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Measurement and Prediction of the Sound Transmission Loss for Various Sample Positions

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In a standard Sound Transmission Loss (STL) test, a sample is placed between two test chambers. Based on the sound level reduction the material provides and various acoustical characteristics of the test chambers, the STL is determined. The opening in which the sample is mounted and sealed can vary in size and depth depending on the test method and chamber construction. Where the test sample is mounted within the fixture is up to the experimenter. Past research has indicated that when following the ASTM E90 test, placing the sample in the middle of the test tunnel yields a minimum STL value. An alternate test method (SAE J1400) is in common use for the measurement of smaller test samples, typically found in the transportation industry. This technique utilizes a sample of known sound transmission loss, such as a limp vinyl barrier, as a correlation sample to determine the STL. Receiving chamber microphones are also typically placed very close to the sample. As such, the influence of the test tunnel and the location of the sample can influence the resulting reported STL values. This paper presents measured and predicted STL values for different tunnel acoustical conditions and different sample positions.

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1. INTRODUCTION

Various techniques and standards exist for the measurement of Sound Transmission Loss (STL)[1-5]. Common to all is the presence of a source chamber, a receiving chamber and a partition between the two that includes a fixture for holding the sample of interest. Depending on the laboratory construction, the partition between the two test chambers can be fairly thin (approximately 20 cm) to fairly thick (100+ cm). While standards are vague regarding the placement of the sample within the tunnel, often various laboratories will have a preferred location, such as closest to the source chamber or closest to the receiving chamber but typically not in the center.

Various studies have been published examining the placement of samples in the test partition, (tunnel) and have shown that placing the sample in the center of the tunnel typically yields lower STL values[6-10]. Larger panels reduce the tunnel effect, and the niche effect can be minimized if the sample is placed at either end of the tunnel.

For the transportation industry, the common sound transmission loss test standard is SAE J1400(10) "Laboratory Measurement of the Airborne Sound Barrier Performance of Automotive Materials and Assemblies". In this test method, a correlation factor (CF) is used to determine the STL. To determine the CF, the noise reduction of a limp mass is measured in a test fixture between a reverberation room and a receiving chamber. This is typically accomplished by subtracting the sound pressure level measured in a receiving chamber from the spatially averaged sound pressure level in the reverberation chamber. The correlation factor is then determined from a comparison of the measured noise reduction (MNR) to the calculated STL of the limp barrier sample according to Equation 1:

$$\text{CF} = \text{MNR} - \text{STL (known reference sample)} \tag{1}$$

The STL of a limp mass reference sample is calculated according to Equation 2:

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

With:

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

Then the STL of the unknown sample is calculated according to Equation 3 using the MNR of the unknown sample and the CF from the reference sample

$$\text{TL(unknown)} = \text{MNR} - \text{CF} \tag{3}$$

Since a correlation factor is utilized for STL measurements, it is unknown if tunnel effects will still influence the values with the sample at various locations within the tunnel.

2. TEST METHOD (SAE J1400)

A series of experiments were carried out to determine the influence of the tunnel position on the measured CF and STL. One of the features of the SAE J1400 test methodology is the receiving chamber is not defined. In many laboratories the receiving chamber is anechoic or highly sound absorptive but it can also be reverberant. Many laboratories line the receiving chamber side of the tunnel with sound absorptive material to reduce acoustic modes which may develop inside the tunnel. The presence or lack of sound absorption in the tunnel was also examined in this study.

Three test sample locations were selected in the tunnel: position (1) located close to the reverberation chamber, position (2) near the middle of the tunnel, and position (3) close to the receiving chamber. For the first two positions, 50 mm thick urethane film faced sound absorptive foam was placed on the tunnel walls. This material was selected as it provided peak absorption near the tunnel cross modes. At each location, both a limp mass and a double wall steel sample (J1400 Control Sample) were measured.

In the Blachford Acoustics Laboratory, two stationary microphones are used in the receiving room, shown in Figure 1, and a rotating microphone is used to obtain a spatially averaged sound pressure level in the source room. Broadband sound encompassing the 100 through 8000 Hz one-third octave bands is produced in the source room and the resulting noise reduction is measured in the receiving chamber. The noise reduction is measured by subtracting the average sound level in the receiving room from the average sound pressure level in the source room over a 32 second average. A total of 10 sets of measurements are performed and the final NR determined through averaging the sets.

The sample used for the CF was a 1.95 lb/ft^2 mass loaded vinyl sample. The estimated critical frequency is above 8,000 Hz. For the test frequencies of interest, the sample is expected to follow mass law.

The test sample used was the SAE J1400 control sample. This is a 25mm thick double wall steel sample with fiberglass filling the cavity. Construction details are provided in the SAE J1400 standard.

Figure 1. Blachford Acoustics Laboratory STL Fixture viewed from source room.

3. EXPERIMENTAL RESULTS

Measured correlation factors for the limp mass sample at positions 1-3 are shown in Figure 2. Note that since position 3 is closest to the reception chamber, there is no tunnel after the sample, so no foam could be added to the tunnel walls.

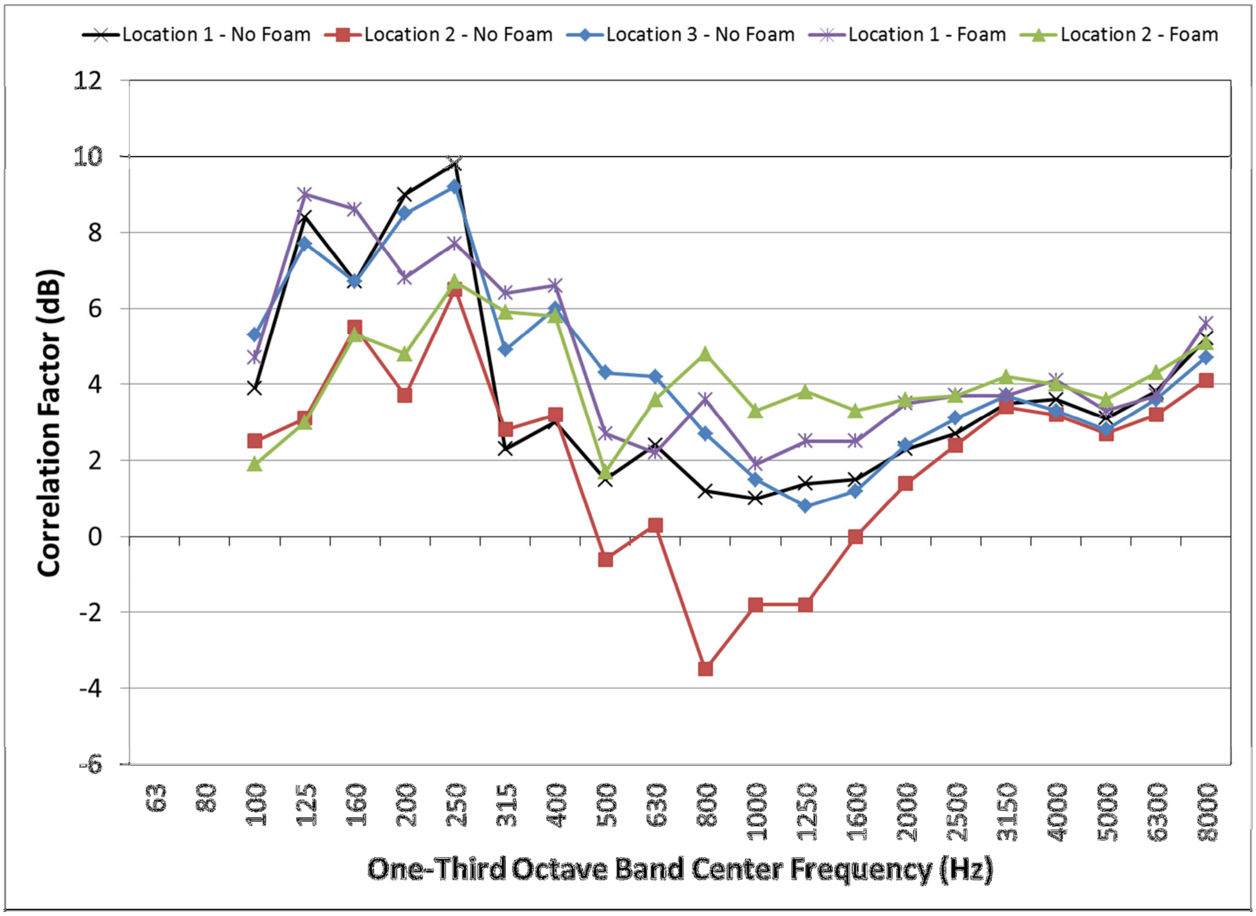

Figure 2. Measured Correlation Factors at Positions 1-3

SAE J1400 recommends: "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." Except for position 2, the middle position, without added sound absorption in the tunnel, all of the test cases fall within +10/-0 dB. As a lower correlation factor is considered better, the best test case appears to be having the sample in the middle of the tunnel with sound absorptive material applied to the tunnel walls.

Measured STL values for the control sample at positions 1-3 are shown in Figure 3. Note again that since position 3 is closest to the reception chamber, there is no tunnel after the sample, so no foam could be added to the tunnel walls.

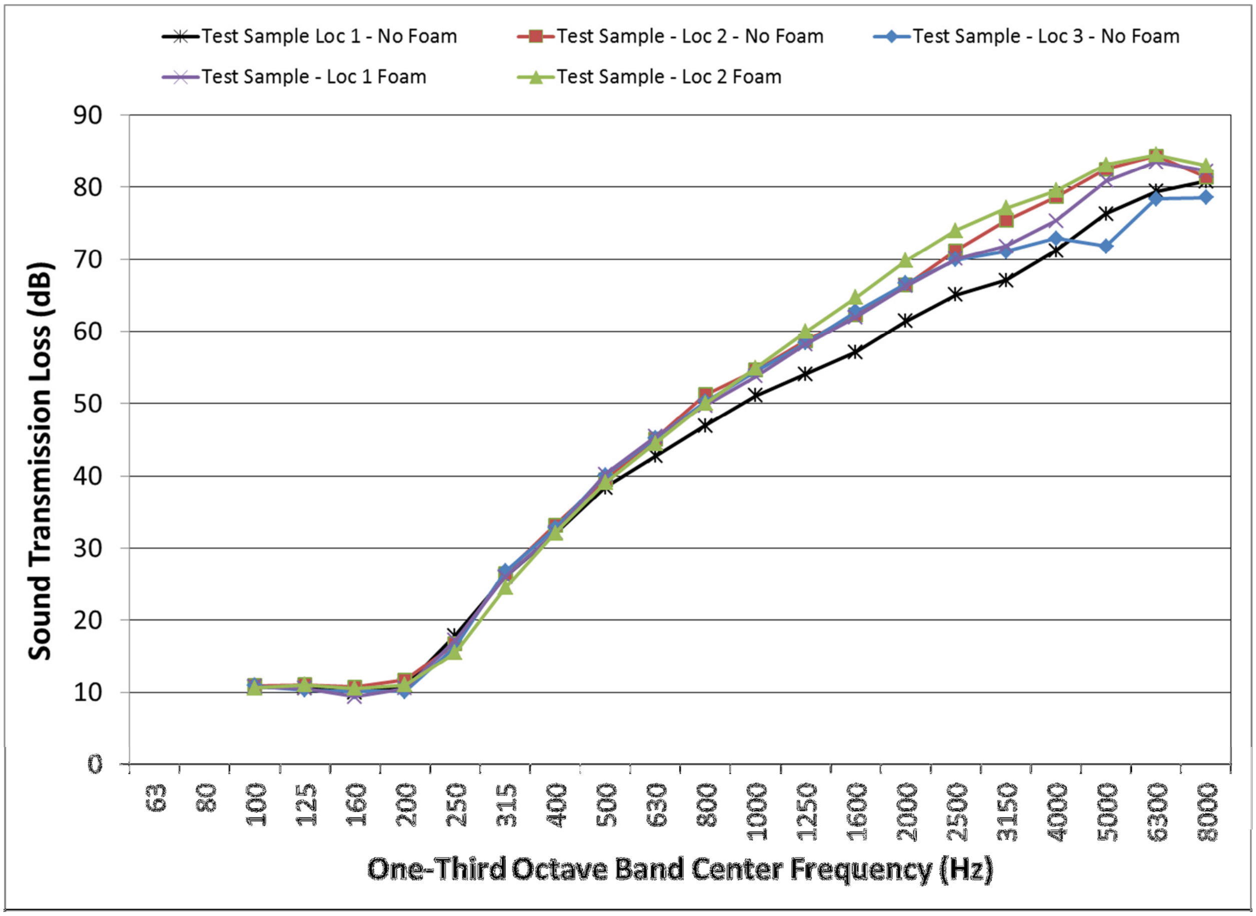

Figure 3. Measured STL of Control Sample at Positions 1-3

Typical repeatability for this test is less than 1 dB below 4,000 Hz and 1-3 dB at frequencies greater than 4,000 Hz and the measurement dynamic range at frequencies greater than 4,000 Hz is in excess of 100 dB. Note that the lowest STL was measured with the sample in position 1 (sample closest to the reverberation chamber) with no foam added to the tunnel walls. This position with the highest STL was the middle position, which is contrary to previous publications. It is likely that the correlation sample corrects for any tunnel niche effects and the differences between the samples are due to flanking or leak paths through the STL fixture.

4. MODELING RESULTS

To verify that a leak in the test fixture could be causing a decrease in the STL near 5,000 Hz for position 3 or above 500 Hz for position 1, the STL of an idealized leak was calculated. The STL of three small openings, 0.03 meters in length and 5, 10 and 20 mm in diameter are shown in Figure 4. Although it is not likely that any gaps in the STL fixture or in the seal around the sample perimeter are circular and of the same length, the trend indicates that the effect of a small opening is a decrease in STL over a narrow frequency range, similar to what was measured in location 3. As the size of the opening increases (as in the r=20 mm case) and as the path length decreases, the decrease in STL becomes more broadband. This is illustrated in Figure 5, where the STL of the leak has been added to the sound transmission loss of a limp barrier. Although the test case is different from the Position 1 case with no foam added to the tunnel, the trend is similar.

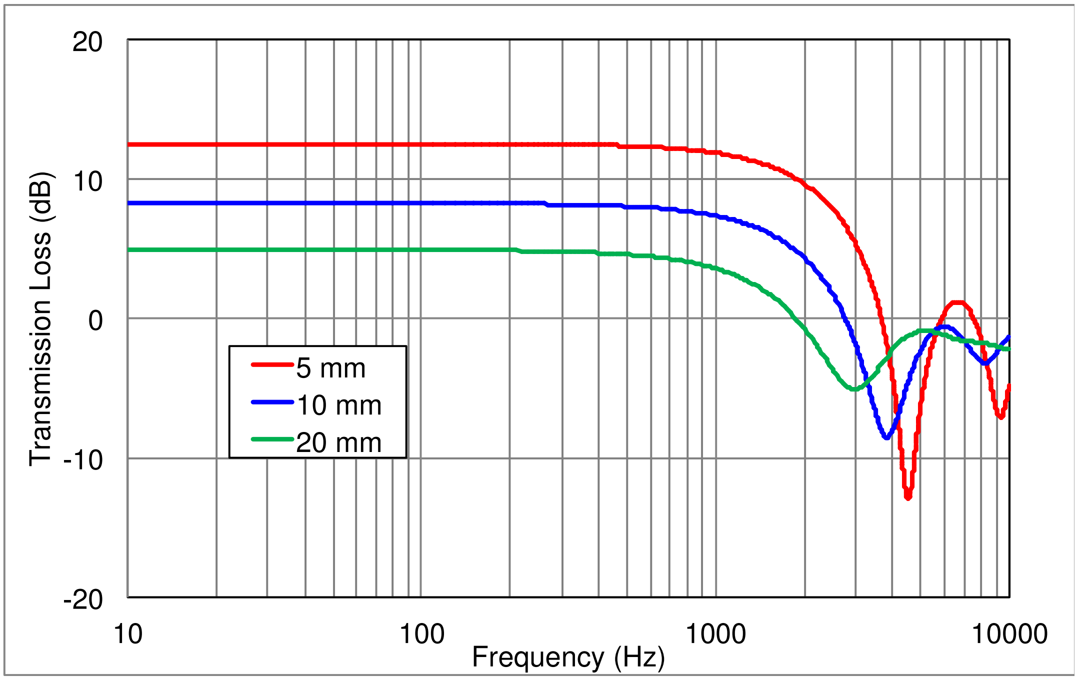

Figure 4. STL of an opening 0.03 meters long with three leak radii

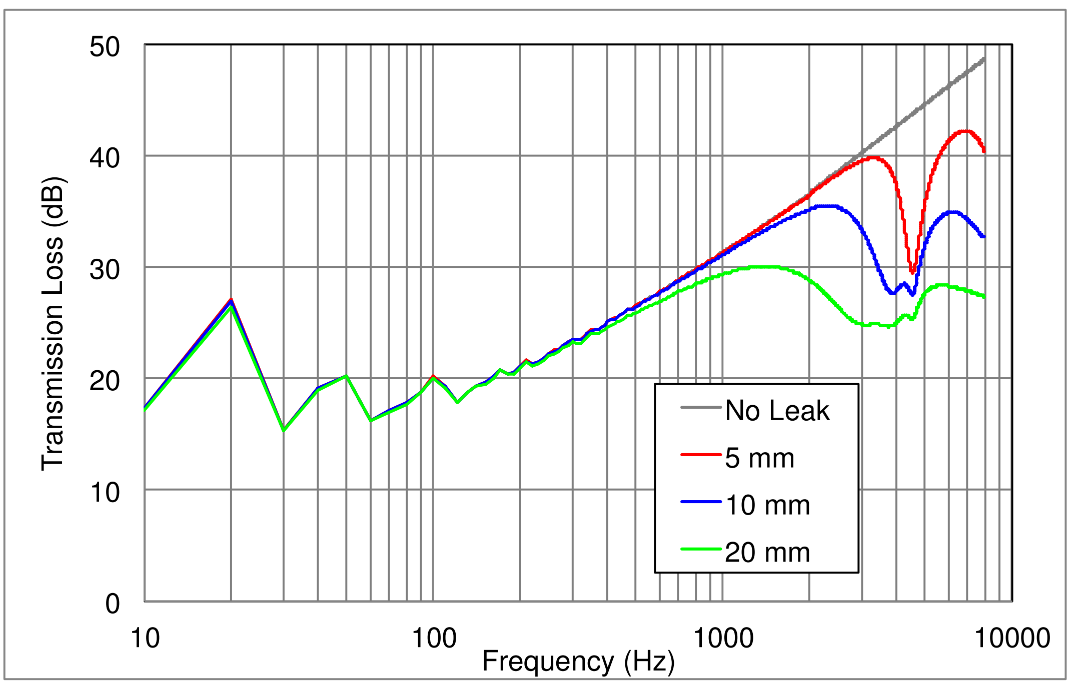

Figure 5. STL of a Limp Mass Barrier with Various Leaks (0.03 meters long with 5 mm, 10 mm, and 20 mm radii)

Next the cavity and test samples were modeled using VA-One as shown in Figure 6. The reverberation room (source room) is modeled as a diffuse acoustic field source acting on a SEA cavity having the same volume as the Blachford source room, and the receiving chamber is modeled as a very large room using SEA. The samples were modeled using a structural FEM model and the tunnel sections on either side of the sample were modeled as FEM cavities.

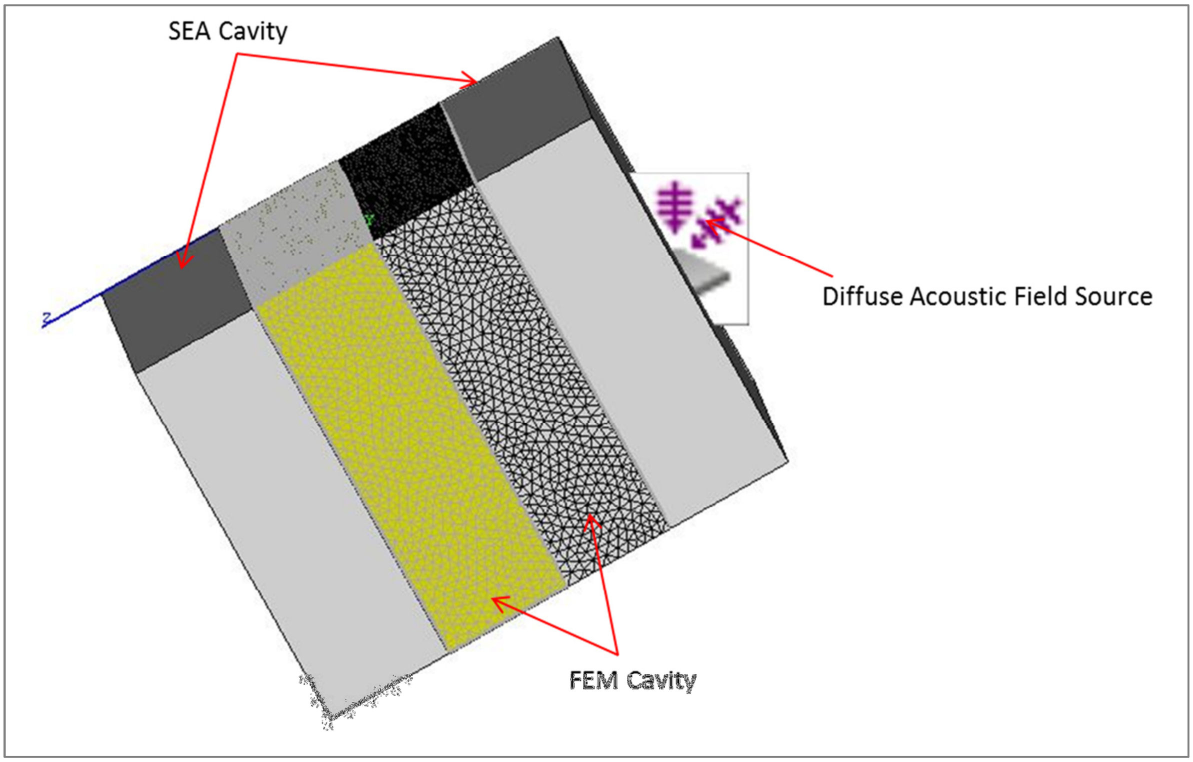

Figure 6. VA-One Model of STL Suite

The noise reduction is obtained from the average sound pressure level in the source SAE cavity and the average SPL on the receiving FEM cavity. This noise reduction is then used to calculate the Correlation Factor based on the mass law calculation (Eq 2) for the limp mass sample. Comparisons are presented in Figures 7 and 8 without and with foam respectively in the tunnel. Note that the simulations were only run to 2,000 Hz and the experimental and calculated data in previous figures is shown to 8000 Hz or higher.

Although simulated and test cases do not exactly match, the trends are similar. Correlation factors are high in the low frequency range (below 500 Hz). The presence of sound absorbing material in the test section reduces the overall range of the correlation factor. Overall, the lowest correlation factor occurs for the Position 2 case with sound absorption on the receiving side of the tunnel.

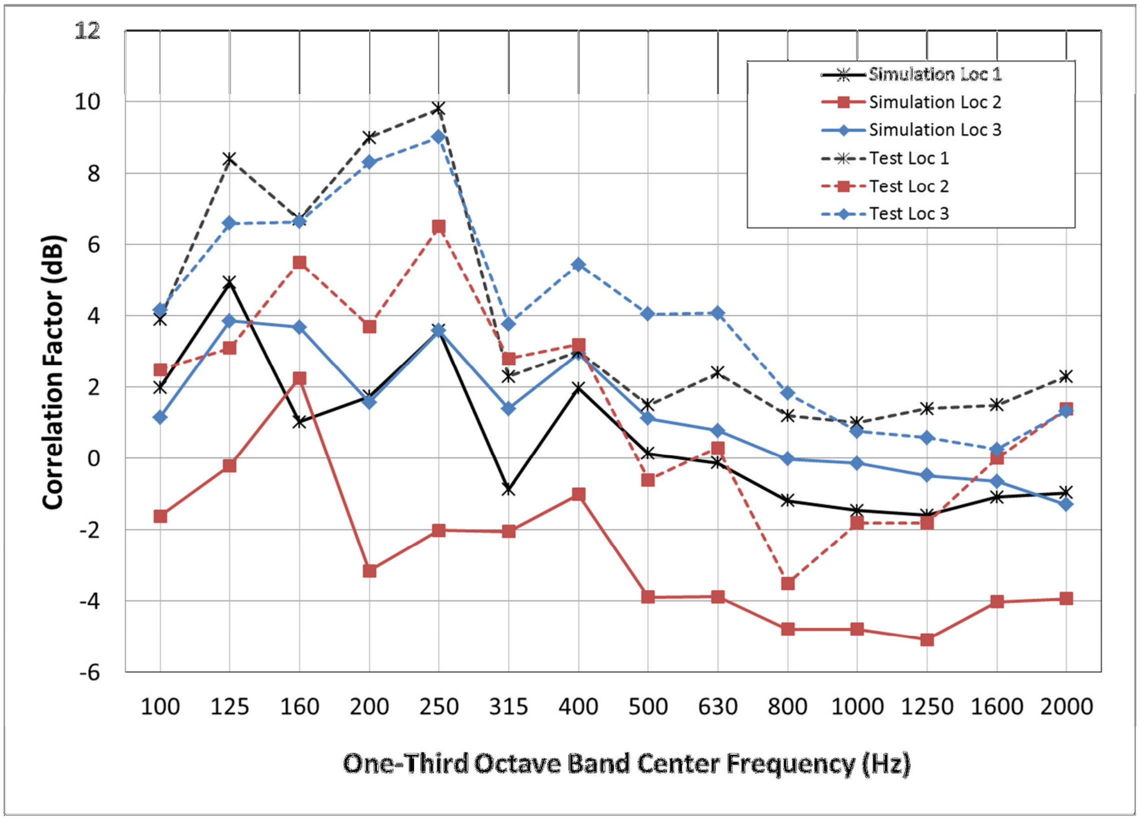

Figure 7. Correlation Factor for Positions 1-3, No Foam

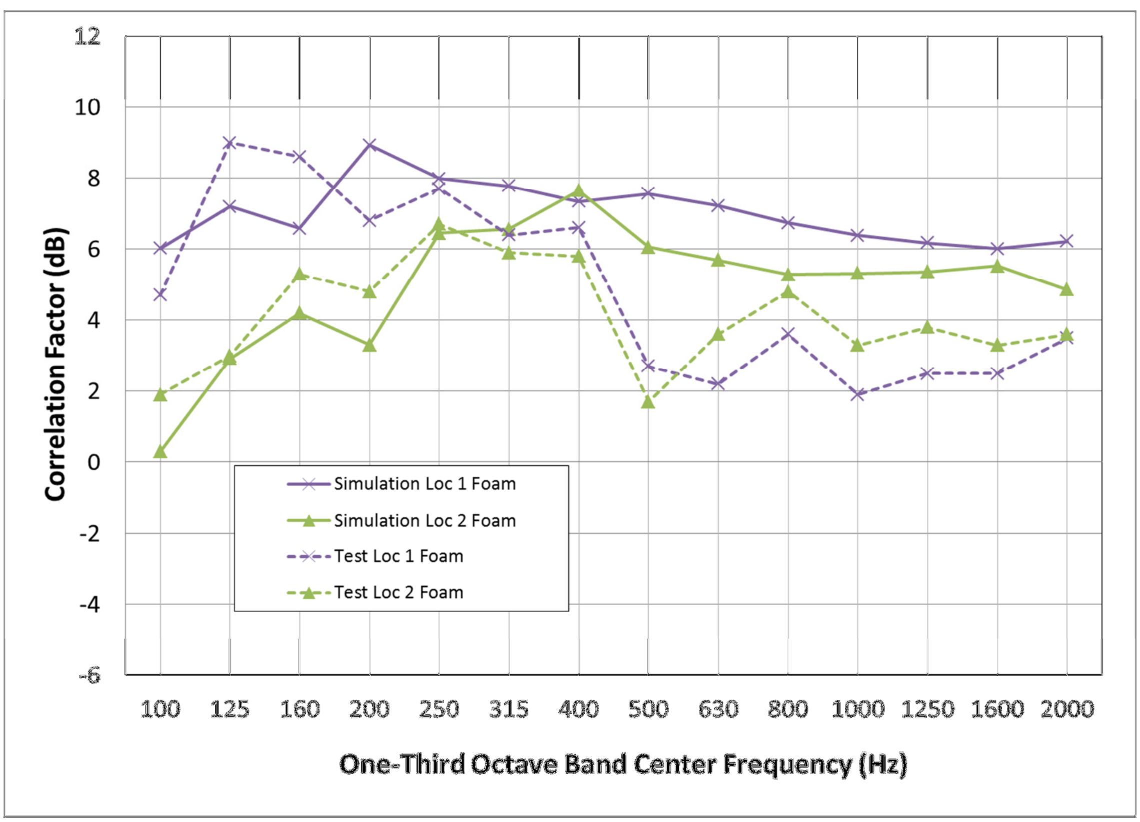

Figure 8. Correlation Factor for Positions 1 and 2 with Foam Applied to the Tunnel Surface

In a similar manner, the J1400 Control Sample was modeled and the STL results are shown in Figures 9 and 10 without and with sound absorptive material in the tunnel respectively. The simulations all provide similar results, but the experimental results show some differences. In all of the modeled test cases, the measured STL remains independent of sample position. We believe this is also true in the experimental measurements and any difference are due to flanking sound in the test fixture. The presence of sound absorptive material in the receiving section of the tunnel produces higher STL results in the experiments, but this is likely due to a reduction in flanking sound and it does not appear in the simulations.

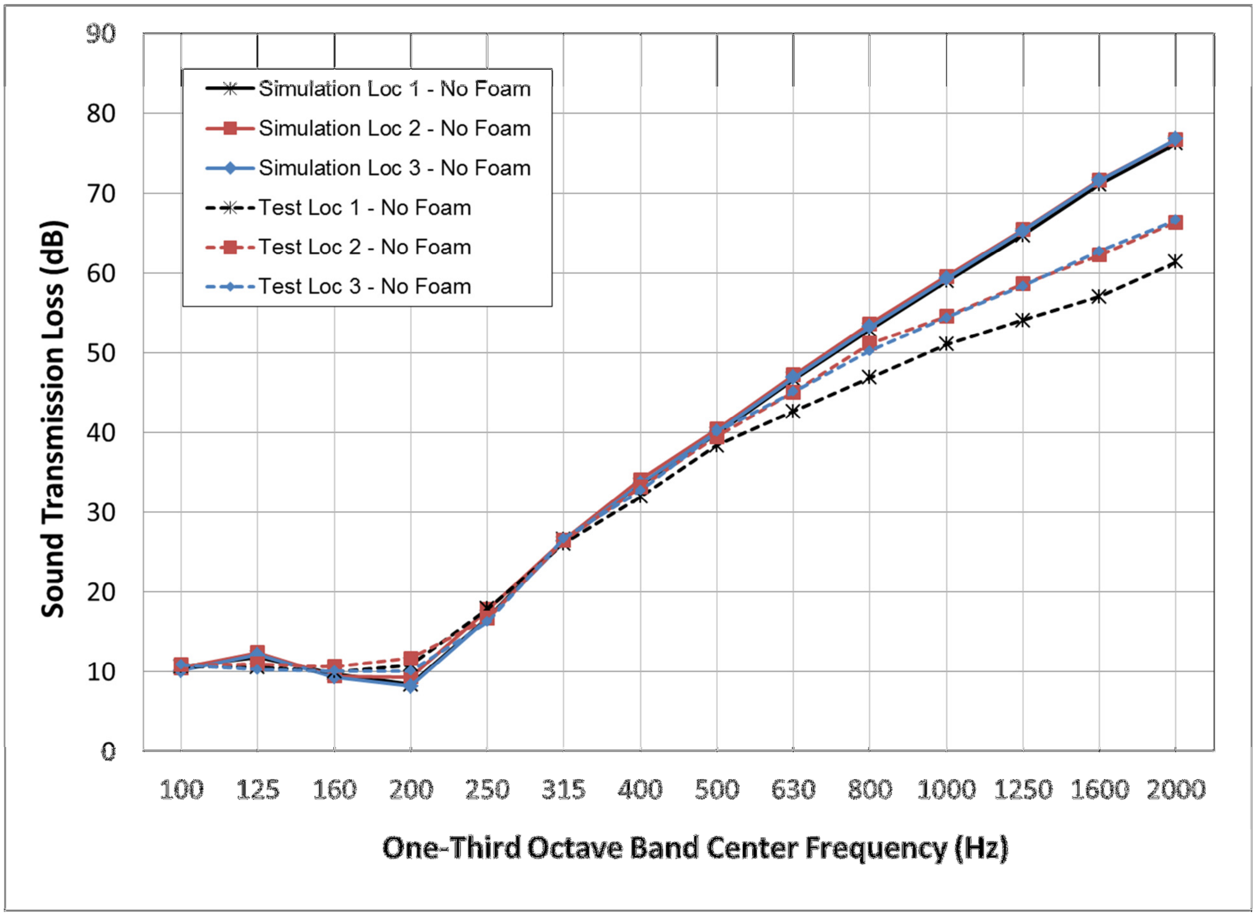

Figure 9. Simulation of J1400 Control Sample, No Sound Absorptive Material in the Test Tunnel

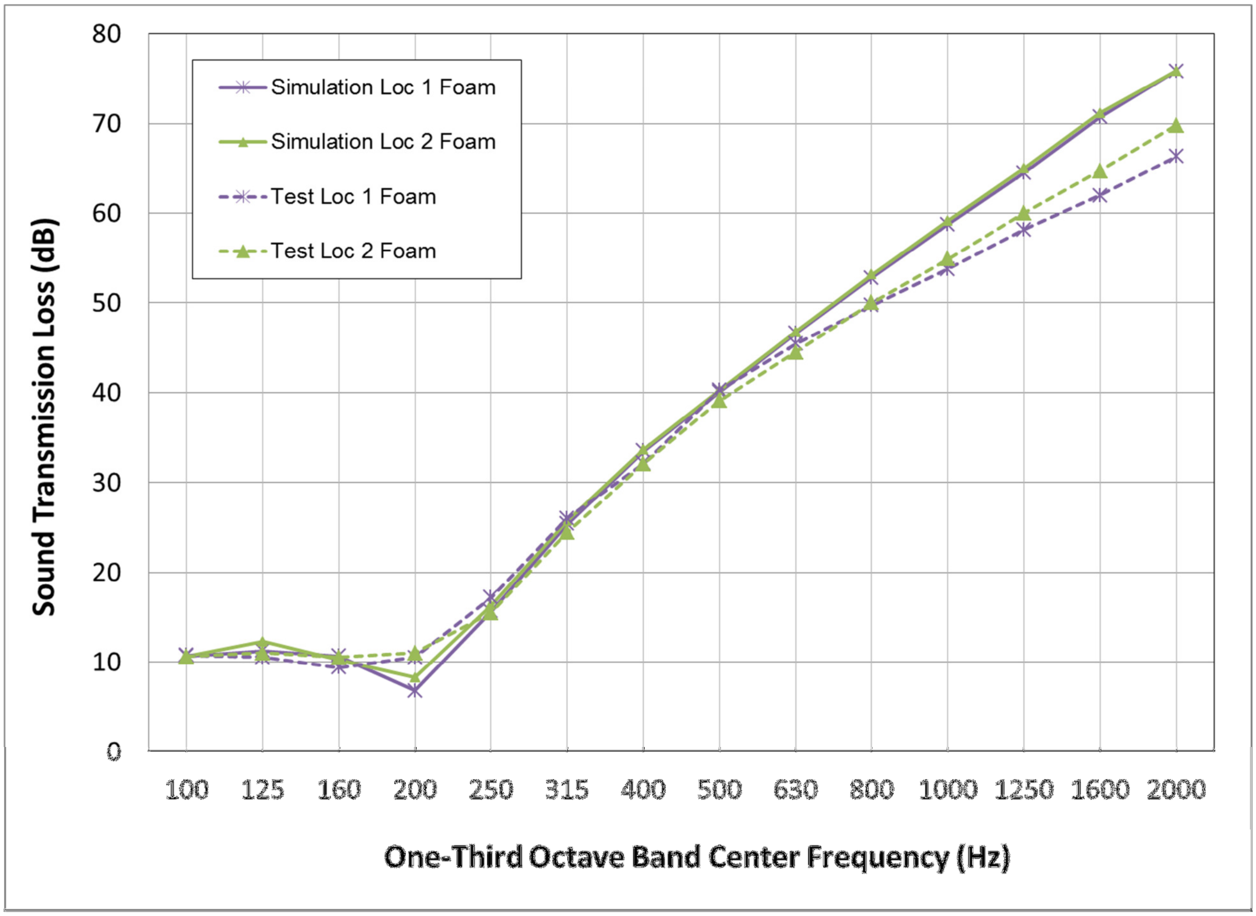

Figure 10. Simulation of J1400 Control Sample, Sound Absorptive Material in the Test Tunnel

5. CONCLUSION

Use of the correlation sample in the SAE J1400 test standard eliminates the tunnel effect found in other test methods. When using the SAE J1400 methodology, the best measurement location is where there is the least flanking sound. The exact location will depend on the individual laboratory and test section construction. Use of the control sample and testing of the sample at various tunnel locations can provide information on the presence of flanking sound and aid in improving STL test results. It is also beneficial to install sound absorptive material in the tunnel between the sample and the receiving chamber as this provides a lower correlation factor and experiment results closer to the simulated values.

6. REFERENCES

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