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Standard Guide for Measurement of In-Duct Sound Pressure Levels from Large Industrial Gas Turbines and Fans[1]

This standard is issued under the fixed designation E2459; 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 guide is intended to provide a simple and consistent procedure for the *in-situ* field measurement of in-duct sound pressure levels in large low pressure industrial air ducts, such as for gas turbines or fans, where considerations such as flow velocity, turbulence or temperature prevent the insertion of sound pressure sensors directly into the flow. This standard guide is intended for both ambient temperature intake air and hot exhaust gas flow in ducts having cross sections of four (4) square meters, or more.

1.2 The described procedure is intended to provide a repeatable and reproducible measure of the in-duct dynamic pressure level at the inlet or exhaust of the gas turbine, or fan. The guide is not intended to quantify the "true" sound pressure level or sound power level. Silencers, as well as Waste Heat Boilers, must be designed using the in-duct sound power level as the basis. Developing the true sound power level based on in-duct measurements of true sound pressure within a complete operating system is complex and procedures are developmental and often proprietary.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Extreme caution is mandatory when working near hot exhaust gas systems and appropriate safety precautions such as the installation of quick acting isolation valves are recommended.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C634 Terminology Relating to Building and Environmental Acoustics

2.2 *ANSI Standards:*

S1.4 Specification for Sound Level Meters[3]

S1.43 Specification for Integrating Averaging Sound Level Meters[3]

3. Terminology

3.1 Definitions of the acoustical terms used in this guide are given in Terminology C634.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *anechoic tube*—a constant diameter tube of sufficient length that a sound wave reflected from the far end of the tube termination arrives at the microphone position sufficiently attenuated that it will not appreciably affect the microphone reading.

3.2.2 *dynamic pressure*—the total instantaneous pressure incident upon the opening of the test port, including the influence of convective turbulence, local tangential modes, localized boundary layer effects at the test port and the indeterminate effects of all duct acoustical modes.

3.2.3 *fixture*—the apparatus containing the microphone fitting which locates the microphone flush with the inside diameter of the anechoic tube, the necessary fittings permitting airtight connection of the fixture and anechoic tube to the test port, and the anechoic tube.

3.2.4 *probe microphone*—a commercially available micro-diameter microphone probe that is inserted into the anechoic termination near the test port connection. Some probes require a pressure compensation connection. Use and installation shall follow manufacturer's procedures/instructions.

3.2.5 *test port*—the hole in the duct wall to which the anechoic tube is connected and whose diameter is equal to the inside diameter of the anechoic tube. In general the term test port, as used herein, will usually include any semi-permanently installed hardware in the wall of the duct permitting closure of the test port when not in use (ball valve and threaded pipe cap, or both) as well as the pipe elements permitting attachment of the fixture and the anechoic tube.

[1] This guide 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, http://www.ansi.org.

4. Summary of Guide

4.1 Key features of this guide:

4.1.1 A through-wall test port opening, 25.4 mm (nominally, 1 in.) or less, to which is connected the fixture, having a constant inside diameter tube, to which the anechoic tube is connected. The test port opening is flush with the inside surface of the duct wall. No apparatus are inserted into the flow path.

4.1.2 The microphone sensor is mounted in the fixture (3.2.3) outboard of the duct wall, with the microphone axis oriented normal to the centerline of the anechoic tube.

4.1.3 The tip of the microphone, usually with a protective grid, is positioned flush with, or more accurately tangential to, the inner wall of the fixture and as close to the duct wall as temperature or access limitations permit.

4.1.4 The diameter of the microphone shall always be less than or equal to the inside diameter of the anechoic tube.

4.1.5 The position of the microphone is critical for high temperature ducts, so as to limit the maximum temperature on the microphone during testing.

4.1.6 The anechoic tube shall have no inner wall discontinuities or changes in diameter that might create reflections or standing waves within the tube. It is important to avoid any protrusion of the apparatus into the gas flow path.

4.1.7 The anechoic termination may be achieved by loosely packing the "cold" end of the tube with mineral wool or steel wool. The tube end should be sealed airtight unless forced air is to be used to ensure adequate cooling of the anechoic tube.

4.1.8 The inner duct wall opening shall be as smooth as practicable, with a minimum of turbulence producing discontinuities at the duct wall inner surface. If the user chooses to mount a protective screen covering the inside duct wall opening, such screen shall not materially influence the sound pressure measurements, or a means of quantifying and accounting for such influence shall be included in the test protocol. (Be aware that such screens can become fouled with particles.)

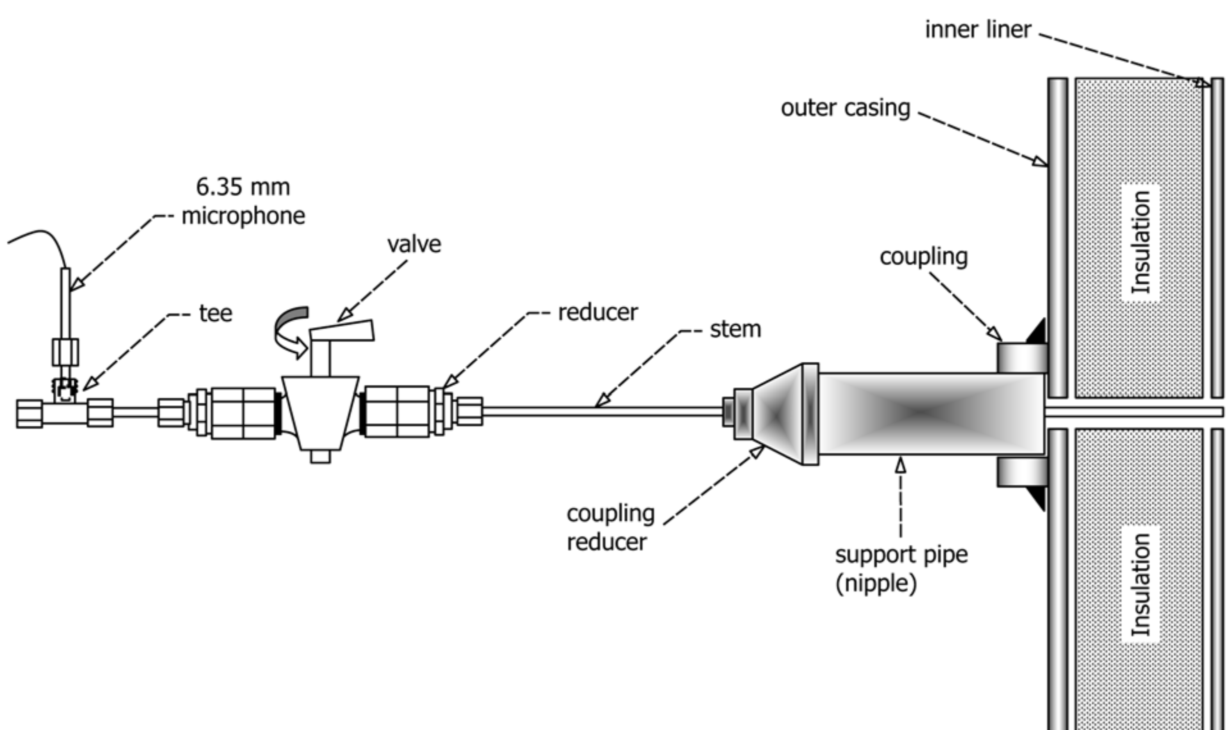
4.1.9 The inner duct wall opening shall be the same inside diameter as the inside diameter of the anechoic tube. That is, this guide does not permit the anechoic tube to be inserted into, or positioned within a duct wall port of larger size, unless means are provided to ensure that the inner wall surface at the test port is restored to a reasonable semblance of a smooth continuous wall surface.

4.2 A sketch of a typical Test Port is shown in Fig. 1. A sketch of a typical Fixture is shown in Fig. 2. Only the initial portion of the otherwise very long Anechoic Tube is depicted in each figure.

5. Significance and Use

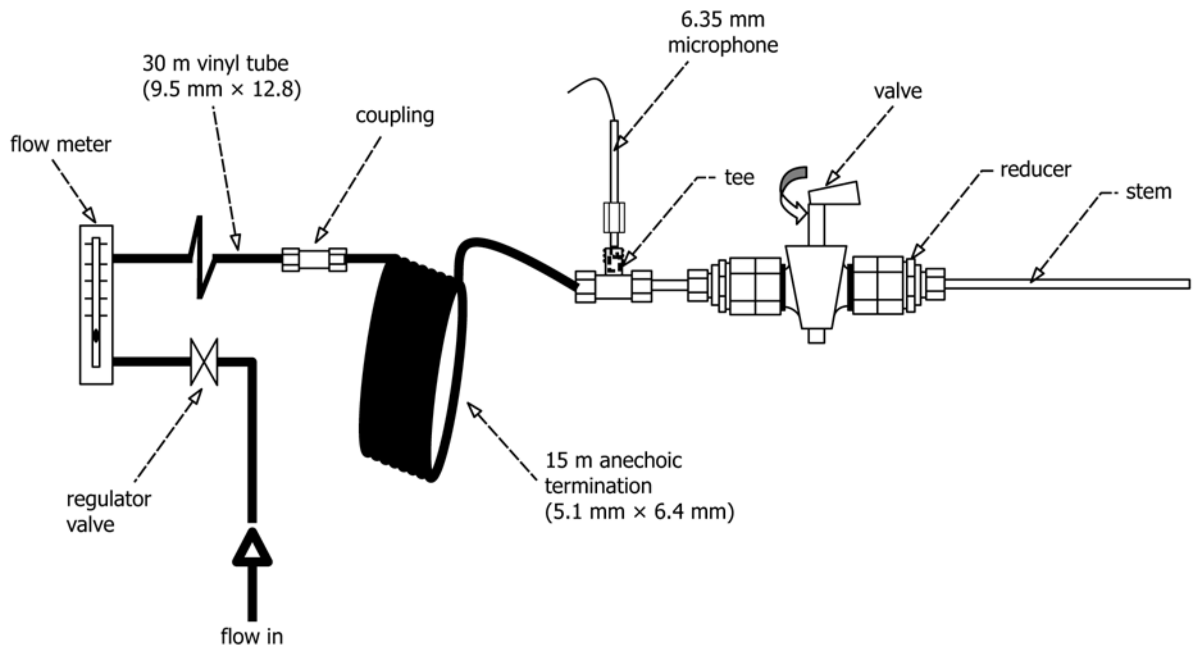
5.1 All noise control features associated with the inlet or exhaust of large industrial fans and gas turbines are, or should be, based upon inlet or exhaust sound power levels in octave bands of frequency. Sound power levels are not directly measurable, however, so they must be calculated indirectly, using estimated or measured duct interior sound pressure levels.

5.2 Estimated in-duct sound pressure level may be obtained by measuring exterior airborne sound pressure levels and applying a transfer function representing the transmission loss



NOTE 1—Showing a typical Fixture (see Fig. 2) installed in an insulated duct wall. Note the stem of the Fixture extends all the way to the inner duct wall surface, occupying a hole in the duct wall only slightly larger than the tube stem O.D.

FIG. 1 Typical Fixture



NOTE 1—Showing a shutoff (ball) valve, a tee connection in which to mount the microphone and various fittings which will maintain a constant inside diameter through the tee connection to the anechoic tube. The example shown uses a ¼ in. microphone attached to a ¼ in. ID anechoic tube. Note that if the orientation of the microphone is vertical, as shown, there is less likelihood of accumulating condensation on the microphone from hot exhaust gases.

FIG. 2 Typical Fixture

of the duct wall. Significant uncertainties are associated with such a procedure, suggesting the need for this guide.

5.3 Estimated in-duct sound pressure level may be obtained by measuring exit plane sound pressure levels and applying a transfer function consisting of the insertion loss through the gas path, including the insertion loss of any silencers. Significant uncertainties are associated with such a procedure, suggesting the need for this guide.

5.4 This guide purports to measure the in-duct sound pressure level directly using type 1 instrumentation per ANSI S1.4 or S1.43. It is limited, however, to the determination of the sound pressure level at the location of the port only and will include the effects of duct acoustical modes, as well as an unknown degree of turbulence and other flow related effects. Methodologies may be devised by the user to minimize such effects. As a rule, the larger the number of test ports used, the better will be the averaged data. Although not prescribed by this guide, cross-channel coherence analysis is also available to the analyst, using ports at different locations along the duct axis, which may yield improvements in data quality.

5.5 This guide is intended for application to equipment in-situ, to be applied to large fans and gas turbines having inlet or exhaust ducts whose cross sectional areas are approximately four (4) square meters, or more, and are therefore not amenable to laboratory testing. All of the field experience on the part of task group members developing this guide has been on gas turbine ducts having cross sections in excess of ten (10) square meters.

5.6 This guide has no known temperature limitations. All of the field experience on the part of task group members developing this guide has been on gas turbine ducts having temperatures between ambient and 700°C.

6. Operating Conditions

6.1 Whenever possible, equipment under test shall be operated in a mode or modes acceptable to all parties to the test. Otherwise, operating conditions must at least be monitored in order that the test results are properly qualified in terms of the parameters most likely to affect the measurements.

7. Apparatus

7.1 *Description of the Apparatus*—See section 4.1 and Figs. 1 and 2.

7.2 *Permissible Range of Anechoic Tube Diameter,* 6 to 25.4 mm (¼ to 1 in.).

7.3 *Permissible Range of Microphone Sizes*—Maximum microphone diameter is nominal 25.4 mm (1 in.). Probe microphones are permissible.

7.4 *Minimum Anechoic Tube Length*—The minimum ratio of the length of the anechoic tube to the tube inner diameter shall be one hundred (L/d > 100). Note that at low frequencies the tube connection is not anechoic. The ¼ wavelength determines the lower usable data range.

7.5 *Types of Materials*—All steel pipe fittings, and metal tube for anechoic tube are preferred. Other materials such as common garden hose could be used for the anechoic tube if it is shown to be adequate in terms of ambient noise calibration.

7.6 Use of shutoff ball valves is highly recommended, especially for hot gas applications.

7.7 *Guides for Creating Anechoic Terminations*—Any acoustically absorptive material such as mineral wool or steel wool is sufficient. The end of the anechoic tube shall be sealed airtight for all hot gas applications, or may be fitted with a pressurized air injection system.

7.8 *Guidelines for Forced Air Insertion into the Anechoic Tube*—In the event pressurized air injection system is used, additional tests shall be performed demonstrating no interference results from the sound of the injection system or flow velocity across the microphone.

7.9 *Frequency Ranges of Interest*—Unless otherwise agreed to by the parties to the test, the frequency range of interest shall be 16 Hz to 10 000 Hz. For low frequency applications ensure that the ¼ wavelength of the anechoic termination is below the range of interest.

8. Procedure

8.1 *Selection of Measurement Positions*—Location of test ports shall be at the discretion of the user. To the maximum extent practicable, the plane of the duct at which test ports are installed should be a region of relatively uniform flow both upstream and downstream; that is, a straight portion of duct, and low velocity. If there are a number of discontinuities in the duct cross sectional area, it would be advisable to locate test ports at midpoints between the discontinuities. For any given plane of test port locations, experience has shown better results when the ports are located away from duct corners. If strong duct acoustical modes are present and the mode shapes are known, avoidance of the acoustical nodes is clearly necessary. It is always advisable to have more than one test port at a given measurement plane and, if possible, ports on at least two sides of the duct. In the event cross channel coherence studies are to be included in the test program, it is recommended that the channels involved in the analysis consist of test ports occupying two different planes along the flow path, separated by a minimum of one-half (½) the larger duct dimension.

8.2 *Transfer Function*—Since the sound pressure level measured at the microphone's position within the anechoic tube will differ from the sound pressure level in the duct, a system correction factor must be determined for the test apparatus. The system correction factor so determined shall be referred to as the transfer function. The transfer function shall be added to the measured sound pressure level. The transfer function shall be the difference in decibels when the measured sound pressure level is subtracted from the reference in-duct sound pressure level, as given in Eq 1. The transfer function test shall be performed as a static (no flow) test, using an artificial sound source, while the machine is off, permitting access to the interior of the duct. If multiple test ports on a given duct are fitted with identical apparatus, differing only in the successive re-mounting of the fixture and anechoic tube to the valved test port, a single transfer function test will suffice for each type of apparatus used. The transfer function shall be determined for each one-third octave band of interest, and shall be applied to the data in the subsequent analysis. The specific guide of performing the transfer function or applying a correction factor shall be unambiguously specified or described in the test report.

$$L_{PId} = L_{PMd} + TF \quad (1)$$

where:

TF = $L_{PRc} - L_{PMc}$ = the transfer function,
L_{PRc} = reference in-duct pressure level, cold,
L_{PMc} = measured pressure level, cold,
L_{PId} = in-duct pressure level, dynamic, and
L_{PMd} = measured pressure level, dynamic.

8.2.1 If the object is to determine the transfer function relative to the mean duct cross-sectional average sound pressure level, then the reference sound pressure level must consist of a spatially averaged sound pressure level measured in sufficient detail over the entire interior duct cross section.

8.2.2 If the object is to determine the transfer function strictly in regard to the in-duct sound pressure level in the immediate vicinity of the test port, then the reference sound pressure level will consist only of the level in the immediate vicinity of the test port itself. The distance from the test port to the reference microphone must be specified and, if applicable, the extent of any spatial averaging achieved by moving the microphone while recording the reference signal.

8.2.3 If the object is to determine the transfer function strictly in regard to the full at-wall sound pressure level at the port face, then the reference sound pressure is determined by inserting a microphone into the test port so that the microphone's protective grid, or probe opening, is flush with the inner wall surface.

8.2.4 The artificial sound source used for any of the above transfer function determinations may be a horn or loudspeaker. The test signal may be white noise or pink noise within each band of interest. The sound source shall be located as far from the test ports as possible, limited only by an adequate signal at the test port. If any means are employed in an attempt to create a more diffuse field at the test port than would normally exist, such as moving baffles coupled with long term averaging, such details shall be included in the Report.

8.3 *Contaminating (Ambient) Noise Influences:*

8.3.1 The effects of contaminating or ambient noise shall be determined and those effects corrected for in the data processing.

8.3.2 Ambient noise and vibration influences may be quantified during equipment operation by simply closing the shutoff ball valve in the Test Port, if used and making a measurement.

8.3.3 Suspending the anechoic termination with bungee or other resilient guides, and ensuring that the anechoic termination is not in contact with the duct wall under test greatly reduces contaminating noise affects.

8.4 *Data Acquisition*—Having established prescribed operating conditions, the sound pressure level at each port is averaged for the prescribed period and the resultant data recorded. If ambient correction factors are to be applied, or are believed to be important, appropriate ambient sound level readings shall be obtained in the immediate vicinity of the test apparatus, external to the duct (break-in noise).

8.5 *Frequency Range of Interest*—Unless otherwise agreed to by the parties to the test, the data at each port shall be recorded at each preferred one-third octave band having center frequencies from 16 Hz to 10 kHz, or in each preferred full octave band having center frequencies from 16 Hz to 8 kHz. Ambient calibration data, airborne ambient sound levels and test port calibration data shall involve the same frequency range.

8.6 *Averaging Time*—Unless otherwise agreed to by the parties to the test, the averaging time shall be one minute, minimum. In the event the agreed upon test procedure limits the frequencies of interest to 100 Hz and higher, the averaging time at each port will be a minimum of 10 seconds.

8.7 *Impedance Correction*—Unless otherwise agreed to by the parties to the test, a correction for hot gas in the duct is not necessary. In the event the agreed upon test procedure requires a correction for this temperature difference, the guidelines presented in Appendix X1 may be helpful.

9. Report

9.1 The report shall include the following information:

9.1.1 A statement that the requirements of this guide were followed and any exceptions noted.

9.1.2 A description of the equipment measured, with model number and drawings, as appropriate. A sketch with dimensions of duct sizes and port positions should be included. Describe operating conditions of any nearby equipment, which might affect the measurements of the equipment under test.

9.1.3 A statement of the operating conditions of the equipment under test and notations regarding anything out of the ordinary, which may have an influence on the measurements.

9.1.4 A description and sketch of the measurement apparatus and fixtures, including critical dimensions.

9.1.5 The recorded data in suitable format.

9.1.6 A discussion of the particulars of the transfer function derivation, other corrections used and any special adjustments or difficulties dictated by test circumstances.

9.1.7 A description of the instruments used including model numbers and serial numbers, and their calibration records.

9.1.8 Date, time, name(s) of the surveyor(s) and witness(es).

TABLE 1 95% Confidence Limits for Reproducibility and Repeatability

	For Octave Bands up to and including 2 KHz	4 KHz Octave Band	8 KHz Octave Band
Repeatability[A]	< ± 2 dB	< ± 2 dB	< ± 3 dB
Reproducibility[B]	< ± 2 dB	< ± 5 dB	< ± 8 dB

[A] The tests upon which repeatability is based ranged from 4 to 8 in number.
[B] Reproducibility in this case represents the difference between the calculated exhaust sound power levels by two separate teams of surveyors using different apparatus but the same test ports on the same gas turbine exhaust duct at different times.

10. Precision and Bias

10.1 *Precision*—The total experience of the task group responsible for this guide constitutes the basis for any assessment of the precision to be expected from the use of this guide. The 95 % confidence limit for the reproducibility and repeatability of the methodology in this standard guide have, to date, been shown to lie within the ranges given in Table 1. The precision for the guide is being determined and will be available in 5 years.

10.2 *Bias*—It is not possible to determine the true absolute values of any of the sound pressure levels being measured in test situations addressed by this test method, so the bias inherent in the test method is unknown.

11. Keywords

11.1 field sound pressure level; gas turbine exhaust noise; gas turbine inlet noise; gas turbine noise; high temperature flow noise; in-duct sound; industrial noise; machinery noise; noise in turbulent flow

APPENDIX

(Nonmandatory Information)

X1. CORRECTION FOR IMPEDANCE MISMATCH DUE TO TEMPERATURE DIFFERENCES

X1.1 *Correction for Hot Gas in the Duct*—For tests involving duct gas temperatures significantly above ambient temperature, there will be a large temperature differential, and therefore an impedance mismatch, between the gas at the test port opening and the temperature of the gas at the face of the microphone. Indeed, the whole point to using an anechoic tube for hot duct gas testing is to preserve the microphone from exposure to hot gas temperatures. Such a temperature differential will yield a reduction in energy as the sound wave passes from the hot to the cold region. In such cases the parties to the test may agree to include a correction factor to account for the fact that the in-duct pressure at the entrance to the test port has undergone an attenuation as it passes to the relatively colder microphone. The correction factor will consist of a calculated value, in decibels, which would need to be added to the measured values in order to correct for the attenuation.

X1.2 When wave energy is transmitted across boundaries from one medium to another, in this case air of differing temperatures, the impedance of each medium affects the energy transmitted across that boundary. This impedance is what is commonly referred to as ρc (rho-c) and the adjustment needs to consider not only the change in ρc but also the angle of incidence (Snell's Law). This geometry and impedance accounts for the energy reflected at the boundary. In the case of probe measurements it is assumed normal incidence thus the angle of incidence can generally be ignored.

X1.3 The reduction in energy from one fluid to another is expressed as:

$$\delta dB = 10\ \text{Log}\left[1/\alpha_t\right] \quad (X1.1)$$

where:

$$\alpha_t = 4\{(\rho c)_1(\rho c)_2/[(\rho c)_1+(\rho c)_2]^2\} \quad (X1.2)$$

and simplifying:

$$\alpha_t = 4\{(\rho c)_1\ /\ (\rho c)_2\ /\ [1+(\rho c)_1/(\rho c)_2]^2\}\} \quad (X1.3)$$

X1.3.1 But if we assume the (gas) density in the duct is the same as at the (probe) microphone, then we can simplify even further by only knowing the speed of sound in the respective media:

$$\alpha_t = 4\{(c_1/c_2)/[1+(c_1/c_2)]^2\} \quad (X1.4)$$

X1.3.2 This adjustment, δdB is applied to the measured level at the microphone. Medium "1" is the air in the duct and medium "2" is at the microphone position.

X1.3.3 The development of these expressions is from Kinsler, Frey, Coppens, and Sanders, *Fundamentals of Acoustics*, pp. 124-126.

X1.4 What is not addressed is if there is any temperature gradient in the probe, which is well beyond the scope of this guide. It must be understood that the probe is well sealed to prevent leakage and the air in the probe is stagnant. In duct temperature can be measured and temperature at the microphone location can be measured.

X1.5 Exhaust gas out the back of a turbine has ρc in the range of 240 rayls and as we know air at standard conditions is about 415 rayls. Now incorporating system backpressure will result in a slight increase in density in the duct as well as at the microphone. Further, if we assume 5 in. wg above atmospheric pressure and the air temperature in the probe is 125°F then the probe ρc is 398 rayls. The exhaust is 240 rayls. Using these values as "indicators" to calculate the adjustment using Eq X1.2 results in only 0.3 dB, which is hardly worth the effort to calculate and if one were to only use a temperature adjustment by using Eq X1.4, where the difference in the speed of sound is significant (c_1 = 598 m/s and c_2 = 361 m/s), surprisingly, we get 0.3 dB again. A series of parametric examples were run finding no real disparity in the two guides.

X1.6 In the calculation of the sound velocity the following was used and should be included:

$$c = (\gamma P_0/\rho_0)^{1/2}\ \text{m/s} \quad (X1.5)$$

where:

γ = ratio of specific heat,
P_0 = gas pressure, and
ρ_0 = gas density in the duct system.