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Designation: ~~E477 – 06a~~ E477 – 13

Standard Test Method for ~~Measuring~~ Laboratory Measurements of Acoustical and Airflow Performance of Duct Liner Materials and Prefabricated Silencers[1]

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 (ε) indicates an editorial change since the last revision or reapproval.

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 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.*~~

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.*

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

~~C384 Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method~~

~~C423 Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method~~

C634 Terminology Relating to Building and Environmental Acoustics

~~E90 Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements~~

~~E795 Practices for Mounting Test Specimens During Sound Absorption Tests~~

2.2 *ANSI Standards:*[3]

S1.1–1994(R2004) Acoustical Terminology

~~S1.11–2004~~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

[1] 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] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

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S12.51–2002/ISO 3741:1999S12.51–2012/ISO 3741:2010 Acoustics-Determination of Sound Power Levels of Noise Sources Using Sound Pressure-Precision Method for Reverberation Rooms

2.3 *AMCA Standards:*[4]

AMCA 300 –96, Reverberant Room Method for Sound Testing of Fans

2.3 *ASHRAE Documents and Standards:*[4]

2001 2009 ASHRAE Handbook, Fundamentals Volume, Chapter 14, Chapter on Fundamentals,Chapter 36, Measurement and Instruments

ANSI/ASHRAE 41.341.3-1989 Standard Method for Pressure Measurement (plus errata dated 5 January 1998)

2.4 *NAIMA Documents and Standards:*[5]

Fibrous Glass Duct Liner Standard, 3rd ed., 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.

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

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

3.2.9 *in-duct sound-attenuating devices*—units designed a device or system intended to reduce the sound that transmits through a duct system.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 solely 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 *noisesound 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.

3.2.11 *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 noise source chamber (through the duct system).

3.2.15 *standard air density* (d_s)—1.202 kg/m^3 (0.075 lb/ft. ^{3}). This corresponds approximately to dry air at 21°C (70°F) and 101.3 kPa (29.92 in. Hg).kPa.

[6] Michaud A. P., Cunefare K. A., "Experimental Investigation of Reflection of Airborne Noise at Duct Terminations" RP-1314, TRNS-00315-2007, ASHRAE Transactions, Salt Lake City, UT, USA, June 2008.

[4] Available from Air Movement and Control Association, 30 W. University Dr., Arlington Heights, IL 60004.

[4] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329.30329, http://www.ashrae.org.

[5] Available from North American Insulation ManufacturesManufacturers Association (NAIMA)(NAIMA), 44 Canal Center Plaza, Suite 310, Alexandria, VA 22314.22314, http://www.naima.org.

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

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

3.2.18 *test run*—pertains to all ~~readings~~measurements and calculations at any one setting of the ~~air flow~~ 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 ~~24 gage,~~0.6 mm, or are flexible, or are of rigid ~~fiberglass~~ glass fiber construction.

3.2.20 *total pressure at a plane of traverse,* ~~*P*~~*(P_t),* Pa ~~(in. water)~~—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 ~~readings~~measurements made with a pitot tube in a cross section of the test duct, perpendicular to the duct length, in accordance with ~~2001~~the *ASHRAE* ~~*Handbook,*~~*Fundamentals Handbook* Chapter ~~14~~on Measurement and Instruments.

3.2.22 *velocity pressure at a plane of traverse,* ~~*P*~~*(P_v),* Pa ~~(in. water)~~—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'*~~*(P'_v),* Pa ~~(in. water)~~—the pressure measured by the differential ~~reading~~measurement of a pitot tube pointed upstream at that point.

~~3.3 *Symbols:*—see *ASHRAE Fundamentals Handbook 2001*~~
~~3.3.1 *D* = air density in reverberation room, kg/m^3 (lb/ft^3).~~
~~3.3.2 *BP* = barometric pressure, kPa (in. Hg).~~
~~3.3.3 t_d = dry bulb temperature, °C (°F).~~
~~3.3.4 *T* = absolute temperature of air in reverberation room, K (°C + 273) or [°R = (°F + 460)].~~
~~3.3.5 P_v = velocity pressure at a plane of transverse, Pa (in. water).~~
~~3.3.6 P_s = static pressure at a plane of transverse, Pa (in. water).~~
~~3.3.7 *V* = average velocity in the duct across the plane of traverse, m/s (ft/min).~~
~~3.3.8 ΔP = pressure differential or pressure drop across the in-duct sound attenuating device, Pa (in. water).~~
~~3.3.9 *Q* = discharge rate, L/s (ft^3/min).~~
~~3.3.10 *K* = values of constant K.~~
~~3.3.11 A_2 = orifice area, m^2 (ft^2).~~
~~G_c = gravitational conversion factor, 9.806 m/s^2 (32.174 ft/s^2).~~
~~3.3.12 *hf* = pressure drop obtained by the pressure taps, Pa (lbf/ft^2).~~

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4. Summary of Test Method

4.1 ~~To measure the insertion loss~~ Insertion loss is measured by comparing the change in sound pressure level due to the insertion of a test ~~specimen, two separate measurements must be made. The sound pressure level in the reverberation room is measured while sound is entering the room through a length of straight or elbow empty duct with a sound source at the far end. The sound pressure level in the reverberation room is measured again after a section of the empty duct has been replaced with the test specimen. The~~ 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 ~~equal to the difference between the two measured sound pressure levels.~~ a function of frequency.

4.2 ~~The airflow generated noise~~ Noise generated by air flowing through the test specimen is measured in ~~terms of frequency band sound power levels while only air flow and no additional fan noise or noise from the noise source chamber passes through the specimen under test.~~ 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. ~~Proper~~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 ~~is a matter of degree, and~~ 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 ~~1.5~~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

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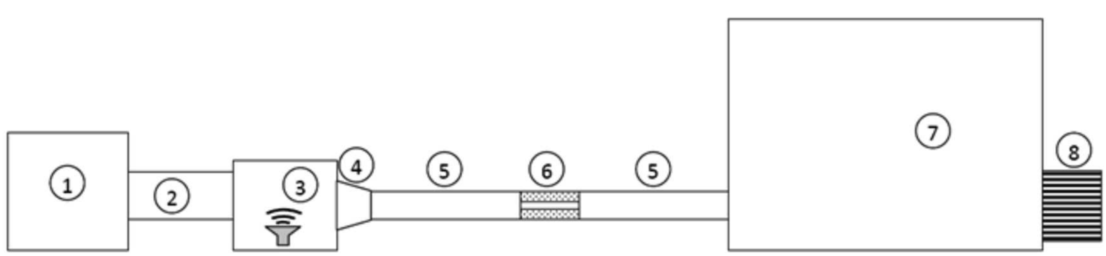
6.1 The test facility shall consist of a ~~signal~~sound source chamber and a reverberation room coupled together by means of a length of straight or elbow duct. Provisions shall be made in the duct system for inserting either a test specimen, or a section of empty duct having the same interior cross-sectional 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~~set-up to accommodate elbow silencer testing (at various angles) is shown in Fig. 2. Airflow and ~~noise~~sound source ~~plenum(s)~~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 ~~signal~~sound source chamber shall be ~~an enclosure~~ 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



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

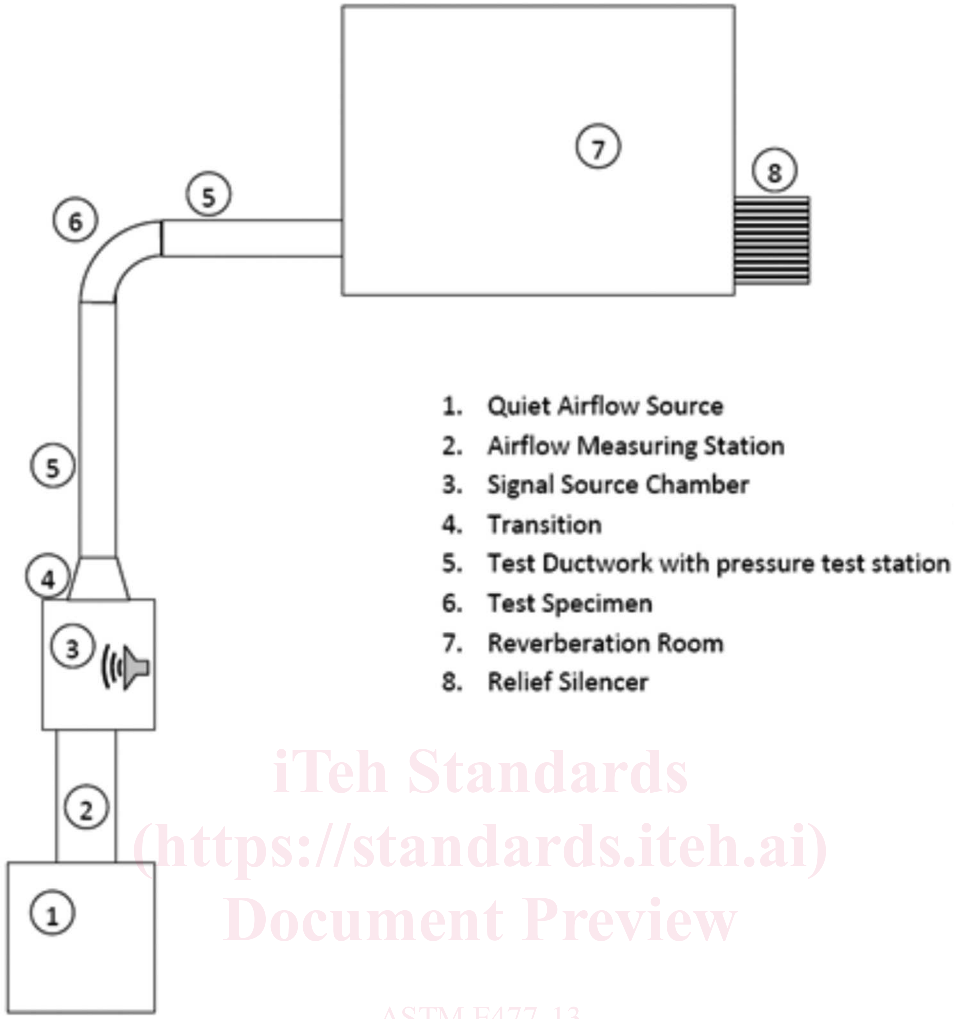


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FIG. ~~3~~2 ~~Test Specimen with Inlet and Outlet Dimensions the Same as the Facility Duct, also Showing Nature of any Required Transitions~~ Typical Facility for Rating Elbow Duct Silencers With or Without Airflow

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. The sound source system shall be structurally isolated from the chamber and duct system. This enclosure should be joined to the duct system through an opening in the chamber having dimensions the same as or greater than the duct. In the latter case, a tapered transition piece is placed between~~ 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^3~~the duct and the opening in the chamber.~~.

6.2.1 The ~~signal~~sound source chamber ~~should~~shall be constructed of ~~material~~materials having sufficient sound transmission loss and be adequately isolated ~~to reduce the possibility of sound~~ from the surrounding environment to minimize noise from the sound source from entering the reverberation ~~room~~chamber by ~~paths~~ any path other than ~~through~~ the duct ~~connecting the signal source chamber and reverberation room.~~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 ~~In order~~ The sound source chamber shall be tested to ensure that the ~~reaction on the sound source remains essentially constant with or without the test specimen in place, the interior wall surfaces of the signal source chamber must be lined with sound-absorbing material. The material shall have a minimum NRC = 0.25, as determined by Test Method~~ acoustic energy transmitted into the test duct is not affected by the insertion of the ~~C423 and Type A mounting per Practices E795 for all the test frequencies but should be kept low enough so that the sound pressure level in the reverberation room is 10 dB above ambient when the test specimen is in place and the sound source is on.~~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

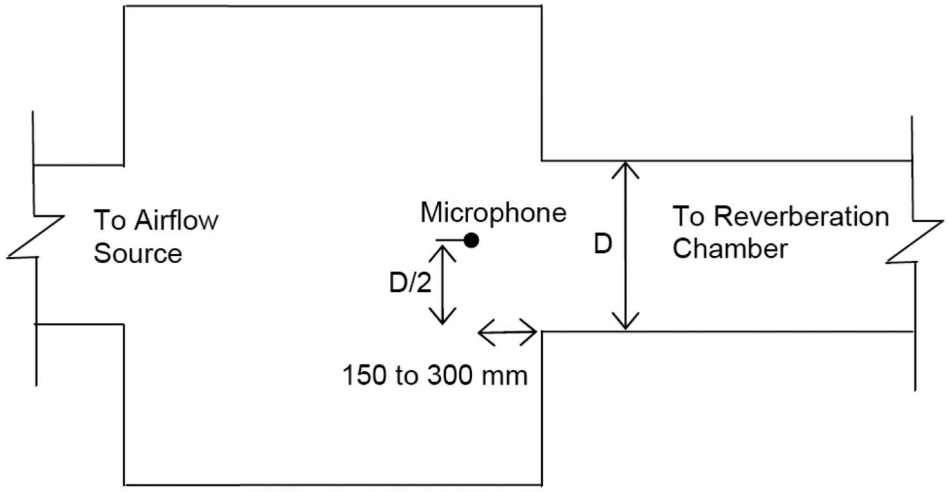

FIG. ~~5~~3 ~~Simulated Semi-Reflective Plenum Configuration~~Sound Source Chamber Microphone Location

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).

~~6.2.3 The physical size of the signal source chamber shall be such that no inside dimension is less than the largest dimension of the duct system and that the sound source is totally enclosed and does not obstruct the opening into the duct.~~

~~6.2.4 A second duct may be attached to the signal source chamber through which quiet airflow can be supplied to the system.~~

6.3 *~~Duct~~ System (Between Sound Source Chamber and Reverberation Room)*—The construction of the duct system shall be of adequate mass ~~(14 gage~~(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 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.~~ 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 ~~5~~five equivalent diameters from the entrance to the test specimen. Similarly downstream, it shall be not less than ~~10~~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 ~~5~~five equivalent duct diameters. The test specimen ~~is to~~ 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 ~~adapt~~connect the ~~test specimen to the facility duct dimensions~~ duct system to the sound source chamber and reverberation room shall be made upstream and downstream of the required duct ~~length. Any transitions to adapt the test specimen to the facility duct dimensions~~ length and shall have an included angle of not greater than 15° (slope no greater than 7.5°). ~~The duct shall terminate at the reverberation room wall abruptly with the same cross-sectional dimensions as the system duct.~~

6.3.3 There are occasions when a ~~silencer,~~silencer designed to be used at the termination of a duct ~~system,~~system must be tested. Testing of such silencers, mounted at the termination of the ~~facility~~ 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.

6.4 *Reverberation Room*—The ~~requirements regarding~~ acoustic and physical environment of the reverberation room ~~are based on those given in Method~~shall be qualified by test to meet E90. ~~If flow-generated noise is to be measured, the room shall be qualified in accordance with ANSI S12.51 or ISO 3741.~~the requirements of ANSI Standard S12.51(R2012)/ISO:3741(2010) Section 5.1, 5.5, Annex A, Annex C and Annex E.

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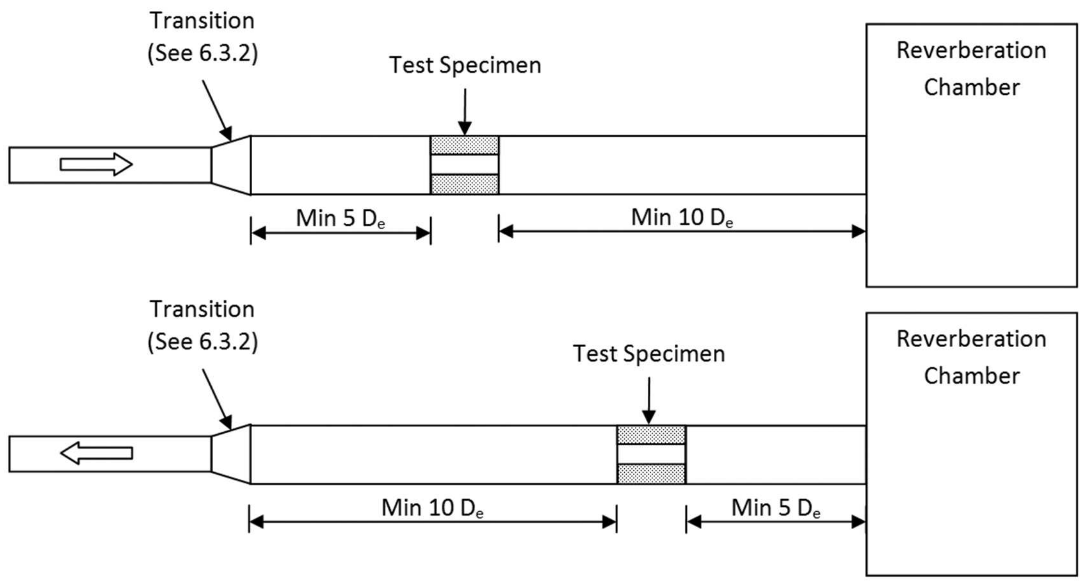

FIG. 4 ~~Section A-A~~Test Specimen with Duct and Transition Requirements

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

~~6.5.1 The bandwidth of each test signal shall be one-third octave. Specifically, the overall frequency response of the electrical system, including the filter or filters in the source and microphone circuits, shall conform to the specifications in ANSI S1.11 for a one-third octave band filter set, Order 3 or higher, Type 1 or better. Filtering may be done in the source or microphone system or partially in both, provided that the required overall characteristic and bandwidth is achieved. Apart from defining the one-third octave bands of test signals, a filter in the microphone system serves to filter out extraneous noise lying outside the test band including possible distortion products in the source system; a filter in the source system serves to concentrate the available power in the test band.~~

~~6.5.2 The minimum range of measurements shall be a series of contiguous one-third octave bands with center frequencies from 50 to 5000 Hz (optional to 10 000 Hz). If desired, the range may be extended in further one-third octave band downward or upward. Note that at this time there is no standard method of qualifying a reverberation room below 100 Hz. However, recent research shows that reproducible data are obtainable for both insertion loss and airflow generated noise at these lower frequencies. Based on this research, the standard deviation for ⅓ octave band measurements increases to about 6 dB at the lowest frequencies.~~

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,~~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 ~~The signal shall be monitored electrically by measuring the loudspeaker voice coil voltage. The test signal at a given band shall be maintained to ±½ dB throughout the test.~~ Power shall be applied to the ~~speaker voice coil~~ loudspeaker system for a ~~minimum~~sufficient time ~~of ½ h prior to conducting tests in order to stabilize speaker output due to voice coil heating.~~ to stabilize theloudspeaker system output to meet the requirements of 6.5.2.

~~6.5.4.1 As an alternate check, a microphone may be used to measure the sound pressure level at a specific position in the empty duct before and after placing the test specimen in the duct. Said position is to be on the signal source side of the test specimen. This applies only to 0 flow conditions.~~

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.

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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 ~~calibratable~~calibrated flowmeter ~~instruments.~~instrument. A pitot traverse may also be used (see ~~2.4~~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.~~ 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 ~~readings~~measurements shall be made at planes at least ~~2~~two~~½~~ ~~duct~~ and a half.duct diameters (or equivalent diameters for rectangular ducts) upstream from the inlet to the test specimen and at least ~~5~~five duct diameters downstream from the outlet of the test specimen. A piezometer ring or pitot traverse shall be used to ensure accurate pressure ~~readings.~~ 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.

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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 ~~noise~~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 (1/2-in.)~~12 mm bead of mastic material (for example, building duct and conduit sealing compound, rubber gaskets, or similar material) between the flanges that connect the test specimen to the inlet and outlet duct sections. The duct system duct sections may also be decoupled in a similar manner and separated by at least a ~~6-mm (~~6 mm~~¼-in.)~~ gap between the flanges after they have been bolted or clamped together and the resulting gap between flanges sealed.

8.2 The substitution duct shall be the same sheet metal gage as the system duct except for lined duct specimen tests. In this case, the substitution duct shall be constructed of the same sheet metal gage as the specimen. If the test specimen is an elbow silencer, the substitution elbow duct shall have the same bend angle as the test specimen. In order to minimize attenuation effects, the substitution elbow duct shall be a radius ~~geometry:~~geometry

~~(*inside radius* = 1 × *duct width*; *outside radius* = 2 × *duct width*)~~

according to:

$$r_{inner} = w_{duct} \tag{1}$$

$$r_{outer} = 2 \times w_{duct} \tag{2}$$

where:

r_{inner} = inner radius,
r_{outer} = outer radius, and

w_{duct} = duct width.

8.3 Duct liner materials should be applied to another duct as a separate assembly which then becomes a test specimen. Application should conform to the generally accepted trade methods used (NAIMA) and shall be specified in the report.

8.3.1 The free (inside) area of the lined duct section shall be the same as the free area of the removable duct section; that is, the outside dimensions of the lined duct will be larger than the unlined.

~~8.4 For a thin-walled duct, it is likely that the amount of absorption (and breakout) of the test specimen, as a result of duct flexure and low transmission loss, will significantly affect the measured insertion loss. If the specimen wall material is thinner than 24 gage, or is flexible, or is of rigid fiberglass construction, then a simulated plenum shall be fitted around it to provide a semi-reflective environment (see Fig. 4 and Fig. 5). This can be accomplished by mounting a 19-mm (¾-in.) thick plywood reflector 50 mm (2 in.) above and below the test specimen.~~

~~NOTE 1—The 50-mm (2in.) distance has been chosen to simulate a reasonable plenum clearance. Other distances may affect the test results, however the magnitude of these differences has not been determined.~~

~~Both reflectors shall be 1.2 m (4 ft) wide and long enough to project not less than 0.6 m (2 ft) beyond the ends of the specimen. The test specimen shall be centered in the plywood reflectors. The sides of the plenum as indicated in Fig. 5, shall be 19-mm (0.75-in.) thick plywood, lined with 2 to 3-lb density absorptive (glass fiber) lining 0.15 m (6 in.) thick.~~

8.4 *Size:*

8.4.1 The smallest dimension should be not less than ~~0.610 m (2 ft),~~ 610 mm, and may not be less than ~~0.305 m (1 ft)~~ 150 mm except for prefabricated duct, where the smallest dimension may be that which is normally supplied by the manufacturer. The largest dimensions of the test specimen shall not exceed the limits of the test facility. Transition ducts for the purpose of mating the test specimen geometry to the laboratory duct system geometry may be used, provided that the requirements of 6.3.2 are met. If inlet and outlet transition elements form a part of the test specimen, then this should be fully described in the report.

8.4.2 There is no restriction on the length of prefabricated silencers. Duct liner materials and flexible duct shall be ~~3 m (10 ft)~~ 3000 mm long. In addition to this length, longer specimens of duct liner materials and flexible duct may also be ~~tested.~~ tested and reported. Shorter lengths may be ~~evaluated~~tested, but ~~will~~shall not be ~~considered~~ reported as being conducted in accordance with this ~~standard and shall be noted in the test report.~~standard.

~~NOTE 2—The length of duct liner materials and flexible duct controls attenuation. 3-m (10-ft) length has been chosen as representative of the length used in actual installations.~~

NOTE 1—The length of duct liner materials and flexible duct controls attenuation. 3000 mm length has been chosen as representative of the length used in actual installations.

9. Measurement of Insertion Loss (With or Without Airflow)

9.1 The purpose of the measurement is to find the change in sound power ~~level~~ delivered to the reverberation room before and after the test specimen is inserted into the duct system under conditions of forward and reverse airflow or without airflow. Since the absorption of the reverberation room is the same during the two measurements, the change in sound power level is equal to the change in average sound pressure level in the reverberation room and, by definition, equal to the insertion loss. A sample calculation for each required calculation is provided in Annex A4.

~~9.1.1 To maintain constant absorption in the test system, the temperature and relative humidity must be kept within 3 °C (5 °F) and 5% RH for the entire test (including empty duct measurements and each flow condition).~~

9.2 With the sound source on, and for each condition of test (that is, with and without the test specimen in the duct system, and with and without airflow), measure the average one-third-octave band sound pressure level in the reverberation room ($L_{p,s}$ and $L_{p,empty\ duct}$) and the sound source chamber to the nearest 0.1 dB. All microphone locations used for qualification and sound level measurements shall be the same.

9.2.1 *Sound Source Chamber Monitoring Microphone*—The measured average sound levels in the source chamber with and without the test specimen installed shall not exceed the level difference specified in section 6.2.2.2. If the difference in levels exceed these values the system shall be modified until the measurement requirements are satisfied.

9.2.2 *Reverberation Room Microphone(s)*—~~Sound field sampling techniques and microphone requirements shall be in accordance with ANSI S12.51 with two exceptions as detailed below:~~No microphone position or point on a traverse shall be less than 1.5 m from any reverberation room surface or less than 0.5 m from any diffuser surface.

9.2.2.1 *Microphone Traverse*—If a ~~moving~~traversing microphone is used, the ~~path length of the microphone traverse shall be a minimum of 3*λ/2, where λ is the wavelength of sound at the lowest midband frequency of interest (for example, minimum 33 feet path length for 50 Hz).~~ space averaging of the sound data shall be measured using a microphone traversing at a constant speed, not to exceed 1m/s, over a path length greater than or equal to 10.3 m. The microphone traverse path shall not lie in any plane within 10° of any room surface. A whole number of traverses shall be completed during the analyzer measurement time interval.

9.2.2.2 *Fixed Microphones*—~~The acceptable limits for standard deviations for the one-third-octave bands centered at 50, 63 and 80 Hz shall be 2.0 dB for each band.~~If a fixed microphone or microphones are used, measurements shall be made at 6 or more locations that are spaced at least 3.4 m from each other. The entire array of microphones shall not share a common plane.

9.2.3 The averaging time for each one-third-octave band measurement shall be at least ~~20~~30 s.

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~~9.2.3 Use the same microphone positions for the entire test, that is, for sound pressure level measurements with and without the test specimen installed in the duct.~~

9.2.4 ~~Measurements shall be taken at a~~ A sufficient number of ~~different positions~~ measurements shall be taken so that the 95% confidence interval of the average sound pressure level is not more than ~~±1~~1 dB in all frequency bands, except for the bands centered at 50, 63 and 80 Hz for which it shall not be more than ~~±~~2 dB. If a rotating microphone boom is used to ~~measure the average sound pressure level,~~ qualify the room as described in section 6.4~~the microphone and boom shall be setup, located, operated and qualified in accordance with ANSI S12.51 to achieve the above accuracy.~~ , the same requirements for confidence interval limits shall be met with an appropriate number of successive measurements.

9.3 As with any measurement methodology, it is imperative to ensure that the value being measured is not contaminated by background levels, or that they are accounted for in the final data set. Compare the various measurements with their associated background noise levels (signal-to-noise) to determine the need for system modification or mathematical correction, or both. Practical and reasonable modifications should be made as necessary to avoid using any mathematical corrections whatsoever.

9.3.1 Background noise levels ($L_{p,b}$) in the reverberation chamber shall be measured in accordance with the procedures specified in 9.2 with all sound sources turned off and no airflow through the system. Check the background noise levels before and after any series of sound pressure level measurements, when background noise conditions are noticeably different, or every time there is a duct system rig change. If the measured background noise levels are within 5 dB, the arithmetic average of the values shall be used. If the difference in measured background noise levels is greater than 5 dB, repeat the series of measurements.

9.3.2 Flanking transmission, which is part of the background noise, shall be determined by inserting an obstruction with a high sound transmission loss in the duct system between the test specimen and the reverberation ~~room, then observing the levels in the reverberation room with the sound~~room as shown in Annex A3~~source generating the same sound power levels to be used for the test. A~~ . The test specimen (duct silencer) ~~should~~shall be in place for the flanking test. The length of the obstruction shall not be more than 20% of the distance between the test specimen and the reverberation room. ~~The background noise level due to flanking shall be at least 5 dB below (and to avoid data corrections, at least 10 dB below) the measured silenced level for the various test conditions, with and without airflow, in all~~Flanking sound levels in the reverberation room shall be measured in accordance with the procedures and requirements of section 9.2 ~~one-third-octave bands of~~and section 6.2.2.2 ~~interest.~~ without airflow. The flanking test shall be conducted ~~at least once per year, or anytime there is a change in the test setup that could modify the flanking test results.~~for each test specimen. If the flanking sound pressure level is more than 2dB above the background sound pressure level, the flanking sound pressure level shall be corrected according to:

$$Lp_{f'} = 10\log\left(10^{0.1 \cdot L_{p,f}} - 10^{0.1 \cdot L_{p,b}}\right) \quad (3)$$

where:

$L_{p,b}$ = background sound pressure level measured in the reverberation room with the sound source off and no airflow through the silencer in decibels,
$L_{p,f}$ = sound pressure level measured in the reverberation room during the flanking test in decibels, and
$L_{p,f'}$ = sound pressure level measured in the reverberation room during the flanking test corrected for background sound in decibels.

~~9.3.2 Compare the measured silenced sound pressure levels with the airflow generated noise levels determined in Section 10. The background noise due to generated noise shall be at least 5 dB below (and to avoid data corrections, at least 10 dB below) the measured silenced levels in all one-third-octave bands of interest.~~

9.3.3 The airflow generated noise levels ($L_{p,gn}$) measured according to section 10.3~~If the measured silenced levels are at least 10~~ shall be compared to the measured background sound levels. If the airflow generated noise sound pressure level is more than 2 dB above the background ~~noise levels due to flanking and airflow generated noise, no corrections or system modifications are required. If these ideal conditions cannot be achieved, but the measured silenced levels are at least 5 dB above these background levels, corrections may be made for each one-third-octave band level at a specific test velocity~~ sound pressure level, the airflow generated noise level shall be corrected according to:

$$Lp_{gn'} = 10\log\left(10^{0.1 \cdot L_{p,gn}} - 10^{0.1 \cdot L_{p,b}}\right) \quad (4)$$

~~as follows:~~

$$L_{p'} = 10 log\left(10^{\left(\frac{L_{p,s}}{10}\right)} - 10^{\left(\frac{L_{p,f}}{10}\right)} - 10^{\left(\frac{L_{p,gn}}{10}\right)}\right) \quad (1)$$

where:

~~$L_{p'}$ = corrected sound pressure level (in specific one-third-octave band).~~
~~$L_{p,s}$ = Silenced sound pressure level measured in the reverberation room (with or without airflow through the silencer).~~
~~$L_{p,f}$ = Sound pressure level measured in the reverberation room during the flanking test.~~

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