SAE International™ SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Laboratory Measurement of the Airborne Sound Barrier Performance of Flat Materials and Assemblies

RATIONALE

This document defines alternative methods to ASTM E 90 and ASTM E 2249 for measuring sound transmission loss (STL) of noise control or other flat sample materials.

FOREWORD

This SAE Recommended Practice has been significantly modified to suggest ways to improve inter-laboratory reproducibility based on the results and recommendations of a round robin study conducted by the SAE Acoustical Materials Committee. Although the fundamental methodology of this procedure has not been changed from previous revisions of this standard, the accuracy of the reference sample field incident STL calculation has been improved, particularly for low surface density materials. In addition, the materials and construction of a Control Sample with target STL values are now defined.

INTRODUCTION

This document is intended to provide a means of measuring the performance of materials according to their sound transmission loss properties. At each test frequency the sound transmission loss (STL) is determined based on the measured noise reduction of the test specimen using a correlation factor (CF). The respective CF for the test condition is determined as the differences between the measured noise reduction (MNR) of a homogeneous limp panel, such as lead, and its theoretically calculated field-incidence sound transmission loss. This test standard then recognizes that many laboratories have measurement variances that can be corrected to a certain extent using this methodology.

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1. SCOPE

This SAE Recommended Practice presents a test procedure for determining the airborne sound insulation performance of materials and composite layers of materials commonly found in mobility, industrial and commercial products under conditions of representative size and sound incidence so as to allow better correlation with in-use sound insulator performance. The frequency range of interest is typically 125 to 8000 Hz 1/3 octave band center frequencies.

This test method is designed for testing flat samples, although in some applications the methodology can be extended to evaluate formed parts, pass-throughs, or other assemblies to determine their acoustical properties. For non-flat parts or assemblies where transmitted sound varies strongly across the test sample surface, a more appropriate methodology would be ASTM E90 (with a reverberant receiving chamber) or ASTM E 2249 (intensity method with an anechoic or hemi-anechoic receiving chamber).

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J184 Qualifying a Sound Data Acquisition System

Ebbitt, G. and Hansen, M., "Mass Law - Calculations and Measurements," SAE Technical Paper 2007-01-2201, 2007

2.1.2 ANSI Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ANSI S1.1 Acoustical Terminology

ANSI S1.4a Specification for Sound Level Meters

ANSI S1.40 Specification for Acoustical Calibrators

ANSI S1.11 Specification for Octave Band and Fractional Octave Band Filter Sets

2.1.3 INCE Publications

Available from INCE, 9100 Purdue Road, Suite 200, Indianapolis, Indiana, 46268. Tel: (317) 735-4063, www.inceusa.org.

Beranek, Leo L., Noise and Vibration Control, Revised Edition, Institute of Noise Control Engineering, New York, 1989

2.1.4 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E90 Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions

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

ASTM E2249 Standard Test Method for Laboratory Measurement of Airborne Transmission Loss of Building Partitions and Elements Using Sound Intensity

3. INSTRUMENTATION

Instrumentation to be used is as follows:

3.1 Sound Level Meter

A sound level meter that meets the Type 1 requirements of ANSI S1.4a is required. As an alternative to making direct measurements using a qualified sound level meter, a microphone, measuring amplifier and a sound data acquisition system may be used, provided the system meets the requirements of SAE J184.

3.2 Filter Requirements

A third-octave filter set covering the range of center frequencies of interest. The filters shall meet the Class III requirements of ANSI S1.11.

3.3 Microphone Calibrator

A sound level calibrator that meets the Class 1 requirements of ANSI S1.40.

3.4 Source Room Speakers

An acoustical sound generating system shall be selected to generate random noise containing a continuous distribution of frequencies over each test band.

3.5 Instrumentation

A schematic diagram of the instrumentation is shown in Figure 1.

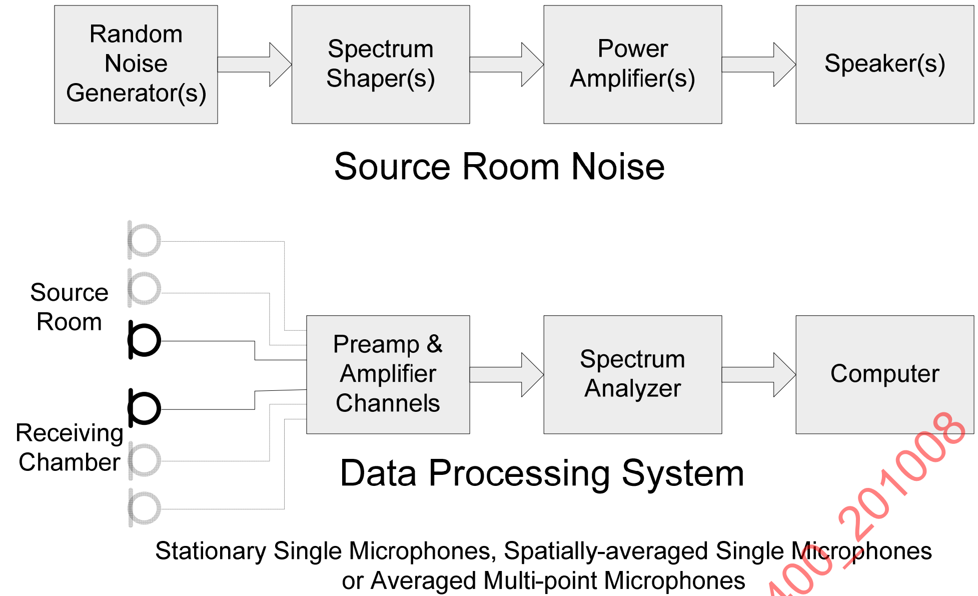

FIGURE 1 - TYPICAL MEASUREMENT SYSTEM

3.6 Ambient Sensors

Temperature and humidity sensors should be used to monitor and record ambient test conditions in the source and receiving chambers, preferably in the vicinity of the sample mounting location.

4. FACILITIES

A schematic diagram of a typical measurement facility is shown in Figure 2.

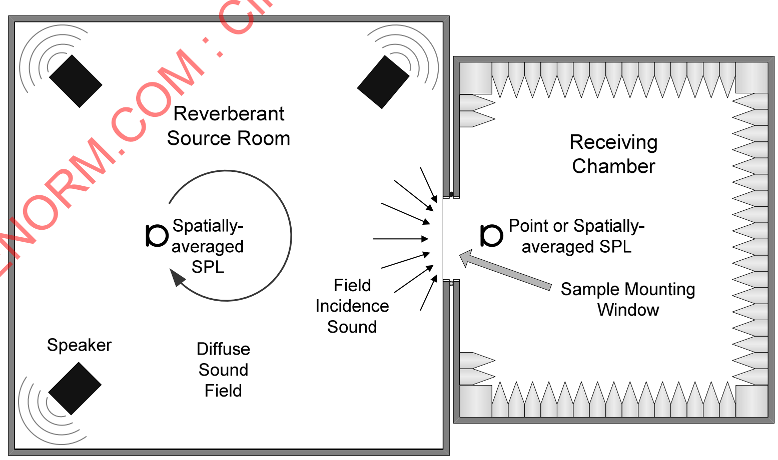

FIGURE 2 - TYPICAL MEASUREMENT FACILITY

4.1 Layout of Chambers

Two adjacent chambers are located such that they share a common test window, into which test samples are mounted. The two chambers must be isolated from each other so that the only significant transmission path is through the sample window. Test windows are normally oriented in the vertical plane, but may also be oriented horizontally or even non-orthogonally to the vertical or horizontal planes.

4.2 Receiving Chamber

It is recommended that the receiving chamber be fully anechoic in order to minimize the influence of flanking paths and modal coupling between the chambers. However, good results can also be achieved with semi-anechoic or even reverberant receiving chamber designs if proper care is taken for isolation between the chambers, modal decoupling through the test window and spatial averaging of receiving chamber microphone(s).

4.3 Chamber Sizes

Source room volume is required to be at least 50 m^3 (1765 ft^3), with 200 m^3 (7100 ft^3) being the recommended volume. Room/chamber sizes should be established based on the assurance that there are at least twenty (20) natural frequency modes within the lowest 1/3 octave frequency band of interest for good diffusion of sound. Room proportions of 1:1.26:1.59 are also recommended for good diffusion and modal separation. Reverberant receiving chamber proportions should be the same; but sized at least 10% smaller or larger in interior volume to avoid natural frequencies which coincide with the source room. It is also advisable to keep receiving chamber boundaries and sound absorber elements at least ¼ wavelength from the sample test window. See ASTM E 90, Appendix X2 for further details.

4.4 Source Room Lower Cutoff Frequency and Diffusion

To qualify a test chamber once it has been built or whenever changes are made to the chamber which may affect diffusion, it is recommended that the population standard deviation of twenty randomly located sound pressure measurements in the source room be no more than 2 dB at 200 Hz 1/3 octave center frequency and above, with a representative test sample mounted in the test window. Microphones should be spaced at least 1/4 wavelength from each other, from diffusers and from any room boundaries at the lowest measurement frequency. Diffusion in the reverberation source room can be enhanced by the use of rotating or stationary diffusers. See Section 6.3 of ASTM E 90 regarding the use of diffusers to reduce the variability of sound pressure levels within the source room. See 4.9 regarding proper location and orientation of source room speaker(s).

4.5 Ambient Conditions

Source and receiving chamber temperatures should be controlled to 22 °C ± 5 °C. Relative humidity should be controlled for both chambers at 40 to 70%. Temperature and humidity should not vary by more than ±3 °C and ±5% R.H between measurements of the reference sample(s) and the test sample(s).

4.6 Facility Design

The source and receiver chambers should have wall constructions of a sufficient STL to minimize flanking paths into the receiving chamber. If the existing isolation between test chambers is adequate, supplemental insulation added to potential flanking noise surfaces should have little or no effect on measured STL of maximum transmission loss samples. If supplemental insulation is beneficial, it should be left in place where feasible.

4.7 Maximum Measurement Capability

When the STL of the wall(s) separating the receiving chamber from the source room is not sufficiently greater than the sample under test, the measurements may be compromised by sound transmitted from source to receiving chamber via paths other than through the specimen under test. The maximum STL measurement capability of the system should be determined by measuring the STL of an insulator assembly composed of a 10 to 50 mm foam or fiber decoupler layer in combination with a 2 to 10 kg/m^2 septum or barrier layer. Continue to add successive insulator assemblies and measure STL after adding each insulator assembly until no further changes in STL are noted (less than 1.0 dB change at all frequencies). The maximum STL capability is limited by flanking paths or residual noise in the overall measurement system. Measured sample STL values should fall at least 10 dB below maximum STL capability levels at all frequencies. Maximum STL levels can be improved by increasing the STL of the common wall between the rooms, by improving the sample sealing system, increasing the structure-borne vibration isolation between rooms or by decreasing the residual noise of the measurement system. Maximum STL measurement capability does not need to be run with every sample; but, it should be measured periodically (recommended annually) or whenever changes may have been made affecting the measurement facility and/or data acquisition system.

4.8 Test Sample Fixture

A test sample fixture should hold the test sample securely between the source and receiving chambers. The fixture should be well sealed to prevent leakage between the source and receiving chambers through the fixture (see recommended sample mounting system in Appendix A). The fixture should provide means to maintain typical in-use contact between the various layers of the test assembly. Unless intended, care must be taken to assure that no air gaps are induced in a multilayer assembly or within sample layers during sample mounting or sealing. Although it is common practice to use a vertical test window orientation, horizontal test windows may provide a means of using gravity to naturally hold test layers properly together or to represent the in-use compression of layers.

4.9 Loudspeakers

One or more broadband loudspeakers of sufficient sound power capability should be used to produce sound pressure levels in the receiving chamber at least 10 dB above the noise floor of the measurement system and chamber at all frequencies with the test sample in place. It is recommended that sound spectrum shaping in the source room be utilized in order to reduce the span between the lowest and highest levels versus frequency of the measured sound spectrum in the receiving chamber to within the dynamic range capability of the measurement system. Typically, a source room sound pressure spectrum rising at 6 dB/octave will significantly reduce the dynamic range requirements in the receiving chamber. Selection, exact placement and orientation of the loudspeaker(s) within the source room are often trial-and-error processes to achieve desired source levels and diffusion. Should multiple loudspeakers be used, it is recommended that uncorrelated signals be fed to the broadband loudspeaker sources for best low frequency diffusion. To help define proper loudspeaker placement and orientation, the population standard deviation of the randomly located or spatially averaged sound pressure measurements in the source room should follow the population standard deviation guideline as previously defined in 4.4.

Once placed and qualified, loudspeaker position(s) and orientations must be maintained for all tests.

4.10 Microphones

One or more microphones shall be positioned within the source and receiving chambers. The number and spacing of microphone positions required in each room depends on the statistical precision desired in the time and space average band sound pressure levels. Randomly placed microphones or the traverse of a spatially averaged microphone should maintain at least 1/4 wavelength distances from room boundaries, room diffusers, noise sources and the test sample window at the lowest test frequency. The exact number and placement of source and receiving chamber microphones for best results is often a trial-and-error process. However, the population standard deviation of the randomly located or spatially averaged sound pressure measurements in the source room should still follow the population standard deviation guideline as previously defined in 4.4 – i.e., be no more than 2 dB at 200 Hz 1/3 octave center frequency and above, with a representative test sample mounted in the test window.

Note that the construction of a control sample is defined in 6.3, with target STL values that are defined in 6.4. These can be used to aid in the above trial-and-error process.

Once placed, microphone positions must be maintained throughout the test sequence and ideally for all tests.

4.11 Test Window Opening

The size of the test window opening between the source room and the receiving chamber also limits the lowest frequency at which measurements can be reliably made (see Table 1).

TABLE 1 - MINIMUM DIAGONAL DIMENSION OF TEST WINDOW AT LOWEST MEASUREMENT FREQUENCY

Lowest 1/3 Octave Band Measurement Frequency	Minimum Diagonal of Test Window Opening	
Hz	m	(ft)
25	3.83	(12.6)
31.5	3.04	(10.0)
40	2.42	(7.9)
50	1.92	(6.3)
63	1.53	(5.0)
80	1.21	(4.0)
100	0.96	(3.2)
125	0.76	(2.5)
160	0.61	(2.0)
200	0.48	(1.6)
250	0.38	(1.3)
315	0.30	(1.0)
400	0.24	(0.8)
500	0.19	(0.6)

NOTE: Calculations use sound speed of 343 m/s (1125 ft/s) corresponding with an air temperature of 20 °C (68 °F)
NOTE: Diagonal dimensions are based on 1/4 wavelength calculations at the lower frequency limit for each 1/3 octave band.

5. PROCEDURE

5.1 Sample Mounting

Test samples must be mounted and sealed completely within the test fixture so as to ensure a minimum of sound flanking the test sample. The recommended sample mounting system is shown in Appendix A.

5.2 Sample Conditioning

Test samples should be conditioned to the same temperature and humidity as the test chambers for at least 12 h prior to testing.

5.3 Measurements

5.3.1 Background Noise

Background noise levels within both the source and receiving chambers shall be measured and noted in all measurement bands and averaged over all measurement positions for each measurement series. Background noise levels in the receiving chamber must be measured at the same gain settings as during normal measurements in order to include the noise floor of the measurement system. Ultra-low noise microphones and preamps are available for laboratory use and can be effective in lowering the noise floor of the measurement system.

5.3.2 Reference Sample

Install and seal the reference sample, a homogeneous limp material such as lead, PVC sheet, EVA sheet or another monolithic limp material that does not show a critical frequency phenomenon in the frequency range of interest, into the test opening so that its field-incidence STL can be calculated from the relation:

$$\text{STL(reference sample)} = -0.192 + 10\log(\beta^2) - 10\log\left[\ln\left(\frac{\beta^2+1}{0.043227\beta^2+1}\right)\right] \quad \text{(Eq. 1)}$$

where:

$\beta = \rho_s\omega / 2\rho_0 c_0$
ω = 2 π f
f = the center frequency of the one-third octave measurement band
ρ_s = surface density of the reference sample (kg/m^2)
ρ_0 = volumetric density of air (kg/m^3) at measurement barometric pressure, temperature and humidity
c_0 = speed of sound (m/s) at measurement temperature and humidity

5.3.3 Reference Sample Surface Density

The surface density of the reference sample should be selected to be within 50 to 200% of the surface density of each test panel or multi-layer test assembly as long as the requirements of section 5.3.1 are met and the reference sample surface density does not exceed 10.0 kg/m^2. Reference samples of different surface densities may be required to cover various test sample materials.

5.3.4 Signal-to-Noise Ratios

The source signals may be amplified or filtered versus frequency so that, with the test sample sealed in place, the source room and receiving chamber signal levels are each at least 5 dB, and preferably more than 15 dB, higher than the background noise levels within the respective chambers and within the dynamic range capability of the measurement system at all frequencies of interest.

5.3.5 Measurement Conditions

The time and spatially-averaged third-octave band levels in both the source and receiving chambers shall be measured and recorded over the desired measurement bands with the reference sample sealed into the fixture in the test opening. Optionally, time averaged, single point measurements may be used on the receiving side of the sample mounting window if they can be shown to give STL results within ±2.0 dB at all measurement frequencies to time and spatially-averaged measurements. Averaging times shall be long enough to provide an estimate of the time-averaged level to within ±0.5 dB for 95% confidence limits at all measurement frequencies. See 5.5.4 and Appendix B. Measurement distance to the sample mounting plane and number of measurement positions in the receiving chamber which give best results will vary from lab to lab and are usually determined through trial and error. However, in order to minimize variability, measurements away from the immediate nearfield of the test sample and test aperture may be needed, as long as background noise considerations are also observed.

Note that the construction of a control sample is defined in 6.3, with target STL values defined in 6.4. These can be used to aid in the above trial-and-error process.

5.3.6 Test Samples

After removing the reference sample, the test sample is installed and sealed into the same opening and in the same manner as the reference sample. The measurements are then repeated as in 5.3.5. The test sample may be a homogeneous single layer material, a multi-layer material, a combination of multilayer materials with a sheet metal backing, a porous material without an impervious layer, or any of the previous materials with a pass-through, opening or intentional leakage path. The results for each of these systems are compared to the results for the reference sample tested in 5.3.5. If microphones are moved during test sample mounting, they must be accurately replaced (within 3 mm) to the same positions as in prior measurements, including reference sample measurements.

5.4 Data Analysis

The following procedures are used to calculate the field incidence STL of the test sample.

5.4.1 Background Noise Correction

If necessary, correct for background noise levels at each measured third octave frequency band of interest and at each microphone for both the source and receiving chambers using the equation:

$$L_S = 10 \log_{10}(10^{L_C/10} - 10^{L_B/10}) \quad \text{(Eq. 2)}$$

where:

L_S = corrected sound pressure level of the signal, dB
L_C = sound pressure level of the signal and background noise combined, dB
L_B = sound pressure level of the background noise alone, dB

NOTE: If L_C - L_B is less than 5 dB, use L_S = L_C - 1.3 dB. Correction is not necessary if L_C - L_B is greater than or equal to 15 dB.

5.4.2 Measured Noise Reduction

For both the reference sample and the test sample, compute the measured noise reduction (MNR) at each one-third octave band of interest. Using the corrected band pressure levels, if required, for each measurement band, subtract the receiving chamber band pressure level from the source room band pressure level to obtain the MNR for both samples. Where applicable, use spatially-averaged values for source and/or receiving room/chamber.

$$MNR_f = SPL_f \text{ (source room)} - SPL_f \text{ (receiving chamber)}$$

NOTE: Subscript "f" indicates frequency-dependent variables

5.4.3 Correlation Factors

Determine the correlation factor applicable to the test opening and source/receiving chamber pair at each test frequency (CF_f) as the difference between the measured noise reduction of the reference sample, MNR_f (reference) and its calculated STL_f (reference).

$$CF_f = MNR_f \text{ (reference)} - STL_f \text{ (reference)} \quad \text{(Eq. 3)}$$

NOTE: Correlation factors at all frequencies should fall within +10/-0 dB for a well-implemented test system, +15/-0 dB for a typical system and should not exceed the range of +15/-5 dB. Methods to reduce the correlation factor without major facility changes would include changing the position of the receiving microphone(s), increasing the absorption in the receiving chamber, improving the sealing and/or sample mounting system, increasing the number of receiving room microphones, averages or spatial averaging in the receiving room.

NOTE: The correlation factors (CFf) determined using this methodology are subsequently used for computing the STL of multi-wall samples as well as single wall samples.

5.4.4 Sound Transmission Loss

Compute the sound transmission loss (STL_f) of the test sample at each test frequency by subtracting the CF_f from the MNR_f of the test sample:

$$STL_f\ (sample) = MNR_f\ (sample) - CF_f \qquad (Eq. 4)$$

STL_f (sample) at each frequency band of interest should be rounded to the nearest whole dB.

5.5 Reporting

The following shall be included when reporting results of these test procedures.

5.5.1 Basic Information

Measurement date, test location, person performing tests, sample description(s) and reference sample(s) used. It is also required to specifically state any deviations to the SAE J1400 procedure requirements, if any.

5.5.2 Ambient Conditions

Ambient temperature and humidity conditions in each test chamber at time of measurements.

5.5.3 Sound Transmission Loss

Sound transmission loss rounded to the nearest whole dB versus 1/3 octave center frequencies in Hz. Measurements which have been corrected for background noise should be marked with an asterisk and a note explaining such. See 5.4.1.

5.5.4 Confidence Limits

95% Confidence Limits in dB versus 1/3 octave center frequencies in Hz as defined in Appendix B. Calculations for Confidence Limits do not have to be made for each test, but should be done annually or following any changes made to the chamber and/or measurement system which may affect Confidence Limits.

5.5.5 Maximum Measurement Capability

Maximum STL capability rounded to the nearest whole dB versus 1/3 octave center frequencies in Hz. See 4.7.

6. GENERAL COMMENTS

6.1 Qualified personnel

It is essential that technically qualified personnel trained in the current techniques of sound measurements select equipment and perform the tests.

6.2 Routine Calibration

Instrumentation manufacturers' or quality standard recommended calibration practices should be followed before each test.

6.3 Control Sample Construction

A control sample has been developed to aid in the assessment and minimization of intra-laboratory variability and/or bias. See Appendix C for construction details. Specific sources of construction materials are mentioned as guidelines. Alternative sources may work as well.

6.4 Control Sample Target Results

The following table is based on a weighted average of multiple control samples produced independently and tested in a number of independent test laboratories. All qualified laboratories should be able to reproduce these results within 3 dB at all frequencies. Laboratories having trouble with reproducibility particularly below 1000 Hz should seek improvements as suggested in 4.3 and 4.8. If measured STL is too low relative to target levels above 2500 Hz, improvements as suggested in 4.6 and 4.9 are recommended.

TABLE 2 - TARGET SOUND TRANSMISSION LOSS VALUES - CONTROL SAMPLE

1/3 Octave Center Frequency [Hz]	Sound Transmission Loss [dB]
125	10
160	9
200	10
250	16
315	25
400	33
500	40
630	45
800	50
1000	54
1250	59
1600	63
2000	66
2500	69
3150	72
4000	74
5000	77
6300	79
8000	82
10000	86

7. NOTES

7.1 Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE ACOUSTICAL MATERIALS COMMITTEE