Designation: E477 – 06a

Standard Test Method for Measuring 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.*

1.5 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 field conditions.

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 Specification Octave, Half-Octave and Third-Octave Band Filter Sets

S12.51–2002/ISO 3741:1999 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

2.4 *ASHRAE Documents and Standards:*[5]

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

ANSI/ASHRAE 41.3 Method for Pressure Measurement

2.5 *NAIMA Documents and Standards:*[6]

Fibrous Glass Duct Liner Standard 3rd ed., 2002

3. Terminology

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.

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[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.

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

[5] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329.

[6] Available from North American Insulation Manufactures Association (NAIMA) 44 Canal Center Plaza, Suite 310 Alexandria, VA 22314.

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

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

3.2.5 *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.

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

3.2.7 *in-duct sound-attenuating devices*—units designed to reduce the sound that transmits through a duct system.

3.2.8 *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.

3.2.9 *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.

3.2.10 *noise 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).

3.2.12 *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).

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

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

3.2.15 *test run*—pertains to all readings and calculations at any one setting of the air flow throttling device.

3.2.16 *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, or are flexible, or are of rigid fiberglass construction.

3.2.17 *total pressure at a plane of traverse, 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.

3.2.18 *traverse*—a series of readings made with a pitot tube in a cross section of the test duct, perpendicular to the duct length, in accordance with *2001 ASHRAE Handbook*, Chapter 14 Measurement and Instruments.

3.2.19 *velocity pressure at a plane of traverse, 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.

3.2.20 *velocity pressure at a point, P'_v,* Pa (in. water)—the pressure measured by the differential reading 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).

4. Summary of Test Method

4.1 To measure the insertion loss 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 insertion loss is equal to the difference between the two measured sound pressure levels.

4.2 The airflow generated noise 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.

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.

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 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 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.

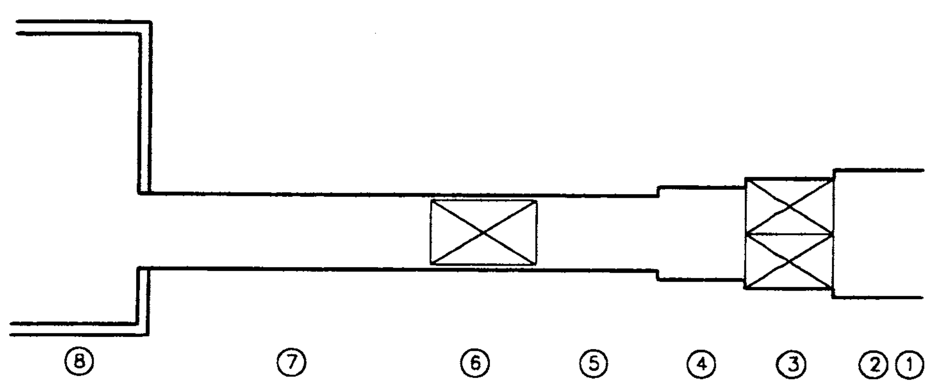
6. Test Facilities

6.1 The test facility shall consist of a signal 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 noise source plenum(s) 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 source chamber shall be an enclosure 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 the duct and the opening in the chamber.

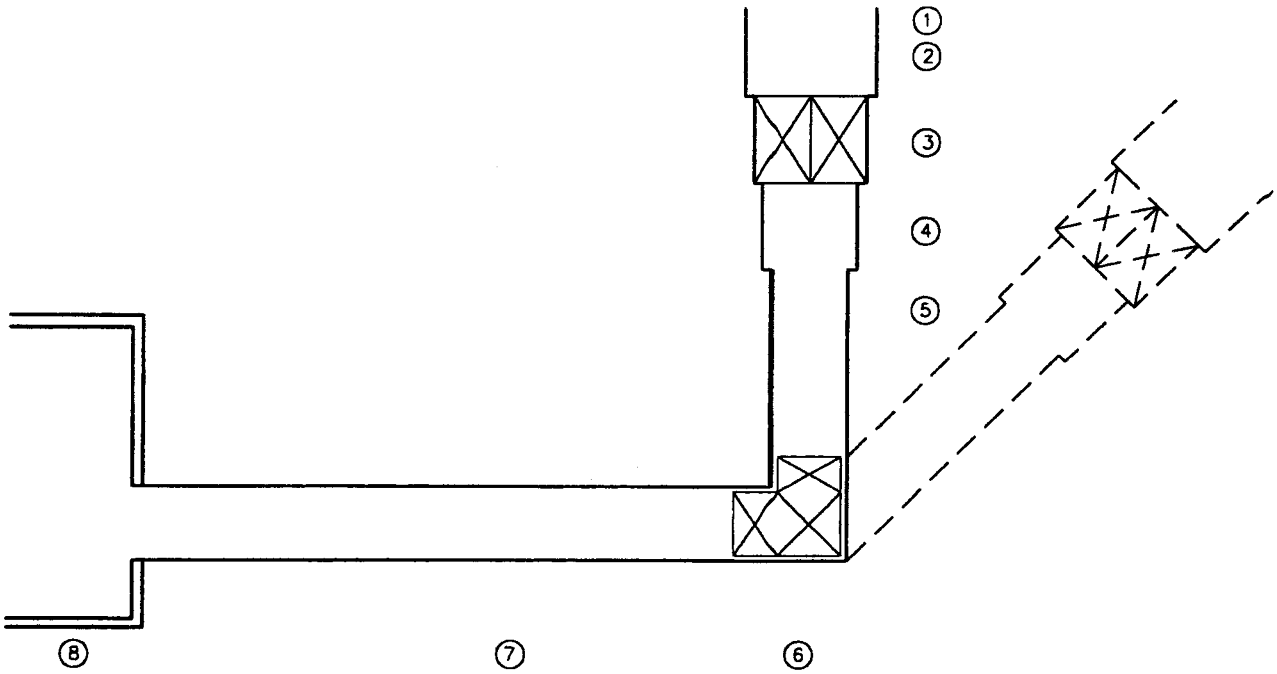
6.2.1 The signal source chamber should be constructed of material having sufficient sound transmission loss and be adequately isolated to reduce the possibility of sound entering the reverberation room by paths other than through the duct connecting the signal source chamber and reverberation room.

6.2.2 In order 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



1 – Airflow measurement station
2 – System fan
3 – System silencer
4 – Signal source chamber
5 – Upstream pressure test station for forward (+ve) airflow and downstream pressure test station for reverse (−ve) airflow
6 – Straight silencer under test
7 – Downstream pressure test station for forward (+ve) airflow and upstream pressure test station for reverse (−ve) airflow
8 – Reverberation room

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



1 – Airflow measurement station
2 – System fan
3 – System silencer
4 – Signal source chamber
5 – Upstream pressure test station for forward (+ve) airflow and downstream pressure test station for reverse (−ve) airflow
6 – Elbow silencer under test
7 – Downstream pressure test station for forward (+ve) airflow and upstream pressure test station for reverse (−ve) airflow
8 – Reverberation room

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

must be lined with sound-absorbing material. The material shall have a minimum NRC = 0.25, as determined by Test Method 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.

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 Source Chamber and Reverberation Room)*—The construction of the duct system shall be of adequate mass (14 gage 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. The duct length upstream, regardless of the shape of the test specimen and layout of test facility, shall be not less than 5 equivalent diameters from the entrance to the test specimen. Similarly downstream, it shall be not less than 10 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 equivalent duct diameters. The test specimen is to 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 to adapt the test specimen to the facility duct dimensions shall be made upstream and downstream of the required duct length. Any transitions to adapt the test specimen to the facility duct dimensions 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, designed to be used at the termination of a duct system, must be tested. Testing of such silencers, mounted at the termination of the facility duct 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 the reverberation room are based on those given in Method E90. If flow-generated noise is to be measured, the room shall be qualified in accordance with ANSI S12.51 or ISO 3741.

6.5 *Test Signal*—The sound signals delivered to the loudspeaker system for these tests shall form a series of bands of pink noise.

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.

6.5.3 The sound source in the 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 source chamber such that it does not beam directly into the duct system.

6.5.4 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 for a minimum time of ½ h prior to conducting tests in order to stabilize speaker output due to voice coil heating.

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.

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 flowmeter instruments. A pitot traverse may also be used (see 2.4).

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 readings shall be made at planes at least 2½ duct diameters (or equivalent diameters for rectangular ducts) upstream from the inlet to the test specimen and at least 5 duct diameters downstream from the outlet of the test specimen. A piezometer ring or pitot traverse shall be used to ensure accurate pressure readings.

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 noise 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.) 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

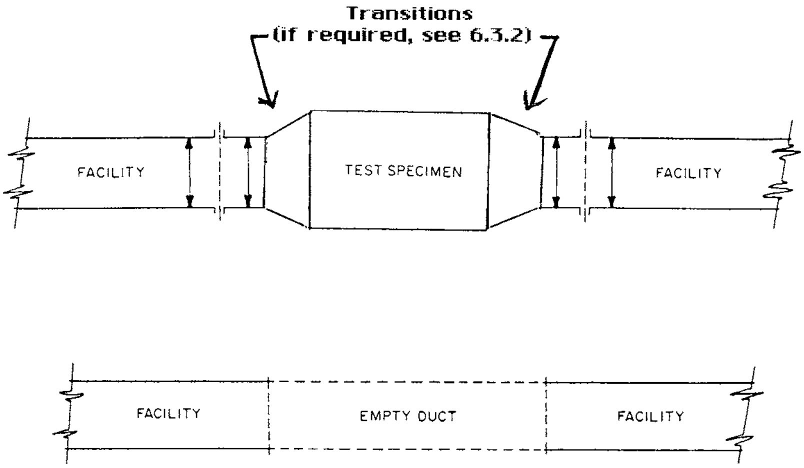


FIG. 3 Test Specimen with Inlet and Outlet Dimensions the Same as the Facility Duct, also Showing Nature of any Required Transitions

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 (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:

$$(\textit{inside radius} = 1 \times \textit{duct width};\ \textit{outside radius} = 2 \times \textit{duct width})$$

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.

8.5 *Size:*

8.5.1 The smallest dimension should be not less than 0.610 m (2 ft), and may not be less than 0.305 m (1 ft) 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.

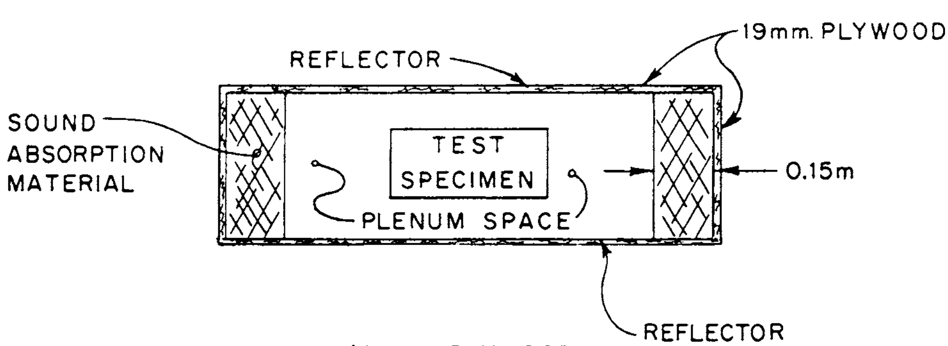


FIG. 4 Section A-A