cover it with the other half. The ice ball surface will now

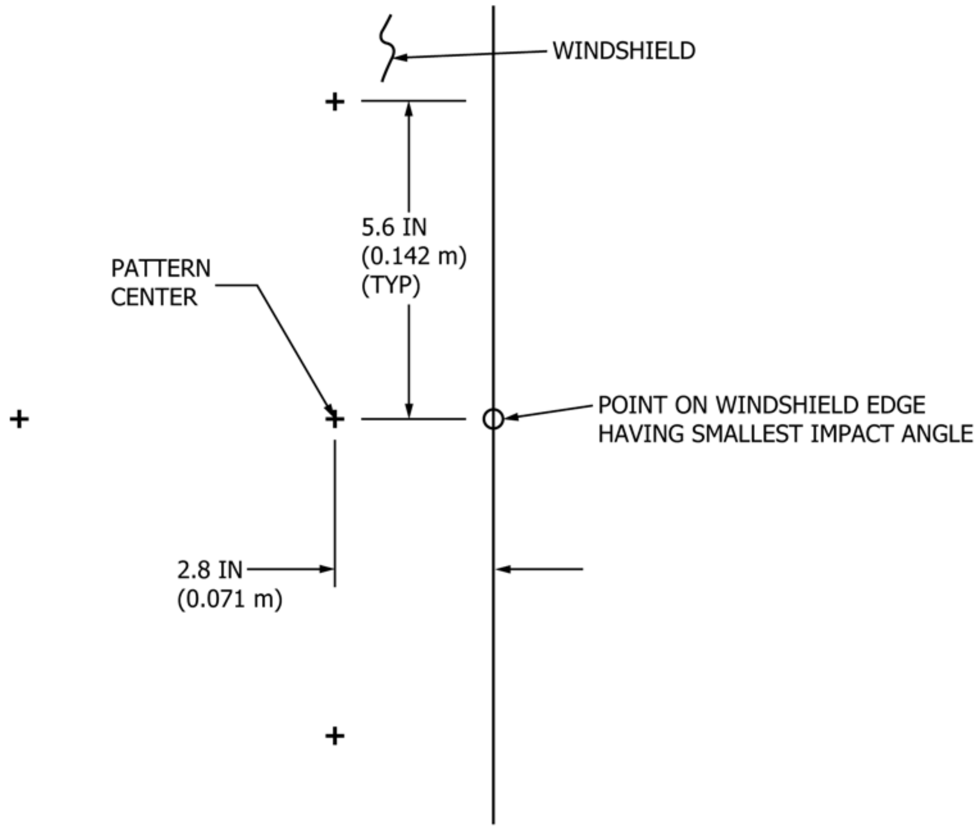


FIG. 9 Impact Pattern Location for Windshield Edge Test

TABLE 3 Standardization of Ice Balls

Ice Ball Size, in. (mm)	Weight, lb (g)	Toler-ance	Filler Weight, lb (g)	Toler-ance
0.5 (13)	0.0023 (1.0)		0.0003 (0.14)	
1.0 (25)	0.018 (8.2)	±5%	0.0022 (1)	±30%
2.0 (51)	0.146 (66.4)		0.0176 (8)	

refreeze to the contour of the sabot. The plastic wrapping will keep the ice from adhering to the sabot.

11.2.8 Place the sabot on the launcher, screw on the breech, insert the powder cartridge, and close the breech.

11.2.9 Clear the test area.

11.2.10 Conduct the countdown.

11.2.11 Fire the shot.

11.2.12 Clear the area and record the data.

12. Report

12.1 The test report shall contain, as a minimum, the following:

12.1.1 How the calibrations were made and accuracy maintained,

12.1.2 The test conditions such as test specimen description,

12.1.3 The ice ball and condition desired and measured velocities, and weight.

12.1.4 The target location and angle of impact, and

12.1.5 A detailed description of the resulting damage following impact tests with each ice ball size including before and after photographs. Any test specimen damage shall be noted.

12.2 The hail impact tolerance level to be included in the test report will be found by testing with the small ice balls and then, using the same test specimen, working up in ice ball size. The tolerance level is defined as the size of the largest ice balls that did not create unacceptable damage. Thus, the tolerance level will be classified as ½ in. (13 mm), 1.0 in. (25 mm), 2.0 in. (51 mm), or undetermined.

13. Precision and Bias

13.1 Since each test specimen is unique and is tested to destruction, it is not possible to establish a numerical statement of precision or bias.

14. Keywords

14.1 hail; ice; impact; transparent enclosures