Designation: C 423 – 00

Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method[1]

This standard is issued under the fixed designation C 423; 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 Department of Defense.

1. Scope

1.1 This test method covers the measurement of sound absorption in a reverberation room by measuring decay rate. Procedures for measuring the absorption of a room, the absorption of an object, such as an office screen, and the sound absorption coefficients of a specimen of sound absorptive material, such as acoustical ceiling tile, are described.

1.2 *Field Measurements*—Although this test method primarily covers laboratory measurements, the test method described in 4.1 can be used for making field measurements of the absorption of rooms (see also 5.5). A non-standard method to measure the absorption of rooms in the field is described in Appendix X2.

1.3 This test method includes information on laboratory accreditation (see Annex A1), asymmetrical screens (see Annex A2), and reverberation room qualification (see Annex A3).

1.4 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 634 Terminology Relating to Environmental Acoustics[2]

E 548 Practice for Generic Criteria for Use in Evaluation of Testing and Inspection Agencies[3]

E 795 Practices for Mounting Test Specimens During Sound Absorption Tests[2]

2.2 *ANSI Standards:*

S1.6 Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements[4]

S1.11 Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters[4]

S1.26 Method for the Calculation of the Absorption of Sound by the Atmosphere[4]

3. Terminology

3.1 Except as noted in 3.3, the terms and symbols used in this test method are defined in Terminology C 634. The following definition is not currently included in Terminology C 634:

3.1.1 *sound absorption average, SAA*—a single number rating, the average, rounded off to the nearest 0.01, of the sound absorption coefficients of a material for the twelve one-third octave bands from 200 through 2500 Hz, inclusive, measured according to this test method.

3.1.1.1 *Discussion*—The sound absorption coefficients shall be rounded off to the nearest 0.01 before averaging. If the unrounded average is an exact midpoint, round to the next higher multiple of 0.01. For example, report 0.625 as 0.63.

3.2 In previous versions of this test method a single number rating, called the noise reduction coefficient (NRC), was defined as follows:

> ″Round the average of the sound absorption coefficients for 250, 500, 1000, and 2000 Hz to the nearest multiple of 0.05. If the unrounded average is an exact midpoint, round to the next higher multiple of 0.05. For example, 0.625 and 0.675 would be reported as 0.65 and 0.70, respectively.″

The noise reduction coefficient shall be reported in order to provide comparison with values reported in the past see 12.1.3).

3.3 *Definition of Term Specific to This Standard*—The following term has the meaning noted for this test method only:

3.3.1 *output interval, Δt, [T], s—of a real-time analyzer*, the time between successive outputs; this time is not necessarily the same as the integration time.

4. Summary of Test Method

4.1 *Measurement of the Sound Absorption of a Room*:

4.1.1 A band of random noise is used as a test signal and turned on long enough (about the time for 20 dB decay in the test band with the smallest decay rate) for the sound pressure level to reach a steady state. When the signal is turned off, the sound pressure level will decrease and the decay rate in each frequency band may be determined by measuring the slope of a straight line fitted to the sound pressure level of the average

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[1] This test method is under the jurisdiction of ASTM Committee E33 on Environmental Acoustics and is the direct responsibility of Subcommittee E-33.01 on Sound Absorption.

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[2] *Annual Book of ASTM Standards,* Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

decay curve. The absorption of the room and its contents is calculated, based on the assumptions that the incident sound field is diffuse before and during decay and that no additional energy enters the room during decay, from the Sabine formula:

$$A = 0.9210 \frac{Vd}{c} \quad (1)$$

where:

A = sound absorption, m^2 or Sab,
V = volume of reverberation room, m^3 or ft^3,
c = speed of sound (calculated according to 11.13), m/s or ft/s, and
d = decay rate, dB/s,

These conditions must be fulfilled if the measurement is to have meaning. The sound absorption calculated according to Eq 1 is sometimes called the Sabine absorption.

4.1.2 In general, sound absorption is a function of frequency and measurements are made in a series of frequency bands.

4.2 *Measurement of a Sound Absorption Coefficient*—The absorption of the reverberation room is measured as outlined in 4.1 both before and after placing a specimen of material to be tested in the room. The increase in absorption divided by the area of the test specimen is the dimensionless sound absorption coefficient. In inch-pound units it is reported with the dimensionless "unit" sabin per square foot, Sab/ft^2.

4.3 *Measurement of the Sound Absorption of an Object Such as an Office Screen, a Theater Chair, or a Space Absorber*—The absorption of the reverberation room is measured as outlined in 4.1 both before and after placing one or several identical objects in the room. The increase in absorption divided by the number of objects is the absorption in square meters per object or sabins per object.

5. Significance and Use

5.1 Measurement of the sound absorption of a room is part of the procedure for other acoustical measurements, such as determining the sound power level of a noise source or the sound transmission loss of a partition. It is also used in certain calculations such as predicting the sound pressure level in a room when the sound power level of a noise source in the room is known.

5.2 The sound absorption coefficient of a surface is a property of the material composing the surface. It is ideally defined as the fraction of the randomly incident sound power absorbed by the surface, but in this test method it is operationally defined in 4.2. The relationship between the theoretically defined and the operationally measured coefficients is under continuing study.

5.3 Diffraction effects[5] usually cause the apparent area of a specimen to be greater than its geometrical area, thereby increasing the coefficients measured according to this test method. When the test specimen is highly absorptive, these values may exceed unity.

5.4 The coefficients measured by this test method should be used with caution because not only are the areas encountered in practical usage usually larger than the test specimen, but also the sound field is rarely diffuse. In the laboratory, measurements must be made under reproducible conditions, but in practical usage the conditions that determine the effective absorption are often unpredictable. Regardless of the differences and the necessity for judgment, coefficients measured by this test method have been used successfully by architects and consultants in the acoustical design of architectural spaces.

5.5 *Field Measurements*—When sound absorption measurements are made in a building in which the size and shape of the room are not under the operator's control, the approximation to a diffuse sound field is not likely to be very close. This matter should be considered when assessing the accuracy of measurements made under field conditions. (See Appendix X2 for a procedure that can be used in the field with less sophisticated instrumentation.)

6. Interferences

6.1 Changes in temperature and relative humidity during the course of a measurement may have a large effect on the decay rate, especially at high frequencies and at low relative humidities. The effects are described quantitatively in ANSI S1.26. These effects due to temperature and relative humidity changes can be accounted for by the procedure in 6.2.

6.2 It is advisable to make measurements in the room when it is empty and in the room when it contains the test specimen under conditions of temperature and relative humidity so nearly the same that the adjustments due to air absorption do not differ significantly. In any case, the relative humidity in the room shall be greater than 40 % during the test. Unless the conditions given in Table 1 are satisfied, decay rates for the measurements in the 1000 Hz one-third octave band and above in both the empty room and in the room containing the test specimen shall be adjusted by subtracting the decay rate due to air absorption, determined according to ANSI S1.26, from the decay rate calculated according to 11.4 (see especially 11.4.1 and 11.4.2).

NOTE 1—The absorption coefficients given in Table 1 of the version of ANSI S1.26 current when this test method was written are in units of dB/km. The corresponding decay rates in dB/s are obtained by multiplying by the speed of sound in m/s and dividing by 1000, as follows:

$$d_{air} = \frac{mc}{1000} \quad (2)$$

TABLE 1 Requirements for the Temperature and the Relative Humidity During Decay Rate Measurement When Adjustment Is Not Made for Air Absorption[A]

Relative Humidity During Measurements, %	Permitted Range of Relative Humidity (Δ RH), %	Permitted Range of Temperature (Δ T), °C	Minimum Allowed Temperature, °C
Through 60	3	3	10
Above 60	5	5	10

[A]The permitted ranges in the second and third columns are the highest measured relative humidity or temperature minus the lowest measured relative humidity or temperature, respectively.

[5] Chrisler, V., "Dependence of Sound Absorption Upon the Area and Distribution of the Absorbent Material," *Journal of Research*, National Bureau of Standards, Vol 13, 1934, p. 169: Northwood, T. D., Grisaru, M. T., and Medcof, M. A., "Absorption of Sound by a Strip of Absorptive Material in a Diffuse Sound Field," *Journal of the Acoustical Society of America*, Vol 31, 1959, p. 595: and Northwood, T. D., "Absorption of Diffuse Sound by a Strip or Rectangular Patch of Absorptive Material," *Journal of the Acoustical Society of America*, Vol 35, 1963, p. 1173.

where:

d_{air} = decay rate due to sound absorption by the air, dB/s,
m = absorption coefficient, dB/km, from Table 1 of ANSI S1.26, and
c = speed of sound, m/s, calculated according to 11.13.

7. Reverberation Room

7.1 *Description*—A reverberation room is a room designed so that the reverberant sound field closely approximates a diffuse sound field both in the steady state, when the sound source is on, and during decay, after the sound source has stopped.

7.2 *Construction*:

7.2.1 The room is best constructed of massive masonry or concrete materials, but other materials, such as well-damped steel, may be used. Lighter construction may be excessively absorptive, especially at frequencies below 200 Hz.

7.2.2 The average absorption coefficient of the room surfaces at each frequency, determined by dividing the absorption of the empty room (measured according to Sections 10 and 11) by the area of the room surfaces, including both sides of the diffusers (see 7.4), shall be less than or equal to 0.05 after allowance has been made for atmospheric absorption according to ANSI S1.26.

7.2.3 The room shall be isolated sufficiently to keep outside noises and structural vibrations from interfering with the measurements.

7.3 *Size and Shape*—The volume of the room shall be no less than 125 m^3. It is recommended that the volume be 200 m^3 or greater. No two room dimensions shall be equal nor shall the ratio of the largest to the smallest dimension be greater than 2:1. (See 11.12 on calculating room volume.)

7.4 *Sound Diffusion*:

7.4.1 Means shall be taken to ensure an approximation to a diffuse sound field both before and during decay. Experience has shown that a satisfactory approximation can be achieved with a number of sound-reflective panels hung or distributed with random orientations about the volume of the room. It is strongly recommended that some of these panels be mounted on a rotating shaft or otherwise kept moving, presenting, in effect, a room that continually changes its shape.

7.4.2 The goal is to achieve a rapid and continuous interchange of energy between the directions of sound propagation, thereby increasing the probability that each surface area of the room is exposed to sound of the same intensity.

7.4.3 Laboratories are strongly encouraged to follow the procedures in Appendix X1 to determine the necessary area of diffusing panels to maximize the measured absorption coefficients. If these procedures are followed, the data collected shall be preserved and made available on request. If the procedures in Appendix X1 are not followed, the surface area of the diffusing elements in the room (both faces) shall be at least 25 % of the surface area of the reverberation room. (See Note X1.1.)

7.4.4 The reverberation room shall be qualified according to Annex A3.

7.5 *Background Noise*—The level of the background noise in each measurement band, which includes both the ambient acoustical noise in the reverberation room and the electrical noise in the measuring instruments, shall be at least 15 dB below the lowest level used to calculate decay rate (see 11.3).

8. Instrumentation

8.1 *Sound Source*—The sound source shall be one or more loudspeaker systems in a configuration such that the test facility satisfies the qualifications of Annex A3. With adequate diffusion, loudspeakers facing into the trihedral corners of the room will satisfy these requirements. The sound pressure level produced when the source is on and the sound in the reverberation room is in the steady state shall be at least 45 dB above the background noise in each measurement band.

NOTE 2—The value of 45 dB is the minimum value required by this method. In fact, the steady state may need more than 45 dB above the background noise to satisfy the requirements of 7.5 and 11.3.

8.2 *Test Signal*—The test signal shall be a band of random noise with a continuous spectrum covering the range over which measurements are made. The frequency range of the measurements shall include the one-third octave bands with midband frequencies, as defined in ANSI S1.6, from 100 Hz to 5000 Hz.

8.3 *Microphones*—The microphone or microphones used to measure decay rate shall be omnidirectional with a flat (± 1 dB within any one-third octave band) random-incidence amplitude response over the range of frequencies and sound pressure levels used for decay rate measurements.

8.4 *Electronic Instrumentation*—The electronic instruments used to measure sound pressure levels shall be functionally equivalent to the instruments specified in 8.4.1 and 8.4.2.

8.4.1 *Real-time Analyzer*—Sound pressure level measurements shall be made with a one-third octave band real-time analyzer or functional equivalent. The analyzer shall be capable of measuring with an integration time of 50 ms or less and an output interval of 50 ms or less using either linear or exponential averaging. Linear averaging is preferred. The filter response of the analyzer shall be Order 3 or better according to ANSI S1.11.

NOTE 3—The response of the real-time analyzer should be checked to determine the minimum decay rate that can be measured at a given integration time setting by feeding a signal directly into the analyzer input and measuring the decay rate when the signal is turned off. The decay rate measured by this check should be at least three times the decay rate measured during a sound absorption measurement.

8.4.2 *Control and Storage Circuitry*—Control and storage circuitry shall be provided to:

8.4.2.1 Turn the source on and off and start and stop the real-time analyzer as specified in Section 10, and

8.4.2.2 Store the levels measured during decays as required by Section 10.

9. Test Specimen

9.1 *Floor, Wall, or Ceiling Specimens for Absorption Coefficient*:

9.1.1 The specimen shall be a rectangular patch assembled from one or more pieces. An area of 6.69 m^2 (72 ft^2) is customary and recommended, in a shape 2.44 by 2.74 m (8 by 9 ft). An area less than 5.57 m^2(60 ft^2) shall not be used, and extreme aspect ratios, such as long narrow strips, shall be avoided.

9.1.2 *Mounting*—Insofar as its acoustical properties are concerned, the specimen shall be mounted in a way that simulates actual installation. The types of mountings most commonly used are specified in Practices E 795. If a mounting fixture is used, it shall be removed from the reverberation room during the empty room tests unless it can be shown that the mounting fixture does not contribute to the empty room sound absorption.

9.1.3 *Placement*—The specimen may be placed on the floor of the reverberation room for convenience of measurement. It is best to avoid symmetry: do not place the specimen in the exact center of the floor or with its sides parallel to the walls. When the orientation of the specimen may affect its acoustical properties (if, for instance, the specimen is a curtain), provision shall be made for mounting in the usual position. No part of the specimen shall be closer than 0.75 m to a reflective surface other than the one backing it.

9.1.4 *Precautions*—When testing ceiling materials it is important that sound be prevented from entering the specimen by any path other than through the front surface. For this reason, the sides of the specimen should be covered tightly with non-absorptive material and any paths to the back of the specimen should be sealed. See Practices E 795 for methods to seal the edges of test specimens.

9.2 *Specimens that are Office Screens*:

9.2.1 *Size*—For test purposes, an office screen shall have an overall area, measured on one side and including the frame, of not less than 2.32 m^2 (25 ft^2). For the purpose of determining the sound absorption coefficient, α, the total area of the screen is the area of the two sides. It does not include the area of the edges, that is, the product of the perimeter of the screen and its thickness. Should the screens submitted for test be too small, two or more should be fitted together to make, in effect, a single screen. To prevent extreme aspect ratios, the ratio of the screen or combined-screen height (including frame) to width (including frame) used to calculate the total area shall be no greater than 2:1 and no less than 1:2.

9.2.2 *Number of Screens*—For a standard test the absorption of an office screen shall be measured with just one screen or a combination of screens that are fitted together to make, in effect, a single screen (see 9.2.1) in the reverberation room. It is the result of this measurement that is to be used when screens of different kinds are compared. However, if desired, two or more screens may be tested at the same time provided all details of the arrangement are described in the report. The details shall include distances from each other and the room boundaries, and the angles they make with each other.

9.2.3 *Placement*—The office screen shall be free-standing, at least 0.75 m away from the room boundaries and other reflective surfaces except the floor, and not parallel to the walls.

9.2.4 For office screens that have different sound-absorptive constructions on either side of the central plane of the screen, see Annex A2.

9.3 *Specimens that are Detached Objects*—The absorption of objects, such as space absorbers, theater chairs, or ceiling baffles, is dependent on the number tested together and their distance from each other and from the room boundaries. Complete information shall be given in the report.

9.4 *Preconditioning*—The test specimen shall be allowed to adjust to the temperature and humidity in the reverberation room before tests are performed.

10. Procedure for Measuring Decay Rate

10.1 *Microphone Positions*:

10.1.1 If a fixed microphone or microphones are used, make measurements at five or more positions which are at least 1.5 m apart, and at least 0.75 m from any surface of the test specimen.

10.1.2 If a moving microphone is used, the microphone path shall be at least 0.75 m from any surface of the room or test specimen. The same limit shall apply to the distance from any fixed diffusing element (excluding edges). The length of the microphone path shall be at least 7.5 m. Longer paths are preferred since they improve the precision of the measurements at low frequencies.

10.1.3 If moving or rotating diffusers are used, the period of the diffusers, the time between the beginning of successive decays and the period of the motion of the microphone should be adjusted to spread out the points at which decays start, as much as feasible, over the positions of the diffusers and the positions of the microphone.

10.2 *Number of Decays*:

10.2.1 Measure at least 50 decays in each room condition (that is, in the empty room and in the room with the test specimen).

10.2.2 If stationary microphone positions are used, measure the same number of decays, at least 10 decays, at each microphone position.

NOTE 4—It is no longer required (as it was in previous versions of this test method) not to use decays that deviate substantially from a straight line over the measuring range when graphed on a logarithmic scale. Reverberation rooms that satisfy the requirements of Section 7 provide the best diffusion that is practically achievable and, hence, are as likely as possible to be free from nonlinear decays.

10.3 *Analyzer Settings*:

10.3.1 If the real time analyzer has settings for both integration time and output interval, the integration time of the analyzer shall be between 90 and 100 % of the output interval time.

10.3.2 The output interval shall be short enough to provide at least five measurement points that satisfy 11.3 in every measurement band. Whenever conditions permit, the output interval shall be adjusted to provide at least ten measurement points that satisfy 11.3 in every measurement band.

10.3.3 The output shall include all of the one-third octave bands in the frequency range from 100 to 5000 Hz, inclusive, specified by ANSI S1.6.

10.4 *Measurement of Decay Rate*:

10.4.1 Turn on the test signal until the sound pressure level in each measurement band is steady (see 4.1).

10.4.2 Turn off the test signal and start measuring sound pressure level in each measurement band either immediately or after 100 ms (see Fig. 1). (If measurement of sound pressure levels is started immediately when the test signal is turned off, data collected before the first 100 ms have elapsed may be viewed or retained for informational purposes, but these data

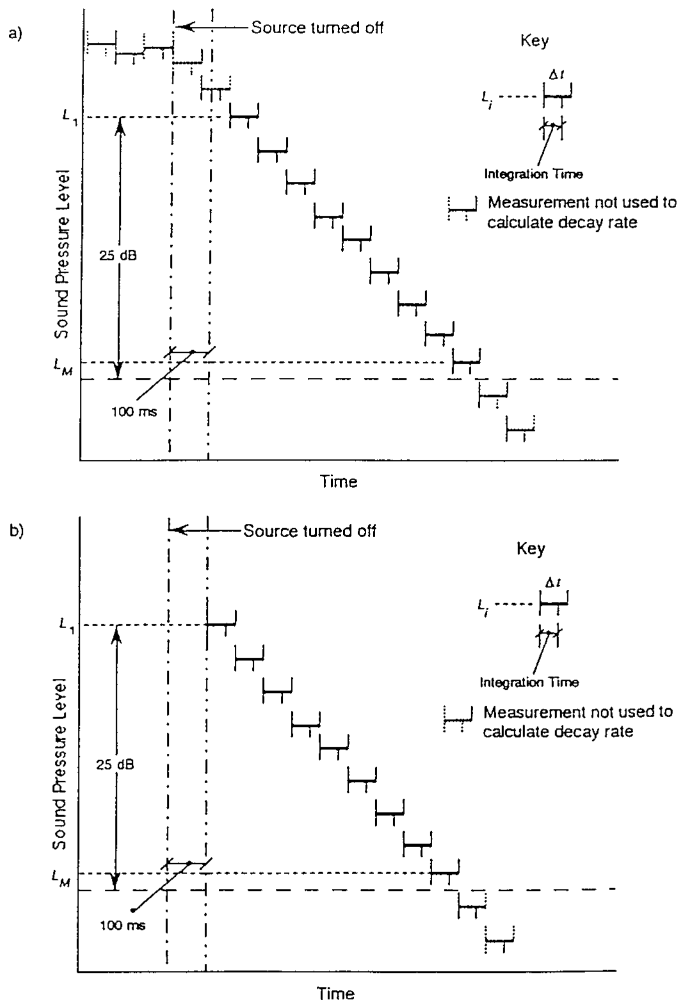

FIG. 1 Schematic Example of a Decay Measurement—a) Starting the Real-Time Analyzer When the Source Stops: b) Starting the Real-Time Analyzer 100 ms After the Source Stops

are not used in the calculation of decay curves.)

10.4.3 Measure and store the sound pressure level in each measurement band every Δt seconds (see 3.3.1) until the level is about 32 dB below the steady state level (see 7.5).

10.4.4 Store the measured levels and repeat this procedure the number of times required by 10.2.

11. Calculations

11.1 In each measurement band, calculate the points in the average decay curve, defined as follows:

$$(L_i) = \frac{1}{N}\sum_{j=0}^{N} L_{ij} \tag{3}$$

where:

i and j = integers,

(L_i) = average of the sound pressure levels measured at the ith data point in each of N decays,

N = the number of decays, at least 50, and

L_{ij} = the sound pressure level measured at the ith data point during the jth decay.

11.2 In each measurement band, the first data point to be used to calculate the decay rate shall be the first data point for which integration begins at least 100 ms after the test signal was turned off.

11.3 In each measurement band the number of data points in the average decay, M, shall be the maximum value of the index, i, for which:

$$(L_1) - (L_i) \leq 25dB \tag{4}$$

where (L_1) is the average of the first data points satisfying 11.2 (see Fig. 1).

11.4 In every measurement band, calculate the unadjusted decay rate, which is the negative of the slope of the linear, first-order regression on the average decay curve of Eq 3, using:

$$d' = \frac{6}{M(M^2 - 1)\Delta t}\left[(M + 1)\sum_{i=1}^{M}(L_i) - 2\sum_{i=1}^{M} i\,(L_i)\right] \tag{5}$$

where d' is the unadjusted decay rate, dB/s, and M is defined in 11.3.

11.4.1 If the decay rate is to be adjusted by subtracting the decay rate due to air absorption as noted in 6.2, then:

$$d = d' - d_{air} \tag{6}$$

11.4.2 Otherwise:

$$d = d' \tag{7}$$

11.5 The procedures of 11.1, 11.2, 11.3, and 11.4 may be used to calculate decay rates for each microphone position. In this case the average of the decay rates in each measurement band over all microphone positions shall be used to calculate sound absorption.

11.6 The calculation of sound absorption of the reverberation room using the Sabine formula (Eq 1) is described in 4.1.1.

11.7 In every measurement band calculate the absorption added to the room by the test specimen as follows:

$$A = A_2 - A_1 \quad (8)$$

where:

A = absorption of the specimen, m^2 or Sab,
A_1 = absorption of the empty reverberation room, m^2 or Sab, and
A_2 = absorption of the room after the specimen has been installed, m^2 or Sab.

11.8 For each test frequency, calculate the sound absorption coefficient of the test specimen and round to the nearest 0.01 as follows:

$$\alpha = (A_2 - A_1)/S + \alpha_1 \quad (9)$$

where:

α = absorption coefficient of test specimen, no units or Sab/ft^2,
S = area of test specimen, m^2 or ft^2, and
α_1 = absorption coefficient of the surface covered by the specimen.

11.9 The absorption coefficient, α_1, of the room surface covered by the specimen should be added when it is significant. However, the absorption coefficients of a smooth, hard, rigid surface, such as a reverberation room floor, are so small that they may be neglected. No adjustment shall be made for such a floor covered by the specimen.

NOTE 5—The magnitude of the absorption coefficient of an ideal surface due to viscous and thermal losses in a thin layer of air next to the surface has been calculated.[6] For random incidence the result is $\alpha = 0.00018\ f^{1/2}$, where f = frequency in Hz.

11.10 Since diffraction effects make the measured results greater than the ideal to a degree not yet completely understood, no adjustments shall be made in the coefficients for this cause.

11.11 *Absorption Coefficients of Office Screens*—Since an office screen is tested freestanding and does not cover any other absorptive surface, calculate the coefficients and round to the nearest 0.01 as follows:

$$\alpha = (A_2 - A_1)/S \quad (10)$$

where:

$A_2 - A_1$ = absorption added to the room by the test specimen, and
S = total overall area of the screen (see 9.2.1).

These are the standard coefficients for each test frequency to be reported for tests conducted in accordance with this test method.

NOTE 6—Previously reporting additional absorption coefficients attributable only to the absorptive portions of an office screen face was allowed. Due to both the technical difficulties in separating the effects of absorptive and non-absorptive portions of such a face and the inability in clearly defining an absorptive area, such coefficients are no longer allowed under this standard. Absorption coefficients for the full faces of asymmetrically constructed office screens are discussed in Annex A2.

11.12 *Volume*—Calculate the volume of the room carefully. It is not exactly the product of the three dimensions of the room. Recesses and other irregularities can account sometimes for more than 1 % of the volume. A large test specimen may effectively subtract from the volume of the room enough to introduce significant error in the calculated absorption. When the volume of the test specimen is greater than 1 % of the room volume, the volume of the test specimen shall be excluded from the room volume.

11.13 *Speed of Sound*—The speed of sound, *c*, shall be calculated for the conditions existing at the time of each test. The following formulas, reliable to four significant figures when the precision of the temperature measurement is adequate, shall be used:

$$c = 20.047\sqrt{273.15 + T°C}\ m/s \quad (11)$$

or

$$c = 49.022\sqrt{459.67 + T°F}\ ft/s \quad (12)$$

where $T°C$ and $T°F$ are the temperature in degrees Celsius and degrees Fahrenheit, respectively. Eq 11 is calculated in m/s and Eq 12 is calculated in ft/s.

12. Report

12.1 The report shall include the following:

12.1.1 A statement, if true in every respect, that the test was conducted according to this test method. If not true in every respect, the exceptions shall be noted.

12.1.2 A description of the test specimen, its size, mounting, weight, and any other details that may be necessary to identify another sample of the same material or kind of object. When sound absorption coefficients are reported, the area used to calculate them shall be reported. Mountings that are defined in Practices E 795 may be described by citing the applicable type designation.

12.1.3 When the specimen is an extended plane surface or an office screen, the results to be reported are the absorption coefficients at the eighteen measuring frequencies rounded to the nearest multiple of 0.01, together with the sound absorption average (SAA) and the noise reduction coefficient (NRC).

12.1.4 When the specimen is a number of isolated objects, the results to be reported are the absorption at each frequency in m^2 per unit or Sab per unit. The number of objects, their distance from each other, and their positions in the reverberation room shall be included.

12.2 A complete description of the laboratory and its measurement procedures shall also be a part of the report. If not included, it shall be easily available to those who request it. The description of measurement procedures shall state the averaging algorithm (for example, linear or exponential) that was used.

12.3 The report on reverberation room qualification (required by A3.2.2) shall also be a part of the report. If not included, it shall be easily available to those who request it.

[6] Cremer, L., and Muller, H. A., *Principles and Applications of Room Acoustics*, Applied Science Publishers, LTD, v. 2,p. 126.

13. Precision and Bias

13.1 An inter-laboratory comparison series was conducted beginning in 1980 to evaluate Test Method C 423-80, and establish repeatability and reproducibility limits for the data obtained using that version. Fourteen laboratories participated in the round robin[7]. The repeatability and reproducibility values reported in this section are based on that round robin series.

13.1.1 For the purposes of this standard, the repeatability, *r*, is the value below which the absolute difference between two single test results obtained with the same method on identical test material, under the same conditions may be expected to lie with a probability of 95 %.

13.1.2 For the purposes of this standard, the reproducibility, *R*, is the value below which the absolute difference between two single test results obtained with the same method on identical test material, in a different laboratory may be expected to lie with a probability of 95 %.

13.2 Although the test procedures required by this test method are somewhat different from those required by Test Method C 423-80, the results of the round robin are believed to be fair estimates of repeatability and reproducibility for this test method.

13.3 Estimates for repeatability and reproducibility for a specimen in a Type A mounting, based on the results of the round robin, are listed in Table 2 together with the mean value of the absorption coefficient at each frequency.

13.4 Estimates for repeatability and reproducibility values for a specimen in a Type E-400 mounting, based on the results of the round robin, are listed in Table 3 together with the mean value of the absorption coefficient at each frequency.

[7] Supporting research data for the round robin may be obtained from ASTM Headquarters. Request RR: E-33-1005.

TABLE 2 Estimates of Reproducibility, *R*, and Repeatability, *r*, of the Sound Absorption Coefficients of a Specimen in a Type A Mounting

Mid-Band Frequency, Hz	Absorption Coefficient	*R*	*r*
125	0.27	0.14	0.06
250	0.82	0.18	0.05
500	1.1	0.12	0.06
1000	1.03	0.10	0.05
2000	0.97	0.10	0.05
4000	0.95	0.13	0.07

TABLE 3 Estimates of Reproducibility, *R*, and Repeatability, *r*, of the Sound Absorption Coefficients of a Specimen in a Type E-400 Mounting

Mid-Band Frequency, Hz	Absorption Coefficient	*R*	*r*
125	0.67	0.27	0.06
250	0.83	0.24	0.07
500	0.96	0.09	0.05
1000	1.03	0.14	0.03
2000	1.01	0.19	0.04
4000	0.96	0.16	0.04

13.5 Strictly speaking, the estimates in Tables 2 and 3 are applicable only to specimens with sound absorption coefficients and mountings similar to those used during the round robin.

13.6 Repeatability and reproducibility values are given only at the mid-band frequencies 125, 250, 500, 1000, 2000, and 4000 Hz. Repeatability and reproducibility values at the intervening frequencies can be interpolated, but the reliability of such interpolations is not known.

14. Keywords

14.1 acoustical; acoustics; decay rate; noise; noise reduction coefficient; reverberation room

ANNEXES

(Mandatory Information)

A1. LABORATORY ACCREDITATION

A1.1 *Scope*—This annex describes procedures to be followed in accrediting a testing laboratory to perform tests in accordance with this test method.

A1.2 *Summary of Procedures:*

A1.2.1 The laboratory shall allow the accrediting agency to make an on-site inspection.

A1.2.2 The laboratory shall show that it satisfies the criteria of Practice E 548.

A1.2.3 The laboratory shall show that it is in compliance with mandatory parts of this test method, that is, those parts that contain the words "shall" or "must."

A1.2.4 The laboratory shall provide a report describing qualification tests according to Annex A3.

A1.2.5 The laboratory shall report the results of its ongoing tests of its reference specimen as described in A1.3.

A1.3 *Reference Tests:*

A1.3.1 The laboratory shall maintain a reference specimen to be used during periodic tests for quality assurance. The reference specimen shall be suitable for both Type A and Type E mountings as specified in Practices E 795. It should be so constructed or formed that it will not deteriorate quickly with use. Its absorptive properties should remain stable during at least ten years of use. The sound absorption coefficients of the reference specimen shall be at least 0.20 when measured in a Type A mounting at frequencies of 200 Hz and above.

NOTE A1.1—The specimen designated as "Sound Absorbing Panel—

October 1964 Standard Sample" has been found to be a suitable reference specimen[8].

A1.3.2 The laboratory shall measure the sound absorption of the reference specimen at the standard test frequencies at least once per year in a Type A mounting and once a year in a Type E-400 mounting.

A1.3.3 The sound absorption coefficients and their standard deviations shall be analyzed by the control chart method described in Part 3 of ASTM MNL 7[9,10] . The analysis shall be according to the subsection entitled "Control—No Standard Given."

A1.3.4 The laboratory shall keep a record of the empty room sound absorption for each time that tests are performed according with this test method.

[8] A drawing of this specimen is available at a nominal charge from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. Request Adjunct PCN 12-304230-10.

[9] MNL 7, *Manual on Presentation of Data and Control Chart Analysis*, Sixth Edition, ASTM, p. 54.

[10] The values in this table are based on unpublished data from the National Research Council of Canada and Owens Corning Corporation.

A2. SPECIMENS THAT ARE ASYMMETRICAL OFFICE SCREENS

A2.1 *Description*—Most office screens are symmetrical, that is, when viewed on edge they have the same construction on either side of their center plane. An asymmetrical screen is one that has different construction on either side of its center plane such as one with a sound absorptive face and a sound reflective face.

A2.2 *Purpose:*

A2.2.1 The purpose of this annex is to determine the sound absorption coefficients for each face of an asymmetrical office screen in a manner similar to that used for symmetrical office screens.

A2.2.2 This annex is not appropriate for determining the sound absorption coefficients for office screens with a solid septum near the center plane of the panel. The procedures of this annex shall not be used for determining the sound absorption coefficients for office screens with such a solid septum near the center plane of the panel.

A2.3 *Specimen Preparation:*

A2.3.1 Two specimens shall be prepared as follows:

A2.3.1.1 *Specimen A*— Two identical office screens shall be fastened together face-to-face with faces of the same construction exposed and with a 13-mm (½-in.) thick sheet of gypsum board between them. This assembly shall be clamped together at all corners. The edges of the assembly shall be partially covered in order to approximate the sound absorption provided by the edges of a single screen. To accomplish this, the perimeter of the gypsum board between the two screens and one half the area of the edges of the screens shall be closely fitted with a wood or metal frame. Since small gaps between screens can affect the results, there shall be minimal air spaces between the assembly and frame. In all other respects the specimen shall be prepared in accordance with 9.2.

A2.3.1.2 *Specimen B*— The second face construction of the screens used in A2.3.1 shall be exposed. In all other respects the specimen preparation shall be the same as in A2.3.1.

A2.4 *Test Method*—Both specimens shall be tested in accordance with this test method.

A2.5 *Report*—The report shall be in accordance with 12.1.4. Results for both specimens shall be reported separately and clearly identified.

A3. TESTS TO QUALIFY THE REVERBERATION ROOM

A3.1 *Scope:*

A3.1.1 This annex covers tests that must be performed to qualify a reverberation room to perform tests according to this test method:

A3.1.1.1 Measurement of the variation of the decay rate with microphone position in the reverberation room with no test specimen, and

A3.1.1.2 Measurement of the variation of the decay rate with test specimen position.

A3.2 *Frequency of Qualification Tests:*

A3.2.1 The tests shall each be performed at least once during the commissioning of a reverberation room for these measurements and whenever significant changes are made to the reverberation room.

A3.2.2 A report on the results of these tests shall be kept on record.

A3.3 *Measurement of the Variation of Decay Rate with Microphone Position in the Reverberation Room with no Test Specimen:*

A3.3.1 Select at least five microphone positions that satisfy the requirements of 10.1. The microphone must be stationary at each position during the measurements.

A3.3.2 At each microphone position make at least 20 decay measurements according to 10.4. One or several loudspeakers operating simultaneously may be used to generate the sound.

A3.3.3 For each microphone position, calculate the decay rate according to 11.4.

A3.3.4 At each frequency, calculate the standard deviation of decay rate over microphone positions, s_M, using:

$$s_M = \left(\frac{1}{N_M - 1}\sum_{i=1}^{N_M}(d_{Mi} - (d_M))^2\right)^{\frac{1}{2}} \quad \text{(A3.1)}$$

where:

N_M = number of stationary microphone positions,

d_{Mi} = decay rate at the *i*th microphone position, and

$(d_M) = \frac{1}{N_M}\sum_{i=1}^{N_M} d_{Mi}$ = the decay rate averaged over all microphone positions.

A3.3.5 The 95 % uncertainty range for the measurement of average room decay rate is $(d_M) - as_M$ to $(d_M) + as_M$ where the factor a, given in Table A3.1 is:

$$a = t_{n-1}/\sqrt{N_M} \quad \text{(A3.2)}$$

where:

t_{n-1} = Student's t, and

n = N_M.

A3.4 *Test for Variation of Decay Rate with Test Specimen Position:*

A3.4.1 Use a test specimen satisfying 9.1 on a Type A mounting as described in Practices E 795. The sound absorption coefficients of the specimen at frequencies of 200 Hz and above shall be at least 0.20. It is recommended that if the laboratory routinely carries out tests with specimens in an E 400 mounting or, with office screens, that the series of tests described here also be performed with such specimens.

A3.4.2 Select at least three test specimen positions uniformly distributed around the reverberation room floor and satisfying 9.1.3. The overlap between specimen positions should be minimized. It is recommended that no pair of specimen positions overlap by more than 25 %.

A3.4.3 For each test specimen position measure and calculate the decay rate according to Sections 10 and 11.

A3.4.4 For each specimen position, calculate the decay rate using Eq 5 and adjust for air absorption as appropriate using Eq 6 or Eq 7.

A3.4.5 Calculate the standard deviation of the decay rate using:

$$s_s = \left(\frac{1}{N_s - 1}\sum_{i=1}^{N_s}(d_i - (d_s))^2\right)^{\frac{1}{2}} \quad \text{(A3.3)}$$

where:

s_S = standard deviation of the decay rates over specimen position,

N_S = number of specimen positions,

d_i = decay rate measured at the *i*th specimen position, and

$(d_s) = \frac{1}{N_s}\sum_{i=1} d_i$ = the decay rate averaged over all specimen positions.

A3.4.6 At each test frequency the relative standard deviation of the decay rate, $s_S/(d_S)$, shall be no greater than the value listed in Table A3.2.

TABLE A3.1 Factors for 95 % Confidence Limits for Averages

Number of Measurements, *n*	Factor *a* for Confidence Limits, $X \pm as$
4	1.591
5	1.241
6	1.050
7	0.925
8	0.836
9	0.769
10	0.715
11	0.672
12	0.635

TABLE A3.2 Maximum Relative Values for Variation of Decay Rate with Microphone Position in the Empty Room and for Variation of Decay Rate with Specimen Position[10]

Octave Mid-Band Frequency, Hz	s_M/<d_M>	s_S/<d_S>,
100	0.11	0.07
125	0.07	0.04
160	0.04	0.04
200	0.03	0.04
250	0.03	0.03
315	0.03	0.03
400	0.03	0.03
500	0.02	0.02
630	0.02	0.02
800	0.02	0.02
1000	0.02	0.02
1250	0.02	0.02
1600	0.02	0.02
2000	0.02	0.02
2500	0.02	0.02
3150	0.02	0.02
4000	0.02	0.02
5000	0.02	0.02

APPENDIXES

(Nonmandatory Information)

X1. TESTS TO EXPLORE THE PERFORMANCE OF THE REVERBERATION ROOM

X1.1 *Factors Influencing Sound Field Uniformity:*

X1.1.1 The sound field in a reverberation room is only an approximation of a diffuse sound field. To help promote measurement quality, the parameters that may change the measured decaying sound field should be explored in the reverberation room. The list of such factors that may influence the variation of the measured decay rate includes:

X1.1.1.1 The temperature and humidity in the reverberation room,

X1.1.1.2 The position of the measurement microphone,

X1.1.1.3 The position of the test specimen, and

X1.1.1.4 The type, number and positions of diffusers in the reverberation room.

X1.1.2 The influence of temperature and humidity and the adjustment for such influence is discussed in 6.1, 6.2 and 11.4 of the main body of this standard. The influences of microphone position and specimen position and the assessment of these influences are discussed in Annex A3.

X1.1.3 This appendix covers the exploration of influences of room diffusion and sound source position. This appendix also covers the exploration of the influence of specimen position when the specimen is a large specimen other than an office screen. It is recommended that these tests be performed when the reverberation room is initially commissioned and whenever significant changes are made to the reverberation room. The report of the results of these tests should be kept on record.

X1.2 *Diffusing Panels:*

X1.2.1 *Diffusers:*

X1.2.1.1 Acceptable diffusion can be achieved by using fixed and rotating diffusers. Ideally, these diffusing elements should be damped sheets of a material with low sound absorption and a mass per unit area of at least 5 kg/m^2. Diffusers with areas of approximately 3 m^2(for one side) are recommended. The sheets may be corrugated or slightly curved and should be oriented at random and positioned throughout the room. Rotating diffusers are strongly recommended.

X1.2.1.2 If rotating diffusers are used, the decay repetition frequency and the frequency of rotation of the diffuser should not be in the ratio of small whole numbers.

X1.2.2 *Determination of Number of Diffusers:*

X1.2.2.1 A suitable test specimen, about 50-mm thick is prepared from homogeneous, porous absorbing material. Panels of glass or rock wools with densities in the range 40 to 100 kg/m^3, or polyurethane foams are satisfactory. The reference specimen described in Annex A1 may be suitable for these measurements. The dimensions and mounting conditions of the test specimen shall be in accordance with 9.1.

X1.2.2.2 Sound absorption measurements are made on the test specimen with no diffusers, with a small number of diffusers (approximately 5 m^2), and as the quantity of diffusers is increased in approximately 5 m^2 steps.

X1.2.2.3 For each set of measurements the mean value of the sound absorption coefficients, in the range 500 to 4000 Hz, is calculated and these values are plotted against the total area or number of diffusers used in each case.

X1.2.2.4 It will be found that the mean sound absorption coefficient approaches a maximum and thereafter remains constant or decreases with increasing numbers of diffusers. The optimum total area or number of diffusers is chosen as that which first achieves this maximum value.

NOTE X1.1—From experience, it has been found that in rectangular rooms the area (both sides) of diffusers required to achieve satisfactory diffusion is 15 to 25 % of the total surface area of the room.

X1.3 *Test for Variation of Decay Rate with Loudspeaker Position:*

X1.3.1 Use a test specimen satisfying 9.1 on a Type A mounting as described in Practices E 795. The sound absorption coefficients of the specimen at frequencies of 200 Hz and above shall be at least 0.20.

X1.3.2 Place the test specimen in a position that satisfies 9.1.3.

X1.3.3 The sound source shall satisfy 8.1. If the source comprises more than one loudspeaker system, determine the geometric center of the loudspeaker arrangement. Select at least three source positions with center of the source are at least 1.5 m apart.

X1.3.4 For each source position measure the decay rate according to Section 10.

X1.3.5 For each source position calculate the decay rate using Eq 5 and adjust for air absorption as appropriate using Eq 6 or Eq 7.

X1.3.6 Calculate the standard deviation of the decay rate using:

$$s_{ss} = \left(\frac{1}{N_{ss} - 1} \sum_{i=1}^{N_s} (d_i - (d_{ss}))^2 \right)^{\frac{1}{2}} \quad \text{(X1.1)}$$

where:

s_{SS} = standard deviation of the decay rate over source position,

N_{SS} = number of source positions,

d_i = decay rate measured at the *i*th source position, and

$(d_{ss}) = \frac{1}{N_s} \sum_{i=1}^{N_s} d_i$ = the decay rate averages over all source positions.

X1.4 *Measurement of the Variation of Decay Rate with Position of Large Specimens Other Than Office Screens:*

X1.4.1 The measured absorption coefficients for certain specimens may depend on the position of the specimen in the room. It is recommended that laboratory operators investigate the size of the variations for different specimen types, following procedures such as those in Annex A3, to establish the appropriate number of positions for routine testing. The coefficients for specimens that have low sound absorption at low frequencies usually do not show much variation when the specimen is moved and there is no need to use more than one position for such specimens.

X1.4.2 In some reverberation rooms it may not be possible to find positions for a large specimen that are significantly far apart and do not overlap. In such cases there may be little point in attempting to make these measurements. As a guide, it is recommended that no pair of specimen positions overlap by more than 25 %. Laboratories that are able to meet this criterion are encouraged to make these measurements and, where deemed necessary, use more than one specimen position for routine measurements.

X2. FIELD TEST METHOD SUITABLE FOR OBTAINING DECAY RATES AND ROOM SOUND ABSORPTION

X2.1 *Scope:*

X2.1.1 When sound absorption measurements are made in a building in which the size and shape of the room are not under the operator's control, the approximation to a diffuse sound field is not likely to be very close. This matter should be considered when assessing the accuracy of measurements made under field conditions.

X2.1.2 The test described in this appendix is not acceptable for laboratory use or for measurement of the sound absorption and sound absorption coefficients of a specimen.

X2.2 *Sound Source*—The sound source shall be a loudspeaker system placed preferably in a trihedral corner of the room. At least two loudspeaker positions in different corners shall be used.

X2.3 *Test Signal*—The test signal shall be bands of random noise with a continuous frequency spectrum. The bandwidth shall be no wider than one-third octave, limited by the passband of the microphone circuit. The center frequencies shall be selected from the series 125, 250, 500, 1000, 2000, and 4000 Hz, with all six frequencies required for a standard test. If intermediate frequencies or frequencies outside this range are desired, they shall be chosen from the preferred frequencies in ANSI S1.6 unless there are compelling reasons to the contrary.

X2.4 *Procedure:*

X2.4.1 The filters used shall conform to the specifications of ANSI S1.11 for a one third octave band filter set, Order 3 or higher, Type 1 or better. Other instruments used to measure the decay time or decay rate are not specified.

X2.4.2 *Range*—Make measurements over the decay range specified in the main section of this standard. Follow the requirements for background noise. Check that decays are not excessively curved because of feedback from adjacent spaces or vibrating walls. In such cases, the range of the decay curve used to estimate the decay rate may be less than 25 dB to use only data from the early, linear part of the decay. Decay curvature may not always be identifiable unless averaged decay curves are examined.

X2.4.3 *Microphone Position*—Use at least 4 microphone positions at least 1 m apart.

X2.4.4 Collect at least 5 decays at each microphone position.

X2.4.5 Instead of fixed microphone, a rotating microphone with an arm length of at least 1 m may be used. In that case, collect at least 15 decays with the rotating microphone.

X2.5 *Calculation*—The absorption of the room and its contents is calculated from the Sabine formula, Eq 1.

X3. CALCULATION AND USE OF PRECISION DATA

X3.1 *Scope*—This appendix contains:

X3.1.1 Guidance on using the precision and bias data in Section 13 to estimate the uncertainty of measurements according to this test method,

X3.1.2 Expressions for calculating the standard deviation and uncertainty of decay rate measured according to this test method, and

X3.1.3 Guidance for using the calculated standard deviation or uncertainty of the measured decay rate for quality assurance in the laboratory.

X3.2 *Using Precision Data to Estimate the Uncertainty of a Measurement*

X3.2.1 Subject to the limitations noted in X3.2.2, the repeatability and reproducibility standard deviations listed in Tables 2 and 3 can be used to estimate the uncertainty of a test result obtained according to this test method.

X3.2.2 *Limitations*—The reliability of uncertainty estimates based on the repeatability and reproducibility values listed in Tables 2 and 3 may be limited because of the following factors:

X3.2.2.1 Repeatability and reproducibility values are available only at the octave mid-band frequencies (125, 250, 500, 1000, 2000, and 4000 Hz). Standard deviations at the intervening frequencies can be interpolated, but the reliability of such interpolations is not known.

X3.2.2.2 A previous version of this test method, C 423-80, was used by the laboratories that participated in the round robin from which the repeatability and reproducibility data were obtained. Although tests according to this test method would have satisfied the requirements of C423-80, the effect of having all laboratories use this test method is not known.

X3.2.2.3 The repeatability and reproducibility values listed in Tables 2 and 3 are applicable, strictly speaking, only to the test specimens used during the round robin test series. The listed repeatabilities and reproducibilities may not be reliable for specimens that differ significantly in composition and construction from the round robin specimens.

X3.2.3 *Calculations*—The sound absorption coefficients measured according to this test method are assumed to be drawn from a normal population. Calculate the uncertainty of a coefficient drawn from this universe as follows:

X3.2.3.1 Calculate the estimated standard deviation of the universe from which the measurements are obtained:

$$S_U = (S_L^2 + S_r^2)^{1/2} \quad \text{(X3.1)}$$

where:

S_U = standard deviation of the universe of measurements,
S_L = reproducibility standard deviation from Table 2 or Table 3, and
S_r = repeatability standard deviation from Table 2 or Table 3.

X3.2.3.2 Calculate the 95 % confidence uncertainty of the measured coefficient, using the estimated standard deviation:

$$\Delta\alpha = 1.96 S_U \quad \text{(X3.2)}$$

where $\Delta\alpha$ is the estimated uncertainty of the measured coefficient.

X3.3 *The Standard Deviation and Uncertainty of Decay Rate:*

X3.3.1 When the decay rate is measured according to this test method and calculated according to Eq 5, an estimate for the standard deviation of the decay rate, *s(d′)*, is given by[11]:

$$s(d') = \left[\frac{1}{M-2} \left(\frac{12(\sum_{i=1}^{M}(L_i^2) - M^{-2}(\sum_{i=1}^{M}(L_i))^2)}{(M^2-1)\Delta^2 t} - d'^2 \right) \right]^{\frac{1}{2}} \quad \text{(X3.3)}$$

[11] See Draper, N. and Smith, H., *Applied Regression Analysis*, 2nd ed. John Wiley and Sons, 1981.

X3.3.2 An estimate for the uncertainty of the decay rate, $\Delta d'$, is given by:

$$\Delta d' = t_{M-2,95} s(d') \quad \text{(X3.4)}$$

where $t_{M-2,95}$ is Student's *t* for M-2 degrees of freedom and 95 % confidence.

X3.3.3 *Limitations*—The expressions in Eq X3.3 and Eq X3.4 depend on the assumption that the levels measured during a decay are normally distributed about the linear, first order regression curve whose slope is estimated by -*d′*, and that variance of the normal distribution is independent of the time during the decay. The reliability of these assumptions, applied to sound decays in a reverberation room, has not been investigated. Nevertheless, these expressions are useful in estimating, roughly at least, the variability of the measured decay rates.

X3.4 *Using the Standard Deviation and Uncertainty of Decay Rate for Quality Assurance*

X3.4.1 The standard deviation given by Eq X3.3, calculated after every decay measurement in a facility that regularly performs tests according to this test method, can be used in a quality assurance program to monitor the variability of measurement. See Part 3 of ASTM MNL 7[9] for further guidance.

X3.4.2 A further procedure, helpful for quality assurance, is to calculate the decay rate, Eq 5, and its standard deviation, Eq X3.3, for each microphone position. Apart from insignificant rounding errors and differences of ± 1 in *M* (see 11.2) the average of the decay rates over all microphone positions should equal the decay rate determined according to 11.1, 11.2, 11.3, and 11.4.