



Designation: E477 – 13<sup>ε1</sup>

# Standard Test Method for Laboratory Measurements of Acoustical and Airflow Performance of Duct Liner Materials and Prefabricated Silencers<sup>1</sup>

This standard is issued under the fixed designation E477; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

<sup>ε1</sup> NOTE—Equations 9 and 10 were editorially corrected in September 2015.

## 1. Scope

1.1 This test method covers the laboratory testing of some of the acoustical properties of sound attenuating devices including duct liner materials, integral ducts, and in-duct absorptive straight and elbow silencers used in the ventilation systems of buildings. Procedures are described for the measurement of acoustical insertion loss, airflow generated noise, and pressure drop as a function of airflow.

1.2 Excluded from the scope are reactive mufflers and those designed for uses other than in ventilation systems, such as automobile mufflers.

1.3 This test method includes a provision for a simulated semi-reflective plenum to fit around thin-walled duct and silencer test specimens, since the acoustical environments around such thin-walled specimens can affect the measured insertion loss.

1.4 This method tests the performance of the specimen in well-defined and controlled conditions. If the specimen is installed in the field in any different manner, the results may be different. This standard does not provide estimating procedures for determining the actual installed performance of the specimen under field conditions.

1.5 The values stated in SI units are to be regarded as standard. The values in parentheses are provided for information only.

1.6 *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.*

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee E33 on Building and Environmental Acoustics and is the direct responsibility of Subcommittee E33.08 on Mechanical and Electrical System Noise.

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## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

C634 Terminology Relating to Building and Environmental Acoustics

### 2.2 ANSI Standards:<sup>3</sup>

S1.1–1994(R2004) Acoustical Terminology

S1.11–2004(R2009) Specification Octave, Half-Octave and Third-Octave Band Filter Sets

S1.43-1997(R2007) Specifications for Integrating-Averaging Sound Level Meters

S12.5-2006/ISO 6926:1999(R2011) Requirements for the Performance and Calibration of Reference Sound Sources Used for the Determination of Sound Power Levels

S12.51–2012/ISO 3741:2010 Acoustics-Determination of Sound Power Levels of Noise Sources Using Sound Pressure-Precision Method for Reverberation Rooms

### 2.3 ASHRAE Documents and Standards:<sup>4</sup>

2009 ASHRAE Handbook, Fundamentals, Chapter 36, Measurement and Instruments

ANSI/ASHRAE 41.3-1989 Standard Method for Pressure Measurement (plus errata dated 5 January 1998)

### 2.4 NAIMA Documents and Standards:<sup>5</sup>

Fibrous Glass Duct Liner Standard, Publication AH124, Third Edition, 2002

## 3. Terminology

3.1 *Definitions*—The acoustical terms used in this method are consistent with Terminology C634, and ANSI S1.1.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

<sup>4</sup> Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, <http://www.ashrae.org>.

<sup>5</sup> Available from North American Insulation Manufacturers Association (NAIMA), 44 Canal Center Plaza, Suite 310, Alexandria, VA 22314, <http://www.naima.org>.

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *acoustical duct liner material*—a material that has sound absorptive properties and is attached to the inside wall of a duct to attenuate the sound that propagates down that section of duct.

3.2.2 *airflow generated noise*—the sound created by aerodynamic turbulence caused by air flowing through a device.

3.2.3 *background noise*—the total sound pressure level of all noise sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal.

3.2.4 *dynamic insertion loss*—insertion loss measured with air flowing through the test specimen.

3.2.5 *empty duct measurements*—acoustical measurements of sound propagation through the duct system when no test specimen is inserted in this system.

3.2.6 *end reflection loss (ERL)*—sound energy reflected back into the duct at the termination of duct into a large space.

3.2.7 *equivalent diameter of rectangular ducts*— $\{4(W \times H)/\pi\}^{1/2}$ , where  $W$  and  $H$  are the width and height of the duct specimen connection, respectively.

3.2.8 *forward flow (+)*—(a) the condition where air flows through a sound attenuating device in the same direction as the propagation of sound; (b) the airflow from the sound source chamber to the reverberation room (through the duct system).

3.2.9 *in-duct sound-attenuating devices*—a device or system intended to reduce the sound power propagating inside the duct from one duct section to another.

3.2.10 *insertion loss (IL)*—the reduction in sound power level, in decibels, due to the placement of a sound-attenuating device in the path of transmission, for example, the test duct system, between a sound source and the given location—which in this standard is the reverberation room.

3.2.11 *integral duct*—a duct formed from an integral composite of materials, typically having a porous inner layer to provide sound absorption, with an impervious outer surface.

3.2.12 *reference sound source (RSS)*—a portable, aerodynamic sound source that produces a known stable broadband sound power output.

3.2.13 *reverse flow (–)*—(a) the condition where air flows through a sound attenuating device in the opposite direction to the propagation of sound; (b) the airflow from the reverberation room to the sound source chamber (through the duct system).

3.2.14 *sound source chamber*—an enclosure, near one end of the duct system, in which one or more sources are located for the purpose of generating sound, which is transmitted through the duct system to the reverberation room, located at the other end.

3.2.15 *standard air density ( $d_s$ )*—1.202 kg/m<sup>3</sup>. This corresponds approximately to dry air at 21°C and 101.3 kPa.

3.2.16 *static pressure at a plane of traverse, ( $P_s$ )*, Pa—the arithmetic average of the static pressure at points in the plane of traverse.

3.2.17 *static pressure at a point, ( $P'_s$ )*, Pa—the pressure measured by the static connection of a pitot tube pointed upstream at that point.

3.2.18 *test run*—pertains to all measurements and calculations at any one setting of the airflow throttling device.

3.2.19 *thin-walled duct*—a duct or silencer whose wall mass or stiffness are low enough to allow significant energy to escape into the surrounding environment. This term applies to ducts whose walls are thinner than 0.6 mm, or are flexible, or are of rigid glass fiber construction.

3.2.20 *total pressure at a plane of traverse, ( $P_t$ )*, Pa—the algebraic sum of the velocity pressure at the plane of traverse and the static pressure at the plane of traverse.

3.2.21 *traverse*—a series of measurements made with a pitot tube in a cross section of the test duct, perpendicular to the duct length, in accordance with the *ASHRAE Fundamentals Handbook* Chapter on Measurement and Instruments.

3.2.22 *velocity pressure at a plane of traverse, ( $P_v$ )*, Pa—the square of the average of the square roots of the velocity pressures at points in the plane of traverse.

3.2.23 *velocity pressure at a point, ( $P'_v$ )*, Pa—the pressure measured by the differential measurement of a pitot tube pointed upstream at that point.

## 4. Summary of Test Method

4.1 Insertion loss is measured by comparing the change in sound pressure level due to the insertion of a test specimen into a duct system connecting a reverberation room to a sound source chamber. When insertion loss is measured with air flowing through the test specimen, the measured quantity is dynamic insertion loss. The sound signal is created by a system of loudspeakers within the sound source chamber and transmitted through the system ductwork to the reverberation room. The intent of the method is that the airborne path through the duct is the dominant means of sound transmission between the sound source chamber and the reverberation room. Measurements are made in a series of frequency bands because insertion loss is a function of frequency.

4.2 Noise generated by air flowing through the test specimen is measured in the reverberation room and expressed in terms of a computed sound power level within each frequency band.

4.3 Pressure drop performance is obtained by measuring the static pressure at designated locations upstream and downstream of the test specimen at various airflow settings. The pressure drop and airflow may be measured with a variety of standard acceptable instrumentation such as piezometer rings, flow nozzles, orifices, etc. However, the method described herein is the pitot tube and manometer method.

4.4 It is the intent of this test method that corrections due to background and flanking noise be eliminated or minimized as much as possible. Where corrections are unavoidable, the data are to be marked as corrected and shall indicate the magnitude of the corrections made as described in Sections 9 and 10.

## 5. Significance and Use

5.1 Specimens tested using this standard, for example, duct silencers, are used to control sound propagation through ventilation ducts. The results gathered from testing specimens to this standard can be used to estimate the reduction in fan sound levels in ducted airflow systems caused by including a sound attenuating device in the system. The device can be a component in a source-path-receiver analysis where calculations are performed to determine the resultant sound level in an occupied space. Correct selection of a sound attenuating device can enable a designer to achieve in-space background noise criteria.

5.2 The insertion loss of a silencer varies with frequency and with the direction and speed of airflow. Because silencers partially obstruct the air path and provide resistance to airflow, two other effects must be quantified: pressure drop and airflow-generated noise. Both increase with increasing air speeds; thus data are required for several airflows to correctly characterize performance.

5.3 The aerodynamic results from testing specimens to the standard can be used as information for the system design engineer to determine the amount of static pressure drop resistance to be overcome by the system fan(s). Guidelines for appropriate maximum allowable pressure drop for a sound attenuating element have been established in the design community and are based on the procedures described herein.

5.4 As stated previously in 1.4 of this test method, the actual performance of a sound attenuating device as installed in an air duct system may be significantly different than reported based on the test procedure herein. This standard does not provide guidance to the user on these system effects.

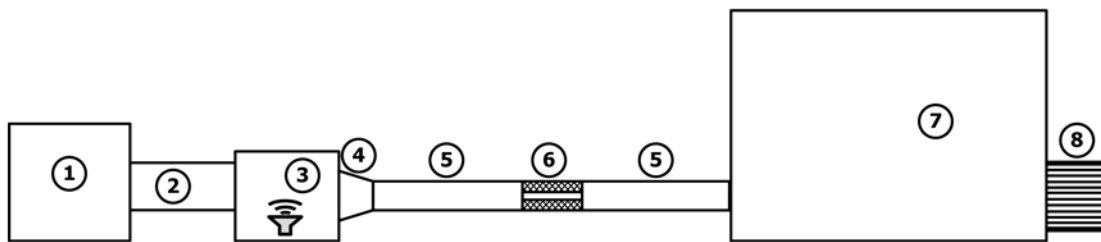
5.5 Silencers are often designed to be used under conditions which do not duplicate the test set-ups of this standard. Mock-ups and specialized test set-ups to determine performance of sound attenuating devices in non-standard configurations may be based on this test method but cannot be

considered to be in full conformance with this test method. See [Annex A2](#) for further information regarding such tests.

## 6. Test Facilities

6.1 The test facility shall consist of a sound source chamber and a reverberation room coupled together by means of a length of straight or elbow duct. Provisions shall be made in the duct system for inserting either a test specimen, or a section of empty duct having the same interior cross-sectional dimensions at the duct connection points, length, and shape (for elbow testing) as the test specimen. An example of a facility set-up to accommodate straight silencer testing is shown in [Fig. 1](#). An example of a facility set-up to accommodate elbow silencer testing (at various angles) is shown in [Fig. 2](#). Airflow and sound source chamber may be at a fixed or a mobile location within the test facility to accommodate straight and/or elbow silencer testing.

6.2 *Signal Source Chamber*—The sound source chamber shall be a device (as shown schematically in [Fig. 1](#)) containing two openings if testing will be conducted with airflow through the test specimen. One opening connects to the test duct and the reverberation chamber, and the other opening connects to the duct from the fan system. The sound source chamber openings for these two ducts shall have the same dimensions (or larger) as the connecting duct. It is recommended that a flared (tapered) opening be provided for the test duct to minimize flow generated noise. The recommended sound source chamber opening dimension is 2 times the duct dimension for the test duct connecting to the reverberation chamber. The sound source (loudspeaker) shall be structurally isolated from the sound source chamber and the connecting duct systems. The sound source chamber shall be large enough to accommodate one or more sound sources with a minimum clearance between the sound source diaphragm and the sound source chamber walls of at least 250 mm in all directions. The recommended minimum volume of the sound source chamber is 10 m<sup>3</sup>.



1. Quiet Airflow Source
2. Airflow Measuring Station
3. Signal Source Chamber
4. Transition
5. Test Ductwork with pressure test station
6. Test Specimen
7. Reverberation Room
8. Relief Silencer

**FIG. 1 Typical Facility for Rating Straight Duct Silencers With or Without Airflow**

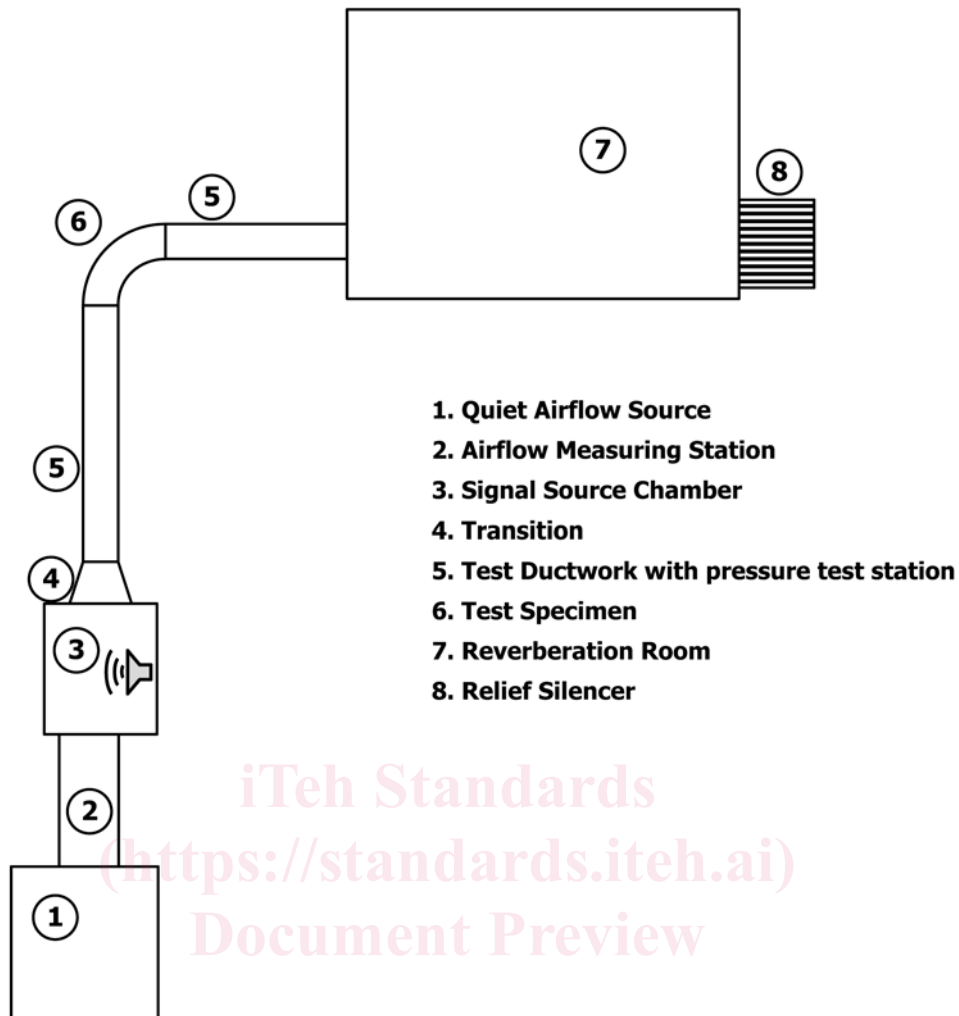


FIG. 2 Typical Facility for Rating Elbow Duct Silencers With or Without Airflow

6.2.1 The sound source chamber shall be constructed of materials having sufficient sound transmission loss and be adequately isolated from the surrounding environment to minimize noise from the sound source from entering the reverberation chamber by any path other than the duct containing the test specimen. It may be necessary to install sound absorbing materials on the inside surface of the sound source chamber walls to meet the sound source chamber qualification (see 6.2.2).

6.2.2 The sound source chamber shall be tested to ensure that the acoustic energy transmitted into the test duct is not affected by the insertion of the test sample by passing the following qualification test.

6.2.2.1 The positioning of the loudspeaker(s) shall be the same during routine testing and sound source chamber qualification.

6.2.2.2 A measurement microphone (meeting the requirements of section 6.6) shall be used to monitor and qualify the sound source chamber. The sound source chamber microphone shall be located at a point centered on the opening of the duct connecting to the reverberation chamber with the microphone placed 150 mm to 300 mm from the opening as shown in Fig. 3. Sound levels in the source chamber shall be measured with

the test specimen and the flanking test plug installed as per Fig. A3.1 in Annex A3. Repeat the measurement for the empty duct setup. Compute the sound pressure level difference between the two tests as a function of frequency. The sound source chamber is qualified for measurements according to this standard if the difference between the two sound pressure levels is less than 2 dB in each one-third octave band.

6.2.2.3 If the sound source chamber fails to meet the specified tolerance in one or more frequency bands, modifications to the sound source chamber design are required. Improvements that may be required include adding sound absorptive materials to the sound source chamber walls, increasing the size (volume) of the sound source chamber, or repositioning the loudspeakers(s).

6.3 System (Between Sound Source Chamber and Reverberation Room)—The construction of the duct system shall be of adequate mass (1.897 mm or heavier steel) so that any environmental or flanking noises entering the duct system have a negligible effect on the measurements. When testing high insertion loss silencers, it may be necessary to apply a damping material to the outside of the duct walls or increase the transmission loss, or both, by adding one or more layers of

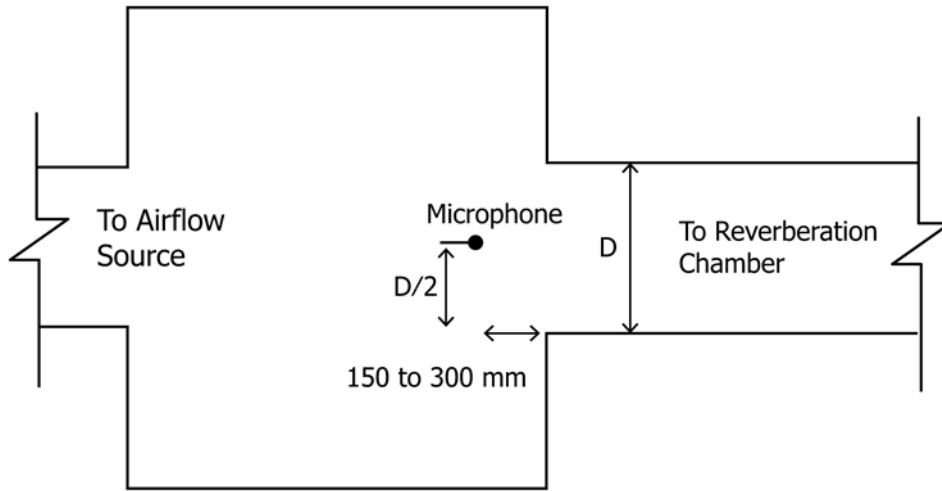


FIG. 3 Sound Source Chamber Microphone Location

gypsum board to the exterior. The interior surface of the duct system shall be smooth and have a low sound absorption coefficient in the frequency range of interest.

6.3.1 The length of the duct system is primarily determined by the requirements of air-flow measurements and is shown in Fig. 4. The test duct length upstream, regardless of the shape of the test specimen and layout of test facility, shall be not less than five equivalent diameters from the entrance to the test specimen. Similarly downstream, it shall be not less than ten duct diameters from the exit of the specimen to the reverberant room, not including the length of any transitions, if airflow is being measured. If airflow is not measured, the downstream length shall be not less than five equivalent duct diameters. The test specimen shall remain in the same position for both the insertion loss and airflow measurements.

6.3.2 The upstream and downstream sections shall have the same cross-sectional dimensions as the entrance and discharge of the test specimen. Any transitions required to connect the duct system to the sound source chamber and reverberation room shall be made upstream and downstream of the required duct length and shall have an included angle of not greater than 15° (slope no greater than 7.5°).

6.3.3 There are occasions when a silencer designed to be used at the termination of a duct system must be tested. Testing of such silencers, mounted at the termination of the duct system or in the reverberation room, shall be considered a special circumstance, and shall be noted as an exception to this test standard in the test report. Full details concerning the mounting and testing must also be included.

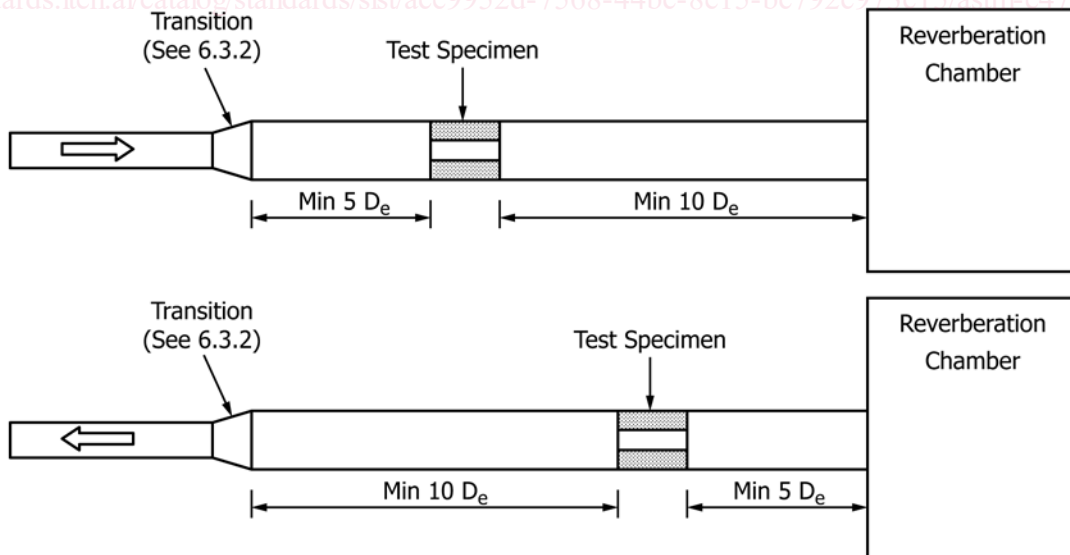


FIG. 4 Test Specimen with Duct and Transition Requirements



6.4 *Reverberation Room*—The acoustic and physical environment of the reverberation room shall be qualified by test to meet the requirements of ANSI Standard S12.51(R2012)/ISO:3741(2010) Section 5.1, 5.5, Annex A, Annex C and Annex E.

6.5 *Test Signal*—The test signal delivered by the loudspeaker system for these tests shall be random pink noise with a continuous frequency spectrum and with equal power per constant percentage bandwidth.

6.5.1 The sound source in the sound source chamber should be a loudspeaker system mounted in a baffle capable of reproducing the lowest test frequency with adequate power. When more than one loudspeaker is used they should be electrically coupled so that they act in phase or in unison in response to a given signal. The loudspeaker should be placed on one side of the sound source chamber such that it does not beam directly into the duct system.

6.5.2 A fixed sound source chamber monitoring microphone meeting the requirements of section 6.6, shall be placed in the sound source chamber to simultaneously monitor the sound pressure levels throughout the insertion loss measurements. The sound source chamber monitoring microphone shall be the same location as the sound source chamber qualification test.

6.5.3 Power shall be applied to the loudspeaker system for a sufficient time to stabilize the loudspeaker system output to meet the requirements of 6.5.2.

6.6 *Acoustical Measurement Apparatus*—Use microphones that are stable and substantially omni-directional in the frequency range of measurement, with a known frequency response for a random incidence sound field. (A 12 mm random-incidence condenser microphone is recommended.) Specifically, microphones, amplifiers, and electronic circuitry to process microphone signals must satisfy the requirements of ANSI S1.43 or IEC 61672 for class 1 sound level meters, except that A, B, and C weighting networks are not required since one-third octave filters are used. All microphones used in testing according to this method shall be of the same type.

6.6.1 *Calibration*—Calibrate each microphone over the whole range of test frequencies as often as necessary to ensure the required accuracy (see ANSI S1.10). A record shall be kept of the calibration data and the dates of calibration.

6.6.2 Calibration checks of the entire measurement system for at least one frequency shall be made at the beginning and end of each day of testing, and if any mechanical, electrical, or environmental changes have occurred. Make the calibration check of the measurement system using an acoustic calibrator that generates a known sound pressure level at the microphone diaphragm and at a known frequency. The class of Calibrator shall be class 1 per ANSI S1.40 or IEC 60942

6.7 *Bandwidth*—The overall frequency response of the filters used to analyze the microphone signals shall, for each test band, conform to the specifications in ANSI S1.11 for a one-third octave band filter set, class 1 or better.

6.8 *Standard Test Frequencies*—Measurements shall be made in all one-third octave bands with mid band frequencies specified in ANSI S1.11 from 50 to 10000 Hz.

## 7. Apparatus and Methods of Measurement for Airflow and Pressure Drop

7.1 The measurement of airflow may be accomplished by employing a venturi, nozzle or orifice, or any other calibrated flowmeter instrument. A pitot traverse may also be used (see 2.3). Airflow measurements shall be accurate to within 5% of values determined by a pitot traverse in accordance with ANSI/ASHRAE Standard 41.2-87 at the pressure measurement location between the source chamber and the test specimen for each airflow setting.

7.1.1 The following information is required prior to each test and once every two hours during the test to ensure accurate airflow setting and measurements: barometric pressure, dry-bulb temperature and relative humidity in the reverberation room. The airflow is to be recalculated each time new data are taken.

7.2 Pressure drop measurements of the test specimen shall be made for at least three airflow settings in accordance with ANSI/ASHRAE Standard 41.3-89. These airflow settings shall be broad enough to cover the full design operating range of the specimen.

7.2.1 The pressure measurements shall be made at planes at least two and a half duct diameters (or equivalent diameters for rectangular ducts) upstream from the inlet to the test specimen and at least five duct diameters downstream from the outlet of the test specimen. A piezometer ring or pitot traverse shall be used to ensure accurate pressure measurements.

7.3 Pitot tubes and other flow measuring devices mounted between the test specimen and the reverberation room shall be removed from the duct system during airflow generated noise measurements if their empty duct noise levels in any one-third octave band are within 10 dB of the airflow noise level of the test specimen.

7.4 The total pressure drop across the silencing element shall be calculated from the upstream and downstream total pressures measured directly or calculated from static and velocity pressures measured at the plane of the transverse. This calculation shall be made and reported without correcting for the pressure drop of the substitution duct.

## 8. Test Specimen

### 8.1 *Installation:*

8.1.1 The test specimen shall be installed in the duct system in a manner normally specified for intended use with the specimen, with the air inlet oriented toward the sound source chamber for forward flow tests. For reverse flow tests, the air inlet shall be oriented toward the reverberation room. Unless the run of duct, in shape and length is the same on both sides of the test specimen, the results for both tests, forward and reverse, may depend on the system. The cross section of the duct system at each connection shall conform to the geometry of the inlet and outlet of the specimen.

8.1.1.1 To reduce the effects of structural flanking, the test specimen shall be decoupled from the inlet and outlet duct sections. This can be accomplished by applying a 12 mm bead of mastic material (for example, building duct and conduit sealing compound, rubber gaskets, or similar material) between