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http://dx.doi.org/10.34917/4332543

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UPGRADING UNLV'S ASTM E477 TEST FACILITY

TO MEET THE CURRENT REQUIREMENTS

OF ASTM E477

by

Ronn Reinier Fojas

Bachelor of Science in Mechanical Engineering
University of Nevada, Las Vegas
2009

A thesis submitted in partial fulfillment of
the requirement for the

Master of Science in Mechanical Engineering

Department of Mechanical Engineering
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University of Nevada, Las Vegas
May 2012

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THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

Ronn Reinier Fojas

entitled

Upgrading UNLV's ASTM E477 Test Facility to Meet the Current Requirements of ASTM E477

be accepted in partial fulfillment of the requirements for the degree of

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May 2012

ABSTRACT

Upgrading UNLV's ASTM E477 Test Facility to Meet the Current Requirements of ASTM E477

by

Ronn Reinier Fojas

Dr. Douglas Reynolds, Examination Committee Chair
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A by-product of Heating, Ventilation, and Air-conditioning (HVAC) systems is noise that is produced by fans, compressors, and other related equipments and the noises from the turbulence that is created by moving air. Sometimes, it is impractical to modify the sources of the noise, which requires designers to modify the path of the noise, the duct system. These modifications might include installing an in-duct silencer or acoustical lining on the inside walls of the ducts. The testing and the precise quantification of the performance of these silencers and duct linings are necessary for any designer to be able to make the correct modifications to the ventilation system. The ASTM E477 code calls for strict standardization of the testing of such noise attenuation devices. The ASTM E477 test facility used by the Center for Mechanical & Environmental Systems Technology (CMEST) at UNLV was first constructed in 1991 and required upgrades to meet the newer revisions of the ASTM code. This study includes making modifications to the facility (1) to increase sound input, (2) reduce sound leakage, and (3) to integrate the measurement systems. These upgrades will bring the facility into compliance with the current version of the ASTM E477 test standard.

ACKNOWLEDGEMENTS

First, I would like to express my appreciation to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) who through Research Project (RP) 1408 funded the research activities in this thesis and to Commercial Acoustics who supplied all of the sheet metal products and materials that were used for the upgrades to UNLV's ASTM E477 Test Facility.

Second, I would like to thank my primary advisor and also principal investigator of this study, Dr. Douglas Reynolds, for sharing his wisdom in the field of acoustics and noise control. I am sure that without his persistence this project would have never gotten this far.

Third, I would like to thank my colleagues namely Ezzat Ayyad, Stoil Pamoukov, Zaccary Poots, and Mohamad Hachem for sacrificing their time to help me in this study. They have suffered many cuts, burns, and damaged clothes. All the hours spent lifting, moving, cutting, drilling, and bending sheet metal, plywood, and particle board will not be left unacknowledged. I would also like to express specials thanks to Zach Mellinger for helping me in the most daunting task of the study: installing the sheet metal lining inside the ducts. This project would never get going if it was not for their help.

Finally, I would like to acknowledge the support my parents had given me in the endeavors that I have chosen. I thank them for being responsible parents and encouraging me to be the best that I can be.

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CHAPTER 1

INDTRODUCTION

1.1. Introduction

"A building is a living thing," said Phillip C. Phillips, the vice-president of Southland Industries during my internship with the company. "It not only breathes in fresh air and drinks clean water but also disposes of its wastes."

Because of the breathing people that occupy the building, it is necessary for a ventilation system to exist in modern buildings. These buildings breathe in outside air by using massive fans. The air then travels through a system of ducts to a heating, ventilation, air-conditioning, and refrigeration (HVAC&R) unit. The conditioned air then travels again through another system of ducts and comes out of diffusers which we usually see in the ceilings.

A by-product of this system of conditioned-air delivery is noise. HVAC noise can be produced by fans that deliver air to ducts that then deliver it to occupied areas in the building by air conditioning compressors and other related equipment, and by turbulent air motion in the air distribution ducts. Just like how air is delivered to the people that occupy the building, noise can propagate through air ducts. When the noise levels get too high, modifications to the source or path of the noise can be done. Although on some systems, modifications to the sound source may not be practical.

Modification to the path of the noise can be the installation of in-duct silencers or the installation of acoustical lining on the inside wall of the duct. In-duct silencers have baffles that may be made of perforated sheet metal on the outside and contain acoustic fiberglass on the inside. Acoustical linings are attached on the inside walls of the ducts

and may be constructed of fiberglass. Of course, not all silencers and linings are made equal. Therefore testing the acoustic performance characteristics of silencers and duct lining materials is necessary so any HVAC&R designer can pick the right silencer or lining appropriately.

The American Society for Testing and Materials (ASTM) developed a standard code for testing these sound attenuators in a ventilation system. They called it ASTM E477, Standard Test Method for Measuring Acoustical and Airflow Performance of Duct Liner Materials and Perforated Silencers. The code calls for a strict set of testing laboratory, equipment, and protocol guidelines.

The Center for Mechanical & Environmental Systems Technology (CMEST) first set up its ASTM E477 testing facility back in 1991. It had a fan room, silencer bank, sound chamber, a large reverberation room, and about 90 feet of ducts in between. "The sound for the ASTM E477 test facility consists of three speaker canisters that are mounted directly to the duct walls of either the supply or return air duct. One canister contains a 500 watt 18-inch diameter low-frequency speaker, the second canister contains a 500 watt 8-inch diameter mid-range speaker, and the third canister contains two 50 watt high-frequency tweeters." [15] Figure 1.1 shows a map drawing of the Multi-function Laboratory in the College of Engineering at UNLV. The CMEST ASTM E477 testing facility is located in this laboratory.

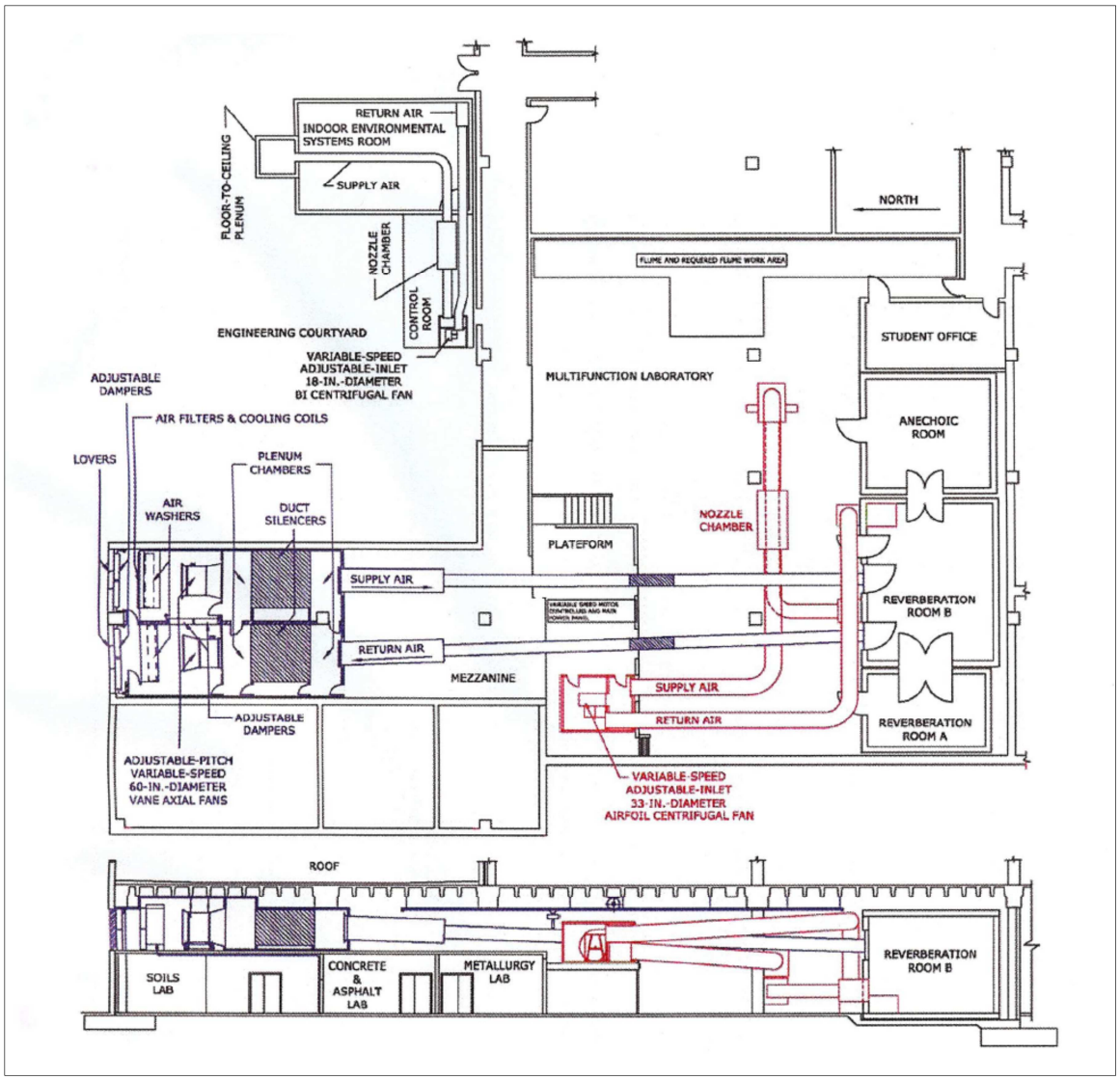

Figure 1.1 – CMEST Laboratory Facilities

The current revision of the ASTM E477 test standard requires CMEST's ASTM E477 test facility to be upgraded. The most significant changes in the upgrade are improved and relocated sound sources and reduced sound transmission through the inside duct walls of the dual-wall ducts in the supply and return air duct lines. These upgrades will bring the facility into compliance with the current version of the ASTM E477 test standard.

1.2. Goals and Objectives

- To upgrade the UNLV ASTM E477 Test Facility to bring it into compliance with the current requirements of ASTM E477 test standard.
- To conduct appropriate sound tests to document that the facility upgrades brought the UNLV ASTM E477 test facility into compliance with the current requirements of ASTM E477 test standard.
- To adequately document the UNLV ASTM E477 test facility upgrades.

CHAPTER 2

REVIEW OF RELATED LITERATURE

2.1. Background

2.1.1. Heating, Ventilating, and Air-Conditioning (HVAC) Noise

Sound in a ventilation system propagates mainly from two sources: (1) aerodynamically generated sound from system air handlers plus sound from other related equipment and (2) from turbulence associated from airflow through and around the duct fittings. Sound from these sources can be transmitted through the duct system into occupied spaces within a building. Sometimes the sound transmitted into occupied building spaces can be judged to be annoying and unacceptably loud. "For most HVAC and other mechanical systems, it is generally not possible for system designers to modify or change the source characteristics of occupied areas within a building. Thus, system designers most often are constrained to modifying the sound and vibration transmission paths to achieve desired background sound levels associated with HVAC and other mechanical systems." [1] This modification of the sound transmission path can include installing some acoustical duct lining or using fabricated duct silencers to reduce the propagation of sound through the ducts.

2.1.2. Acoustical Duct Linings

Acoustical duct linings are used to attenuate the propagation of sound in sheet metal air duct systems. "The dissipation of sound energy is generally accomplished by introducing a porous lining on one or more of the walls of the duct through which the induced draft and unwanted sound travel." [12] While acoustical duct linings primary purpose is to reduce sound transmission, it may also serve another purpose. "Duct lining

serves two purposes: It is a thermal insulant and a sound absorber. While 13-mm thickness may be sufficient for thermal reasons, for acoustical purposes the thickness should be a minimum of 25mm, and 50-mm is often desirable. The minimal low-frequency attenuation provided by thin linings and it is in the low-frequency region that most duct system noise control problems occur." [13]

2.1.3. Performance of Acoustical Duct Linings

The performance of acoustical duct linings in air ducts may vary depending on many variables like the thickness of the lining, the material of the lining, any protective layer that might cover the lining, the loudness of the sound, the size of the duct, the shape of the duct, and airflow velocity. Precise testing is necessary to quantify the performance of these acoustical duct linings in order to predict how they will perform.

2.1.4. Testing of Acoustical Duct Linings

The standard that was used in this study is the ASTM E477-06a test standard and proposed components of its future revision. This standard requires strict guidelines for measuring the performance of duct systems like an acoustically lined sheet metal duct. "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." [14]

2.2. Upgrade Discussion

The decision to upgrade the CMEST ASTM E477 facility was necessary to meet the requirements of new ASTM E477 test standard. The speakers in the existing facility are projecting though openings in the duct walls into the duct. The current ASTM E477 standard requires the speaker to be placed in a sound chamber. Consequently, the existing speakers were replaced by a higher-powered loudspeaker system to provide more duct input sound power to the low- and mid-frequency ranges. The 18-gauge sheet metal panels that comprised inside walls of the dual-walled duct were not sufficient to prevent sound from breaking out of the dual-wall cavity. Therefore, the decision was made to upgrade the inside walls of the dual-wall ducts by adding 12-gauge sheet metal panels on the inside duct walls. A significant research effort was spent committed to determining the appropriate speaker and microphone positions in the sound source chamber that would not only meet the requirements of the ASTM E477 standards, but would also transmit the maximum sound power input to the duct system.

2.3. Pink Noise

"Pink noise is noise which has a continuous frequency spectrum and a constant power within a bandwidth proportional to the center frequency of the band. For example, the power per octave bandwidth has a constant value." [10] All the sound testing data that were included in this report was obtained using pink noise from the speakers. Ambient sound levels were also recorded but only for the purpose of correcting the recorded data while the pink noise was on.

2.4. One-Third Octave Band

"The one-third octave band is a frequency band whose cutoff frequencies have a ratio of 2 to the one-third power, which is approximately 1.26. The cutoff frequencies of 891 Hz and 1112 Hz define the 1000 Hz third-octave band in common use." [11] For all the data that are included in this report, the sound pressure level analyses were obtained using the one-third octave frequency bands.

CHAPTER 3

METHODOLOGY

3.1. UNLV's ASTM E477 Facility

3.1.1. Duct System

The duct system includes two plenum chambers that served as sound chambers, supply and return air double-walled sheet metal square ducts, and a reverberation room (Figure 3.1). Sound generated by the speakers in the supply air sound chamber is projected towards the ducts and measured by microphones in the sound chamber and reverberation room.

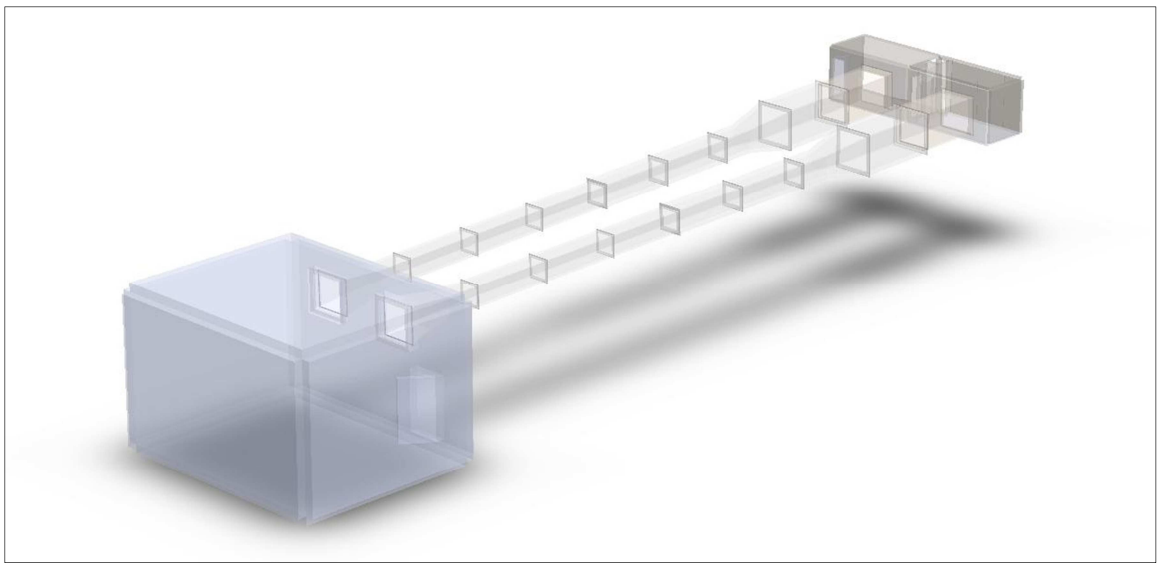

Figure 3.1 - Duct System

3.1.2. Sound Chambers

The speakers are set up in the sound chambers, which are directly connected to the supply and return air double-walled square ducts. The insides of the walls of the

sound chambers are filled with fiber glass while the inside surfaces of the walls and ceiling are perforated sheet metal. The original floor surface was 18-gauge sheet metal. The sides of the sound chambers opposite the duct openings are silencers which are not shown in the Figure 3.2. Both chambers measures about 12-ft x 6-ft x 6.5-ft in length, width, and height, respectively, and 460 ft^3 in volume.

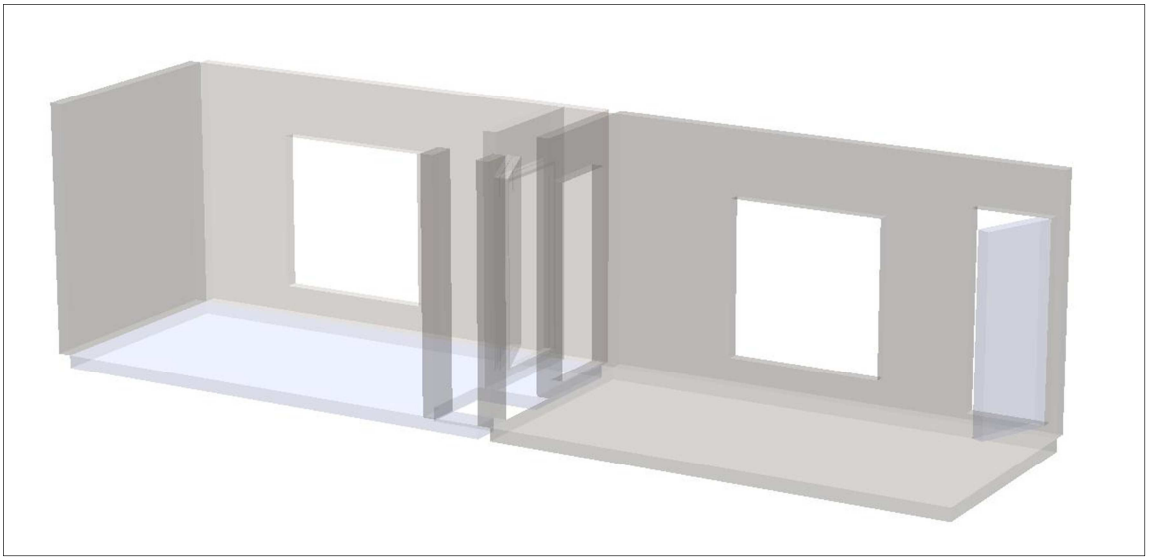

Figure 3.2 - Sound Chambers

3.1.3. Double-walled Square Ducts

The double-walled square ducts have nine 10-ft-long sections (Figure 3.3). Starting from the sound chamber, the first two square ducts have inside measurements of 4-ft x 4-ft. The third section transitions from 4-ft x 4-ft to 2-ft x 2-ft. The next two sections are 2-ft x 2-ft inside with a 4.25 in. cavity between the inside and outside walls while the next three sections after are also 2-ft x 2-ft inside but with a 2.25 in. cavity between the inside and outside walls. The last section is another transition from 2-ft x 2-

ft to 4-ft x 4-ft. The walls of the ducts were originally 18-gauge sheet metal and the cavities between the walls are filled with fiber glass. As part of the facility upgrade, 12-gauge sheet metal panels were attached to all four walls of all of the duct sections.

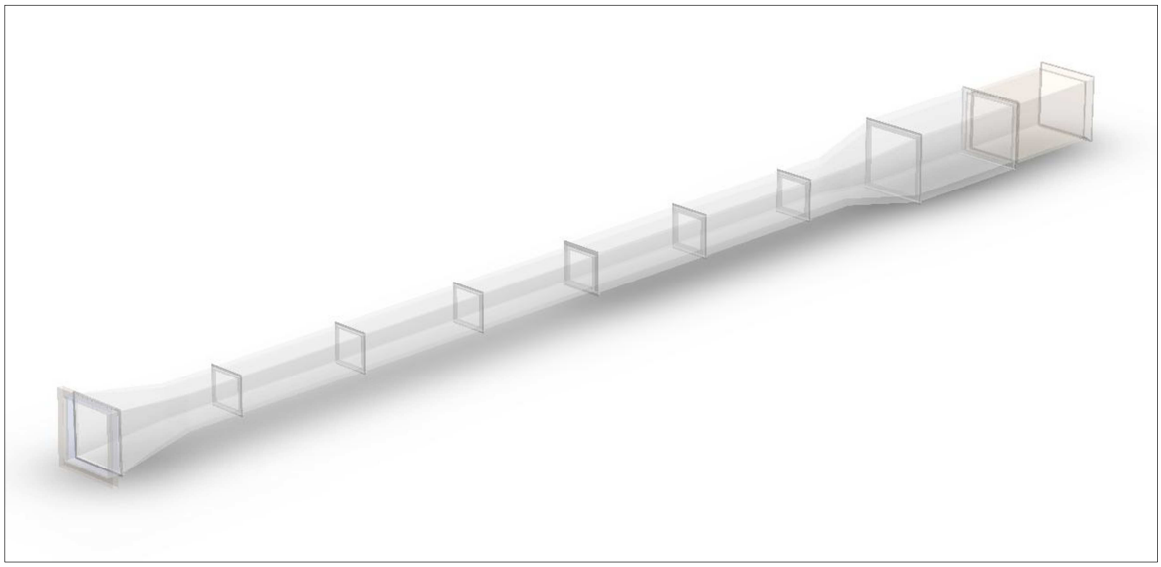

Figure 3.3 - Double-walled Square Ducts

3.1.4. Reverberation Room

The volume of the reverberation room is 9,373 ft^3 (Figure 3.4). It has been qualified for broad band sound testing per ANSI S12.31. Sound absorbers have been placed on the walls to lower the low-frequency and smooth out the mid-frequency reverberation times. [16]

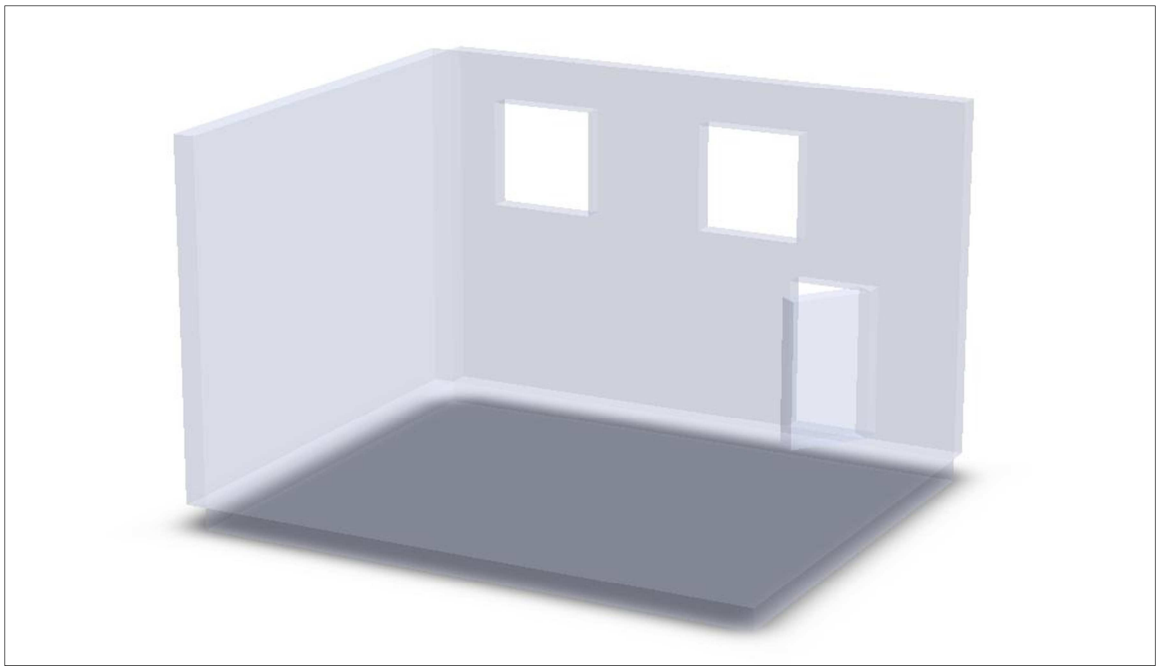

Figure 3.4 - Reverberation Room

3.1.5. Half-cone Turning Vane

The half-cone turning vane is installed in the reverberation room to more efficiently diffuse low-frequency room modes (Figure 3.5). The turning speed is adjustable to different rotational speed settings using a controller outside the reverberation room. [16]

Figure 3.5 – Half-cone Turning Vane

3.2. Equipment

3.2.1. Player

A Hewlett-Packard Pavilion TX2500z laptop computer was used to play a wave file that contains pink noise (Figure 3.6). Sound energy in pink noise is equal in all 1/3 octave frequency bands. The audio output was connected to an equalizer.

Figure 3.6 - HP Pavilion TX2500z Laptop Computer

3.2.2. Equalizer

The Protea Ashly Graphic Equalizer has 4 channels, max level of 20 dBu, and frequency range from 20 Hz to 20,000 Hz (Figure 3.7). Channels 1 and 2 were set for the bass speaker, channel 3 was set for the mid-range speaker, and channel 4 was set for the high-frequency horn drivers. The overall gains for all channels were set to maximum, which is +15. The audio signals from the equalizer were directed to two amplifiers via XLR cables (Figure 3.8). Figure 3.9 to Figure 3.12 show the gain settings that were used for channels 1 - 4 of the equalizer.

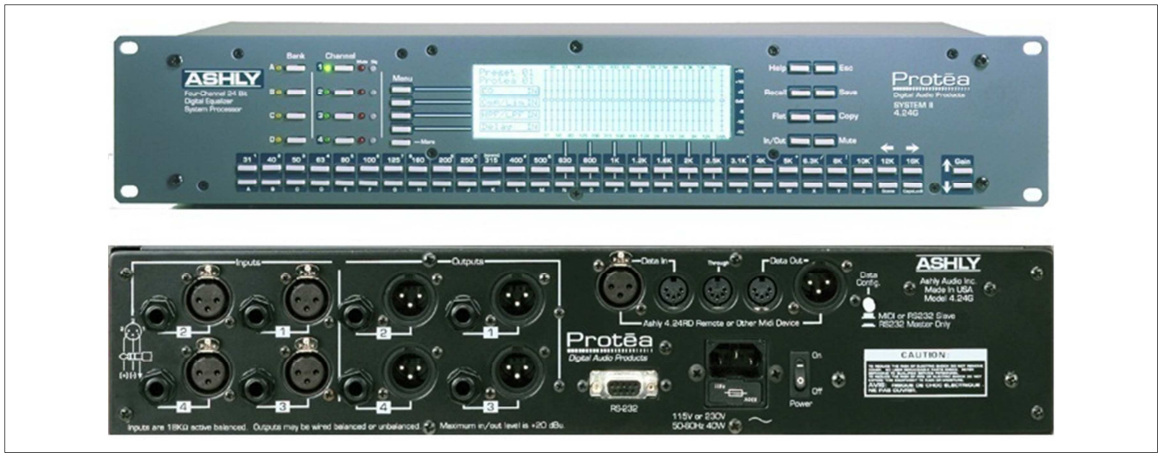

Figure 3.7 - Protea Ashly Digital Graphic Equalizer

Figure 3.8 - Male and Female Ends of XLR Cable

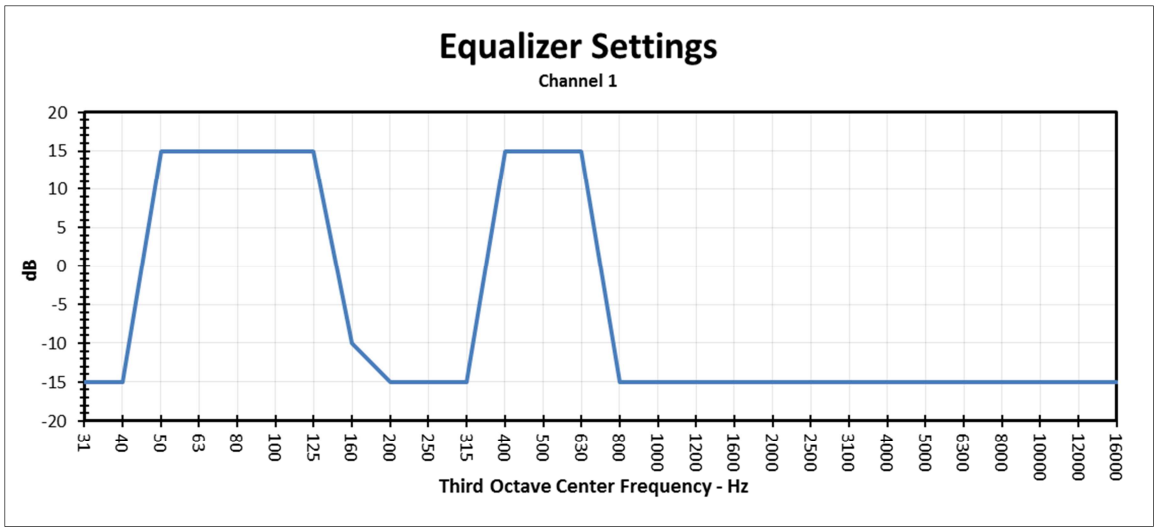

Figure 3.9 - Equalizer Settings Channel 1

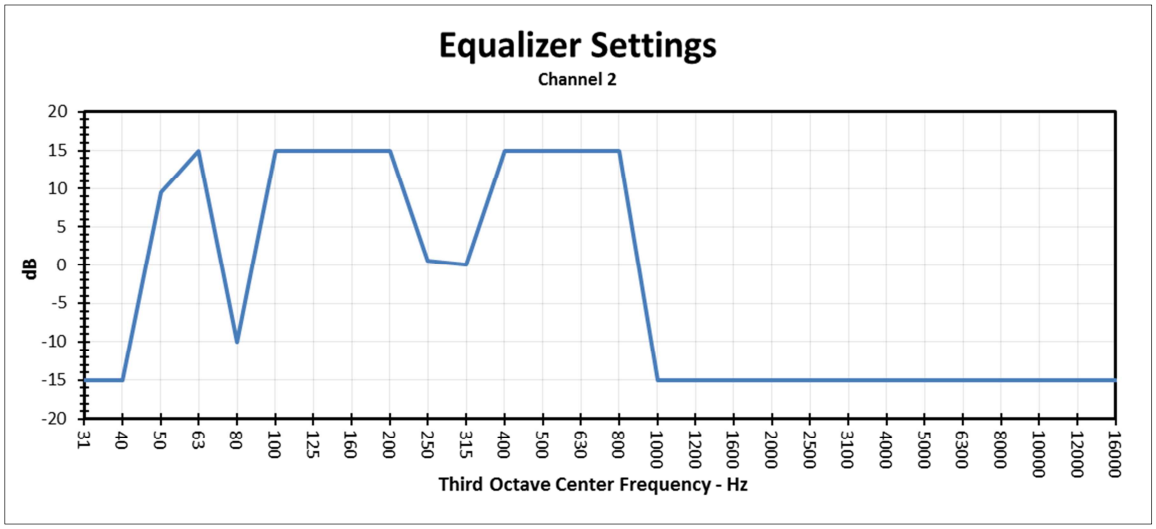

Figure 3.10 - Equalizer Settings Channel 2

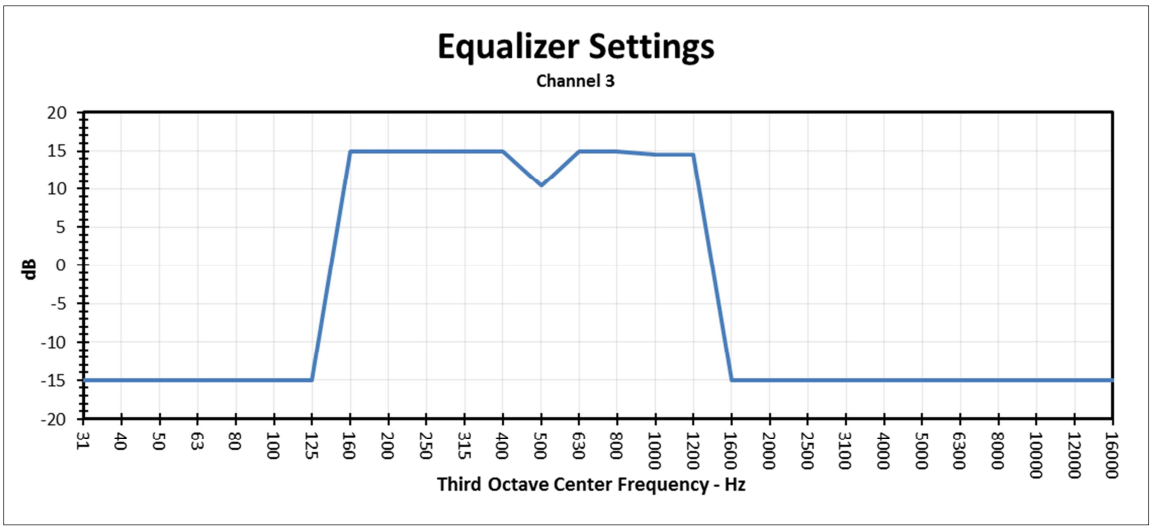

Figure 3.11 - Equalizer Settings Channel 3

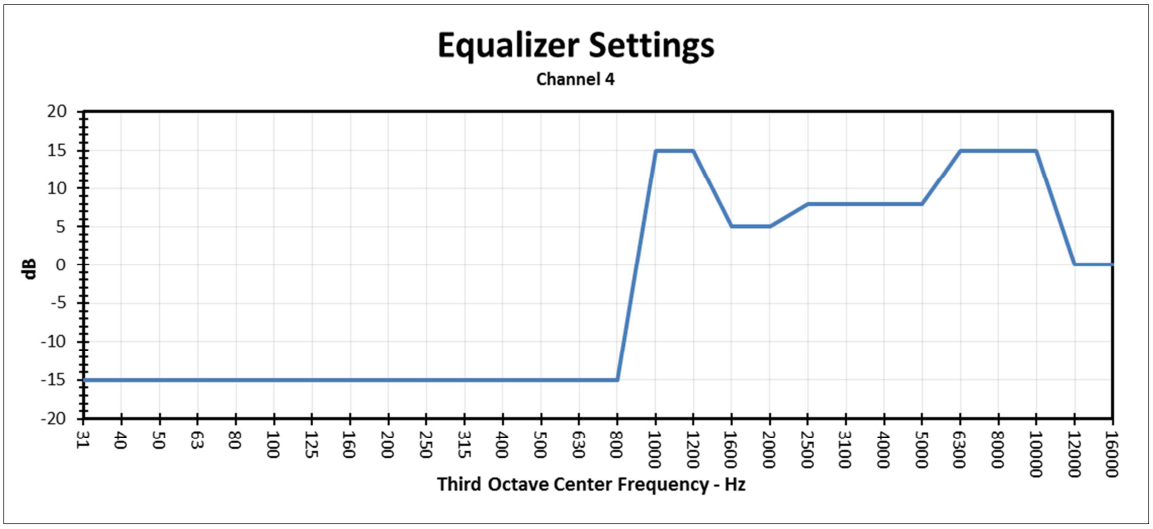

Figure 3.12 - Equalizer Settings Channel 4

3.2.3. Amplifiers

The sound signals from the equalizer were amplified before they reach the speakers. Two amplifiers were used with both capable of handling two inputs. The gain settings were set so that the signals were amplified to within the amplifier's maximum

wattage capacity with minimum clipping. The amplified sound signals were then directed to the speakers by means of 8-gauge speaker cables.

3.2.3.1. Amplifier for Low Frequency Range

Channels 1 and 2 were connected to the QSC PowerLight PL380 amplifier (Figure 3.13). It has a total maximum power output of 8,000 W. Since the signals that go through the amplifiers are separate, each channel would have a maximum power output of 4,000 W.

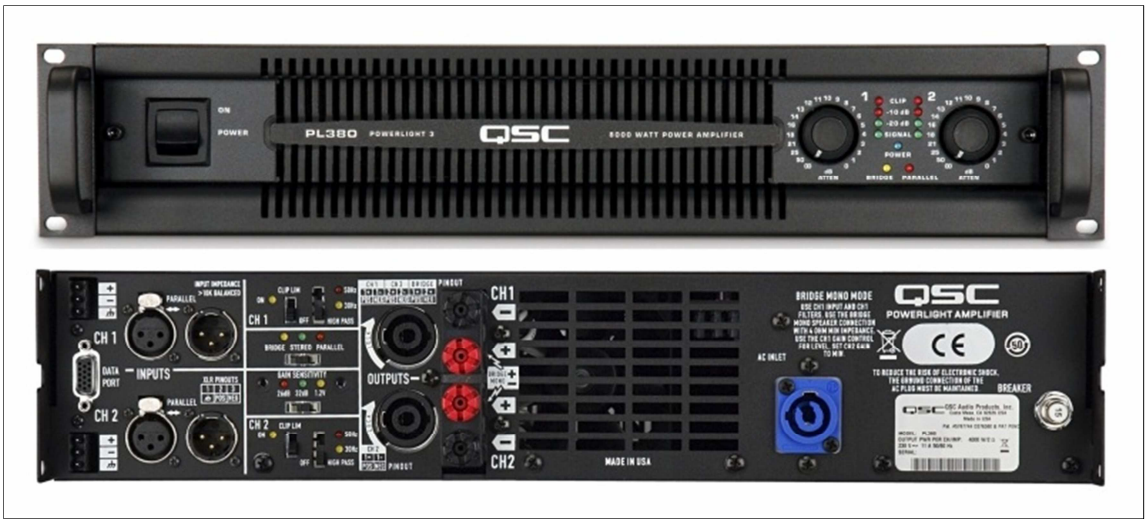

Figure 3.13 - QSC PowerLight PL380 8000W Amplifier

3.2.3.2. Amplifier for Mid and High Frequency Range

Channels 3 and 4 were connected to the QSC PowerLight PL325 amplifier. It has a total maximum power output of 2,500 W (Figure 3.14). Since the signals that go through the amplifiers are separate, each channel would have a maximum power output of 1,250 W.

Figure 3.14 - SQC PowerLight PL325 2500W Amplifier

3.2.4. Speakers

The amplified sound signals from the amplifiers were directed to three speakers; a bass speaker, mid-range speaker, and two horns. One speaker alone is not capable of reproducing the pink noise loud enough across the frequencies being studied, which is from 50 Hz to 10,000 Hz.

3.2.4.1. Low Frequency Range Speakers

The JBL ASB7128 Speaker Unit was used to reproduce low frequency sound from channels 1 and 2 (Figure 3.15). The speaker unit has two individual speakers that can be controlled by two separate inputs. Both are 18-in.-dia. speakers with neodymium. The speaker unit is quite effective for frequencies from 20 Hz to 1,000 Hz (Figure 3.16). [3]

Figure 3.15 - JBL ASB7128 Speakers

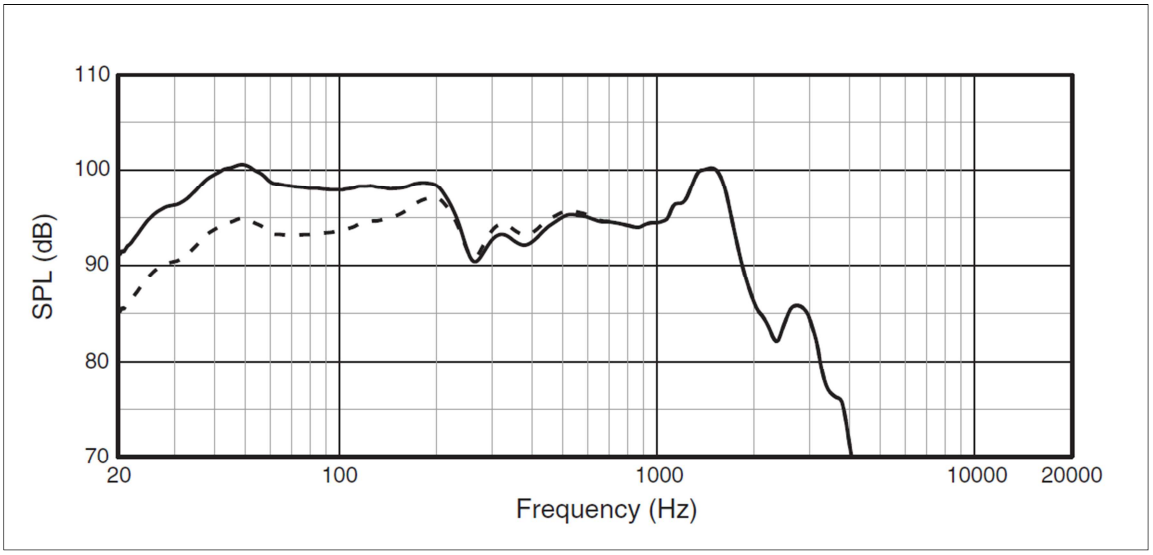

Figure 3.16 - Frequency Response of JBL ASB7128 Speaker [3]

3.2.4.2. Mid Frequency Range Speakers

The JBL AM7215 Speaker Unit was used to reproduce sound frequency between 125 Hz and 1,600 Hz using the signal from channel 3 (Figure 3.17). This speaker unit has one low frequency driver and one high frequency horn driver where both can be controlled by one input. The transducer for the low frequency has a capacity of 1,000 W while the high frequency has a capacity of 100 W. This speaker unit is effective on frequencies from 40 Hz to 20 kHz (Figure 3.18). [4]

Figure 3.17 - JBL AM7215 Speakers

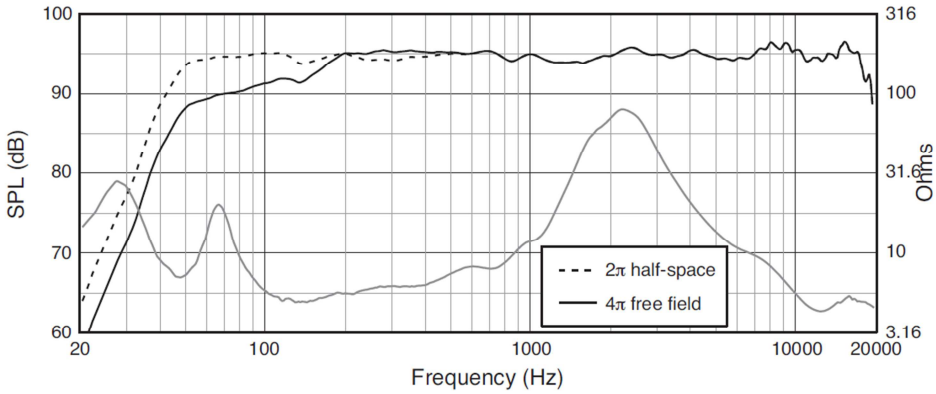

Figure 3.18 - Frequency Response of JBL AM7215 Speaker [4]

3.2.4.3. High Frequency Range Speaker

Two JBL Selenium D4400Ti Drivers coupled with two HL 4750SLF Horns were used to reproduce sound frequency between 1,000 Hz and 20,000 Hz using the signal from channel 4 (Figure 3.19 and Figure 3.20). The channel 4 cable from the amplifier branched into two so that the amplified signal could be passed to both units. Each drive has a capacity of 250 W. They are effective for frequencies from 400 Hz to 20,000 Hz (Figure 3.21). [5]

Figure 3.19 – JBL Selenium D4400Ti Driver

Figure 3.20 - JBL Selenium HL 4750SLF Horn

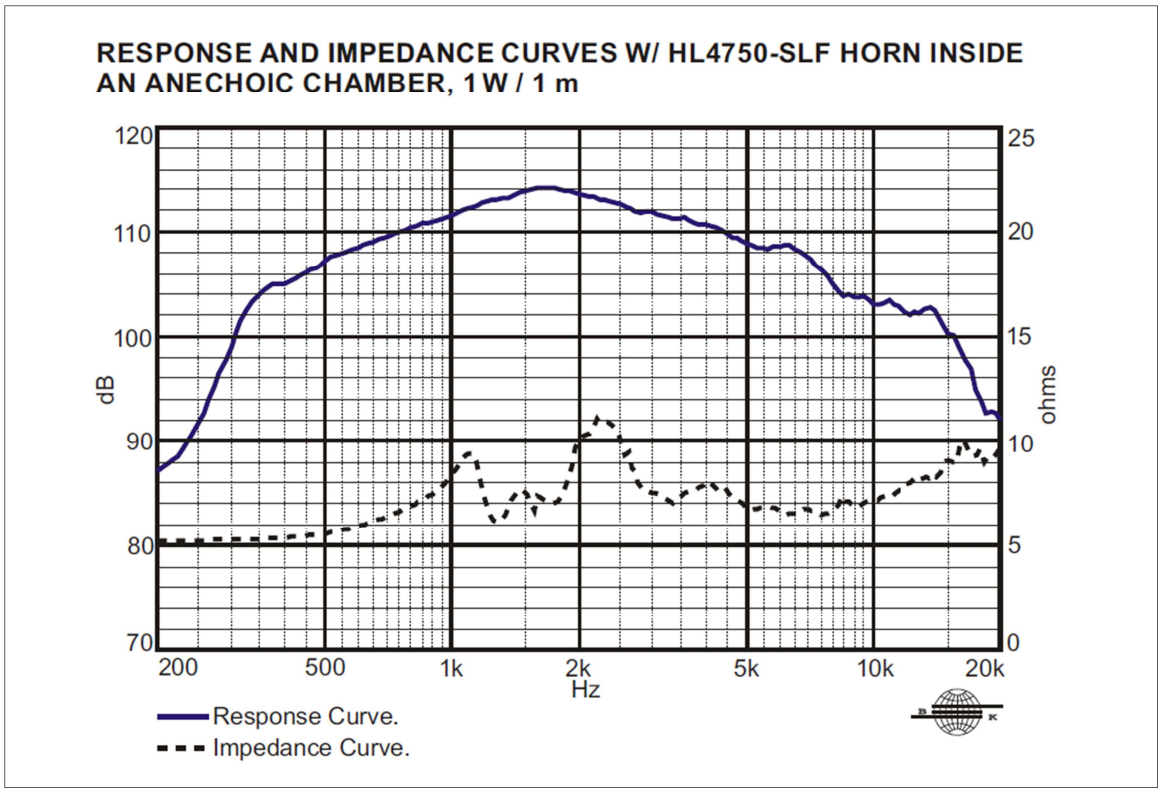

Figure 3.21 - Frequency Response of JBL Selenium D4400Ti Horn Driver [5]

3.2.5. Microphone

The Larson Davis Pre-polarized Condenser Microphone Cartridge Type 4155 was used for the sound tests (Figure 3.22). This equipment contains the diaphragm that senses vibrations in the air and transforms them into electrical signal.

Figure 3.22 - Larson Davis Condenser Microphone Type 4155

3.2.6. Microphone Preamplifier

The Larson Davis PRM902 0590 was used to amplify the signal from the microphone diaphragm (Figure 3.23). This model can drive lines up to 500 feet with frequency response from as low as 0.3 Hz to 2000,000 Hz (Figure 3.24). [6]

Figure 3.23 - Larson Davis PRM902 0590 Preamplifier

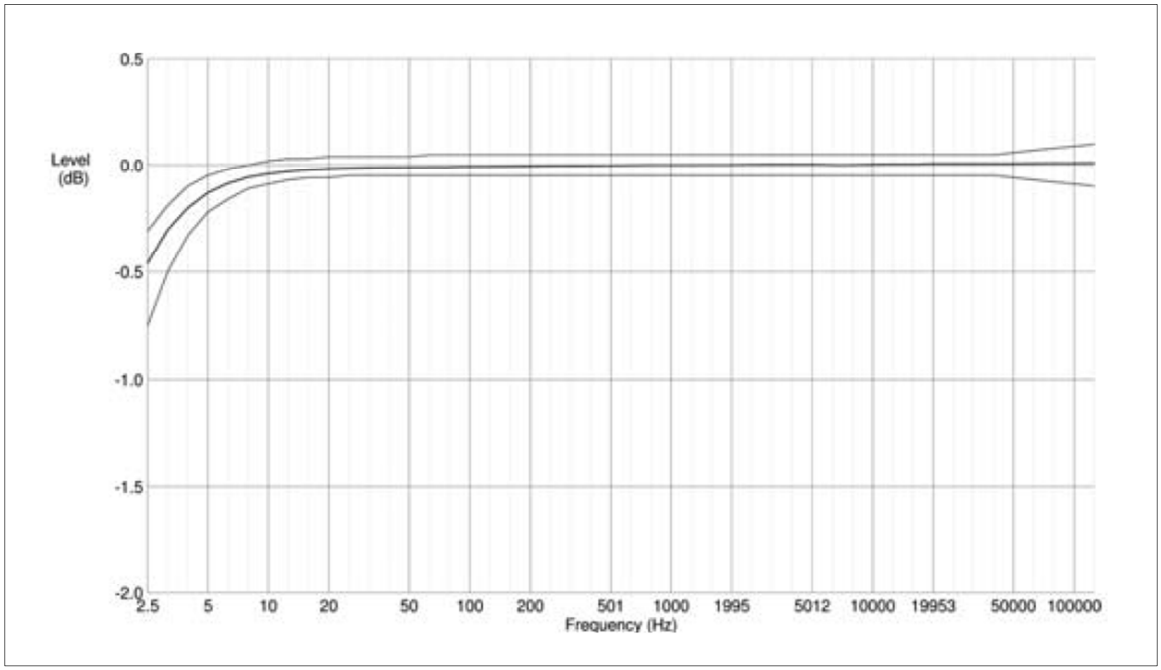

Figure 3.24 - Frequency Response of Larson Davis PRM902 Preamplifier [6]

3.2.7. Microphone Boom

The Norsonic Nor 265 is a sweeping microphone boom (Figure 3.25). It can be used for building acoustic measurements in accordance with ISO 140, reverberations time measurements is accordance with ISO 354, and sound power measurements in accordance with ISO 3740 series. It can sweep at ±90 degrees or ±180 degrees where the sweep times are selectable. [7]

Figure 3.25 – Norsonic Nor 265 Microphone Boom

3.2.8. Sound Analyzer

The sound signal from the preamplifier is transferred to the Larson Davis System 824 Sound Level Meter and Real-Time Analyzer (Figure 3.26). It is capable of 1/1 and 1/3 true digital analyses or 440-line FFT. Sound Spectrum Analyzer (SSA) measures sound pressure level, real-time 1/3 octave frequency analysis, spectral Lns and multiple time histories. Real-time Frequency Analyzer (RTA) provides rapid storage of 1/3

octave spectra at rates to 400/second. Fast Fourier Transform (FFT) with 400-line resolution from 1 Hz to 20,000 Hz for specific frequency investigations. Logging Sound Level Meter (LOG) provides advanced time and data logging features, automatic logging of data associated user-defined noise events. Data stored in the Larson Davis System 824 can be transferred to a computer in the form of comma-separated values (CSV) files (Figure 3.27). [8]

Figure 3.26 - Larson Davis System 824 Sound Analyzer

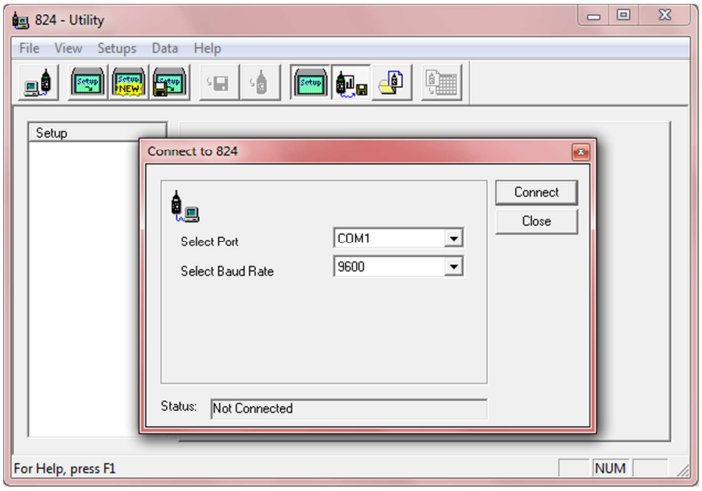

Figure 3.27 - Larson Davis System 824 Utility Software

3.2.9. Calibrator

The Brüel & Kjær Type 4231 Sound Calibrator was used to calibrate the microphone and the Larson Davis System 824 sound analyzer (Figure 3.28). It calibrates at 1,000 Hz and has an accuracy level of ±0.2 dB. The Calibrator conforms to IEC942 (1988) Class 1 and ANSI S1.40-1984 (R 1997). [9]

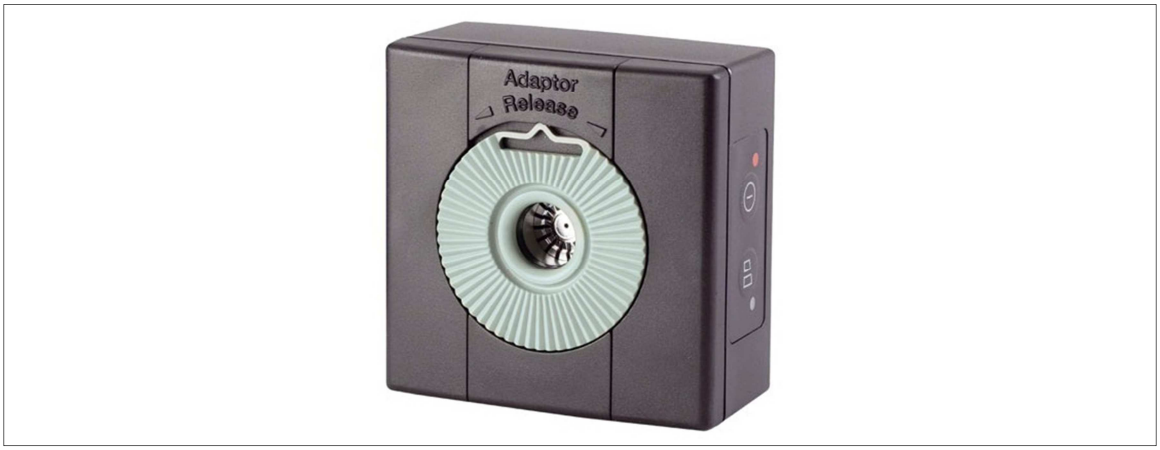

Figure 3.28 - Brüel & Kjær Type 4231 Sound Calibrator

3.2.10. Signal Connection

Figure 3.29 summarizes the connection of equipments starting from the signal generation to the signal processing. An analog sound signal was generated from a laptop computer, processed by an equalizer, amplified by two amplifiers, and then transformed into sound energy by speakers. The sound energy goes through the duct system and is then sensed by a microphone diaphragm and transformed again into analog sound signal then pass to a preamplifier, which is connected to a sound analyzer.

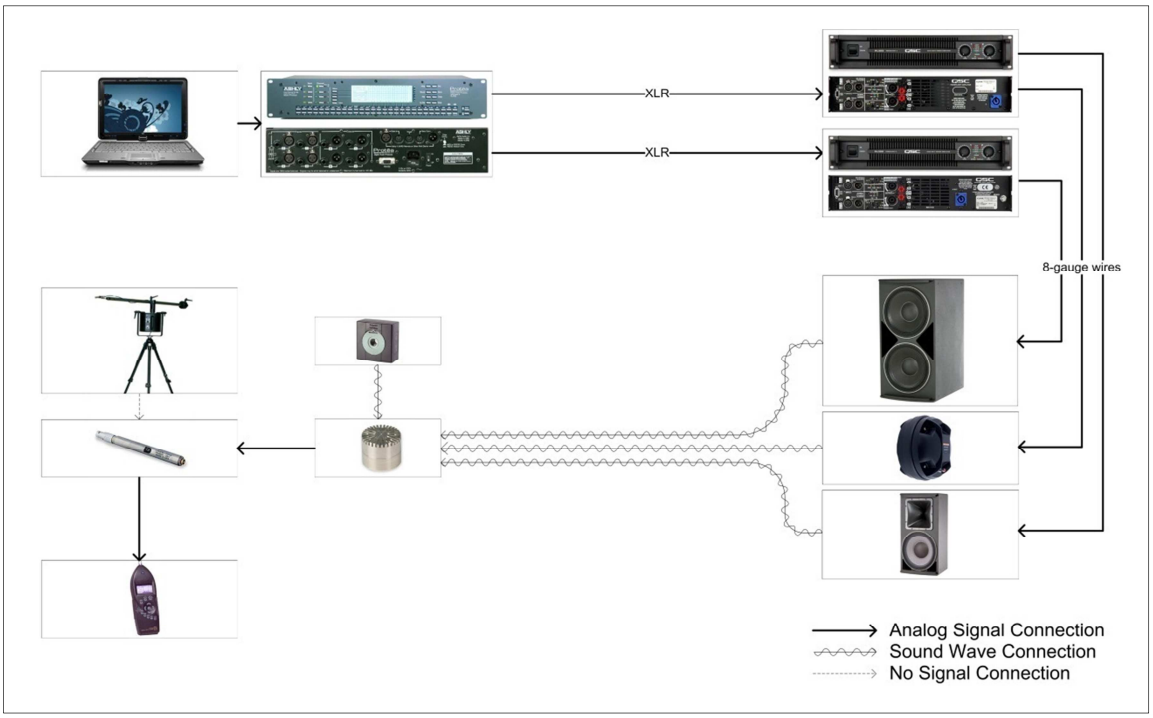

Figure 3.29 – Equipment Signal Connection Diagram

3.2.11. Plug 1

Plug 1 is a sound barrier to be placed inside the duct. It is constructed of two 2-ft x 2-ft 0.75-in.-thick plywood, four 54-in long L-shaped aluminum bars, and 1 lb/ft^3 loaded vinyl. Loaded vinyl is glued to both surfaces of the plywood pieces. With 54-in of space in between the two plywood pieces, they are connected on the corners using the 54-in long L-shaped aluminum. One side of the plug, which is the bottom, is totally covered with loaded vinyl. The other three sides are covered with loaded vinyl except for a 30-in space between the two plywood pieces. Also, the loaded vinyl extends about 4-in pass the length of the L-shaped aluminum to provide an effective surface for the edges of the plug to be taped on the inside surface of the duct to make a better seal. Finally, the

entire cavities in the plug are filled with fiber glass. Figure 3.30 to Figure 3.32 illustrate how the plug is constructed.

Figure 3.30 – Picture of Plug 1

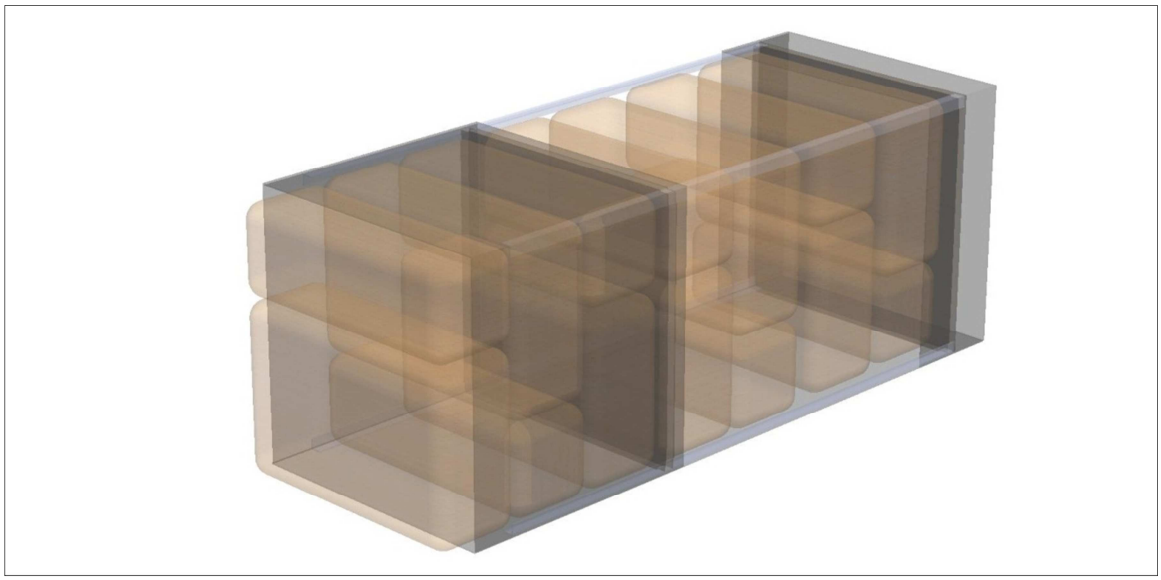

Figure 3.31 – Drawing of Plug 1

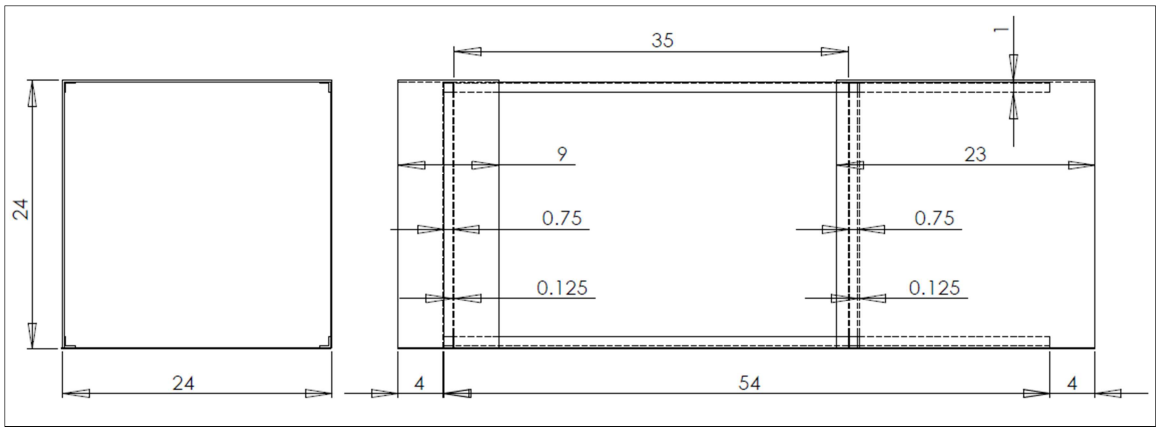

Figure 3.32 – Schematic Drawing of Plug 1 (in inches)

3.2.12. Plug 2

Plug 2 is 2-ft x 2-ft and is made of 0.75-in.-thick plywood. Glued to one side of it is 1 lb/ft^3 loaded vinyl that extends out about 2 inches. There are also two handles on the vinyl side of the plug. When installed, the vinyl that is sticking out bends with the inside walls of duct. Taping the vinyl to the duct using aluminum tape gives a better seal.

Figure 3.33 – Picture of Plug 2

3.2.13. Silencer

The silencer is 2-ft x 2-ft in cross-sectional area and about 7 feet long. Its inside vertical walls are perforated and are filled with fiber glass to absorb sound. The silencer was used together with plug 2.

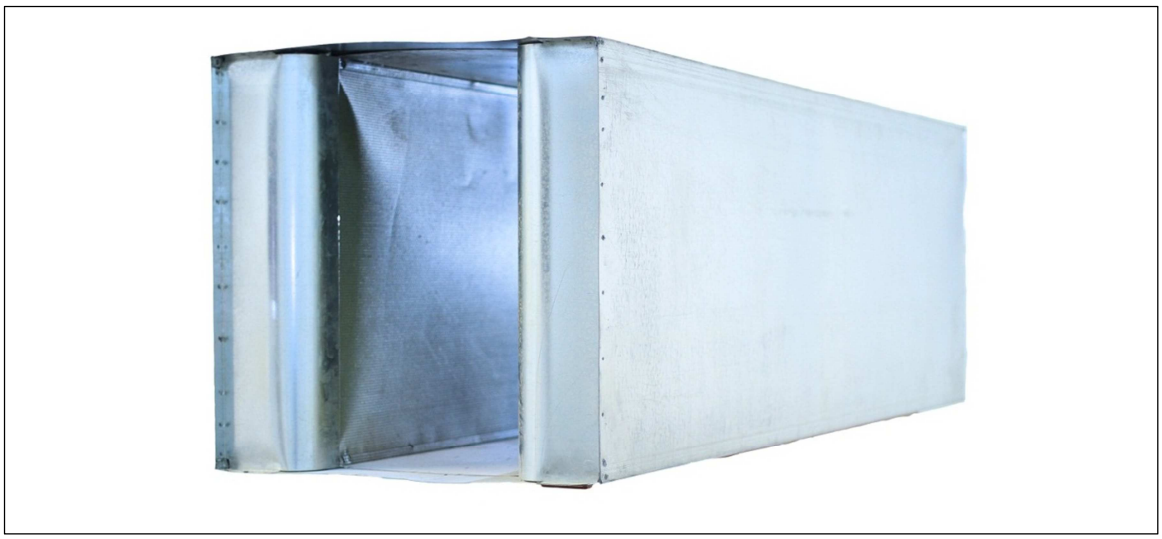

Figure 3.34 – Picture of Silencer

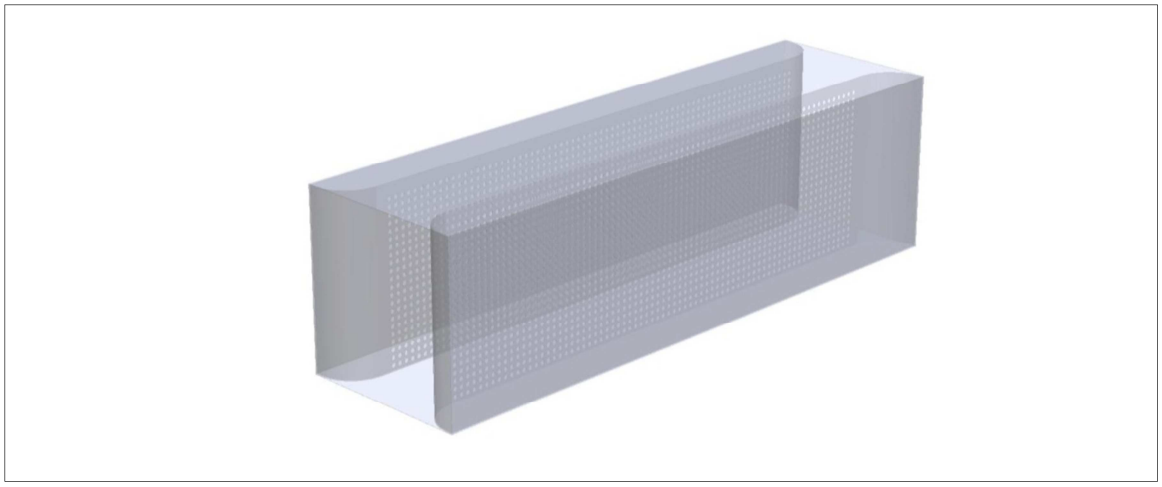

Figure 3.35 – Drawing of Silencer

3.3. Upgrades to the Facility

3.3.1. Integration of Measurement System

The new measurement system will collect data of (1) sound in the reverberation room, (2) sound in the source room, (3) air flow velocity, (4) pressure in the source side of the duct, (5) pressure in the reverberation side of the duct, (6) temperature, and (7) humidity. All the data can be simultaneously collected recorded and analyzed in one computer using National Instruments' software called LabView. Figure 3.36 shows a diagram of the measurement system. More detail of the new measurement system is explained in APPENDIX A.

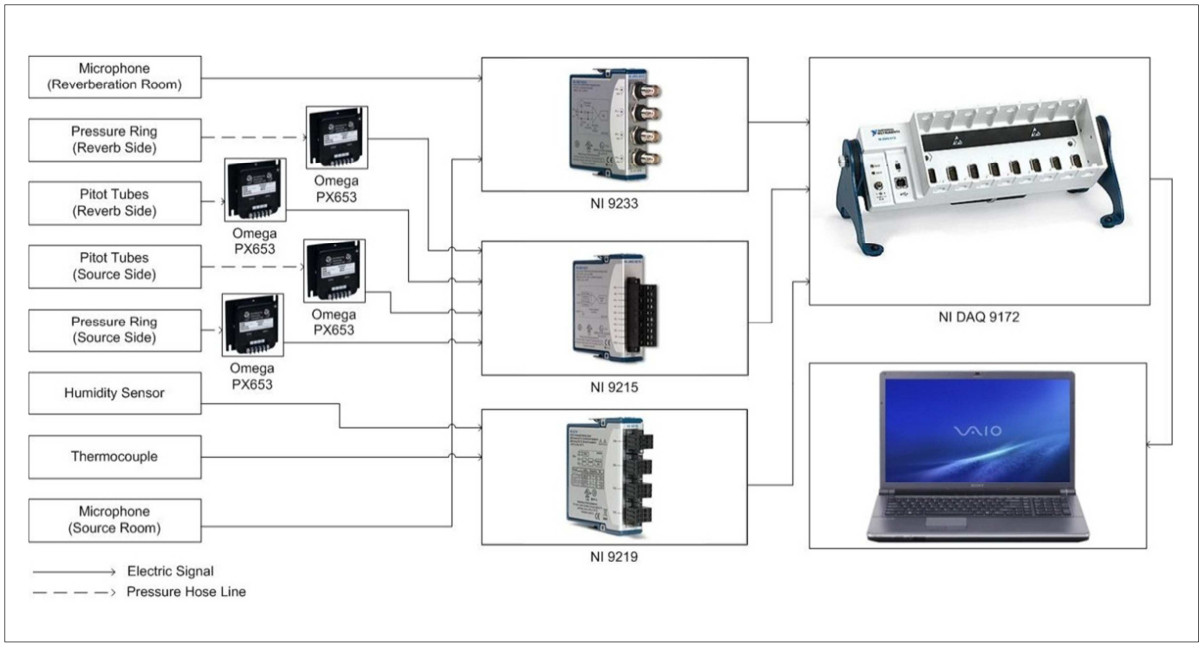

Figure 3.36 – Upgraded Measurement System Diagram

3.3.2. Relocation of Sound Source

One requirement of the code is the relocation of the speakers. The speakers were originally placed inside canisters and attached to the sides of the second duct (Figure 3.37). The speakers need to be relocated inside the sound chamber. A significant of amount of time was spent on how to position the speakers in the sound chamber so that its sound power input to the duct is high.

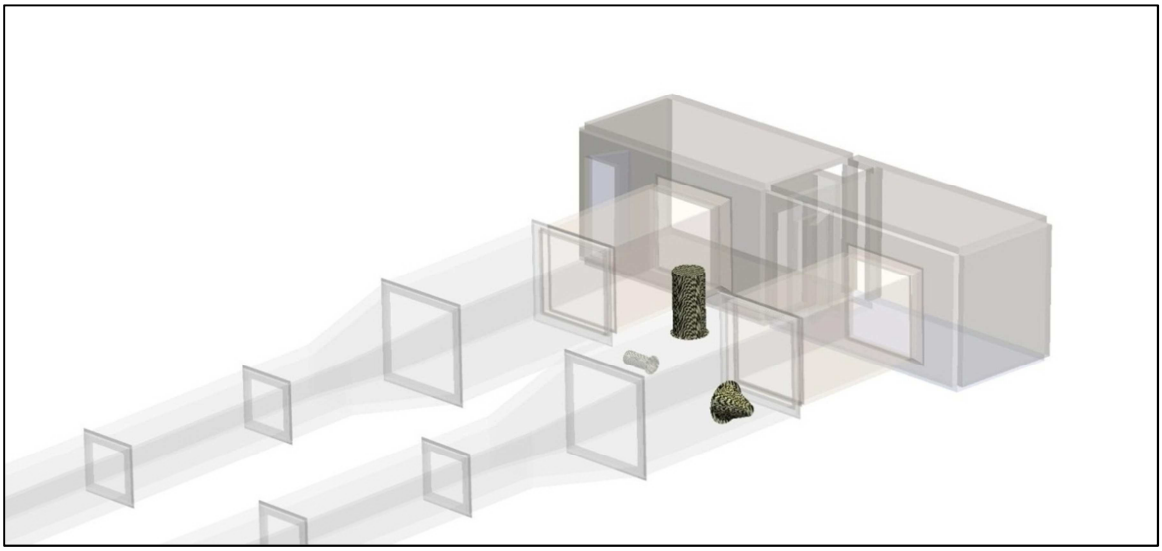

Figure 3.37 – Duct System with Speaker Canisters

3.3.3. Reduction of Sound Leakage

To increase the sound attenuation that can be measured in the facility, sound leakage from the duct system had to be reduced. Both walls of the dual-walled duct were originally made of only 18-gauge sheet metal. In addition, the floor of the sound chamber is also made of 18-gauge sheet metal. To reduce the sound leakage from the system, an additional layer of 12-gauge sheet metal was added to the inside walls of the duct and to the floor of the sound chamber.

3.4. Test Protocol

3.4.1. Sound Pressure Level Measurements

For each speaker position and duct system configuration, the following protocols were followed to obtain sound pressure levels and compare the insertion losses with and without any sound barriers inside the duct.

1. Ambient Sound Test in the Reverberation Room without Plug
2. Sound Test in the Reverberation Room without Plug
3. Sound Test in the Sound Chamber without Plug
4. Ambient Sound Test in the Sound Chamber without Plug
5. Ambient Sound Test in the Sound Chamber with Plug
6. Sound Test in the Sound Chamber with Plug
7. Sound Test in the Reverberation Room with Plug
8. Ambient Sound Test in the Reverberation Room with Plug

3.4.2. Sound Test in the Reverberation Room

The following protocols were followed to obtain sound pressure levels in the reverberation room.

1. Close all doors in both sound chambers.
2. Turn both amplifiers on.
3. Turn turning vane on and set to speed number 3.
4. Connect microphone to wire.
5. Place microphone on the microphone boom.
6. Turn microphone boom on.
7. Run the wire through the reverberation room wall.

8. Close both reverberation room doors.
9. Connect wire to Larson Davis.
10. Connect Larson Davis to power source.
11. Turn Larson Davis on.
12. Set time interval to one minute.
13. Set gain to 0 dB.
14. Turn pink noise on if necessary.
15. Press start on the Larson Davis test and let it run until it stops.
16. Save file.

3.4.3. Sound Testing in the Sound Chamber

The following protocols were followed to obtain sound pressure levels in the sound chamber.

1. Make sure the doors into the reverberation room are closed.
2. Turn pink noise on if necessary.
3. Connect the microphone to the Larson Davis then place the microphone on the stand.
4. Close all the doors of both sound chambers.
5. Turn the Larson Davis on.
6. Set the interval time to 30 seconds.
7. Set the gain to -20 dB.
8. Press start on the Larson Davis test and let it run until it stops.
9. Save file.

3.4.4. Data Processing

3.4.4.1. Adjustment for Ambient Noise

Each saved file from the Larson-Davis was processed in a Microsoft Excel worksheet. The group of worksheets for a specific speaker position and duct configuration were then consolidated in one spreadsheet. All the ambient sound levels were logarithmically subtracted from the sound pressure levels with the pink noise on using the formula below. [1]

$$L_{p(S)} = 10 \cdot \log_{10}\left(10^{L_{p(S+BG)}/10} - 10^{L_{p(BG)}/10}\right) \tag{3.1}$$

The $L_{p(S+BG)}$ designates the sound pressure levels with the pink noise on and $L_{p(BG)}$ designates the sound pressure levels with all the speakers off.

3.4.4.2. Plug Difference in Sound Chamber

The adjusted sound pressure levels in the source chamber with and without any barrier inside the duct were compared to make sure the difference was less than ±1 dB. The goal here was to confirm that the sound chamber sound pressure levels were the same with and without the plug in the duct.

3.4.4.3. Insertion Loss

The insertion loss shows how much sound energy is attenuated from the insertion of a sound barrier in the duct. It is calculated by subtracting the adjusted sound pressure levels in the reverberation room without the plug installed in the duct from the adjusted sound pressure levels in the reverberation room with the plug installed. The following formula is from section 9.4 of the ASTM E477-06a Standards.

$$IL = L_{p,empty_duct} - L_{p,silencer} \tag{3.2}$$

Insertion Loss is designated by IL, the adjusted sound pressure level in the reverberation room without the plug installed in the duct is designated by $L_{p,empty_duct}$, while the adjusted sound pressure level in the reverberation room with the plug installed is designated by $L_{p,silencer}$. [2]

3.5. Test Setup

3.5.1. Duct System Variables

3.5.1.1. Back Board

The back boards were placed to cover the silencers opposite the duct entrance in the sound chamber. They were 0.75-in-thick particle board and were secured by sheet metal screws on the top part of the silencer wall. This configuration variable is referred to as "board" in following sections. Figure 3.38 shows the back board installed in the supply side sound chamber.

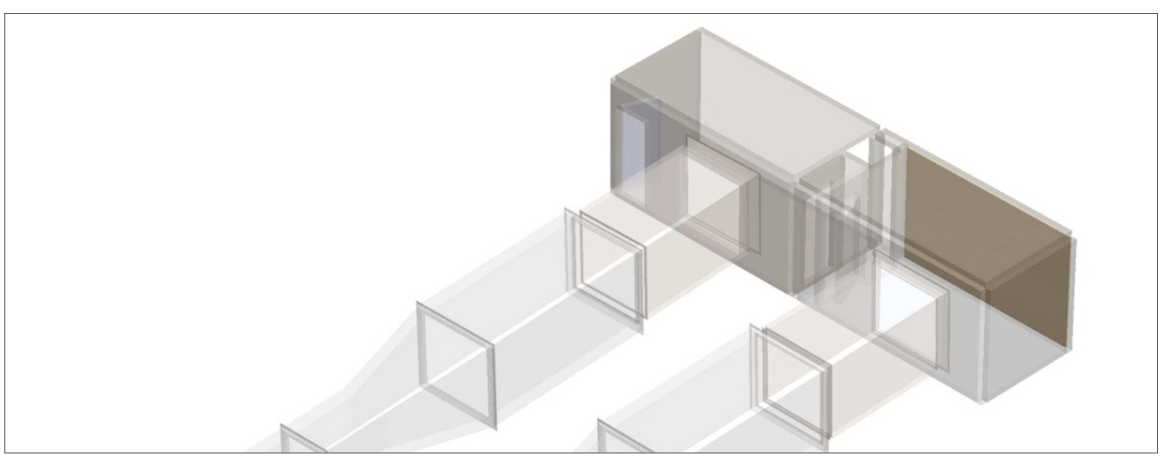

Figure 3.38 – Sound Chambers with Back Board in the Supply Side

3.5.1.2. Sheet Metal Lining on the Floor of Sound Chamber

12-gauge sheet metal panels were placed on the sheet metal floor of the sound chamber to reduce the sound leaking through the floor. The whole floor space was covered with these panels. The sheet metal panels were secured by sheet metal screws. This configuration variable referred to as "floor" in following sections.

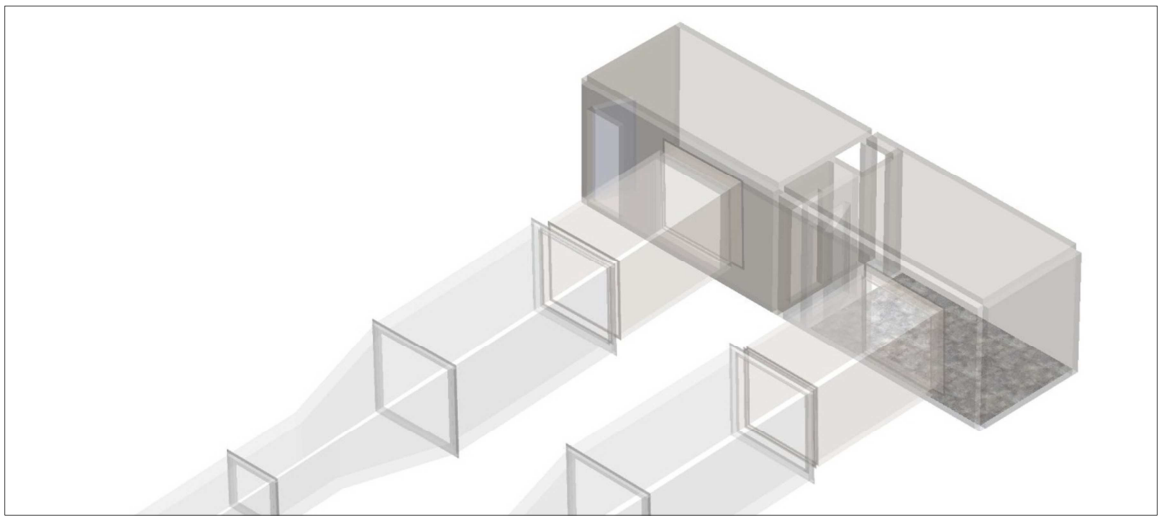

Figure 3.39 – Sound Chambers with Sheet Metal Lining on Sound Chamber Floor

3.5.1.3. Sheet Metal Lining inside the Duct

With the plug installed, it was suspected that sound was leaking though the duct walls into the duct cavity. To reduce this effect, 12-gauge galvanized sheet metal panels was installed on all the walls inside the ducts except on the duct section where the plugs were installed. In addition, the loaded-vinyl that used to connect the last duct section to the reverberation room was replaced by small panels of 12-gauge sheet metal. This configuration variable referred to as "duct" in following sections.

3.5.1.4. Plug 1

Plug 1 was inserted in one section of the ducts to check for sound flanking in the duct system (Figure 3.40). The plug is described in detail under the equipment chapter.

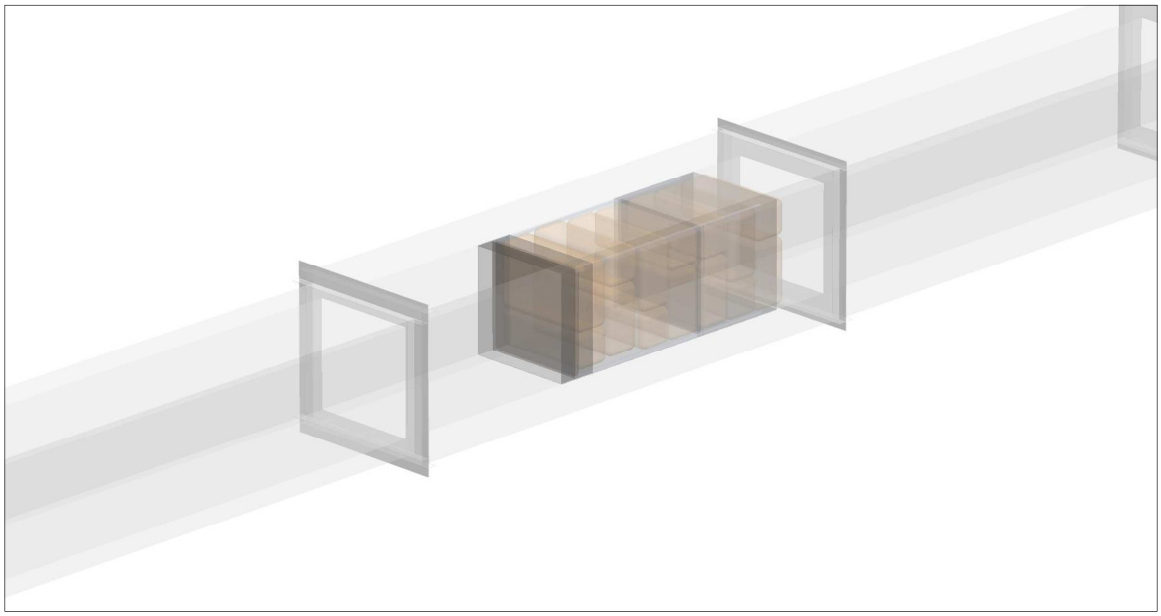

Figure 3.40 – Plug1 inside Duct

3.5.1.5. Plugs 1 and 2

Plug 2 was used at the same time as plug 1 for an additional sound barrier in the duct system (Figure 3.41). The sound barriers were inserted in one section of the ducts for an additional sound flanking test of the duct system. The plugs are described in detail under the equipment chapter.

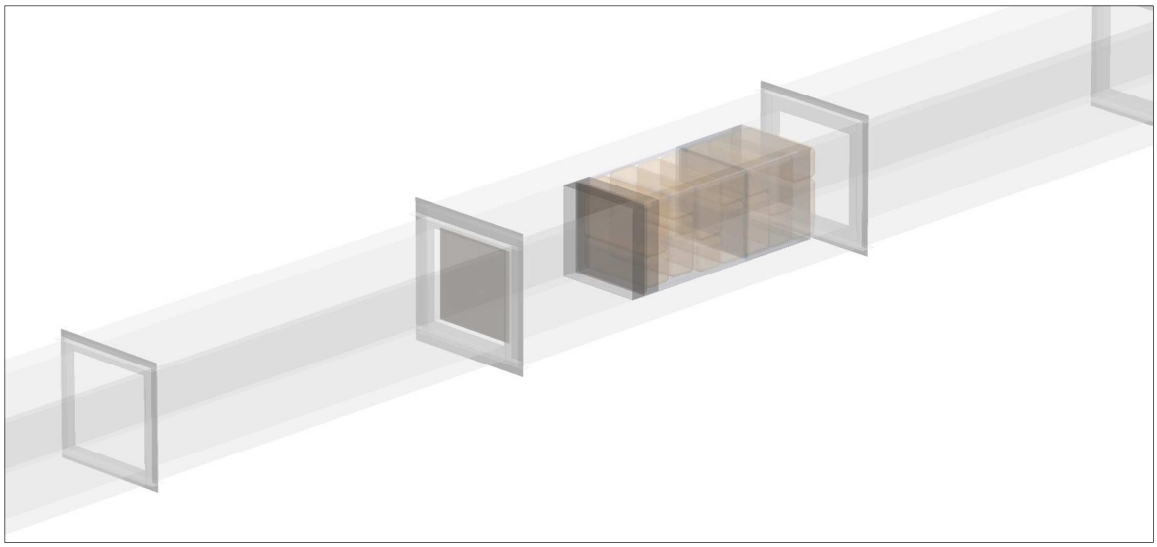

Figure 3.41 – Plugs 1 & 2 inside Duct

3.5.1.6. Silencer & Plug 2

The silencer and plug 2 were used at the same time for an additional sound barrier in the duct system (Figure 3.42). The sound barriers were inserted in one section of the ducts for an additional sound flanking test of the duct system. The silencer and the plug are described in detail under the equipment chapter.

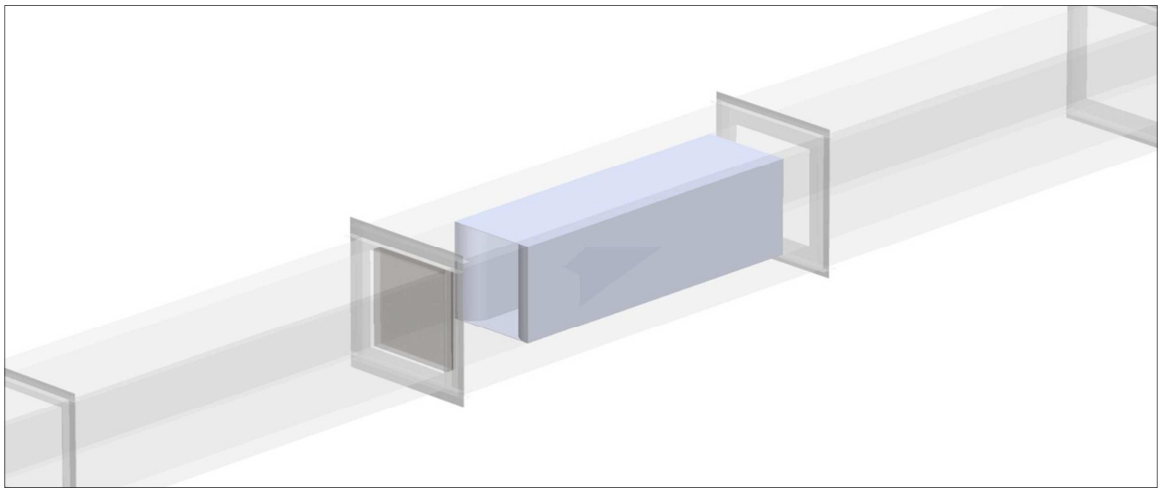

Figure 3.42 – Silencer and Plug 2 inside Duct

3.5.2. Speaker Positions

3.5.2.1. Speaker Position 1

Speaker position 1 has the bass speaker pointed inside the duct as shown in Figure 3.43. It is 21.4 in. from the duct opening and angled at 35 degrees. The mid-range speaker and the horns are 21.2 in. from the duct opening and angled at 25 degrees as shown in Figure 6.6. The microphone on this setup hangs down 16 in. from the top edge of the duct opening and 6 in. to the right of the center.

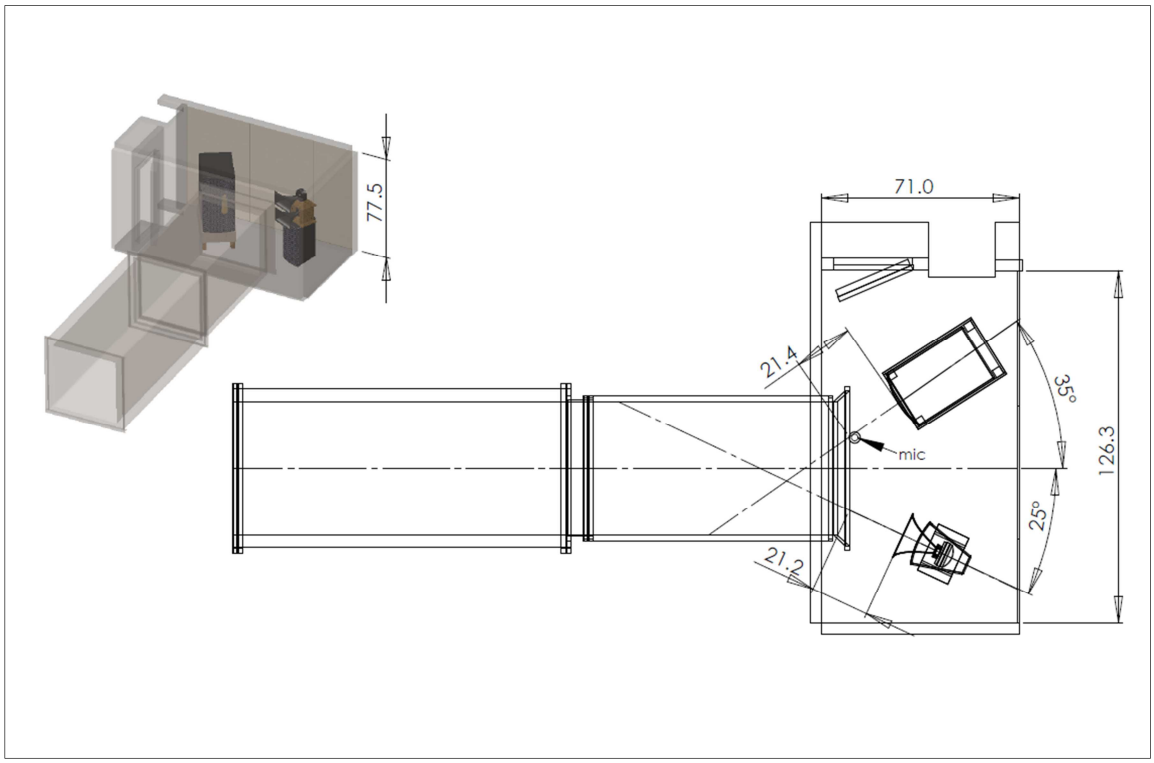

Figure 3.43 – Speaker Position 1

3.5.2.2. Speaker Position 2

Speaker position 2 has the bass speaker, the mid-range speaker, and the horns are pointed inside the sound chamber as shown in Figure 3.44. The bass speaker is angled at 65 degrees while the mid speaker and the horns are angle 58 degrees. The microphone on this setup is positioned right where the center-line axes of the speakers intersect. It is attached on a stand that is 36 in. from the floor and is at the center axis of the duct.

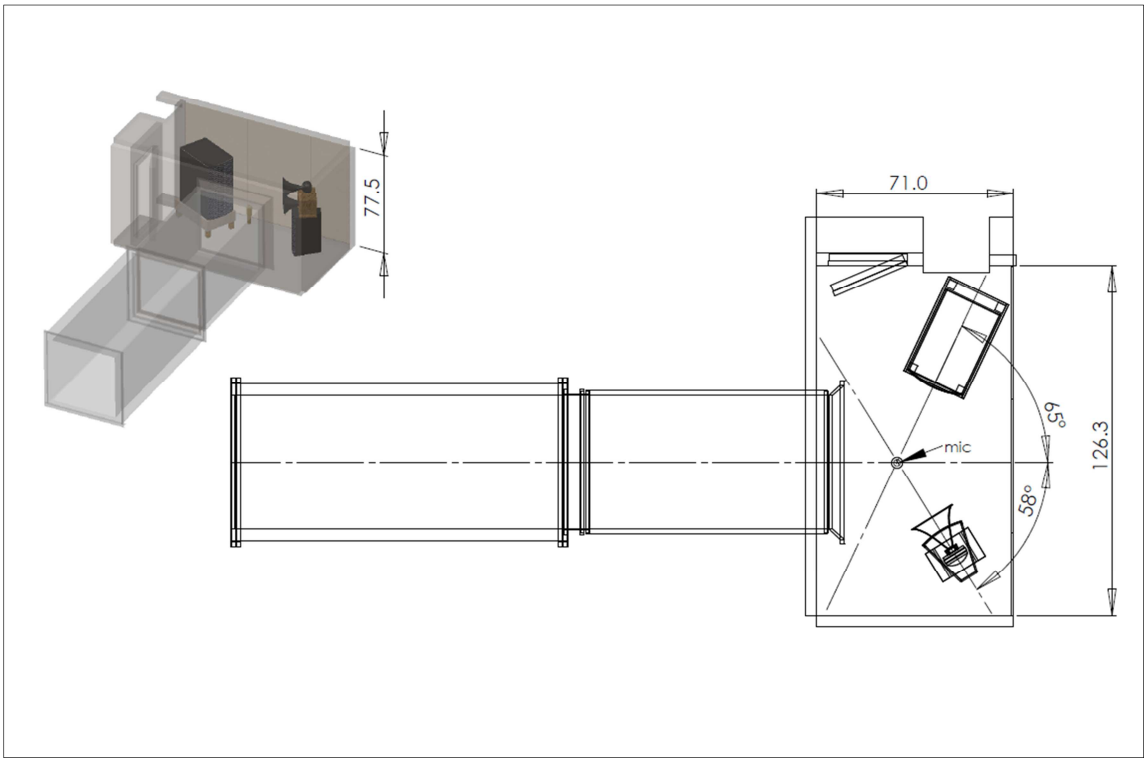

Figure 3.44 – Speaker Position 2

3.5.2.3. Speaker Position 3

Speaker position 3 is similar to speaker position 1, except the speakers are turned so they are pointed towards the corners of the duct opening as shown in Figure 3.45. The bass speaker is angled 61 degrees while the mid speaker and the horns are angled 51 degrees. The microphone on this setup is positioned where the center-line axes of the speakers intersect. It is attached on the stand which is 36 in. from the floor and is at the center axis of the duct.

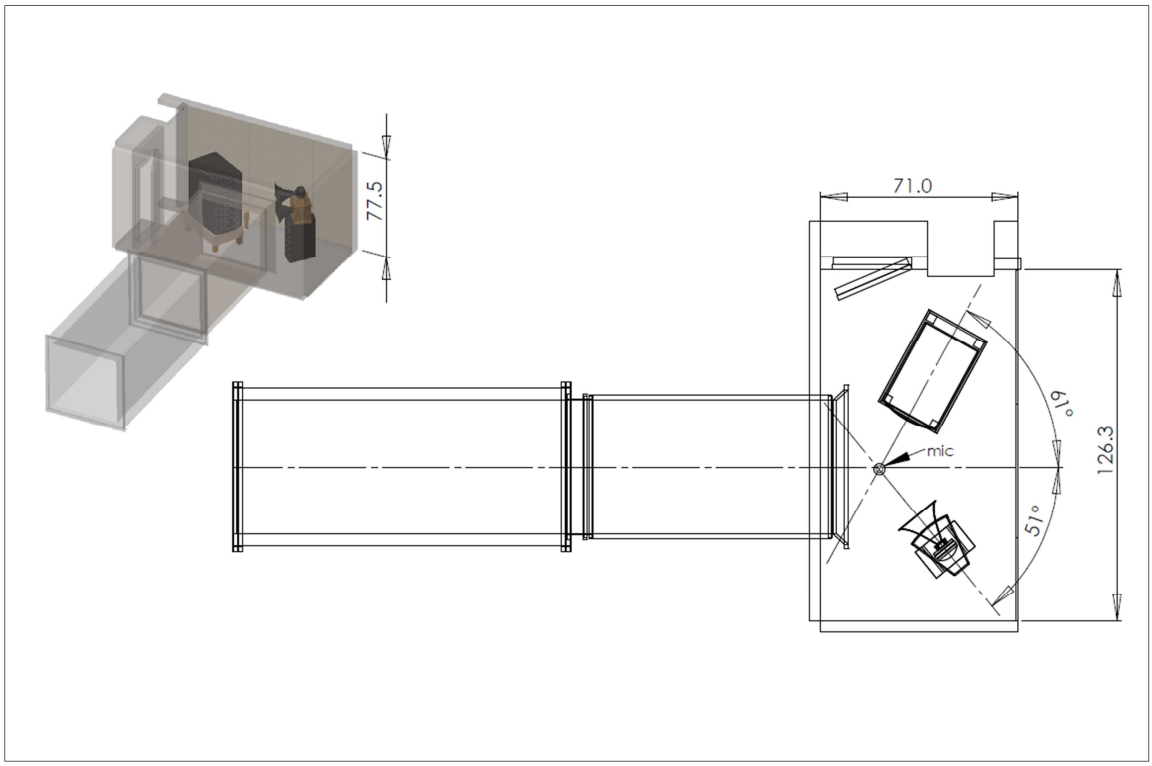

Figure 3.45 – Speaker Position 3

3.5.2.4. Speaker Position 4

Speaker position 4 is similar to speaker position 2, except the speakers are turned so that they are pointed towards the corners of the duct. The bass speaker is angled 60 degrees while the mid-range speaker and the horns are angled 54 degrees. The microphone on this setup is positioned where the center-line axes of the speakers intersect. It is attached on the stand which is 36 in. from the floor and is slightly to the right of the center axis of the duct.

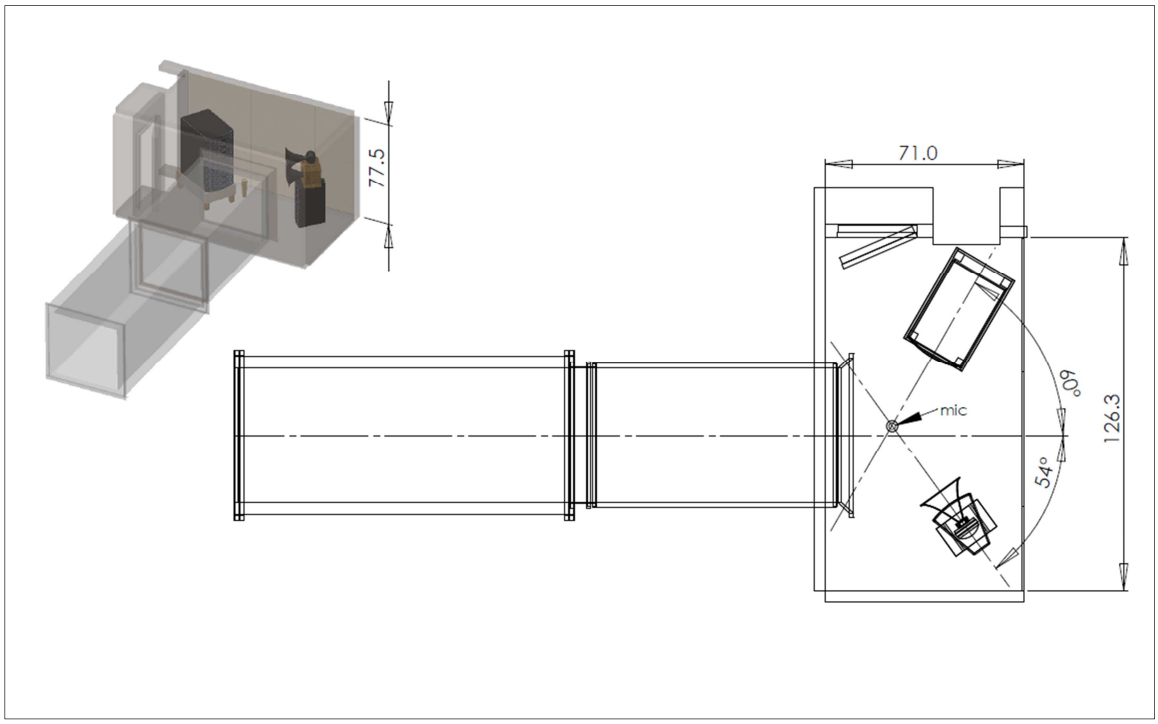

Figure 3.46 – Speaker Position 4

3.5.3. Test Setups for Duct and Speaker Configurations

Duct system configurations are combination of the five variables described in sections 3.5.1 and four speaker positions 3.5.2. Table 3.1 summarizes five duct configurations of the variables in which the four speaker positions were tested while Table 3.2 summarize the five duct variables used in configurations. A total of ten duct and speaker configurations were tested.

Table 3.1 - Table of Test Configurations for Speaker Position

		Speaker Positions			
		1	**2**	**3**	**4**
Duct System Configurations	**A**	Board, Plug 1	Board, Plug 1		Board, Plug 1
	B	Board, Plugs 1 & 2			
	C		Board, Duct, Plug 1	Board, Duct, Plug 1	Board, Duct, Plug 1
	D			Duct, Plug 1	Duct, Plug 1
	E			Floor, Duct, Plug 1	

Table 3.2 - Table of Duct Configuration Variables

Board	Indicates that the back board in the source room is installed. (See 6.1.1.)
Floor	Indicates that additional sheetmetal on the floor of the source room has been installed. (See 6.1.2.)
Duct	Indicates that additional sheetmetal inside the ducts has been installed. (See 6.1.3.)
Plug 1	Indicates that plug 1 was used. (See 6.1.4.)
Plugs 1 & 2	Indicates that plugs 1 & 2 were used. (See 6.1.5.)

3.5.4. Microphone Positions

A total of three microphone positions were tested. For several speaker positions, sound levels were measured in the source room without any sound barrier in the duct then sound levels in the source room were measured again after a sound barrier was inserted in the duct. This test was done to find the microphone position that gives the most consistent sound levels in the source room with and without a sound barrier in the duct. The three microphone positions are described in detail in the following paragraphs.

The **"duct end (D)"** microphone position hangs down about 16-in. from the top edge of the duct opening and about 6-in. to the right of the center line. The microphone holder is attached at the end of a threaded rod. The threaded rod is screwed into a threaded hole of another aluminum piece. The aluminum piece is then bolted to the end of the duct opening.

The **"off-center (O)"** microphone position is positioned 6-in. (away from the bass speaker) where the center-line axes of the bass and mid-range speakers intersect. The microphone holder is attached to the end of a threaded rod. The rod is locked by bolting it to a base to keep it stable. The microphone holder stands 36-in. from the floor.

The **"center (C)"** microphone position is positioned where the center-line axes of the bass and mid-range speakers intersect. It does not have to be located at the center axis of the duct. The microphone holder is attached the end of a threaded rod. The rod is locked by bolting it to a base to keep it stable. The microphone holder stands 36-in. from the floor.

3.5.4.1. Microphone Positions Center & Off-center

For the first microphone position comparison, Duct and speaker configuration 2C was used to compare the source chamber sound levels associated with the center and off-center microphone positions (Figure 3.47). This configuration used speaker position 2 (refer to Section 3.5.2.2 and Figure 3.44) and duct configuration C (refer to Section 3.5.3, Table 3.1, and Table 3.2). The silencer with plug 2 (Figure 3.42) was used as sound barriers in this microphone position comparison.

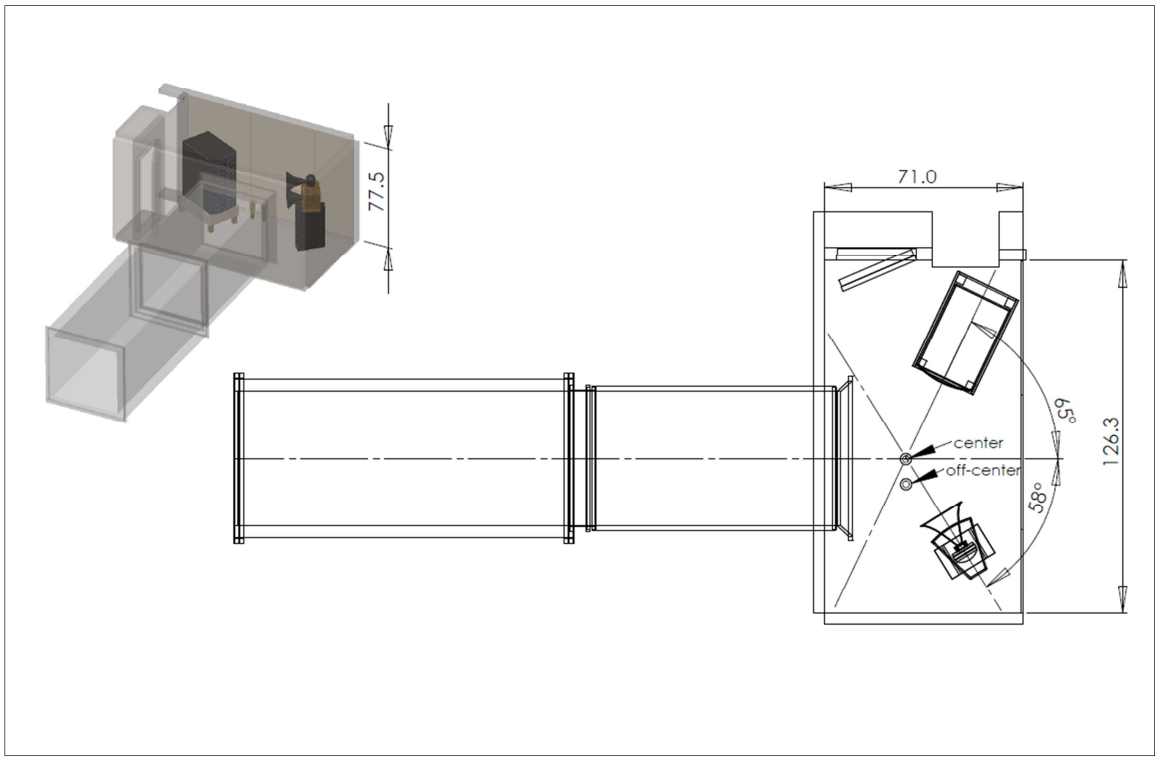

Figure 3.47 – Configuration 2C showing two Microphone Positions

3.5.4.2. Microphone Positions Duct End and Center

For the second and third microphone position comparisons, duct and speaker configuration 3C was used to compare the source chamber sound levels associated with the duct end and center microphone positions (Figure 3.48). This configuration used speaker position 3 (refer to Section 3.5.2.3 and Figure 3.45) and duct configuration C (refer to Section 3.5.3, Table 3.1, and Table 3.2). The silencer with plug 2 (Figure 3.42) was used as sound barriers for the second microphone position comparison while plug 1 (Figure 3.40) was used for the third.

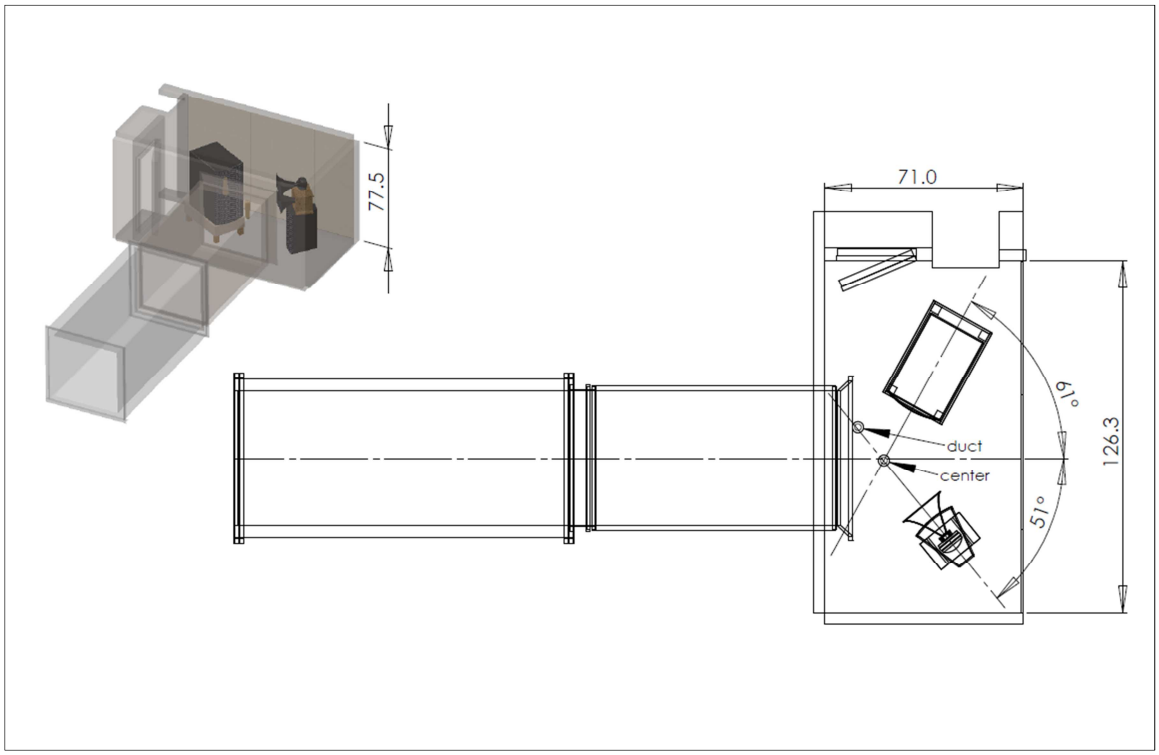

Figure 3.48 – Configuration 3C showing two Microphone Positions

3.5.4.3. Microphone Positions Duct-end, Off-center, and Center

For the fourth microphone position comparison, duct and speaker configuration 4C was used to compare the source chamber sound levels associated with the duct end, off-center, and center microphone positions (Figure 3.49). This configuration uses speaker position 4 (refer to Section 3.5.2.4 and Figure 3.46) .and duct configuration C (refer to Section 3.5.3, Table 3.1, and Table 3.2). Plug 1 (Figure 3.40) was used as sound barrier in this microphone position comparison.

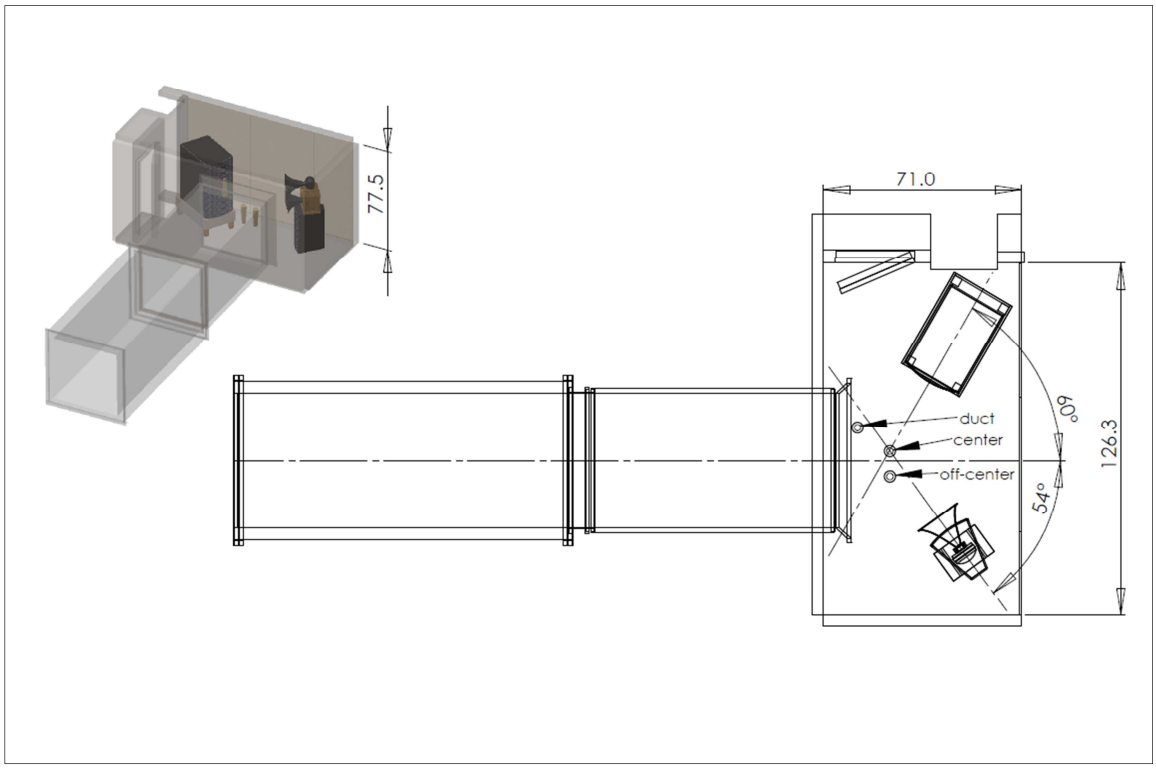

Figure 3.49 – Configuration 4C showing three Microphone Positions

3.5.5. Test Setups for Microphone Positions

Duct and speaker configurations are combination of the variables described in Section 3.5.1, the speaker positions described in Section 3.5.2, and the microphone positions described in Section 3.5.4. Table 3.3 and Table 3.4 show the speaker and microphone configurations that were examined.

Table 3.3 - Test Configurations for Microphone Positions

		Microhpone Positions		
		Duct ("D")	**Off-Center ("O")**	**Center ("C")**
Duct and Speaker Configurations	**2C**		Board, Duct, Silencer & Plug 2	Board, Duct, Silencer & Plug 2
	3C	Board, Duct, Silencer & Plug 2		Board, Duct, Silencer & Plug 2
	3C	Board, Duct, Plug 1		Board, Duct, Plug 1
	4C	Board, Duct, Plug 1	Board, Duct, Plug 1	Board, Duct, Plug 1

Table 3.4 - Duct Configuration Variables

Board	Indicates that the back board in the source room is installed. (See 6.1.1.)
Duct	Indicates that additional sheetmetal inside the ducts has been installed. (See 6.1.3.)
Plug 1	Indicates that plug 1 was used. (See 6.1.4.)
Silencer & Plug 2	Indicates that the silencer and plug 2 were used. (See 6.1.6.)

CHAPTER 4

FINDINGS OF THE STUDY

4.1. Test Results for Duct and Speaker Configurations

4.1.1. Duct Configurations for Speaker Position 1

Table 4.1 and Figure 4.1 show the insertion loss values and Table 4.2 and Figure 4.2 show the source chamber sound level differences for two different duct configurations for speaker position 1. Configuration 1A used plug 1 only while configuration 1B used plugs 1 and 2 at the same time (refer to Figure 3.40 in Section 3.5.1.4 and Figure 3.41 in Section 3.5.1.5).

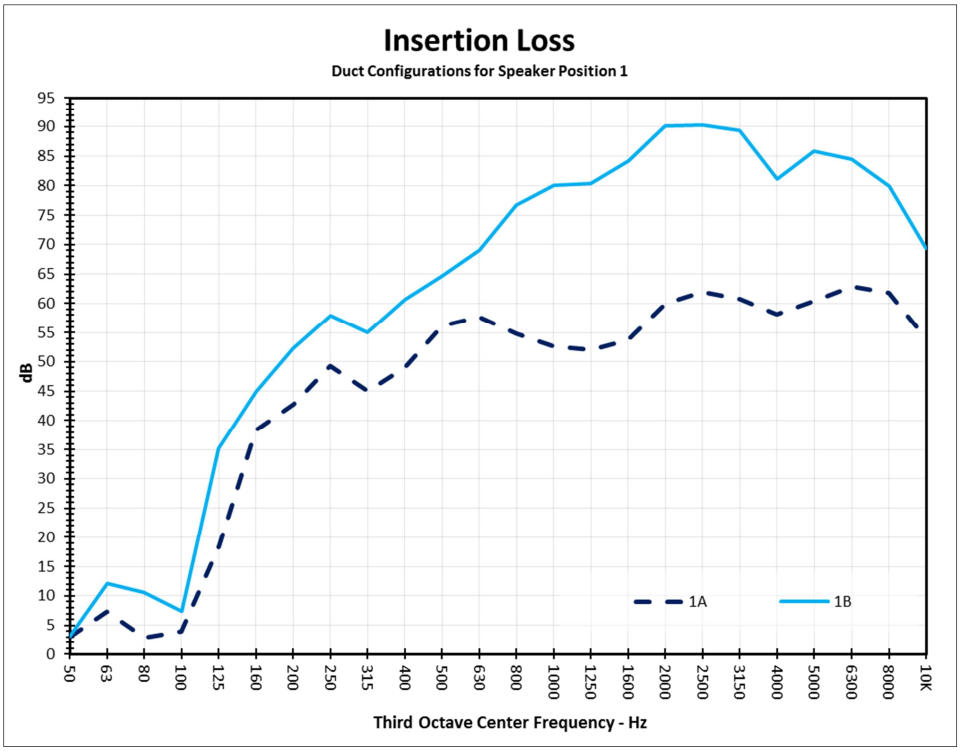

Figure 4.1 - Insertion Loss for Speaker Position 1

Table 4.1 - Insertion Loss for Speaker Position 1

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
1A	3.1	7.3	2.8	4.0	18.4	38.3	42.7	49.2	45.0	49.0	56.2	57.6	54.9	52.7	52.0	53.7	59.9	61.9	60.7	58.1	60.5	62.9	61.9	53.9
1B	3.2	12.1	10.6	7.5	35.2	45.0	52.3	57.9	55.1	60.6	64.6	69.1	76.7	80.0	80.4	84.2	90.2	90.3	89.4	81.2	85.8	84.5	79.9	69.3

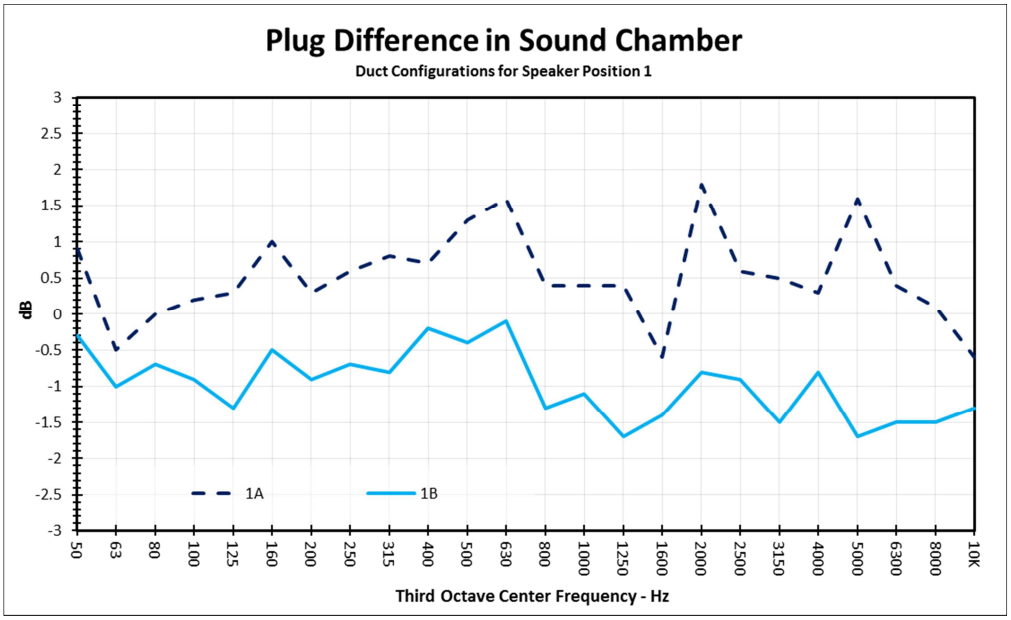

Figure 4.2 – Plug Difference in Sound Chamber for Speaker Position 1

Table 4.2 – Plug Difference for Speaker Position 1

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
1A	0.9	-0.5	0.0	0.2	0.3	1.0	0.3	0.6	0.8	0.7	1.3	1.6	0.4	0.4	0.4	-0.6	1.8	0.6	0.5	0.3	1.6	0.4	0.1	-0.6
1B	-0.3	-1.0	-0.7	-0.9	-1.3	-0.5	-0.9	-0.7	-0.8	-0.2	-0.4	-0.1	-1.3	-1.1	-1.7	-1.4	-0.8	-0.9	-1.5	-0.8	-1.7	-1.5	-1.5	-1.3

4.1.2. Duct Configurations for Speaker Position 2

Table 4.3 and Figure 4.3 show the insertion loss values and Table 4.4 and Figure 4.4 show the source chamber sound level differences for two different duct configurations for speaker position 2. The inside walls of the ducts consisted only of 18-gauge sheet metal for configuration 2A. For configuration 2C, 12-gauge sheet metal

panels were added to all four inside walls of all of the duct sections throughout the entire length of the duct except the section where the plug is. Plug 1 was used for these tests.

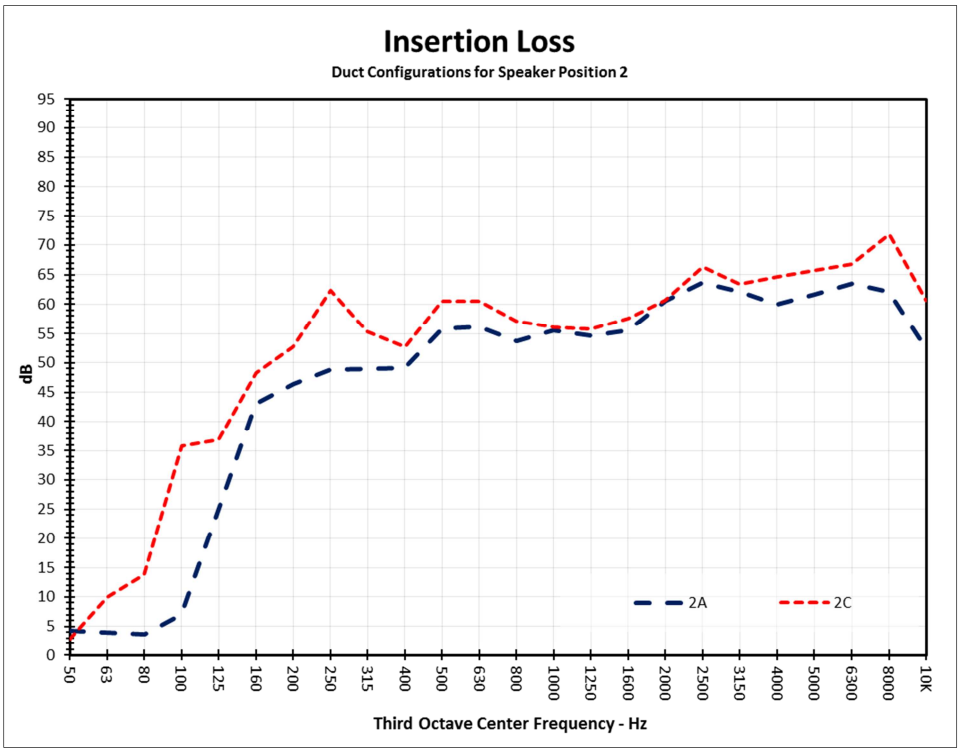

Figure 4.3 - Insertion Loss for Speaker Position 2

Table 4.3 - Insertion Loss for Speaker Position 2

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
2A	4.3	4.0	3.6	7.0	25.1	43.0	46.4	48.8	48.9	49.2	55.9	56.2	53.8	55.6	54.7	55.6	60.6	63.6	62.2	60.0	61.6	63.5	62.1	52.3
2C	2.8	10.0	13.8	35.7	36.9	48.2	52.7	62.3	55.4	52.7	60.5	60.5	57.2	56.1	55.8	57.6	60.6	66.4	63.5	64.6	65.7	66.8	71.8	60.7

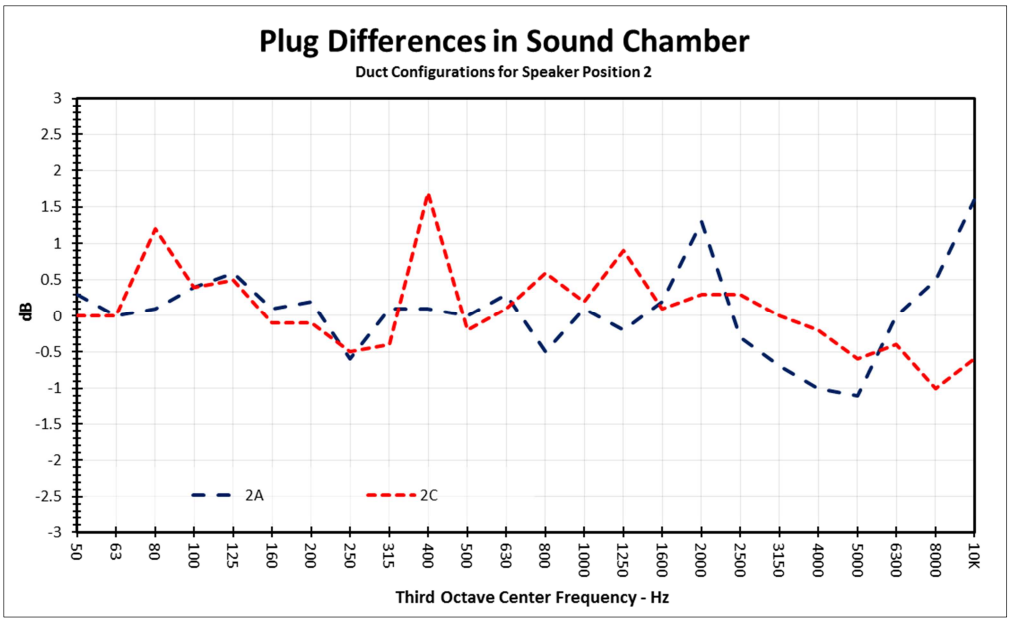

Figure 4.4 – Plug Difference in Sound Chamber Speaker Position 2

Table 4.4 – Plug Difference for Speaker Position 2

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
2A	0.3	0.0	0.1	0.4	0.6	0.1	0.2	-0.6	0.1	0.1	0.0	0.3	-0.5	0.1	-0.2	0.2	1.3	-0.3	-0.7	-1.0	-1.1	0.0	0.5	1.6
2C	0.0	0.0	1.2	0.4	0.5	-0.1	-0.1	-0.5	-0.4	1.7	-0.2	0.1	0.6	0.2	0.9	0.1	0.3	0.3	0.0	-0.2	-0.6	-0.4	-1.0	-0.6

4.1.3. Duct Configurations for Speaker Position 3

Table 4.5 and Figure 4.5 show the insertion loss values, and Table 4.6 and Figure 4.6 show the source chamber sound level differences for three different duct configurations for speaker position 3. 12-gauge sheet metal panels were attached to the inside walls of the duct for configurations 3C, 3D, and 3E. For configuration 3D, the particle board panels covering the silencers behind the sound chamber were removed. For configuration 3E, in addition to removing the particle board panels, 12-gauge sheet metal panels were added on the 18-gauge gauge sheet metal floor of the sound chamber.

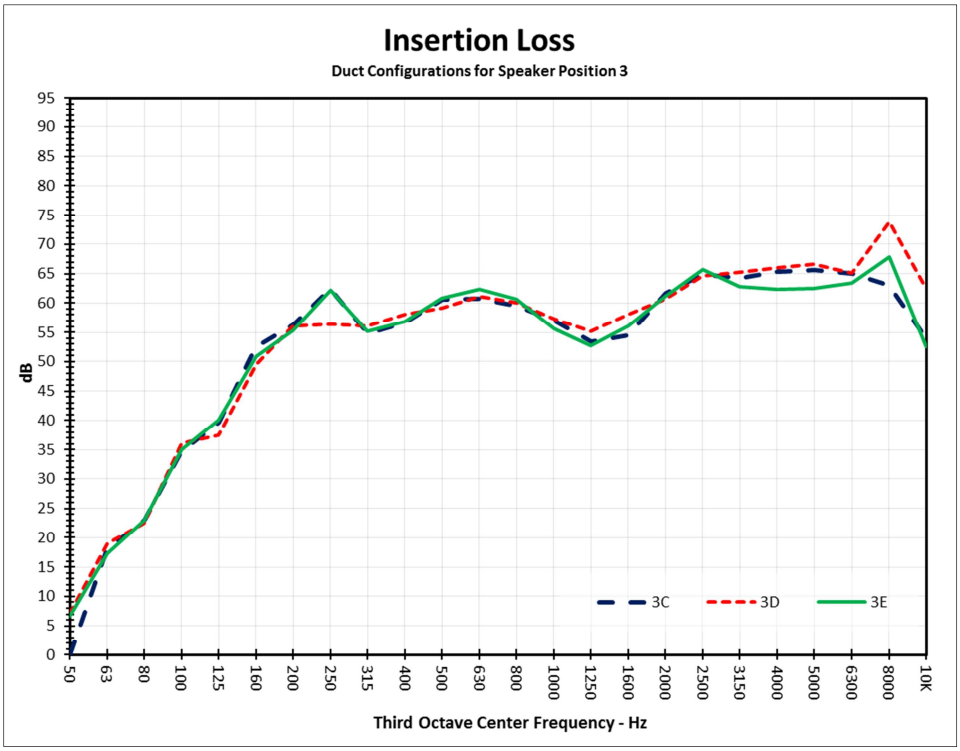

Figure 4.5 - Insertion Loss Speaker Position 3

Table 4.5 - Insertion Loss for Speaker Position 3

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
3C	0.2	18.1	23.0	34.6	39.7	52.5	56.3	62.4	54.7	56.6	60.6	60.7	59.5	57.1	53.4	54.5	61.6	64.8	64.3	65.4	65.6	65.1	63.1	53.9
3D	7.0	18.9	22.5	36.1	37.5	49.6	56.1	56.4	56.1	58.0	59.1	61.2	60.1	57.3	55.2	58.1	60.7	64.7	65.3	66.0	66.6	65.1	73.8	62.5
3E	6.6	17.3	22.9	35.0	40.1	50.8	55.3	62.2	55.1	56.8	60.8	62.4	60.6	55.6	52.8	56.1	61.1	65.7	62.8	62.3	62.5	63.5	67.9	52.6

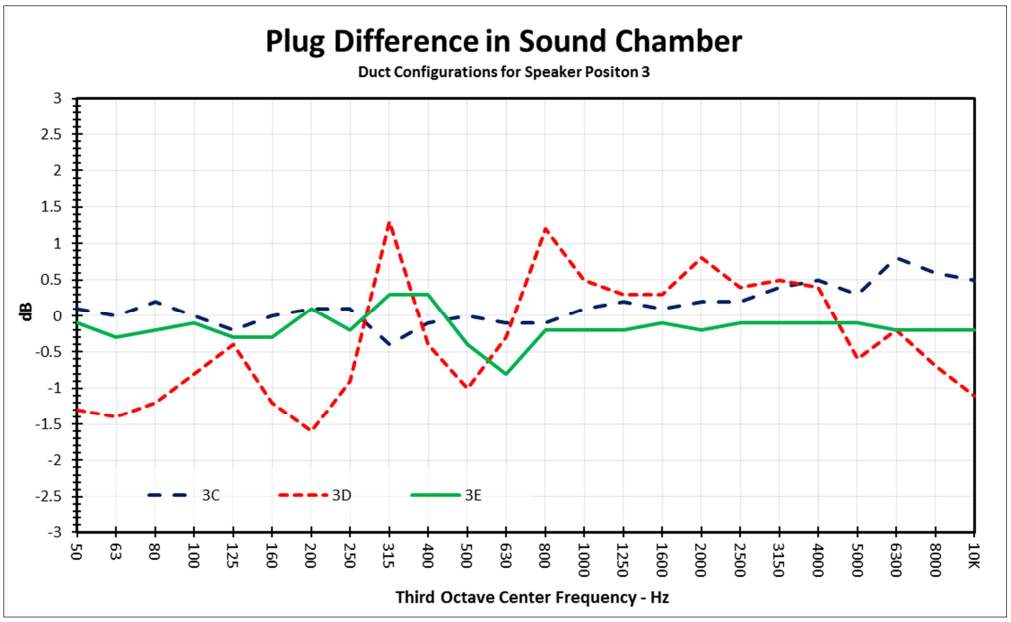

Figure 4.6 – Plug Difference in Sound Chamber for Speaker Position 3

Table 4.6 – Plug Difference for Speaker Position 3

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
3C	0.1	0.0	0.2	0.0	-0.2	0.0	0.1	0.1	-0.4	-0.1	0.0	-0.1	-0.1	0.1	0.2	0.1	0.2	0.2	0.4	0.5	0.3	0.8	0.6	0.5
3D	-1.3	-1.4	-1.2	-0.8	-0.4	-1.2	-1.6	-0.9	1.3	-0.4	-1.0	-0.3	1.2	0.5	0.3	0.3	0.8	0.4	0.5	0.4	-0.6	-0.2	-0.7	-1.1
3E	-0.1	-0.3	-0.2	-0.1	-0.3	-0.3	0.1	-0.2	0.3	0.3	-0.4	-0.8	-0.2	-0.2	-0.2	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2

4.1.4. Duct Configurations for Speaker Position 4

Table 4.7 and Figure 4.7 show the insertion loss values and Table 4.8 and Figure 4.8 show the source chamber sound level differences for different duct configurations for speaker position 4. Configuration 4A does not have the 12-gauge sheet metal lining inside the duct. Configuration 4C had the 12-gauge sheet metal lining installed. The 0.75-in.-thick back board panels were in place for both configurations 4A and 4C. Configuration 4D is similar to configuration 4C except the back board panels were removed.

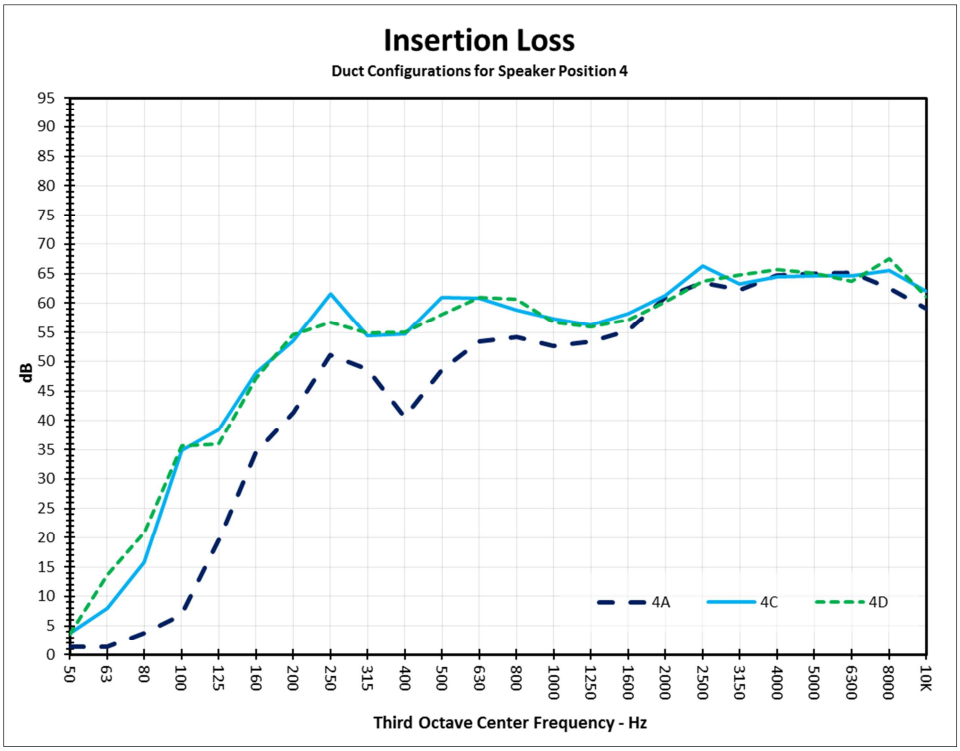

Figure 4.7 - Insertion Loss for Speaker Position 4

Table 4.7 - Insertion Loss for Speaker Position 4

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
4A	1.4	1.4	3.8	6.9	19.7	34.4	41.4	51.2	48.7	40.7	48.7	53.4	54.3	52.7	53.5	55.3	61.1	63.5	62.3	64.7	65.0	65.2	62.6	59.0
4C	3.7	8.1	15.8	34.9	38.4	48.2	53.5	61.6	54.4	54.8	60.9	60.8	58.8	57.3	56.2	58.2	61.2	66.3	63.3	64.5	64.6	64.7	65.5	62.0
4D	3.6	13.6	20.9	35.6	35.9	47.2	54.5	56.8	54.9	55.1	58.1	60.9	60.6	56.8	55.9	57.2	60.1	63.7	64.7	65.8	65.1	63.7	67.5	61.1

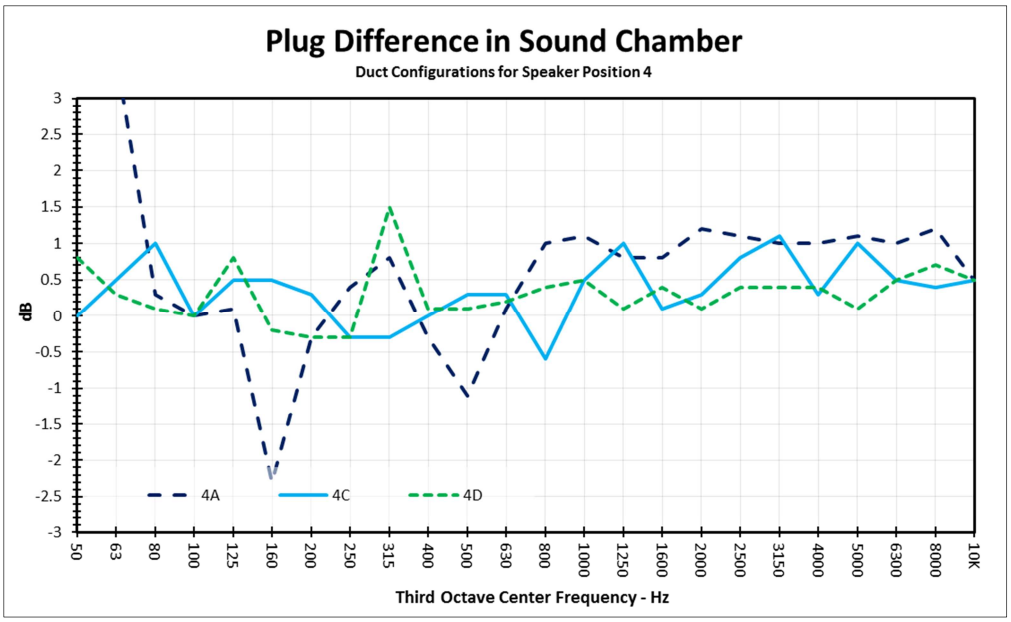

Figure 4.8 – Plug Difference in Sound Chamber for Speaker Position 4

Table 4.8 – Plug Difference for Speaker Position 4

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
4A	4.3	3.6	0.3	0.0	0.1	-2.3	-0.3	0.4	0.8	-0.3	-1.1	0.1	1.0	1.1	0.8	0.8	1.2	1.1	1.0	1.0	1.1	1.0	1.2	0.5
4C	0.0	0.5	1.0	0.0	0.5	0.5	0.3	-0.3	-0.3	0.0	0.3	0.3	-0.6	0.5	1.0	0.1	0.3	0.8	1.1	0.3	1.0	0.5	0.4	0.5
4D	0.8	0.3	0.1	0.0	0.8	-0.2	-0.3	-0.3	1.5	0.1	0.1	0.2	0.4	0.5	0.1	0.4	0.1	0.4	0.4	0.4	0.1	0.5	0.7	0.5

4.2. Test Results for Microphone Positions

4.2.1. Microphone Positions Center and Off-center

Using 2C for duct and speaker configuration and plug 1 for sound barrier, the source chamber sound level differences for microphone positions center ("C") and off-center ("O") are shown in Figure 4.9 and Table 4.9.

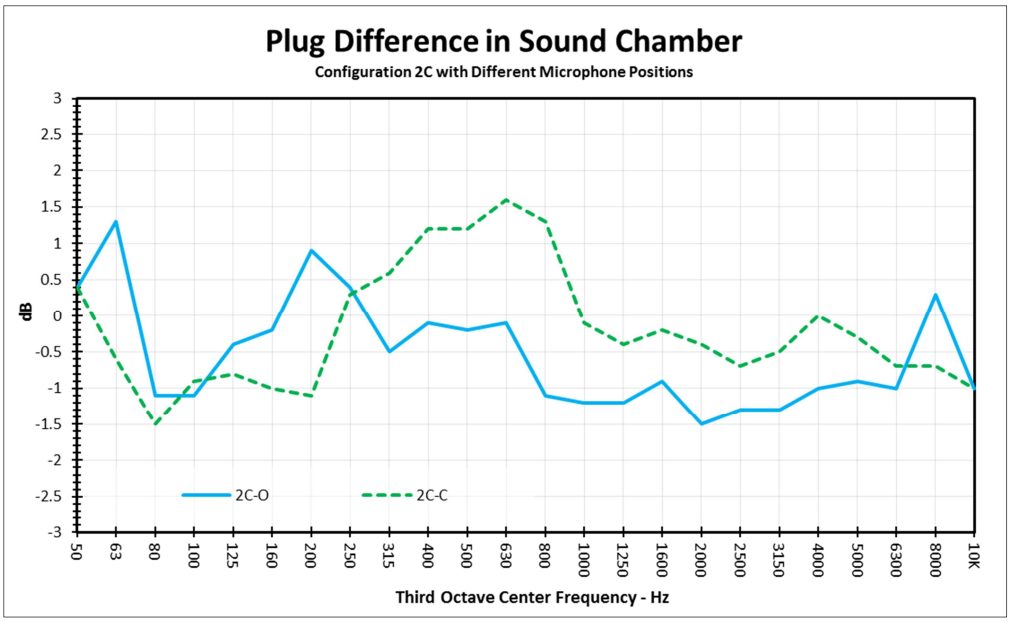

Figure 4.9 – Plug Difference in Sound Chamber for Center and Off-center Microphones Positions using Plug 1

Table 4.9 - Plug Difference in Sound Chamber for Center and Off-center Microphones Positions using Plug 1

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
2C-O	0.4	1.3	-1.1	-1.1	-0.4	-0.2	0.9	0.4	-0.5	-0.1	-0.2	-0.1	-1.1	-1.2	-1.2	-0.9	-1.5	-1.3	-1.3	-1.0	-0.9	-1.0	0.3	-1.0
2C-C	0.4	-0.6	-1.5	-0.9	-0.8	-1.0	-1.1	0.3	0.6	1.2	1.2	1.6	1.3	-0.1	-0.4	-0.2	-0.4	-0.7	-0.5	0.0	-0.3	-0.7	-0.7	-1.0

4.2.2. Microphone Positions Duct End and Center

Using 3C for duct and speaker configuration and plug 1 for sound barrier, the source chamber sound level differences for microphone positions duct end ("D") and center ("C") are shown in Figure 4.10 and Table 4.10.

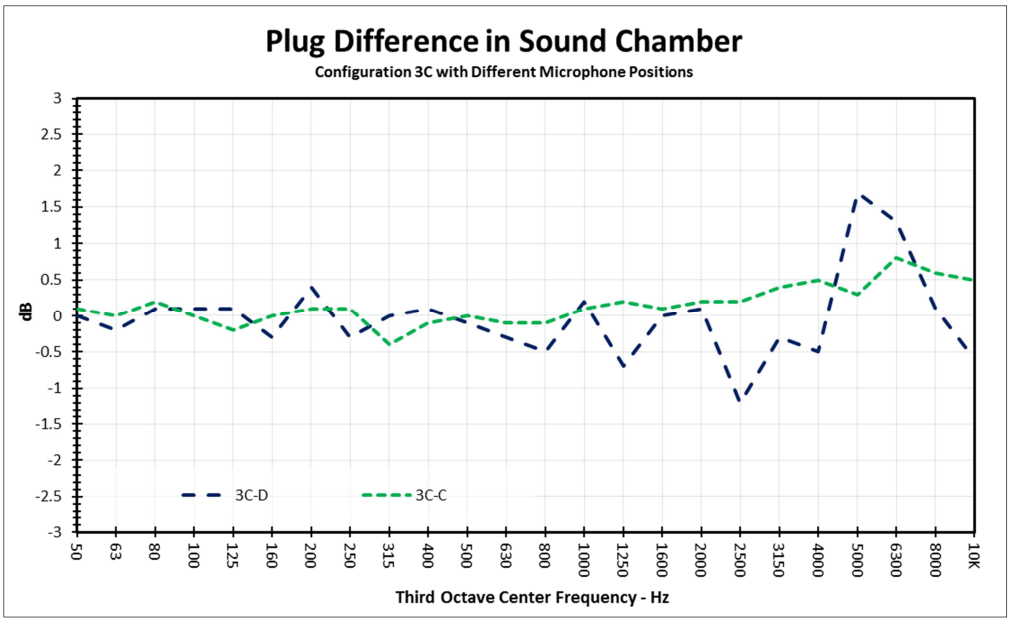

Figure 4.10 – Plug Difference in Sound Chamber for Duct End & Center Microphones Positions using Plug 1

Table 4.10 - Plug Difference in Sound Chamber for Duct End & Center Microphones Positions using Plug 1

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
3C-D	0.0	-0.2	0.1	0.1	0.1	-0.3	0.4	-0.3	0.0	0.1	-0.1	-0.3	-0.5	0.2	-0.7	0.0	0.1	-1.2	-0.3	-0.5	1.7	1.3	0.1	-0.6
3C-C	0.1	0.0	0.2	0.0	-0.2	0.0	0.1	0.1	-0.4	-0.1	0.0	-0.1	-0.1	0.1	0.2	0.1	0.2	0.2	0.4	0.5	0.3	0.8	0.6	0.5

Using 3C for duct and speaker configuration and silencer with plug 2 for sound barrier, the source chamber sound level differences for microphone positions duct end ("D") and center ("C") are shown in Figure 4.11 and Table 4.10.

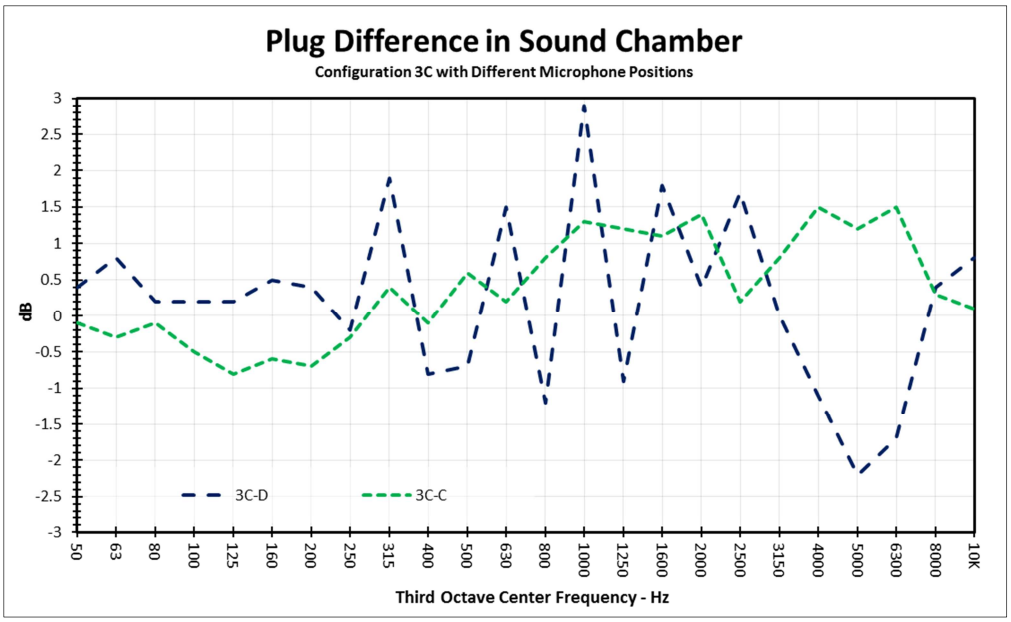

Figure 4.11 – Plug Difference in Sound Chamber for Duct-end & Center Microphones Positions using Silencer with Plug 2

Table 4.11 - Plug Difference in Sound Chamber for Duct-end & Center Microphones Positions using Silencer with Plug 2

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
3C-D	0.4	0.8	0.2	0.2	0.2	0.5	0.4	-0.2	1.9	-0.8	-0.7	1.5	-1.2	2.9	-0.9	1.8	0.4	1.7	0.0	-1.1	-2.2	-1.7	0.4	0.8
3C-C	-0.1	-0.3	-0.1	-0.5	-0.8	-0.6	-0.7	-0.3	0.4	-0.1	0.6	0.2	0.8	1.3	1.2	1.1	1.4	0.2	0.8	1.5	1.2	1.5	0.3	0.1

4.2.3. Microphone Positions Duct-end, Off-center, and Center

Using 4C for duct and speaker configuration and plug 1 for sound barrier, the source chamber sound level differences for microphone positions duct end (“D”), off-center (“O”), and center (“C”) are shown in Figure 4.12 and Table 4.12.

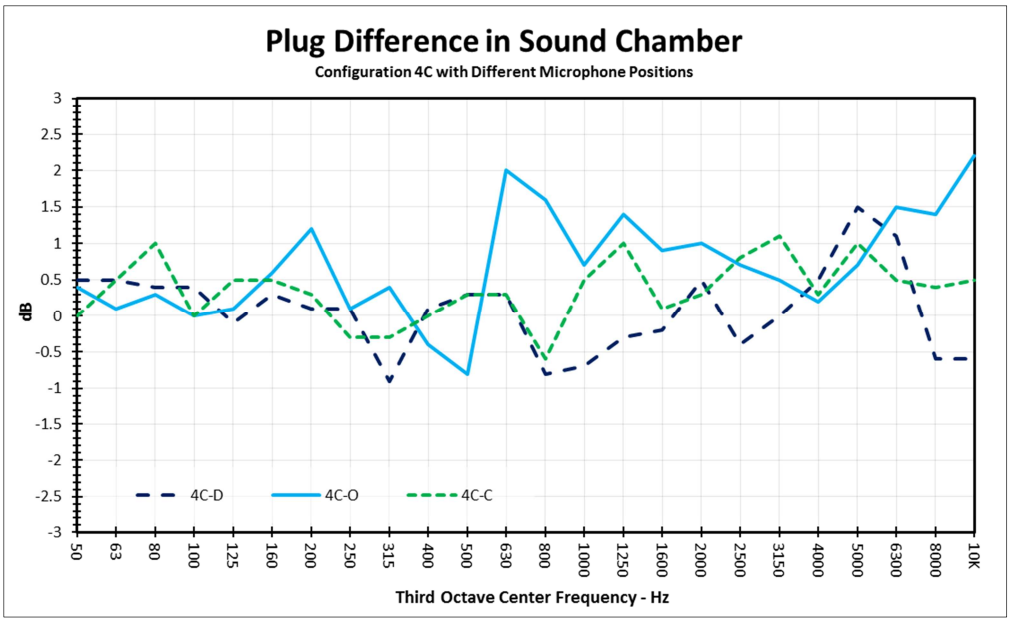

Figure 4.12 – Plug Difference in Sound Chamber for Duct End, Off-center, & Center Microphones Positions using Plug 1

Table 4.12 - Plug Difference in Sound Chamber for Duct End, Off-center, & Center Microphones Positions using Plug 1

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
4C-D	0.5	0.5	0.4	0.4	-0.1	0.3	0.1	0.1	-0.9	0.1	0.3	0.3	-0.8	-0.7	-0.3	-0.2	0.5	-0.4	0.0	0.5	1.5	1.1	-0.6	-0.6
4C-O	0.4	0.1	0.3	0.0	0.1	0.6	1.2	0.1	0.4	-0.4	-0.8	2.0	1.6	0.7	1.4	0.9	1.0	0.7	0.5	0.2	0.7	1.5	1.4	2.2
4C-C	0.0	0.5	1.0	0.0	0.5	0.5	0.3	-0.3	-0.3	0.0	0.3	0.3	-0.6	0.5	1.0	0.1	0.3	0.8	1.1	0.3	1.0	0.5	0.4	0.5

CHAPTER 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1. Discussion of Results

5.1.1. Discussion of Results for Duct and Speaker Configurations

5.1.1.1. Duct Configurations for Speaker Position 1

Although the insertion loss values for duct configuration 1B were higher than for duct configuration 1A, the differences in source chamber sound pressure levels with and without plugs 1 and 2 for both configurations were also high. For this reason, both configurations were unacceptable. Even though both configurations were discarded, the results are included to show that very high insertion loss values can be measured in the mid and high frequency ranges in the CMEST ASTM E477 facility.

5.1.1.2. Duct Configurations for Speaker Position 2

Figure 7.3 shows that the measured insertion loss values were significantly increased in the low- and mid-frequency 1/3 octave frequency bands when the 12-gauge sheet metal panels were added to the walls of the dual-wall ducts. This prevented sound in these frequency bands from being transmitted into the dual-wall duct cavities. Therefore, move sound energy in these frequency bands was transmitted down the duct to the reverberation room. Figure 4.4 shows that the difference in source chamber sound levels with and without plug 1 exceeded ±1 dB in some 1/3 octave frequency bands with duct configuration 2C.

5.1.1.3. Duct Configurations for Speaker Position 3

Figure 4.5 indicates the insertion loss values did not vary much between the three duct configurations that were examined for speaker position 3. However, when the back board panels were removed from the silencer face in configuration 3D, the insertion loss value in the 50 Hz 1/3 octave frequency band was increased from 0.2 dB to 7.0 dB. Figure 4.6 shows that the difference in source chamber sound levels with and without plug 1 exceeded ±1 dB in several 1/3 octave frequency bands with duct configuration 3D. Figure 4.6 also indicates that when 12-gauge sheet metal panels were added to the source chamber floor, the difference in source chamber sound levels were within ±1 dB in all 1/3 octave frequency bands.

5.1.1.4. Duct Configurations for Speaker Position 4

Figure 4.7 shows that the measured insertion loss values were significantly increased in the low- and mid-frequency 1/3 octave frequency bands when the 12-gauge sheet metal panes were added to the walls of the dual-wall ducts. The figure also indicates that when the back board panels were removed from the silencer face, the insertion loss value in the 63 Hz 1/3 octave frequency band increased from 8.1 dB to 13.6 dB and in the 80 Hz 1/3 octave frequency band increased from 15.8 dB to 20.9 dB. Figure 4.8 indicates that the difference in source chamber sound levels with and without plug 1 were within ±1 dB for all 1/3 octave frequency bands for duct configuration 4C except at 3150 Hz where it reached 1.1 dB. For duct configuration 4D, the source chamber sound difference exceeded ±1 dB by 0.5 dB in the 315 Hz 1/3 octave frequency band. Insertion losses tested for speaker position 4 were not conducted for the case where 12-gauge sheet metal panels were added the sound chamber floor. However, it is

anticipated that this would bring the source chamber sound level difference in the 315 Hz 1/3 octave frequency band to within ±1 dB.

5.1.2. Discussion of Results for Microphone Positions

Out of nine testing configurations, only the center ("C") microphone position using speaker position 3 have source chamber sound level differences with and without plug 1 for all 1/3 octave frequency band within ±1 dB. Figure 4.10 and Table 4.10 show that the maximum peak of configuration 3C-C is only 0.8 dB at 8,000 Hz.

In addition, the center ("C") microphone position using speaker position 4 have source chamber sound level differences with and without plug 1 for all 1/3 octave frequency band within ±1 dB limit **except** at one frequency. Figure 4.12 and Table 4.12 show that the maximum peak of configuration 4C-C is only 1.1 dB at 3,150 Hz.

5.2. Summary of Results

5.2.1. Summary of Results for Duct and Speaker Configurations

From ten different test configurations, using four speaker positions and five different duct variables, only three configurations were found to be acceptable: configurations 2C, 3E, and 4D (refer to Table 3.1 and Table 3.2). These configurations were chosen base on their high insertion loss, their low source chamber sound level differences with and without plug 1, and their consistency or smoothness. Their insertion losses are shown in Figure 5.1 and source chamber sound level differences with and without plug 1 are shown in Figure 5.2.

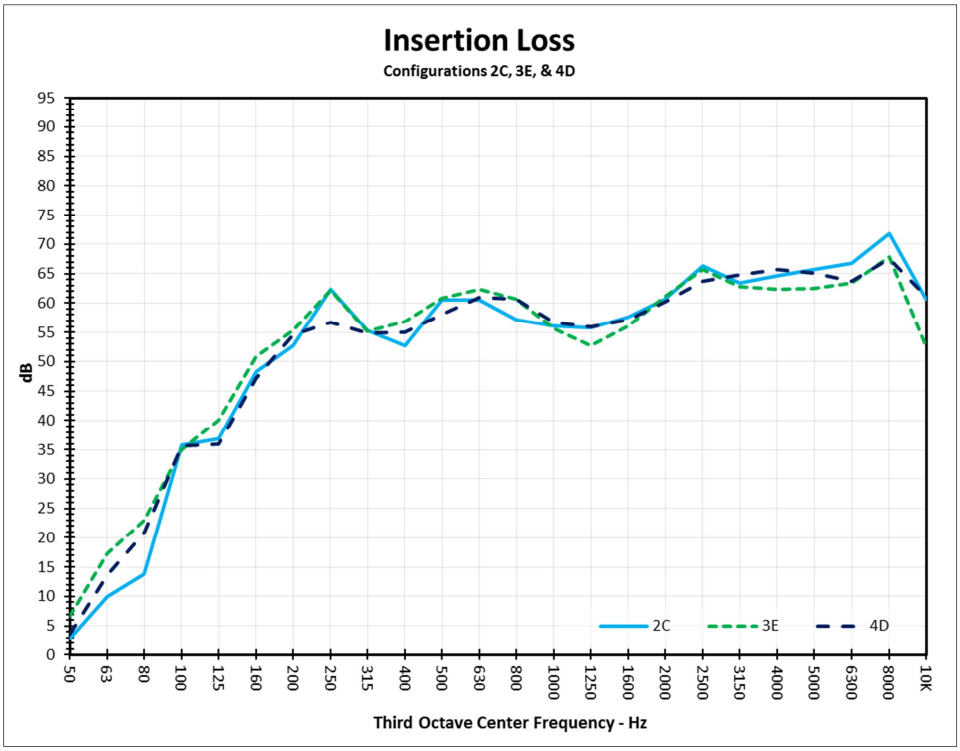

Figure 5.1 - Insertion Loss for Configurations 2C, 3E, & 4D

Table 5.1 - Insertion Loss for Configurations 2C, 3E, & 4D

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
2C	2.8	10.0	13.8	35.7	36.9	48.2	52.7	62.3	55.4	52.7	60.5	60.5	57.2	56.1	55.8	57.6	60.6	66.4	63.5	64.6	65.7	66.8	71.8	60.7
3E	6.6	17.3	22.9	35.0	40.1	50.8	55.3	62.2	55.1	56.8	60.8	62.4	60.6	55.6	52.8	56.1	61.1	65.7	62.8	62.3	62.5	63.5	67.9	52.6
4D	3.6	13.6	20.9	35.6	35.9	47.2	54.5	56.8	54.9	55.1	58.1	60.9	60.6	56.8	55.9	57.2	60.1	63.7	64.7	65.8	65.1	63.7	67.5	61.1

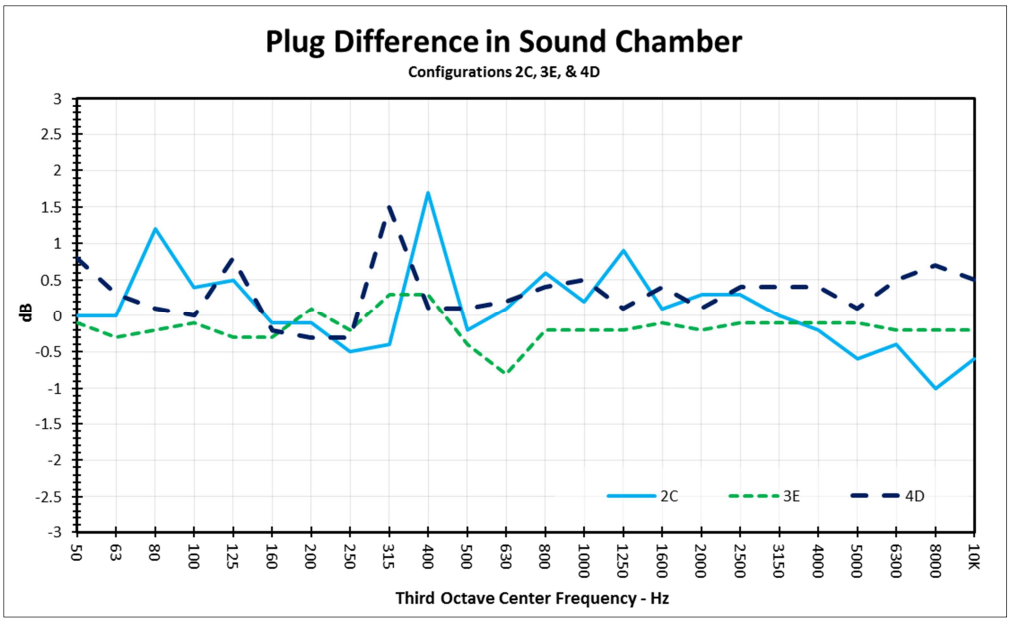

Figure 5.2 – Plug Difference for Configurations 2C, 3E, & 4D

Table 5.2 – Plug Difference in Sound Chamber for Configurations 2C, 3E, & 4D

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
2C	0.0	0.0	1.2	0.4	0.5	-0.1	-0.1	-0.5	-0.4	1.7	-0.2	0.1	0.6	0.2	0.9	0.1	0.3	0.3	0.0	-0.2	-0.6	-0.4	-1.0	-0.6
3E	-0.1	-0.3	-0.2	-0.1	-0.3	-0.3	0.1	-0.2	0.3	0.3	-0.4	-0.8	-0.2	-0.2	-0.2	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2
4D	0.8	0.3	0.1	0.0	0.8	-0.2	-0.3	-0.3	1.5	0.1	0.1	0.2	0.4	0.5	0.1	0.4	0.1	0.4	0.4	0.4	0.1	0.5	0.7	0.5

The three chosen configurations are similar in regards to insertion loss but it is possible to see that configuration 4D is the smoothest. For the source chamber sound level difference with and without plug 1, configuration 3E seems to be the lowest.

5.2.2. Effect of Additional Sheet Metal Lining inside the Duct

Adding a layer of 12-gauge galvanized sheet metal on the inside walls of the dual-wall duct eliminated the sound transmission into the dual-wall duct cavity. The insertion loss values shown for speaker position 2 (Figure 4.3) and speaker position 4 (Figure 4.7) show significant improvements in the low- and mid-frequency 1/3 octave frequency

bands. Figure 5.3 and Table 5.3 show the differences in insertion loss values before and after the additional layer of 12-gauge sheet metal was installed.

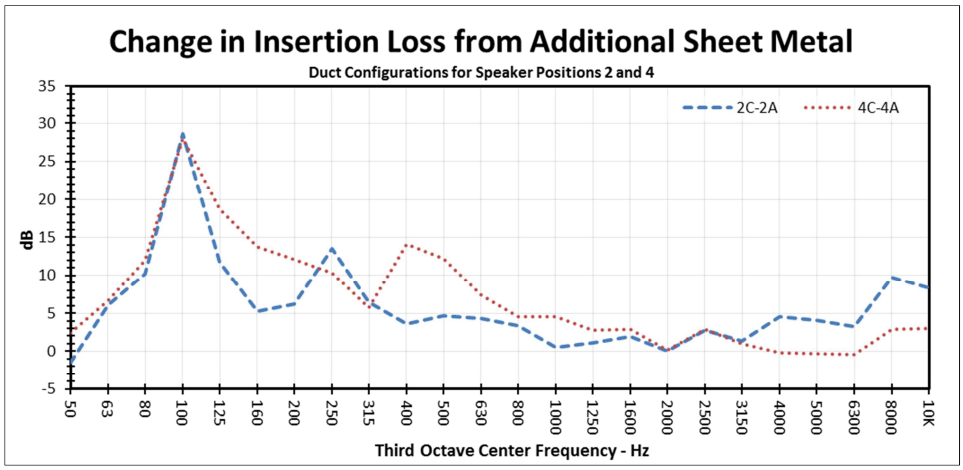

Figure 5.3 – Change in Insertion Loss from Additional Sheet Metal

Table 5.3 – Change in Insertion Loss from Additional Sheet Metal

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
2C-2A	-1.5	6.0	10.2	28.7	11.8	5.3	6.2	13.5	6.4	3.6	4.6	4.3	3.4	0.5	1.1	2.0	0.0	2.7	1.3	4.6	4.1	3.3	9.7	8.4
4C-4A	2.4	6.6	12.0	28.0	18.7	13.7	12.1	10.4	5.7	14.1	12.2	7.4	4.6	4.6	2.8	2.9	0.1	2.9	1.0	-0.2	-0.4	-0.5	2.9	3.0

5.2.3. Effect of Additional Sheet Metal Lining of Sound Chamber Floor

Adding an additional layer of 12-gauge galvanized sheet metal to the floor of the sound chamber significantly reduced the source chamber sound level difference with and without plug 1. Figure 5.4 and Table 5.4 show the source chamber sound level difference before and after the additional layer was installed. Configuration 3D is before the installation while configuration 3E is after. The figure indicates that the magnitudes of the peaks and dips after the installation were all within ±1 dB.

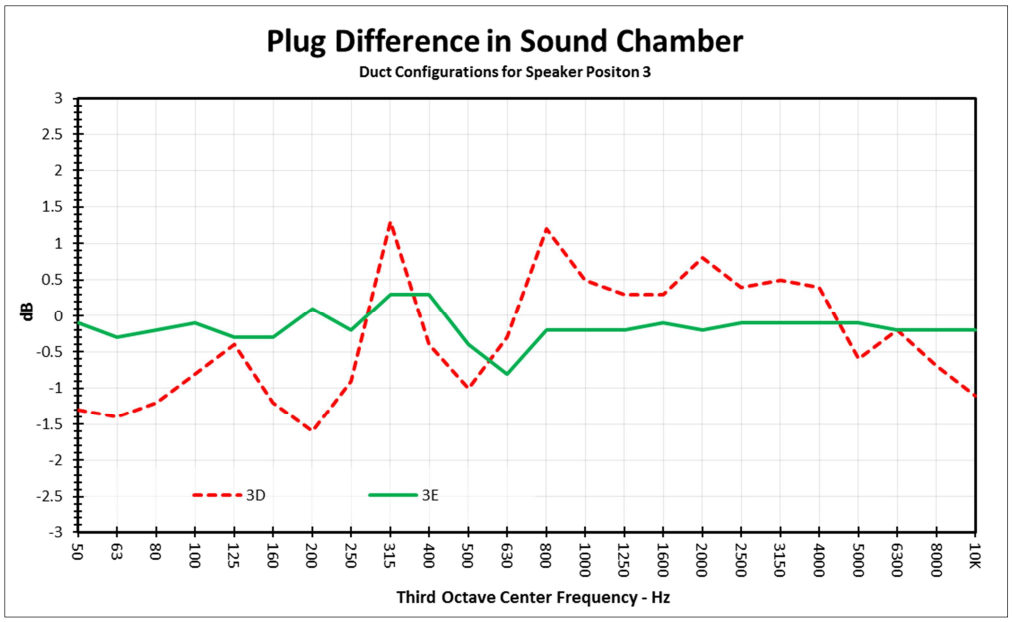

Figure 5.4 – Plug Difference in Sound Chamber Before & After Additional Sheet Metal

Table 5.4 – Plug Difference in Sound Chamber Before & After Additional Sheet Metal

	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10K
3D	-1.3	-1.4	-1.2	-0.8	-0.4	-1.2	-1.6	-0.9	1.3	-0.4	-1.0	-0.3	1.2	0.5	0.3	0.3	0.8	0.4	0.5	0.4	-0.6	-0.2	-0.7	-1.1
3E	-0.1	-0.3	-0.2	-0.1	-0.3	-0.3	0.1	-0.2	0.3	0.3	-0.4	-0.8	-0.2	-0.2	-0.2	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2

5.2.4. Summary of Results for Microphone Positions

The best location for the placement of the source chamber microphone is at the intersection of the center-line axis of the base speaker and mid-range speaker and high-frequency drivers.

5.3. Conclusion

- Duct and speaker configuration 3E is the best configuration that was tested based on its high insertion loss values and low differences in source chamber sound pressure levels with and without plugs.

- The position where the source chamber microphone is placed at the intersection of the center-line axes of the base speaker and mid-range speaker and horn drivers is the best location based on differences in source chamber sound pressure levels with and without plugs.

- The additional 12-gauge sheet metal lining inside the dual-wall duct significantly increased the insertion loss values in the low and mid-range 1/3 octave frequency bands.

- The additional layer of 12-gauge sheet metal on the floor in the sound chamber significantly reduced the differences in source chamber sound pressure levels with and without plugs.

5.4. Recommendations

- An insertion loss test should be conducted for speaker position 4 with the extra 12-gauge sheet metal lining on the floor in the source chamber. This speaker position showed high insertion loss values while the source chamber sound pressure levels with and without plugs exceeded ±1 dB only at 315 Hz. Since the results from speaker position 3 with and without the extra sheet metal lining on the floor showed improvement at 315 Hz, it should work for speaker position 4 too.

- Avoid moving the speakers and microphones throughout the whole duration of testing one configuration. This will minimize the effects of speaker and microphone positions on the measurements of source chamber sound level differences with and without the plug in the test duct.

- Analyze the results statistically. Repetition of the experiments multiple times and the comparison of the results gives a level of confidence to the findings of the study.

- If sheet metal panels are used for the walls of the source chamber, a minimum of 12-gauge sheet metal should be used.

APPENDIX A

INTEGRATION OF MEASUREMENT SYSTEM

A.1. Temperature and Humidity Measurement

The temperature and humidity in the duct are measured only on the source room side. The temperature is measure by a thermocouple while the humidity is measured by an Omega HX92AV-D Humidity Sensor. The signals from both sensors are sent to an NI 9219 module (Figure A.1), which is then connected to the NI DAQ-9172 (Figure A.2).

Figure A.1 – National Instruments NI 9219 Module

Figure A.2 – National Instruments NI DAQ-9172

A.2. Sound Measurement

The new sound measurement system can now measure sound in the source chamber and in the reverberation room simultaneously. Analog sound signals from the microphones are transferred to NI 9233 Module (Figure A.3) which is then connected to the NI DAQ-9172 (Figure A.2). Figure A.4 and Figure A.6 shows the user interface and the program block diagram for sound in the Source Room while Figure A.5 and Figure A.7 shows the user interface and the program block diagram for sound in the Source Room

Figure A.3 – National Instruments NI 9233 Module

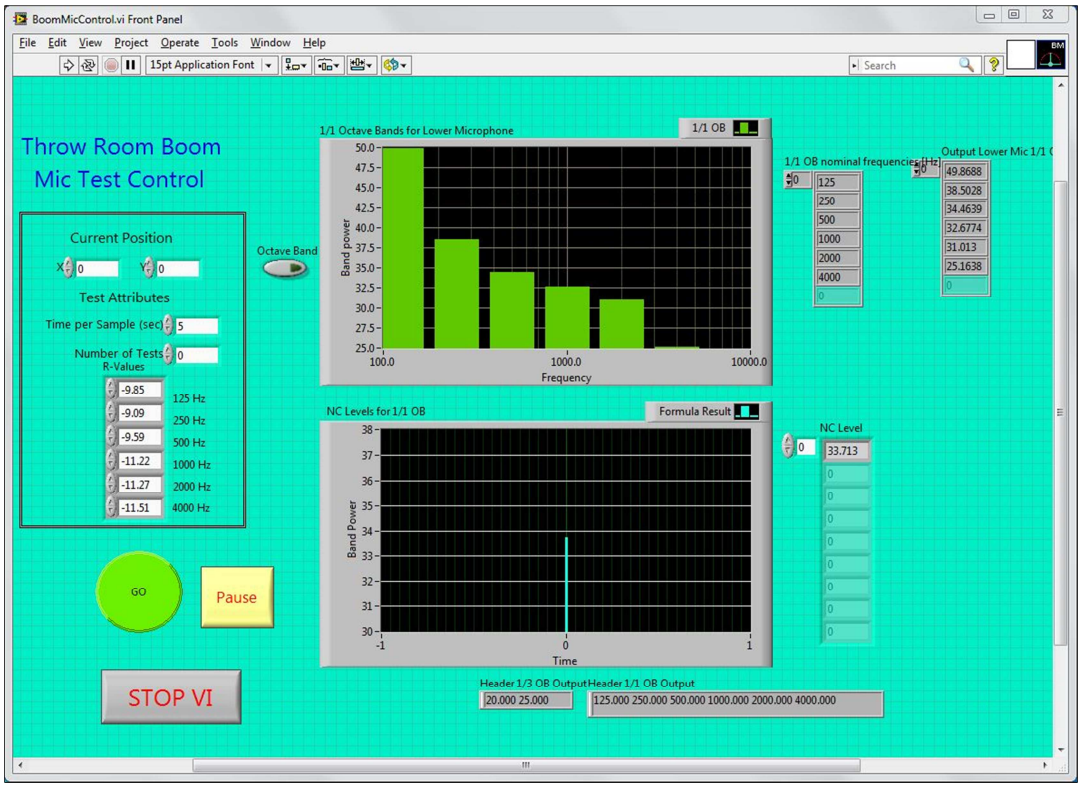

Figure A.4 – National Instruments Lab View Interface for Sound in Source Room

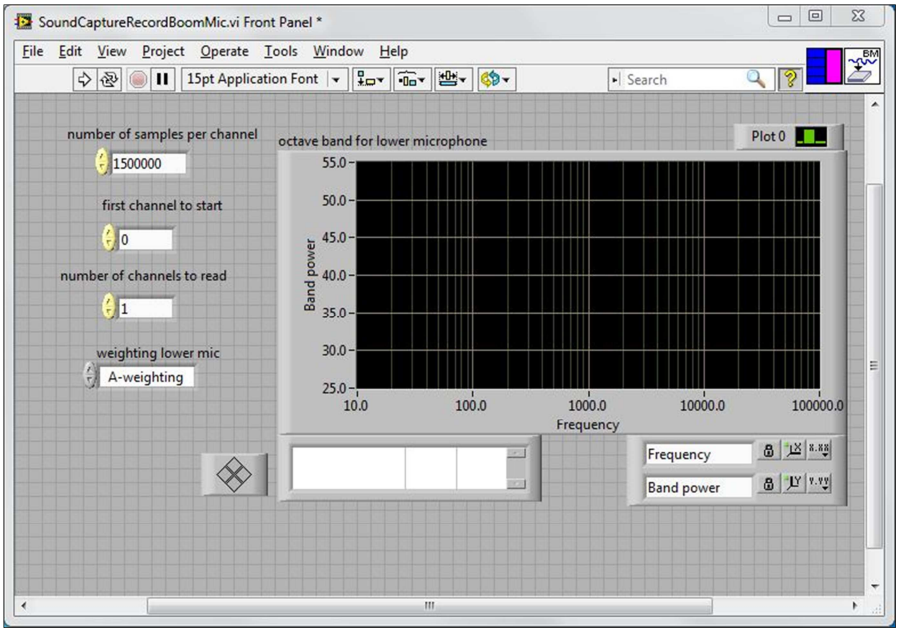

Figure A.5 – National Instruments Lab View Interface for Sound in Reverberation Room

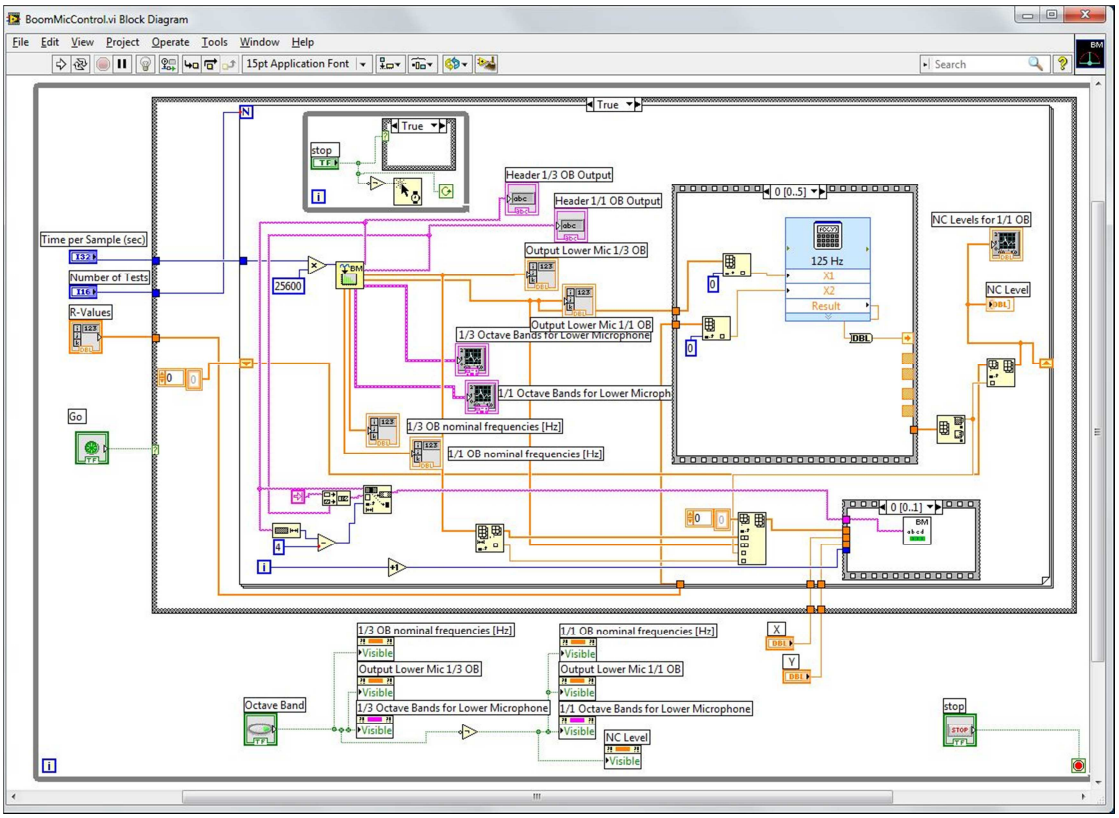

Figure A.6 - National Instruments Lab View Diagram for Sound in Source Room

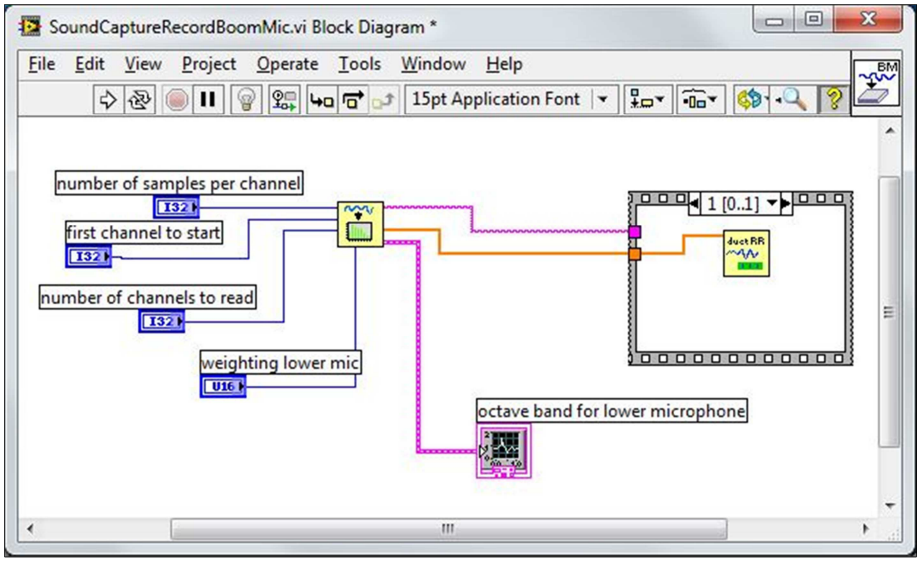

Figure A.7 – National Instruments Lab View Diagram for Sound in Reverberation Room

A.3. Pressure Measurement

The pitot differential pressure in the duct is measured using a pitot tube rake (Figure A.9) and static duct pressure is measured using a piezometric ring that is tapped on all sides of the duct (Figure A.10). Both pressures can be measured on the supply air and return air sides the reverberation room side of the duct. The pressure tube lines from the pitot tube rake and the pitot tube ring connect to a set of Omega PX653 Pressure Transducers via flexible tubes (Figure A.11). The pressure transducers are connected to NI 9215 module (Figure A.8) which is then connected to the NI DAQ-9172 (Figure A.2).

Figure A.8 – NI 9215 Module

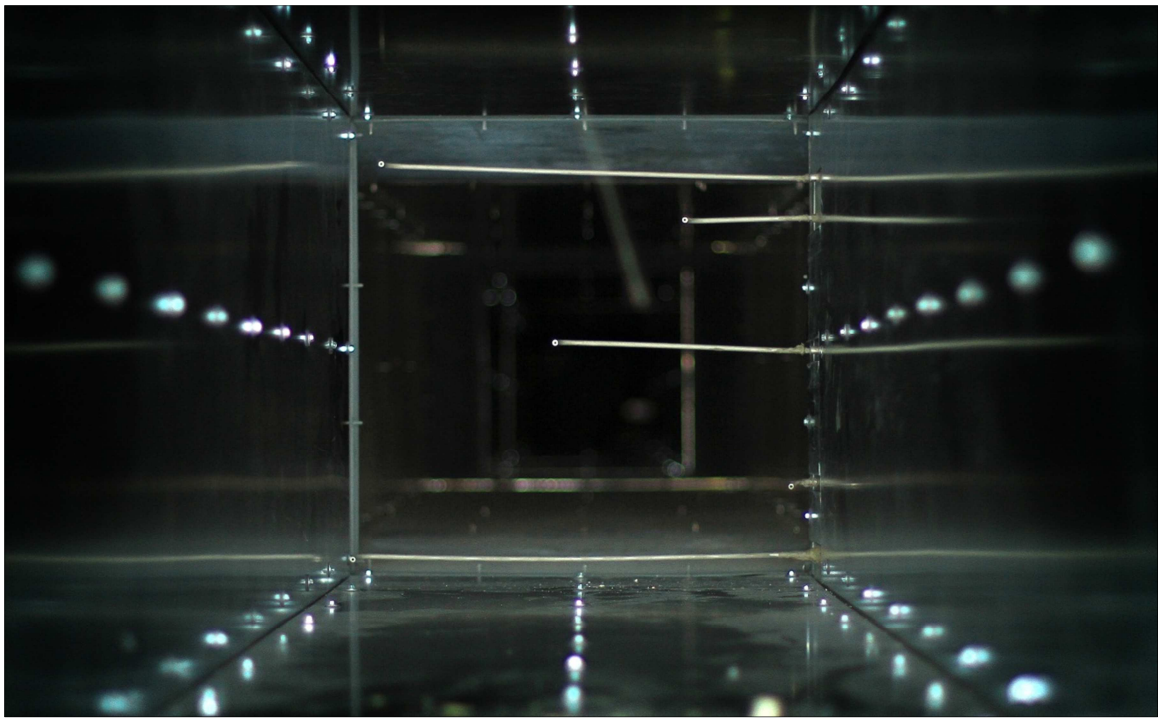

Figure A.9 – Pitot Tube Rake inside Duct

Figure A.10 – Piezometric Ring

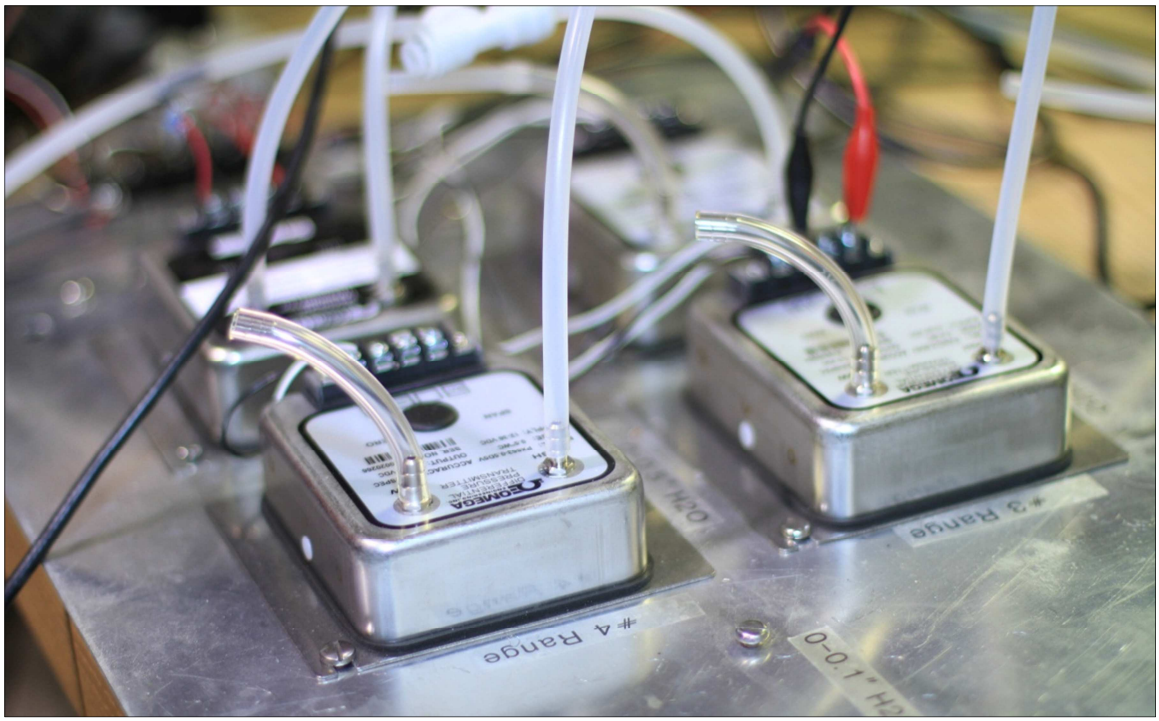

Figure A.11 – Omega PX653 Pressure Transducers

A.4. Airflow Calculations

The pressure level data that were collected from the piezometric ring and the pitot tube rake are used to calculate the airflow inside the duct using equations A.1 to A.12. These equations were derived from the ASHRAE Psychometric Chapter in the ASHRAE Fundamentals Handbook [17]. The input variables are altitude, h (ft), sea pressure level, P_0 (in Hg), location latitude, θ (°), measured pressure, P_{ub} (in Hg), duct air temperature, T_n (°F), duct static pressure, P_s (in H_20), relative humidity, φ, room temperature, T_R (°F), pitot differential pressure, P_v (in H_20). The output variables are duct corrected air density, ρ_n (lb/ft^3), duct velocity, V_d (ft/min), pitot differential pressure, P_v, corrected barometric pressure, P_b (in Hg), flow rate at duct, Q_d (ft^3/min), flow rate at room, Q_r (ft^3/min), duct actual flow rate, $Q_{d,act}$ (ft^3/min), room corrected density, ρ_r (lb/ft^3), room

actual density, $\rho_{r,act}$ (lb/ft^3). Figure A.12 shows the block diagram program for measuring pressure data and the calculation of airflow inside the duct.

$$\Delta P_s = P_0\left(1-\left(0.3048h\frac{0.0065}{288.16}\right)5.2561\right) \tag{A.1}$$

$$C_t = \frac{(1+0.0000102(T_R-62))}{(1+0.0000102(T_R-32))} \tag{A.2}$$

$$C_g = \frac{980.616}{980.665}\left(1-0.0026373\cos\left(2\theta\tfrac{\pi}{180}\right)+0.0000059\cos\left(2\theta\tfrac{\pi}{180}\right)2\right) \tag{A.3}$$

$$P_b = C_t - C_g P_{ub} + \Delta P_s \tag{A.4}$$

$$P_{ws} = 2.036 C_t C_g \exp\begin{pmatrix} -\dfrac{10440.397}{T_R+459.67}-11.29465 \\ -0.027022355(T_R+459.67) \\ +0.00001289036(T_R+459.67)3 \\ +6.5459673\log(T_R+459.67) \end{pmatrix} \tag{A.5}$$

$$P_w = \varphi \cdot P_{ws} \tag{A.6}$$

$$\rho_r = \frac{70.73}{53.35}\frac{P_b-0.378P_w}{T_R+459.67} \tag{A.7}$$

$$\rho_{r,act} = \frac{70.73}{53.35}\frac{P_{ub}-0.378P_w}{T_R+459.67} \tag{A.8}$$

$$\rho_n = \rho_r(P_s+13.63P_b)\frac{T_R+459.67}{13.63P_b(T_n+459.67)} \tag{A.9}$$

$$\rho_{n,act} = \rho_{R,act}(P_s+13.63P_{ub})\frac{T_R+459.67}{13.63P_{ub}(T_n+459.67)} \tag{A.10}$$

$$v_d = 1096\sqrt{\frac{|P_v|}{\rho_n}}\cdot sign(P_v) \tag{A.11}$$

$$v_{d,act} = 1096\sqrt{\frac{|P_v|}{\rho_{n,act}}} \cdot sign(P_v) \tag{A.12}$$

$$Q_d = v_d A_d \tag{A.13}$$

$$Q_{d,act} = v_{d,act} A_d \tag{A.14}$$

$$Q_r = Q_d \frac{\rho_n}{\rho_r} \tag{A.15}$$

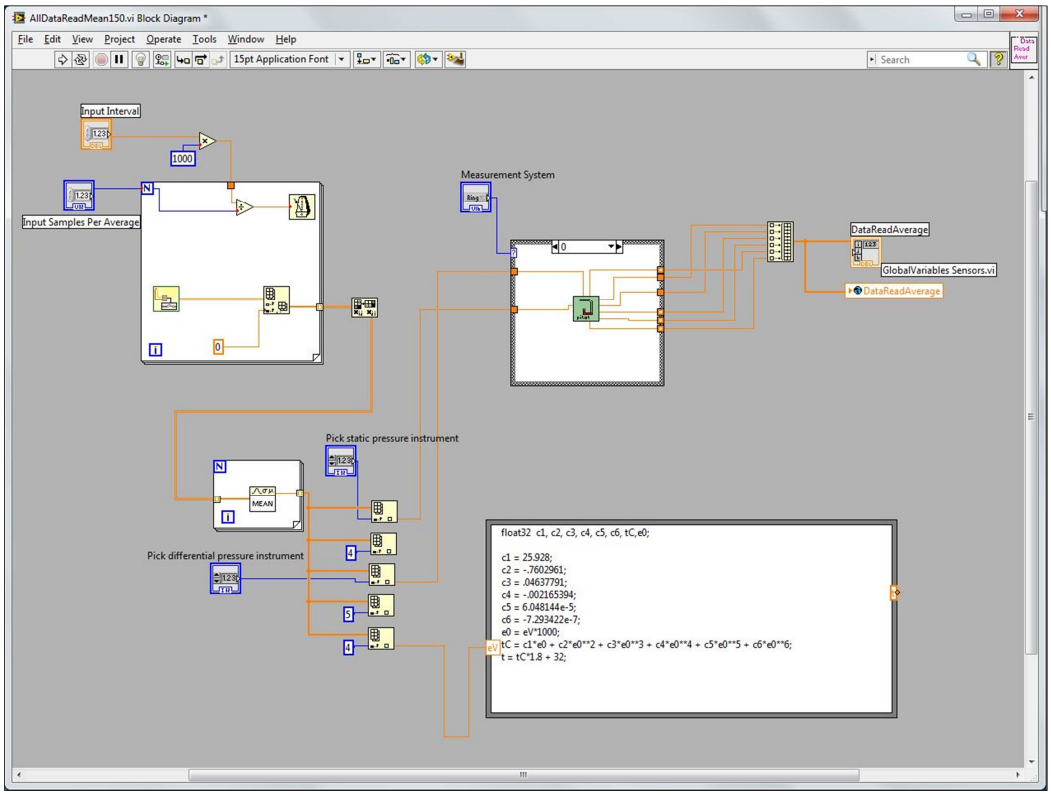

Figure A.12 - National Instruments Lab View Diagram for Airflow Calculation

APPENDIX B

SOUND PRESSURE LEVEL DATA USING PLUG 1

The sound pressure level data shown in this section used either plug 1 (Figure 3.40) or plug 1 with plug 2 (Figure 3.41). Following the protocol specified in section 3.4.1, a total of eight sound tests were conducted for each configuration. These results are tabulated and titled Sound Pressure Level Data from Configuration XX-X, where XX-X specifies which duct configuration, speaker position, and microphone position the data came from.

Out of eight tests, four of them are pink noise levels while the other four are the corresponding ambient levels. The ambient levels for each 1/3 octave frequency band are logarithmically subtracted from the pink noise levels using the equation specified in section 3.4.4.1. These results are tabulated and titled Adjusted Sound Pressure Level Data from Configuration XX-X, where XX-X specifies which duct configuration, speaker position, and microphone position the data came from.

Table B.1 - Sound Pressure Level Data from Configuration 1A-D

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	91.8	98.0	105.1	110.1	105.3	105.9	104.8	103.9	104.8	108.8	105.8	105.7	108.4	112.0	113.8	113.5	111.6	114.3	113.1	111.1	116.6	121.3	119.4	109.8
S	N	N	38.8	43.8	40.5	39.1	42.3	37.3	35.8	35.2	35.2	35.5	35.6	35.7	35.7	35.4	36.2	35.7	36.6	40.6	38.6	39.7	41.2	42.4	44.7	46.3
R	Y	N	54.5	55.7	52.4	50.5	66.6	79.1	80.2	78.0	79.5	82.2	81.0	79.4	80.7	86.1	88.7	88.7	88.8	88.9	87.8	85.0	83.7	82.3	78.0	69.0
R	N	N	40.6	42.0	34.9	33.6	53.2	33.3	31.1	26.8	22.8	25.6	25.5	25.4	31.0	34.2	28.9	30.3	37.5	45.3	33.5	32.5	31.5	35.7	31.5	31.3
S	Y	Y	90.9	98.5	105.1	109.9	105.0	104.9	104.5	103.3	104.0	108.1	104.5	104.1	108.0	111.6	113.4	114.1	109.8	113.7	112.6	110.8	115.0	120.9	119.3	110.4
S	N	Y	50.0	47.3	44.3	39.3	38.7	38.1	36.1	36.6	36.3	35.7	35.7	36.0	36.1	36.5	37.3	36.5	37.2	40.4	39.1	39.9	41.3	42.5	44.9	46.5
R	Y	Y	51.7	48.4	49.6	46.6	49.8	41.2	37.8	30.6	35.0	33.9	28.3	24.9	26.5	33.5	36.7	35.1	29.1	27.7	27.6	27.5	25.0	23.6	24.4	25.7
R	N	Y	41.7	34.7	33.2	33.4	45.2	30.7	26.0	26.0	25.3	25.7	25.7	22.0	18.0	16.7	17.2	16.3	16.4	19.7	18.1	18.9	20.3	21.5	23.7	25.3
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.2 – Adjusted Sound Pressure Level Data from Configuration 1A-D

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	91.8	98.0	105.1	110.1	105.3	105.9	104.8	103.9	104.8	108.8	105.8	105.7	108.4	112.0	113.8	113.5	111.6	114.3	113.1	111.1	116.6	121.3	119.4	109.8
R	Y	N	54.3	55.5	52.3	50.4	66.4	79.1	80.2	78.0	79.5	82.2	81.0	79.4	80.7	86.1	88.7	88.7	88.8	88.9	87.8	85.0	83.7	82.3	78.0	69.0
S	Y	Y	90.9	98.5	105.1	109.9	105.0	104.9	104.5	103.3	104.0	108.1	104.5	104.1	108.0	111.6	113.4	114.1	109.8	113.7	112.6	110.8	115.0	120.9	119.3	110.4
R	Y	Y	51.2	48.2	49.5	46.4	48.0	40.8	37.5	28.8	34.5	33.2	24.8	21.8	25.8	33.4	36.7	35.0	28.9	27.0	27.1	26.9	23.2	19.4	16.1	15.1
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

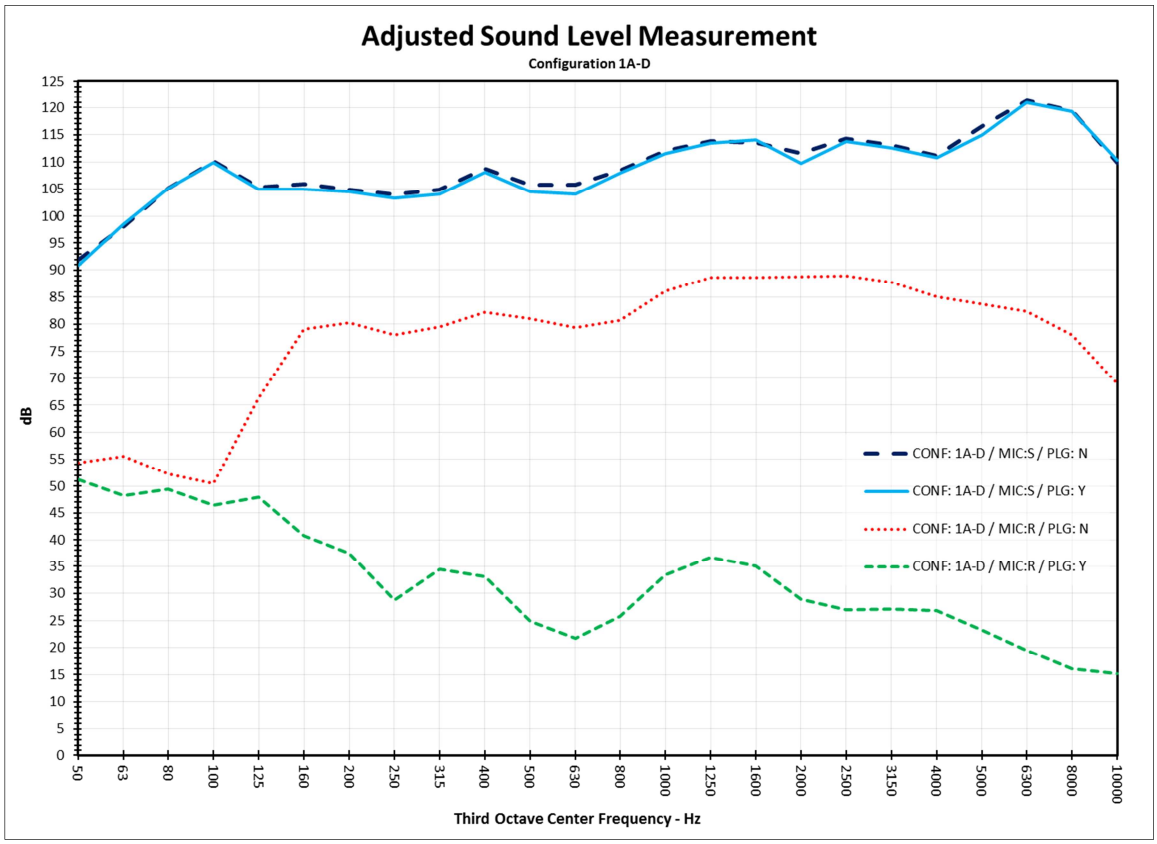

Figure B.1 - Adjusted Sound Pressure Level from Configuration 1A-D

Table B.3 - Sound Pressure Level Data from Configuration 1B-D

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	91.0	99.0	105.0	110.1	104.9	105.4	104.2	103.2	103.4	109.0	105.7	104.6	107.9	111.7	112.7	113.6	110.2	113.7	111.9	111.0	114.7	120.5	118.9	110.3
S	N	N	43.1	45.8	41.5	40.0	38.7	39.3	37.1	35.7	35.1	35.4	35.8	35.7	35.6	35.4	36.1	35.7	36.6	40.6	38.8	39.8	41.1	42.3	44.7	46.3
R	Y	N	54.0	54.5	51.8	50.5	65.9	78.6	80.0	77.9	79.2	82.5	81.0	79.2	82.1	87.5	90.1	90.0	90.2	90.3	89.4	86.8	85.8	84.5	79.9	69.3
R	N	N	40.7	39.5	35.0	32.6	48.0	29.4	29.2	25.0	22.3	22.1	22.1	18.5	17.1	16.9	17.1	16.6	16.8	19.5	18.5	19.2	20.3	21.4	23.7	25.3
S	Y	Y	91.3	100.0	105.7	111.0	106.2	105.9	105.1	103.9	104.2	109.2	106.1	104.7	109.2	112.8	114.4	115.0	111.0	114.6	113.4	111.8	116.4	122.0	120.4	111.6
S	N	Y	39.1	44.4	41.1	39.4	38.5	39.1	37.2	35.5	35.0	35.3	35.7	35.9	35.6	35.3	36.0	35.7	36.6	40.6	38.7	39.8	41.2	42.4	44.8	46.4
R	Y	Y	50.8	43.3	41.6	43.3	35.0	34.6	31.3	27.3	25.8	23.5	21.7	17.0	16.0	16.4	17.4	16.4	16.7	19.3	18.3	19.1	20.3	21.5	23.7	25.3
R	N	Y	37.2	36.5	31.6	31.9	33.0	27.8	28.8	26.4	20.9	18.4	20.2	16.0	15.6	15.8	16.6	16.0	16.7	19.3	18.3	18.9	20.3	21.5	23.8	25.4
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.4 – Adjusted Sound Pressure Level Data from Configuration 1B-D

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	91.0	99.0	105.0	110.1	104.9	105.4	104.2	103.2	103.4	109.0	105.7	104.6	107.9	111.7	112.7	113.6	110.2	113.7	111.9	111.0	114.7	120.5	118.9	110.3
R	Y	N	53.8	54.4	51.7	50.4	65.8	78.6	80.0	77.9	79.2	82.5	81.0	79.2	82.1	87.5	90.1	90.0	90.2	90.3	89.4	86.8	85.8	84.5	79.9	69.3
S	Y	Y	91.3	100.0	105.7	111.0	106.2	105.9	105.1	103.9	104.2	109.2	106.1	104.7	109.2	112.8	114.4	115.0	111.0	114.6	113.4	111.8	116.4	122.0	120.4	111.6
R	Y	Y	50.6	42.3	41.1	43.0	30.7	33.6	27.7	20.0	24.1	21.9	16.4	10.1	5.4	7.5	9.7	5.8	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

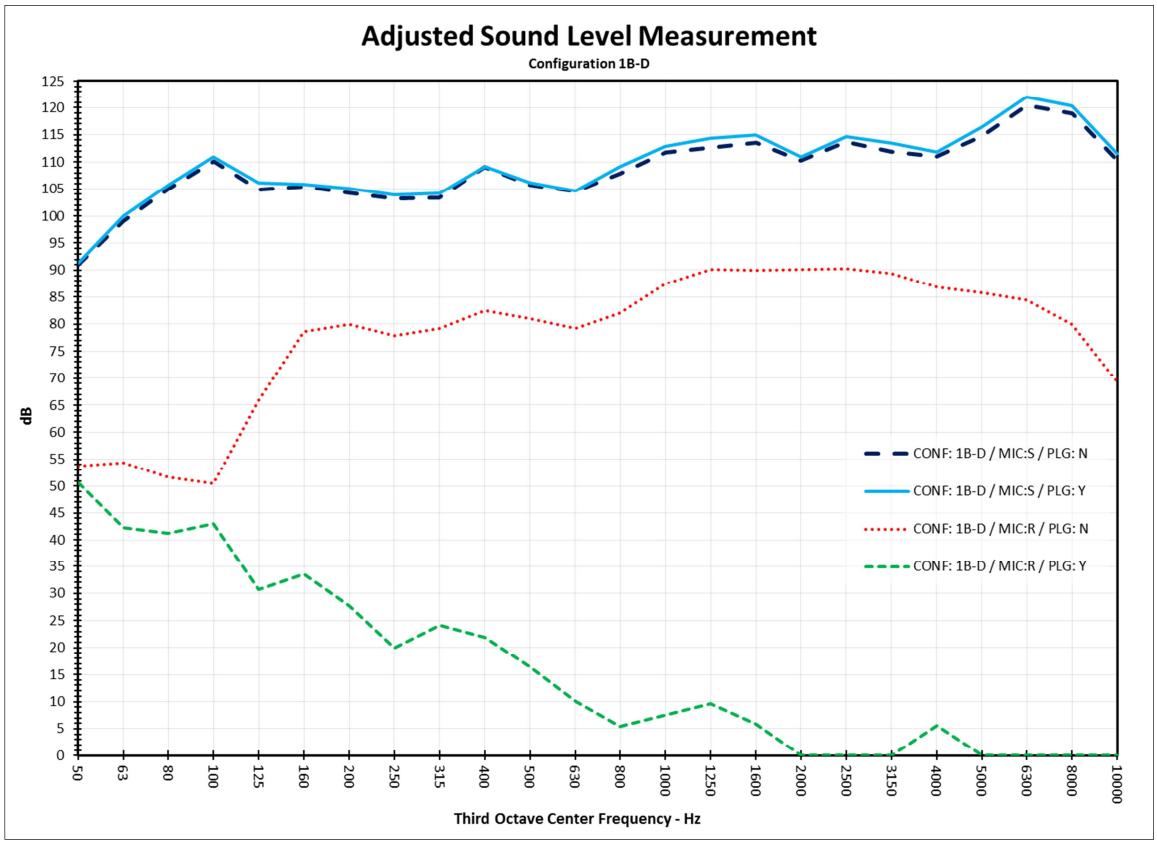

Figure B.2 - Adjusted Sound Pressure Level from Configuration 1B-D

Table B.5 - Sound Pressure Level Data from Configuration 2A-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	111.1	113.7	109.4	112.2	111.1	111.3	107.5	106.0	108.7	109.0	107.3	104.1	100.5	106.9	110.6	108.6	110.1	110.7	109.6	110.3	110.8	114.5	113.5	107.4
S	N	N	49.7	46.7	44.6	39.9	38.8	37.9	36.5	36.5	36.4	35.8	35.7	36.1	36.3	36.7	37.4	36.5	37.2	40.3	39.0	39.9	41.3	42.5	44.9	46.5
R	Y	N	69.4	73.3	65.9	59.8	74.7	87.7	87.2	82.4	85.1	85.6	87.5	84.1	78.8	86.1	89.5	87.8	89.0	89.5	88.1	84.7	83.9	82.4	78.2	68.5
R	N	N	40.6	42.0	34.9	33.6	53.2	33.3	31.1	26.8	22.8	25.6	25.5	25.4	31.0	34.2	28.9	30.3	37.5	45.3	33.5	32.5	31.5	35.7	31.5	31.3
S	Y	Y	110.8	113.7	109.3	111.8	110.5	111.2	107.3	106.6	108.6	108.9	107.3	103.8	101.0	106.8	110.8	108.4	108.8	111.0	110.3	111.3	111.9	114.5	113.0	105.8
S	N	Y	50.0	47.3	44.3	39.3	38.7	38.1	36.1	36.6	36.3	35.7	35.7	36.0	36.1	36.5	37.3	36.5	37.2	40.4	39.1	39.9	41.3	42.5	44.9	46.5
R	Y	Y	65.1	69.3	62.3	52.8	50.9	44.9	40.9	34.3	36.5	36.8	32.6	28.9	25.8	30.7	34.9	32.3	28.7	26.8	26.6	25.7	24.4	23.4	24.4	25.8
R	N	Y	41.7	34.7	33.2	33.4	45.2	30.7	26.0	26.0	25.3	25.7	25.7	22.0	18.0	16.7	17.2	16.3	16.4	19.7	18.1	18.9	20.3	21.5	23.7	25.3
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.6 – Adjusted Sound Pressure Level Data from Configuration 2A-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	111.1	113.7	109.4	112.2	111.1	111.3	107.5	106.0	108.7	109.0	107.3	104.1	100.5	106.9	110.6	108.6	110.1	110.7	109.6	110.3	110.8	114.5	113.5	107.4
R	Y	N	69.4	73.3	65.9	59.8	74.7	87.7	87.2	82.4	85.1	85.6	87.5	84.1	78.8	86.1	89.5	87.8	89.0	89.5	88.1	84.7	83.9	82.4	78.2	68.5
S	Y	Y	110.8	113.7	109.3	111.8	110.5	111.2	107.3	106.6	108.6	108.9	107.3	103.8	101.0	106.8	110.8	108.4	108.8	111.0	110.3	111.3	111.9	114.5	113.0	105.8
R	Y	Y	65.1	69.3	62.3	52.7	49.5	44.7	40.8	33.6	36.2	36.4	31.6	27.9	25.0	30.5	34.8	32.2	28.4	25.9	25.9	24.7	22.3	18.9	16.1	16.2
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

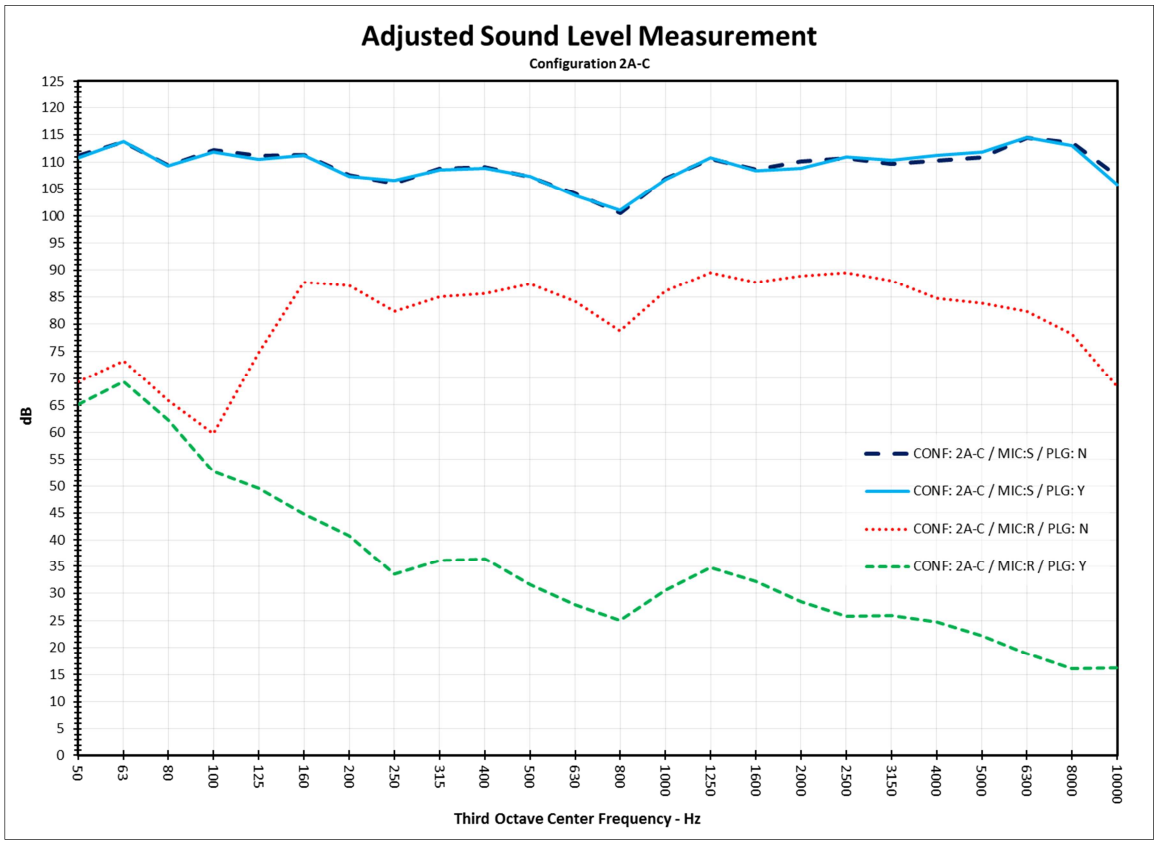

Figure B.3 - Adjusted Sound Pressure Level from Configuration 2A-C

Table B.7 - Sound Pressure Level Data from Configuration 2C-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.6	97.7	104.4	104.0	103.2	106.5	109.7	105.4	107.3	105.5	103.8	103.0	106.4	114.8	119.0	116.4	116.2	117.5	119.4	119.1	120.9	123.3	121.5	115.9
S	N	N	40.8	38.2	38.4	38.0	38.8	37.7	36.4	34.9	34.9	35.3	35.5	35.5	35.1	34.9	36.0	35.6	36.6	40.7	38.6	39.7	41.2	42.3	44.7	46.3
R	Y	N	63.2	66.0	61.0	70.7	74.7	86.2	89.6	89.4	89.9	85.5	88.0	84.0	82.2	86.4	88.7	86.6	85.6	84.9	83.4	79.7	77.0	76.9	71.8	60.7
R	N	N	39.1	38.0	35.1	33.3	45.1	32.9	31.0	29.0	25.2	26.4	26.7	21.6	18.9	17.4	17.9	17.6	17.1	19.8	18.8	19.4	20.2	21.4	23.7	25.3
S	Y	Y	100.6	97.7	103.2	103.6	102.7	106.6	109.8	105.9	107.7	103.8	104.0	102.9	105.8	114.6	118.1	116.3	115.9	117.2	119.4	119.3	121.5	123.7	122.5	116.5
S	N	Y	40.3	37.1	37.7	37.0	36.7	36.6	35.2	34.7	35.0	35.5	35.7	35.7	34.8	34.7	35.9	35.5	36.6	40.7	38.6	39.8	41.2	42.4	44.8	46.4
R	Y	Y	60.4	56.0	47.4	36.5	42.7	38.9	37.7	31.6	34.9	33.4	28.9	25.0	25.7	30.5	33.0	29.3	25.6	22.1	22.2	20.7	20.9	21.9	23.8	25.4
R	N	Y	39.3	36.9	34.3	31.2	41.0	31.8	29.8	29.7	23.9	24.6	23.3	19.7	17.4	16.8	17.5	17.1	16.7	19.6	18.3	19.3	20.4	21.6	23.8	25.4
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.8 – Adjusted Sound Pressure Level Data from Configuration 2C-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.6	97.7	104.4	104.0	103.2	106.5	109.7	105.4	107.3	105.5	103.8	103.0	106.4	114.8	119.0	116.4	116.2	117.5	119.4	119.1	120.9	123.3	121.5	115.9
R	Y	N	63.2	66.0	61.0	70.7	74.7	86.2	89.6	89.4	89.9	85.5	88.0	84.0	82.2	86.4	88.7	86.6	85.6	84.9	83.4	79.7	77.0	76.9	71.8	60.7
S	Y	Y	100.6	97.7	103.2	103.6	102.7	106.6	109.8	105.9	107.7	103.8	104.0	102.9	105.8	114.6	118.1	116.3	115.9	117.2	119.4	119.3	121.5	123.7	122.5	116.5
R	Y	Y	60.4	55.9	47.2	35.0	37.8	38.0	36.9	27.1	34.5	32.8	27.5	23.5	25.0	30.3	32.9	29.0	25.0	18.5	19.9	15.1	11.3	10.1	0.0	0.0
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

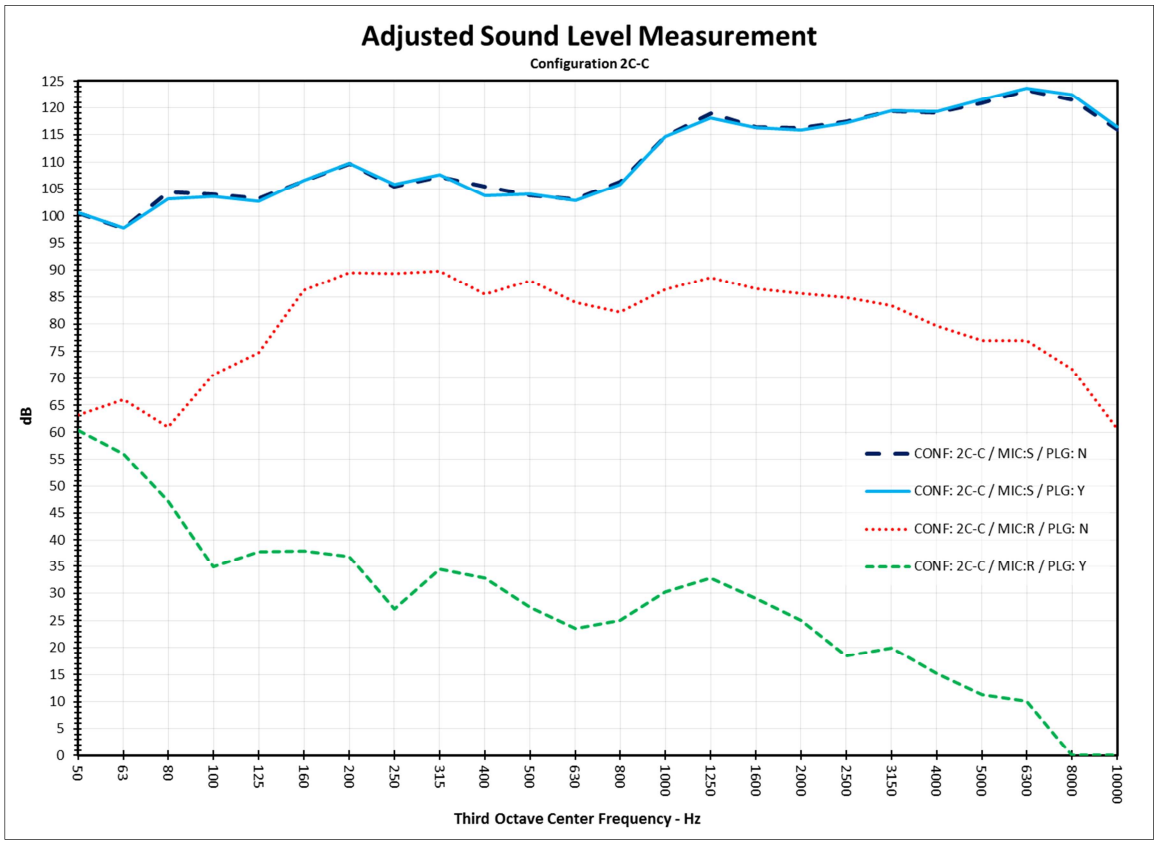

Figure B.4 - Adjusted Sound Pressure Level from Configuration 2C-C

Table B.9 - Sound Pressure Level Data from Configuration 3C-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.5	105.3	109.1	106.7	103.5	110.0	111.5	108.9	103.9	106.3	109.5	102.0	104.9	114.5	114.7	113.8	112.9	113.1	112.5	112.9	115.4	121.5	121.7	115.3
S	N	N	38.9	43.2	41.2	39.2	38.9	37.6	34.9	34.9	35.0	35.7	35.9	35.2	34.0	34.4	35.8	35.6	36.5	40.8	38.6	39.7	41.2	42.4	44.7	46.4
R	Y	N	56.6	63.9	70.9	74.2	79.6	93.4	94.9	90.0	89.1	91.1	89.0	85.5	84.6	87.5	90.1	87.0	86.2	86.1	84.9	81.5	78.4	78.3	73.5	62.9
R	N	N	39.4	37.8	34.2	30.7	44.8	33.2	28.9	28.0	24.7	25.7	23.4	20.0	17.4	16.2	16.9	16.8	16.9	19.8	18.2	19.1	20.4	21.5	23.8	25.4
S	Y	Y	97.5	105.5	109.0	106.6	103.4	110.3	111.1	109.2	103.9	106.2	109.6	102.3	105.4	114.3	115.4	113.8	112.8	114.3	112.8	113.4	113.7	120.2	121.6	115.9
S	N	Y	38.4	43.5	40.7	38.8	37.9	36.7	34.9	34.8	35.4	35.4	35.3	34.8	34.0	34.5	36.0	35.6	36.7	40.6	38.6	39.9	41.3	42.5	44.9	46.5
R	Y	Y	56.4	46.4	48.1	40.1	43.5	41.3	39.0	31.1	34.8	34.9	29.8	26.2	25.8	30.6	36.7	32.6	25.2	23.6	22.6	20.8	21.1	22.1	23.9	25.4
R	N	Y	38.2	37.3	34.9	30.8	41.0	31.2	28.4	28.5	24.6	24.7	24.3	20.7	17.6	16.3	17.0	16.7	16.6	19.8	18.2	19.0	20.4	21.5	23.7	25.3
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.10 – Adjusted Sound Pressure Level Data from Configuration 3C-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.5	105.3	109.1	106.7	103.5	110.0	111.5	108.9	103.9	106.3	109.5	102.0	104.9	114.5	114.7	113.8	112.9	113.1	112.5	112.9	115.4	121.5	121.7	115.3
R	Y	N	56.5	63.9	70.9	74.2	79.6	93.4	94.9	90.0	89.1	91.1	89.0	85.5	84.6	87.5	90.1	87.0	86.2	86.1	84.9	81.5	78.4	78.3	73.5	62.9
S	Y	Y	97.5	105.5	109.0	106.6	103.4	110.3	111.1	109.2	103.9	106.2	109.6	102.3	105.4	114.3	115.4	113.8	112.8	114.3	112.8	113.4	113.7	120.2	121.6	115.9
R	Y	Y	56.3	45.8	47.9	39.6	39.9	40.9	38.6	27.6	34.4	34.5	28.4	24.8	25.1	30.4	36.7	32.5	24.6	21.3	20.6	16.1	12.8	13.2	10.4	9.0
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

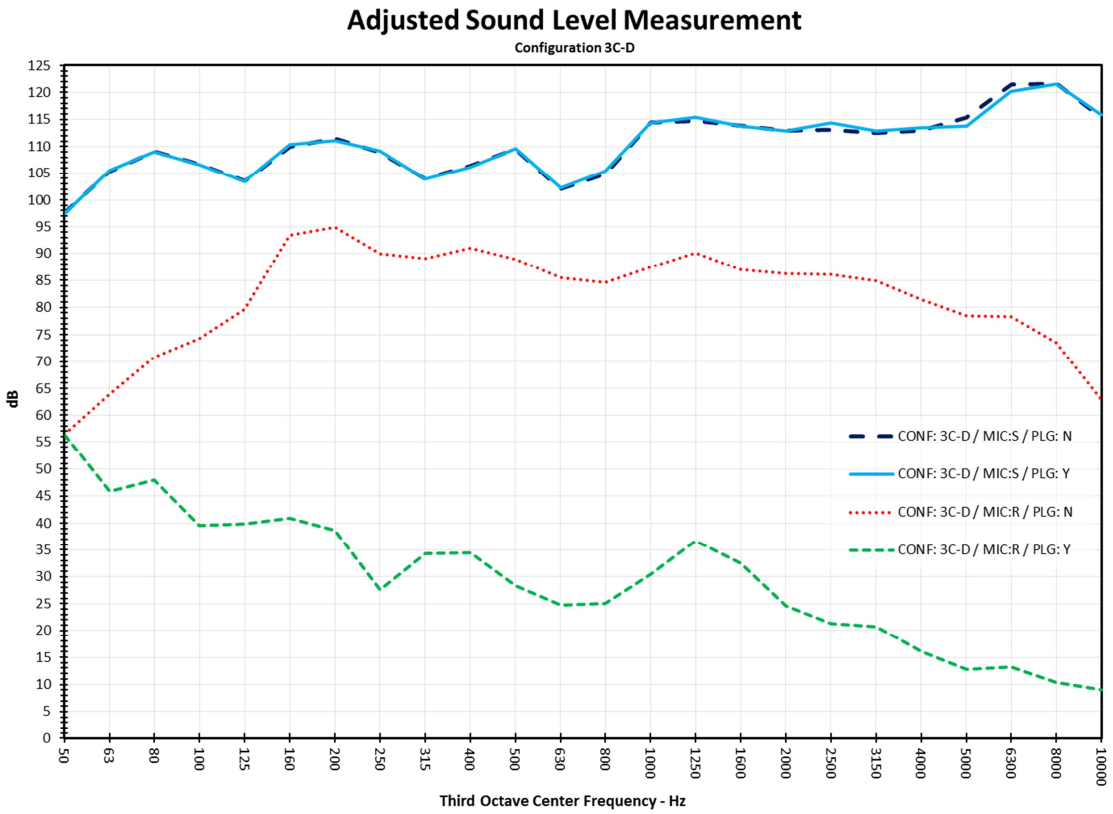

Figure B.5 - Adjusted Sound Pressure Level from Configuration 3C-C

Table B.11 - Sound Pressure Level Data from Configuration 3C-D

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.8	109.0	112.0	107.8	104.2	113.6	114.1	108.6	104.0	112.4	111.9	109.2	110.0	114.5	118.0	115.8	115.4	117.7	119.1	117.7	118.8	122.4	120.1	113.9
S	N	N	38.9	43.2	41.2	39.2	38.9	37.6	34.9	34.9	35.0	35.7	35.9	35.2	34.0	34.4	35.8	35.6	36.5	40.8	38.6	39.7	41.2	42.4	44.7	46.4
R	Y	N	56.6	63.9	70.9	74.2	79.6	93.4	94.9	90.0	89.1	91.1	89.0	85.5	84.6	87.5	90.1	87.0	86.2	86.1	84.9	81.5	78.4	78.3	73.5	62.9
R	N	N	39.4	37.8	34.2	30.7	44.8	33.2	28.9	28.0	24.7	25.7	23.4	20.0	17.4	16.2	16.9	16.8	16.9	19.8	18.2	19.1	20.4	21.5	23.8	25.4
S	Y	Y	97.7	109.0	111.8	107.8	104.4	113.6	114.0	108.5	104.4	112.5	111.9	109.3	110.1	114.4	117.8	115.7	115.2	117.5	118.7	117.2	118.5	121.6	119.5	113.4
S	N	Y	38.4	43.5	40.7	38.8	37.9	36.7	34.9	34.8	35.4	35.4	35.3	34.8	34.0	34.5	36.0	35.6	36.7	40.6	38.6	39.9	41.3	42.5	44.9	46.5
R	Y	Y	56.4	46.4	48.1	40.1	43.5	41.3	39.0	31.1	34.8	34.9	29.8	26.2	25.8	30.6	36.7	32.6	25.2	23.6	22.6	20.8	21.1	22.1	23.9	25.4
R	N	Y	38.2	37.3	34.9	30.8	41.0	31.2	28.4	28.5	24.6	24.7	24.3	20.7	17.6	16.3	17.0	16.7	16.6	19.8	18.2	19.0	20.4	21.5	23.7	25.3

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

Table B.12 – Adjusted Sound Pressure Level Data from Configuration 3C-D

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.8	109.0	112.0	107.8	104.2	113.6	114.1	108.6	104.0	112.4	111.9	109.2	110.0	114.5	118.0	115.8	115.4	117.7	119.1	117.7	118.8	122.4	120.1	113.9
R	Y	N	56.5	63.9	70.9	74.2	79.6	93.4	94.9	90.0	89.1	91.1	89.0	85.5	84.6	87.5	90.1	87.0	86.2	86.1	84.9	81.5	78.4	78.3	73.5	62.9
S	Y	Y	97.7	109.0	111.8	107.8	104.4	113.6	114.0	108.5	104.4	112.5	111.9	109.3	110.1	114.4	117.8	115.7	115.2	117.5	118.7	117.2	118.5	121.6	119.5	113.4
R	Y	Y	56.3	45.8	47.9	39.6	39.9	40.9	38.6	27.6	34.4	34.5	28.4	24.8	25.1	30.4	36.7	32.5	24.6	21.3	20.6	16.1	12.8	13.2	10.4	9.0

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

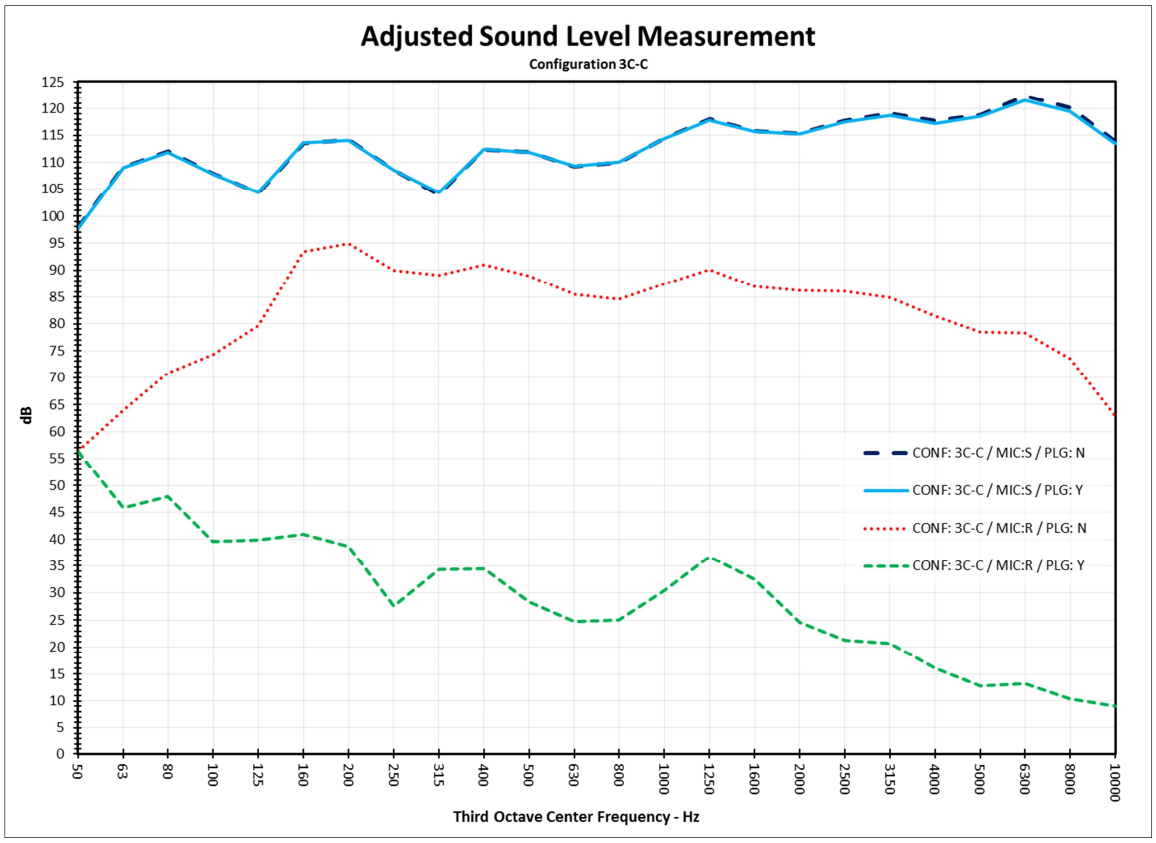

Figure B.6 - Adjusted Sound Pressure Level from Configuration 3C-D

Table B.13 - Sound Pressure Level Data from Configuration 3D-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	102.1	108.2	109.7	105.8	105.2	110.4	112.4	106.7	102.0	111.3	112.7	108.9	110.6	115.5	118.7	116.2	115.9	117.0	118.4	117.9	118.9	120.7	117.8	109.2
S	N	N	41.4	39.2	38.1	37.9	38.5	36.4	35.0	35.0	35.2	35.7	35.3	34.4	33.9	34.6	36.1	35.9	36.8	40.7	38.3	39.2	40.1	40.7	42.0	42.4
R	Y	N	62.9	68.7	69.2	73.8	80.3	90.2	94.2	88.3	87.9	90.1	87.8	86.0	83.8	86.5	89.2	86.4	85.6	85.7	84.8	81.6	78.7	78.7	73.8	62.5
R	N	N	38.5	37.3	34.8	31.6	47.0	33.9	29.4	30.2	25.8	25.0	25.2	21.2	17.8	17.1	17.4	17.0	17.1	19.8	18.2	18.7	19.4	19.9	21.1	21.5
S	Y	Y	103.4	109.6	110.9	106.6	105.6	111.6	114.0	107.6	100.7	111.7	113.7	109.2	109.4	115.0	118.4	115.9	115.1	116.6	117.9	117.5	119.5	120.9	118.5	110.3
S	N	Y	40.6	39.9	38.1	37.5	37.4	36.0	34.8	35.0	35.2	35.6	35.8	35.2	34.3	34.7	36.0	35.8	36.7	40.6	38.4	39.2	40.1	40.7	42.0	42.4
R	Y	Y	56.0	50.1	46.9	38.9	43.2	40.8	38.2	32.1	32.0	32.3	29.1	25.8	25.1	29.6	34.1	28.7	25.8	23.2	22.5	20.9	20.4	20.9	21.2	21.3
R	N	Y	40.6	38.9	34.0	32.7	32.8	26.2	23.5	18.8	18.4	19.2	19.0	18.9	19.4	18.8	18.8	18.0	18.7	19.2	19.5	19.4	19.7	20.0	21.2	21.5
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.14 – Adjusted Sound Pressure Level Data from Configuration 3D-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	102.1	108.2	109.7	105.8	105.2	110.4	112.4	106.7	102.0	111.3	112.7	108.9	110.6	115.5	118.7	116.2	115.9	117.0	118.4	117.9	118.9	120.7	117.8	109.2
R	Y	N	62.9	68.7	69.2	73.8	80.3	90.2	94.2	88.3	87.9	90.1	87.8	86.0	83.8	86.5	89.2	86.4	85.6	85.7	84.8	81.6	78.7	78.7	73.8	62.5
S	Y	Y	103.4	109.6	110.9	106.6	105.6	111.6	114.0	107.6	100.7	111.7	113.7	109.2	109.4	115.0	118.4	115.9	115.1	116.6	117.9	117.5	119.5	120.9	118.5	110.3
R	Y	Y	55.9	49.8	46.7	37.7	42.8	40.6	38.1	31.9	31.8	32.1	28.7	24.8	23.7	29.2	34.0	28.3	24.9	21.0	19.5	15.6	12.1	13.6	0.0	0.0
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

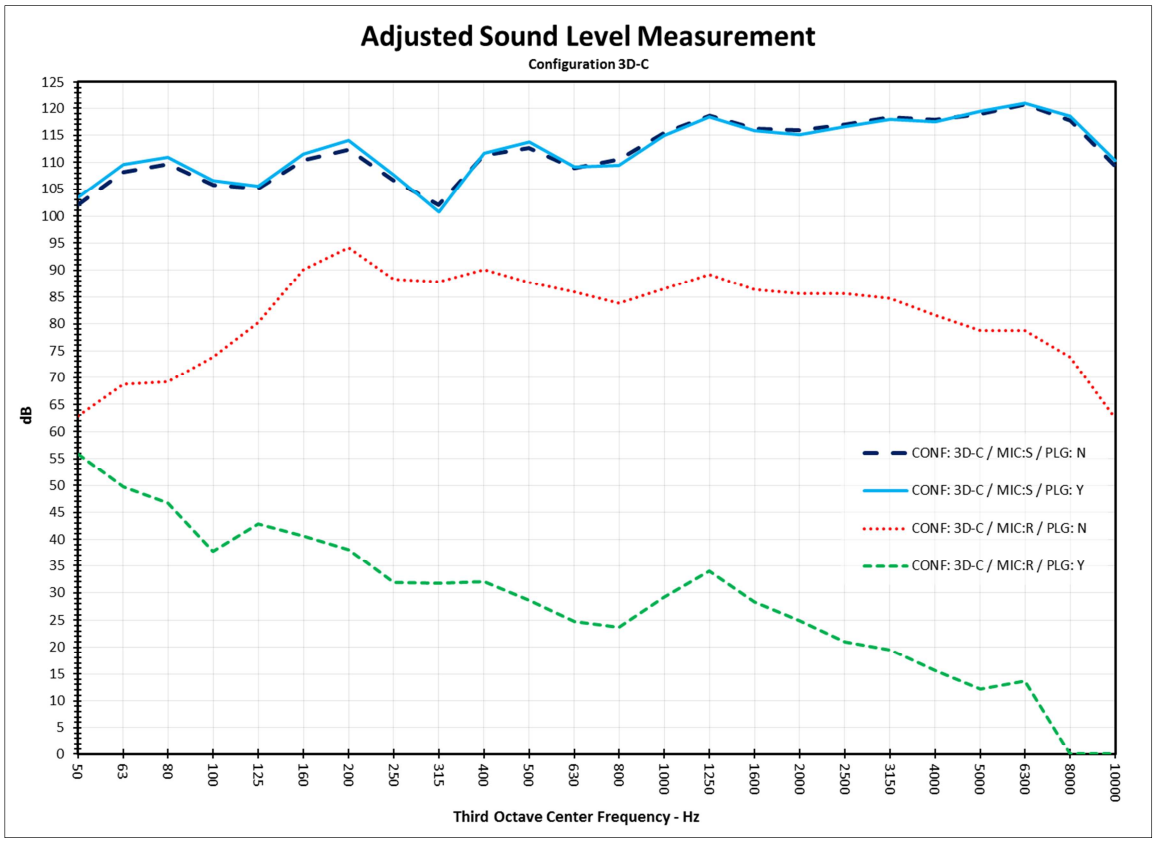

Figure B.7 - Adjusted Sound Pressure Level from Configuration 3D-C

Table B.15 - Sound Pressure Level Data from Configuration 3E-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.2	105.5	107.4	104.1	103.3	109.4	111.1	105.9	104.2	107.4	104.7	101.8	108.2	115.3	119.1	116.4	115.6	117.0	118.5	117.6	118.1	120.4	117.2	109.7
S	N	N	41.4	40.6	38.0	37.5	38.3	36.9	35.3	34.6	35.0	35.5	35.7	35.7	35.0	34.8	36.1	35.8	36.7	40.6	38.3	39.2	40.1	40.6	42.0	42.3
R	Y	N	62.6	68.5	69.6	74.6	81.0	91.1	94.9	89.7	88.8	90.8	88.3	86.0	85.0	86.6	88.6	86.1	84.7	83.6	81.6	76.8	73.4	73.1	67.9	57.6
R	N	N	39.4	37.1	34.6	32.1	46.7	32.6	26.4	24.5	22.7	24.8	23.6	19.1	17.2	16.9	16.8	17.1	16.6	19.6	17.9	18.5	19.3	19.8	21.1	21.4
S	Y	Y	100.3	105.8	107.6	104.2	103.6	109.7	111.0	106.1	103.9	107.1	105.1	102.6	108.4	115.5	119.3	116.5	115.8	117.1	118.6	117.7	118.2	120.6	117.4	109.9
S	N	Y	41.0	41.3	38.3	38.1	37.9	36.0	35.1	34.8	35.3	35.4	35.0	34.5	34.0	34.5	36.0	36.0	36.8	40.6	38.5	39.3	40.2	40.7	42.1	42.5
R	Y	Y	56.1	51.3	46.9	40.2	43.6	40.7	39.9	29.2	34.0	34.4	29.1	24.9	25.1	31.1	35.9	30.2	24.3	21.9	21.3	19.8	19.8	20.2	21.1	21.4
R	N	Y	38.8	36.3	33.5	31.6	40.3	30.4	27.8	24.4	22.3	23.7	23.9	19.1	17.0	16.4	16.5	16.8	16.3	19.7	17.7	18.3	19.2	19.8	21.1	21.3
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.16 – Adjusted Sound Pressure Level Data from Configuration 3E-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.2	105.5	107.4	104.1	103.3	109.4	111.1	105.9	104.2	107.4	104.7	101.8	108.2	115.3	119.1	116.4	115.6	117.0	118.5	117.6	118.1	120.4	117.2	109.7
R	Y	N	62.6	68.5	69.6	74.6	81.0	91.1	94.9	89.7	88.8	90.8	88.3	86.0	85.0	86.6	88.6	86.1	84.7	83.6	81.6	76.8	73.4	73.1	67.9	57.6
S	Y	Y	100.3	105.8	107.6	104.2	103.6	109.7	111.0	106.1	103.9	107.1	105.1	102.6	108.4	115.5	119.3	116.5	115.8	117.1	118.6	117.7	118.2	120.6	117.4	109.9
R	Y	Y	56.0	51.2	46.7	39.6	40.9	40.3	39.6	27.5	33.7	34.0	27.5	23.6	24.4	31.0	35.8	30.0	23.6	17.9	18.8	14.5	10.9	9.6	0.0	5.0
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

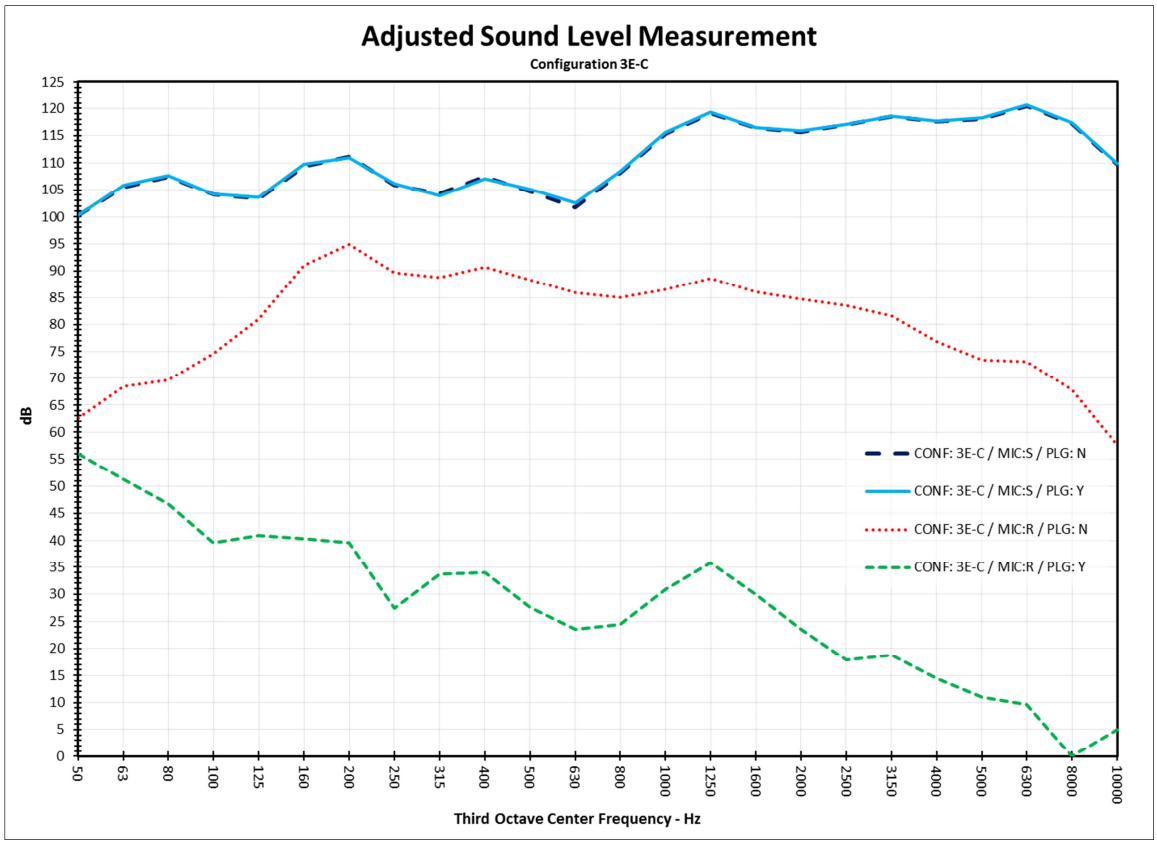

Figure B.8 - Adjusted Sound Pressure Level from Configuration 3E-C

Table B.17 - Sound Pressure Level Data from Configuration 4A-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	99.7	96.7	102.4	109.8	105.1	106.9	107.0	108.1	112.8	109.5	107.8	104.2	107.2	115.0	118.3	116.3	116.1	117.8	118.9	118.2	120.4	122.9	120.8	114.6
S	N	N	52.5	46.1	40.5	39.0	38.5	37.1	35.9	35.0	35.3	35.3	35.5	35.6	35.4	35.3	36.1	35.7	36.6	40.6	38.6	39.7	41.2	42.3	44.7	46.3
R	Y	N	57.0	52.8	45.8	46.9	61.1	73.1	76.4	80.7	81.7	73.5	78.2	77.2	74.7	80.5	85.1	84.7	84.3	83.9	82.0	78.6	77.0	75.2	70.0	59.0
R	N	N	40.6	42.0	34.9	33.6	53.2	33.3	31.1	26.8	22.8	25.6	25.5	25.4	31.0	34.2	28.9	30.3	37.5	45.3	33.5	32.5	31.5	35.7	31.5	31.3
S	Y	Y	95.4	93.1	102.1	109.8	105.0	109.2	107.3	107.7	112.0	109.8	108.9	104.1	106.2	113.9	117.5	115.5	114.9	116.7	117.9	117.2	119.3	121.9	119.6	114.1
S	N	Y	49.5	42.8	38.3	37.8	36.5	36.9	35.4	34.7	35.0	35.3	35.5	35.5	35.2	35.1	36.1	35.7	36.7	40.6	38.7	39.8	41.3	42.5	44.8	46.5
R	Y	Y	55.7	51.1	42.2	40.7	46.5	39.3	35.5	31.1	33.7	33.6	31.0	26.0	22.4	28.1	31.8	29.6	24.0	23.1	22.0	20.1	20.9	21.8	23.8	25.3
R	N	Y	41.7	34.7	33.2	33.4	45.2	30.7	26.0	26.0	25.3	25.7	25.7	22.0	18.0	16.7	17.2	16.3	16.4	19.7	18.1	18.9	20.3	21.5	23.7	25.3

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

Table B.18 – Adjusted Sound Pressure Level Data from Configuration 4A-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	99.7	96.7	102.4	109.8	105.1	106.9	107.0	108.1	112.8	109.5	107.8	104.2	107.2	115.0	118.3	116.3	116.1	117.8	118.9	118.2	120.4	122.9	120.8	114.6
R	Y	N	56.9	52.4	45.4	46.7	60.3	73.1	76.4	80.7	81.7	73.5	78.2	77.2	74.7	80.5	85.1	84.7	84.3	83.9	82.0	78.6	77.0	75.2	70.0	59.0
S	Y	Y	95.4	93.1	102.1	109.8	105.0	109.2	107.3	107.7	112.0	109.8	108.9	104.1	106.2	113.9	117.5	115.5	114.9	116.7	117.9	117.2	119.3	121.9	119.6	114.1
R	Y	Y	55.5	51.0	41.6	39.8	40.6	38.7	35.0	29.5	33.0	32.8	29.5	23.8	20.4	27.8	31.6	29.4	23.2	20.4	19.7	13.9	12.0	10.0	7.4	0.0

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

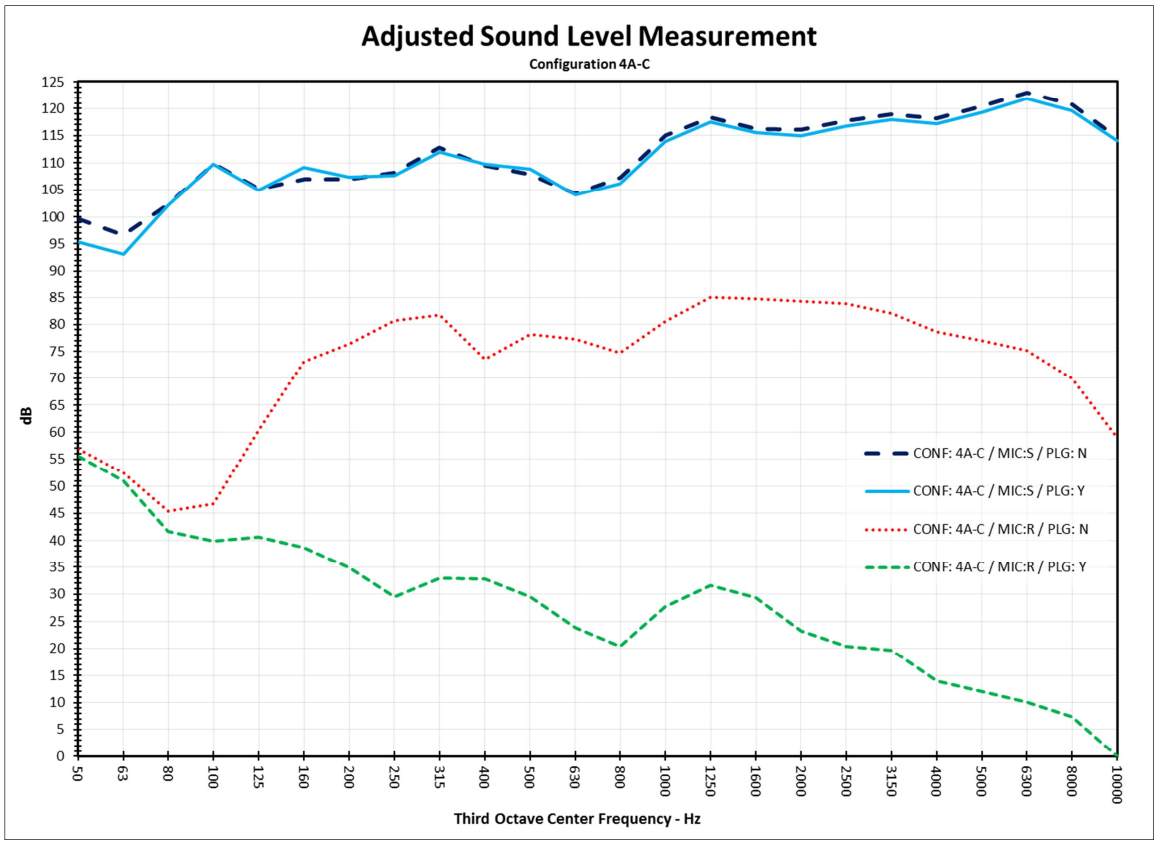

Figure B.9 - Adjusted Sound Pressure Level from Configuration 4A-C

Table B.19 - Sound Pressure Level Data from Configuration 4C-D

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	102.4	103.7	98.8	101.9	100.3	107.1	109.1	107.7	101.8	107.4	106.5	107.3	104.8	110.4	114.8	111.9	111.8	111.9	112.1	112.8	114.8	121.1	120.1	113.5
S	N	N	39.4	42.6	40.7	39.0	39.4	37.4	35.3	34.8	35.3	35.7	36.0	35.1	34.0	34.4	36.0	35.6	36.6	40.7	38.6	39.7	41.2	42.4	44.8	46.4
R	Y	N	63.1	63.4	60.1	70.4	74.6	89.4	91.7	89.2	89.0	88.6	89.3	83.7	83.4	86.9	89.5	87.5	86.1	85.7	84.1	80.7	78.0	77.9	73.0	62.0
R	N	N	38.6	37.7	35.1	31.2	45.6	32.6	28.5	28.3	24.6	24.8	24.6	20.2	17.5	16.3	17.2	16.7	16.7	19.8	18.1	19.0	20.3	21.4	23.7	25.3
S	Y	Y	101.9	103.2	98.4	101.5	100.4	106.8	109.0	107.6	102.7	107.3	106.2	107.0	105.6	111.1	115.1	112.1	111.3	112.3	112.1	112.3	113.3	120.0	120.7	114.1
S	N	Y	39.1	42.2	40.7	39.1	38.5	37.3	35.1	34.8	35.2	35.7	35.7	35.2	34.0	34.5	35.7	35.6	36.5	40.8	38.6	39.7	41.1	42.3	44.7	46.3
R	Y	Y	59.4	55.4	44.7	36.8	42.7	41.7	38.6	31.2	35.0	34.3	29.9	24.7	25.3	29.8	33.4	29.5	25.5	22.6	22.7	20.9	21.1	22.1	23.9	25.4
R	N	Y	39.2	38.0	34.7	30.9	41.6	32.0	28.5	28.7	24.6	24.6	24.6	20.0	17.3	16.2	17.5	16.8	16.9	19.8	18.2	19.1	20.3	21.5	23.8	25.4
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.20 – Adjusted Sound Pressure Level Data from Configuration 4C-D

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	102.4	103.7	98.8	101.9	100.3	107.1	109.1	107.7	101.8	107.4	106.5	107.3	104.8	110.4	114.8	111.9	111.8	111.9	112.1	112.8	114.8	121.1	120.1	113.5
R	Y	N	63.1	63.4	60.1	70.4	74.6	89.4	91.7	89.2	89.0	88.6	89.3	83.7	83.4	86.9	89.5	87.5	86.1	85.7	84.1	80.7	78.0	77.9	73.0	62.0
S	Y	Y	101.9	103.2	98.4	101.5	100.4	106.8	109.0	107.6	102.7	107.3	106.2	107.0	105.6	111.1	115.1	112.1	111.3	112.3	112.1	112.3	113.3	120.0	120.7	114.1
R	Y	Y	59.4	55.3	44.2	35.5	36.2	41.2	38.2	27.6	34.6	33.8	28.4	22.9	24.6	29.6	33.3	29.3	24.9	19.4	20.8	16.2	13.4	13.2	7.5	0.0
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

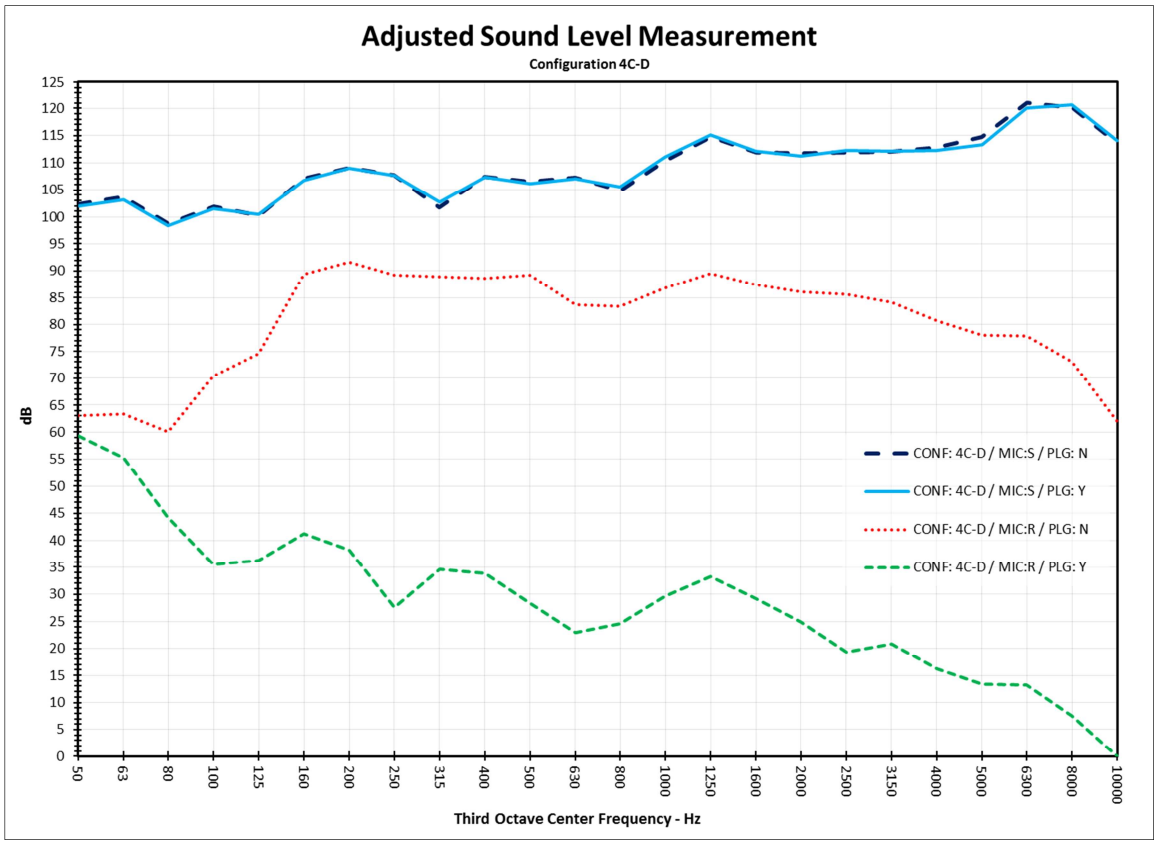

Figure B.10 - Adjusted Sound Pressure Level from Configuration 4C-D

Table B.21 - Sound Pressure Level Data from Configuration 4C-O

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	106.2	97.1	95.6	97.4	100.8	103.0	106.8	104.3	107.1	111.0	105.5	104.7	110.3	115.2	117.7	115.5	115.9	116.8	117.4	115.1	116.9	120.5	119.5	113.1
S	N	N	39.4	42.6	40.7	39.0	39.4	37.4	35.3	34.8	35.3	35.7	36.0	35.1	34.0	34.4	36.0	35.6	36.6	40.7	38.6	39.7	41.2	42.4	44.8	46.4
R	Y	N	63.1	63.4	60.1	70.4	74.6	89.4	91.7	89.2	89.0	88.6	89.3	83.7	83.4	86.9	89.5	87.5	86.1	85.7	84.1	80.7	78.0	77.9	73.0	62.0
R	N	N	38.6	37.7	35.1	31.2	45.6	32.6	28.5	28.3	24.6	24.8	24.6	20.2	17.5	16.3	17.2	16.7	16.7	19.8	18.1	19.0	20.3	21.4	23.7	25.3
S	Y	Y	105.8	97.0	95.3	97.4	100.7	102.4	105.6	104.2	106.7	111.4	106.3	102.7	108.7	114.5	116.3	114.6	114.9	116.1	116.9	114.9	116.2	119.0	118.1	110.9
S	N	Y	39.1	42.2	40.7	39.1	38.5	37.3	35.1	34.8	35.2	35.7	35.7	35.2	34.0	34.5	35.7	35.6	36.5	40.8	38.6	39.7	41.1	42.3	44.7	46.3
R	Y	Y	59.4	55.4	44.7	36.8	42.7	41.7	38.6	31.2	35.0	34.3	29.9	24.7	25.3	29.8	33.4	29.5	25.5	22.6	22.7	20.9	21.1	22.1	23.9	25.4
R	N	Y	39.2	38.0	34.7	30.9	41.6	32.0	28.5	28.7	24.6	24.6	24.6	20.0	17.3	16.2	17.5	16.8	16.9	19.8	18.2	19.1	20.3	21.5	23.8	25.4
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table B.22 – Adjusted Sound Pressure Level Data from Configuration 4C-O

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	106.2	97.1	95.6	97.4	100.8	103.0	106.8	104.3	107.1	111.0	105.5	104.7	110.3	115.2	117.7	115.5	115.9	116.8	117.4	115.1	116.9	120.5	119.5	113.1
R	Y	N	63.1	63.4	60.1	70.4	74.6	89.4	91.7	89.2	89.0	88.6	89.3	83.7	83.4	86.9	89.5	87.5	86.1	85.7	84.1	80.7	78.0	77.9	73.0	62.0
S	Y	Y	105.8	97.0	95.3	97.4	100.7	102.4	105.6	104.2	106.7	111.4	106.3	102.7	108.7	114.5	116.3	114.6	114.9	116.1	116.9	114.9	116.2	119.0	118.1	110.9
R	Y	Y	59.4	55.3	44.2	35.5	36.2	41.2	38.2	27.6	34.6	33.8	28.4	22.9	24.6	29.6	33.3	29.3	24.9	19.4	20.8	16.2	13.4	13.2	7.5	0.0
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

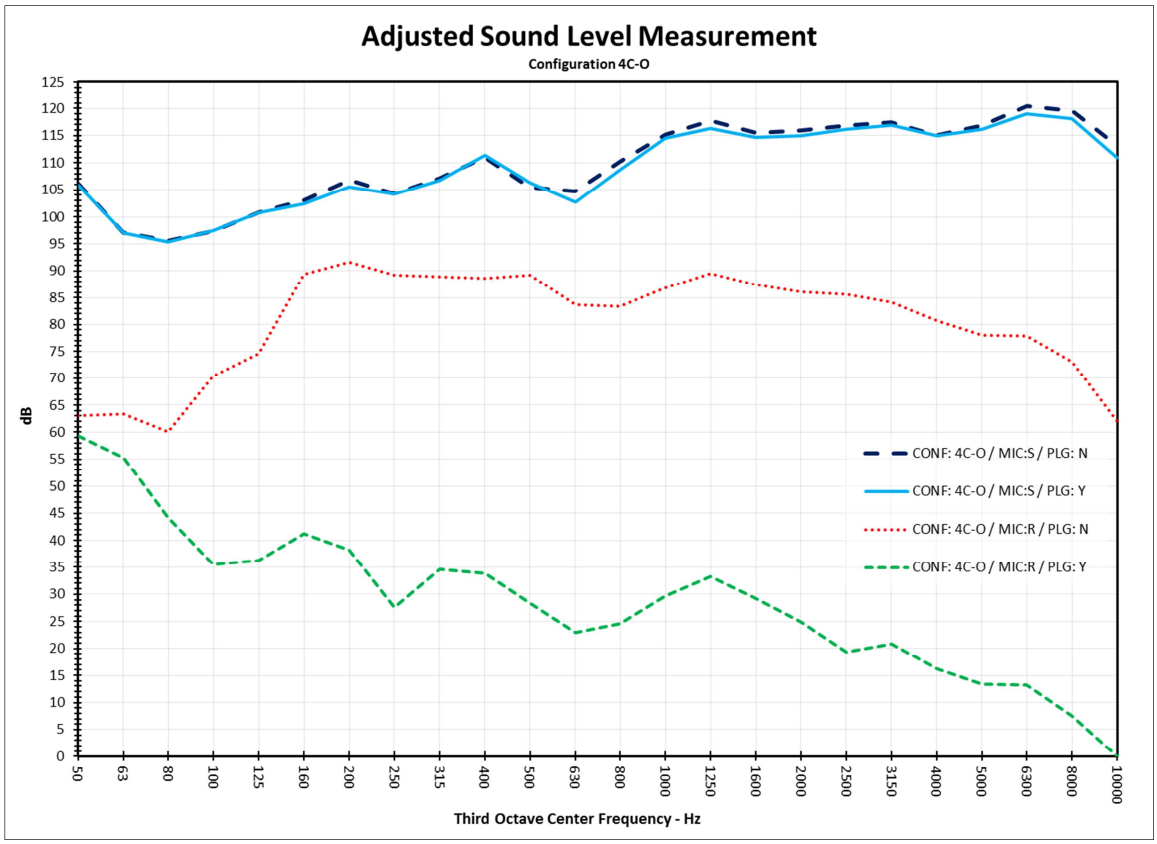

Figure B.11 - Adjusted Sound Pressure Level from Configuration 4C-O

Table B.23 - Sound Pressure Level Data from Configuration 4C-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.2	96.3	101.6	102.2	99.7	107.5	108.8	106.0	107.7	103.1	103.2	101.8	106.5	113.9	117.0	115.2	114.8	116.7	118.0	117.1	119.6	121.3	118.3	111.8
S	N	N	39.4	42.6	40.7	39.0	39.4	37.4	35.3	34.8	35.3	35.7	36.0	35.1	34.0	34.4	36.0	35.6	36.6	40.7	38.6	39.7	41.2	42.4	44.8	46.4
R	Y	N	63.1	63.4	60.1	70.4	74.6	89.4	91.7	89.2	89.0	88.6	89.3	83.7	83.4	86.9	89.5	87.5	86.1	85.7	84.1	80.7	78.0	77.9	73.0	62.0
R	N	N	38.6	37.7	35.1	31.2	45.6	32.6	28.5	28.3	24.6	24.8	24.6	20.2	17.5	16.3	17.2	16.7	16.7	19.8	18.1	19.0	20.3	21.4	23.7	25.3
S	Y	Y	100.2	95.8	100.6	102.2	99.2	107.0	108.5	106.3	108.0	103.1	102.9	101.5	107.1	113.4	116.0	115.1	114.5	115.9	116.9	116.8	118.6	120.8	117.9	111.3
S	N	Y	39.1	42.2	40.7	39.1	38.5	37.3	35.1	34.8	35.2	35.7	35.7	35.2	34.0	34.5	35.7	35.6	36.5	40.8	38.6	39.7	41.1	42.3	44.7	46.3
R	Y	Y	59.4	55.4	44.7	36.8	42.7	41.7	38.6	31.2	35.0	34.3	29.9	24.7	25.3	29.8	33.4	29.5	25.5	22.6	22.7	20.9	21.1	22.1	23.9	25.4
R	N	Y	39.2	38.0	34.7	30.9	41.6	32.0	28.5	28.7	24.6	24.6	24.6	20.0	17.3	16.2	17.5	16.8	16.9	19.8	18.2	19.1	20.3	21.5	23.8	25.4

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

Table B.24 – Adjusted Sound Pressure Level Data from Configuration 4C-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.2	96.3	101.6	102.2	99.7	107.5	108.8	106.0	107.7	103.1	103.2	101.8	106.5	113.9	117.0	115.2	114.8	116.7	118.0	117.1	119.6	121.3	118.3	111.8
R	Y	N	63.1	63.4	60.1	70.4	74.6	89.4	91.7	89.2	89.0	88.6	89.3	83.7	83.4	86.9	89.5	87.5	86.1	85.7	84.1	80.7	78.0	77.9	73.0	62.0
S	Y	Y	100.2	95.8	100.6	102.2	99.2	107.0	108.5	106.3	108.0	103.1	102.9	101.5	107.1	113.4	116.0	115.1	114.5	115.9	116.9	116.8	118.6	120.8	117.9	111.3
R	Y	Y	59.4	55.3	44.2	35.5	36.2	41.2	38.2	27.6	34.6	33.8	28.4	22.9	24.6	29.6	33.3	29.3	24.9	19.4	20.8	16.2	13.4	13.2	7.5	0.0

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

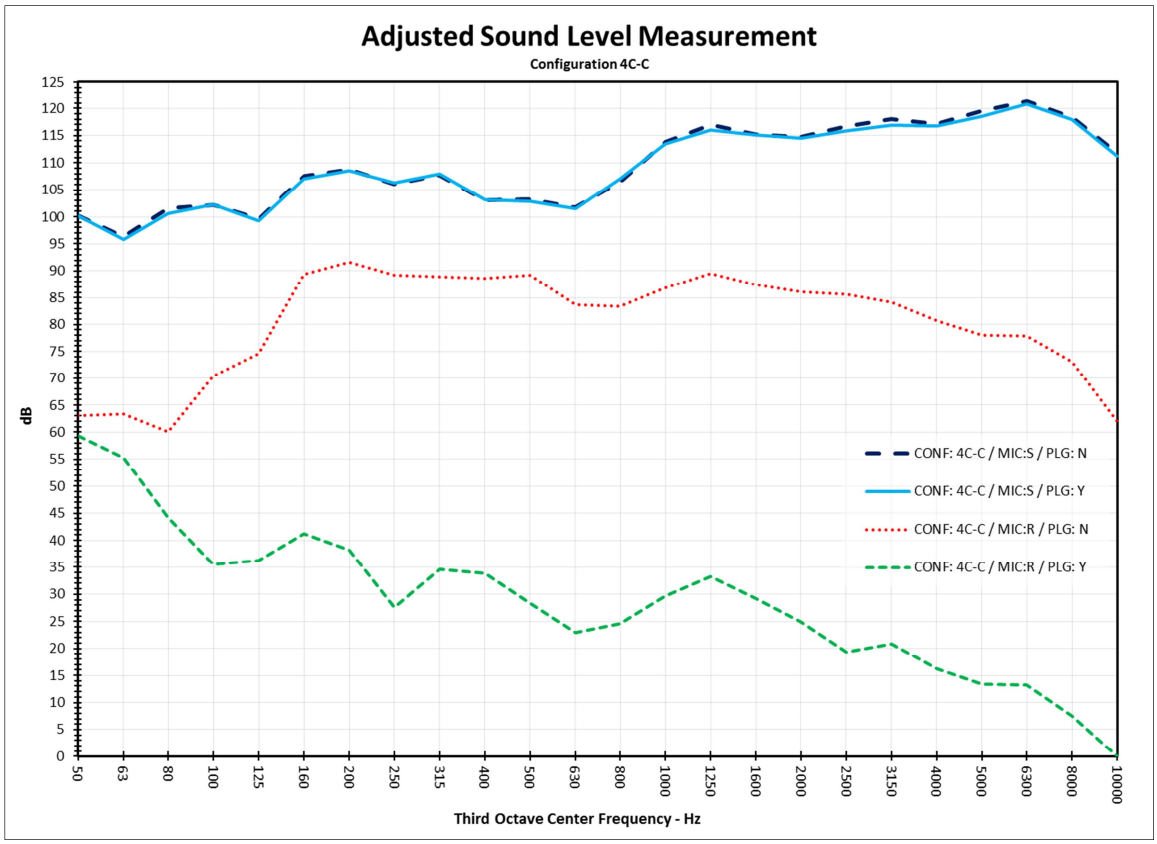

Figure B.12 - Adjusted Sound Pressure Level from Configuration 4C-C

Table B.25 - Sound Pressure Level Data from Configuration 4D-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	101.2	102.6	103.6	102.3	103.5	105.8	110.5	106.6	106.2	106.4	109.2	108.7	109.8	113.4	116.2	115.1	114.8	116.3	117.5	116.9	118.9	121.2	118.1	111.1
S	N	N	41.4	39.2	38.1	37.9	38.5	36.4	35.0	35.0	35.2	35.7	35.3	34.4	33.9	34.6	36.1	35.9	36.8	40.7	38.3	39.2	40.1	40.7	42.0	42.4
R	Y	N	62.0	67.1	63.4	71.1	79.2	86.6	90.8	87.5	85.2	86.1	86.3	83.6	83.2	86.3	88.4	85.6	85.0	84.7	83.6	80.2	77.2	77.3	72.4	61.1
R	N	N	38.5	37.3	34.8	31.6	47.0	33.9	29.4	30.2	25.8	25.0	25.2	21.2	17.8	17.1	17.4	17.0	17.1	19.8	18.2	18.7	19.4	19.9	21.1	21.5
S	Y	Y	100.4	102.3	103.5	102.3	102.7	106.0	110.8	106.9	104.7	106.3	109.1	108.5	109.4	112.9	116.1	114.7	114.7	115.9	117.1	116.5	118.8	120.7	117.4	110.6
S	N	Y	40.6	39.9	38.1	37.5	37.4	36.0	34.8	35.0	35.2	35.6	35.8	35.2	34.3	34.7	36.0	35.8	36.7	40.6	38.4	39.2	40.1	40.7	42.0	42.4
R	Y	Y	58.5	53.6	43.1	37.3	43.7	39.6	36.5	31.0	30.6	31.3	28.7	24.2	24.3	29.9	32.7	28.8	25.8	23.2	22.2	20.6	20.4	20.9	21.3	21.5
R	N	Y	40.6	38.9	34.0	32.7	32.8	26.2	23.5	18.8	18.4	19.2	19.0	18.9	19.4	18.8	18.8	18.0	18.7	19.2	19.5	19.4	19.7	20.0	21.2	21.5

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

Table B.26 – Adjusted Sound Pressure Level Data from Configuration 4D-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	101.2	102.6	103.6	102.3	103.5	105.8	110.5	106.6	106.2	106.4	109.2	108.7	109.8	113.4	116.2	115.1	114.8	116.3	117.5	116.9	118.9	121.2	118.1	111.1
R	Y	N	62.0	67.1	63.4	71.1	79.2	86.6	90.8	87.5	85.2	86.1	86.3	83.6	83.2	86.3	88.4	85.6	85.0	84.7	83.6	80.2	77.2	77.3	72.4	61.1
S	Y	Y	100.4	102.3	103.5	102.3	102.7	106.0	110.8	106.9	104.7	106.3	109.1	108.5	109.4	112.9	116.1	114.7	114.7	115.9	117.1	116.5	118.8	120.7	117.4	110.6
R	Y	Y	58.4	53.5	42.5	35.5	43.3	39.4	36.3	30.7	30.3	31.0	28.2	22.7	22.6	29.5	32.5	28.4	24.9	21.0	18.9	14.4	12.1	13.6	4.9	0.0

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

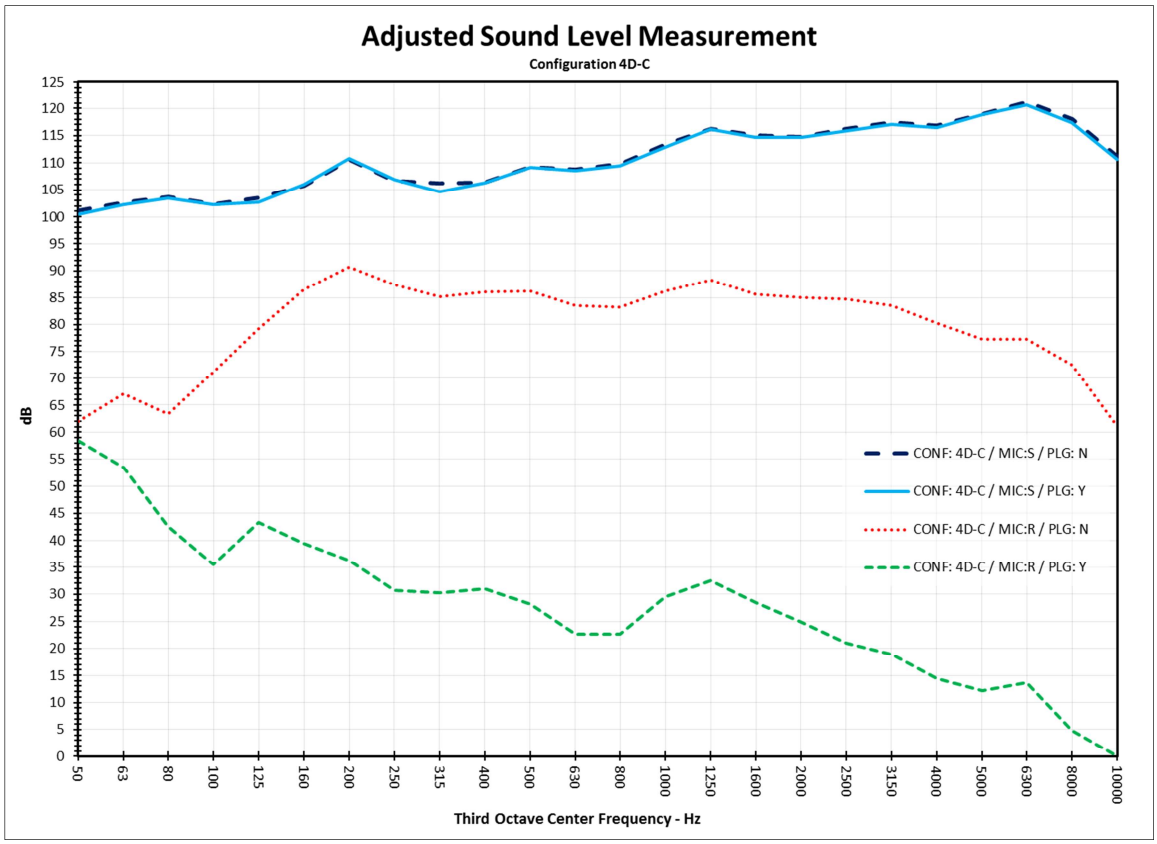

Figure B.13 - Adjusted Sound Pressure Level from Configuration 4D-C

APPENDIX C

SOUND PRESSURE LEVEL DATA USING SILENCER

The sound pressure level data shown in this section used the silencer with plug 2 (Figure 3.42). Following the protocol specified in section 3.4.1, a total of eight sound tests were conducted for each configuration. These results are tabulated and titled Sound Pressure Level Data from Configuration XX-X, where XX-X specifies which duct configuration, speaker position, and microphone position the data came from.

Out of eight tests, four of them are pink noise levels while the other four are the corresponding ambient levels. The ambient levels for each 1/3 octave frequency band are logarithmically subtracted from the pink noise levels using the equation specified in section 3.4.4.1. These results are tabulated and titled Adjusted Sound Pressure Level Data from Configuration XX-X, where XX-X specifies which duct configuration, speaker position, and microphone position the data came from.

Table C.1 - Sound Pressure Level Data from Configuration 2C-O

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	106.5	98.3	95.2	96.4	100.9	101.0	105.1	104.5	106.2	111.2	106.0	105.9	109.4	114.1	116.1	114.4	114.2	115.4	115.8	114.1	115.7	119.5	119.8	111.6
S	N	N	43.8	39.7	36.7	36.0	38.0	36.6	35.0	34.5	35.0	35.2	35.5	35.6	34.7	34.6	36.0	35.6	36.6	40.8	38.6	39.7	41.1	42.3	44.7	46.3
R	Y	N	63.9	65.7	61.3	70.2	74.9	86.3	90.1	89.2	90.3	85.7	87.9	84.3	82.6	86.8	89.1	87.4	86.6	86.5	85.8	82.7	81.2	81.9	78.2	68.4
R	N	N	39.1	37.3	34.5	30.7	45.4	34.1	30.1	31.6	27.6	26.6	27.7	23.1	18.6	17.0	17.9	17.5	17.2	20.2	18.4	19.2	20.4	21.4	23.7	25.3
S	Y	Y	106.1	97.0	96.3	97.5	101.3	101.2	104.2	104.1	106.7	111.3	106.2	106.0	110.5	115.3	117.3	115.3	115.7	116.7	117.1	115.1	116.6	120.5	119.5	112.6
S	N	Y	44.2	40.0	36.4	36.1	38.5	36.3	35.1	35.0	34.9	35.1	35.6	35.6	34.5	34.6	35.9	35.6	36.5	40.8	38.6	39.7	41.2	42.3	44.6	46.3
R	Y	Y	61.3	60.2	48.2	53.4	52.4	52.8	49.7	38.3	36.8	34.5	32.3	28.8	26.9	32.6	39.5	39.2	43.2	44.7	46.7	43.5	41.0	42.5	37.9	28.9
R	N	Y	41.0	39.9	35.5	31.1	39.2	32.3	31.0	32.5	28.2	28.6	29.1	24.9	20.2	18.4	19.0	18.1	18.0	19.7	18.8	19.2	20.4	21.5	23.7	25.3
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table C.2 – Adjusted Sound Pressure Level Data from Configuration 2C-O

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	106.5	98.3	95.2	96.4	100.9	101.0	105.1	104.5	106.2	111.2	106.0	105.9	109.4	114.1	116.1	114.4	114.2	115.4	115.8	114.1	115.7	119.5	119.8	111.6
R	Y	N	63.9	65.7	61.3	70.2	74.9	86.3	90.1	89.2	90.3	85.7	87.9	84.3	82.6	86.8	89.1	87.4	86.6	86.5	85.8	82.7	81.2	81.9	78.2	68.4
S	Y	Y	106.1	97.0	96.3	97.5	101.3	101.2	104.2	104.1	106.7	111.3	106.2	106.0	110.5	115.3	117.3	115.3	115.7	116.7	117.1	115.1	116.6	120.5	119.5	112.6
R	Y	Y	61.3	60.2	48.0	53.4	52.2	52.8	49.6	37.0	36.2	33.2	29.5	26.5	25.9	32.4	39.5	39.2	43.2	44.7	46.7	43.5	41.0	42.5	37.7	26.4
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

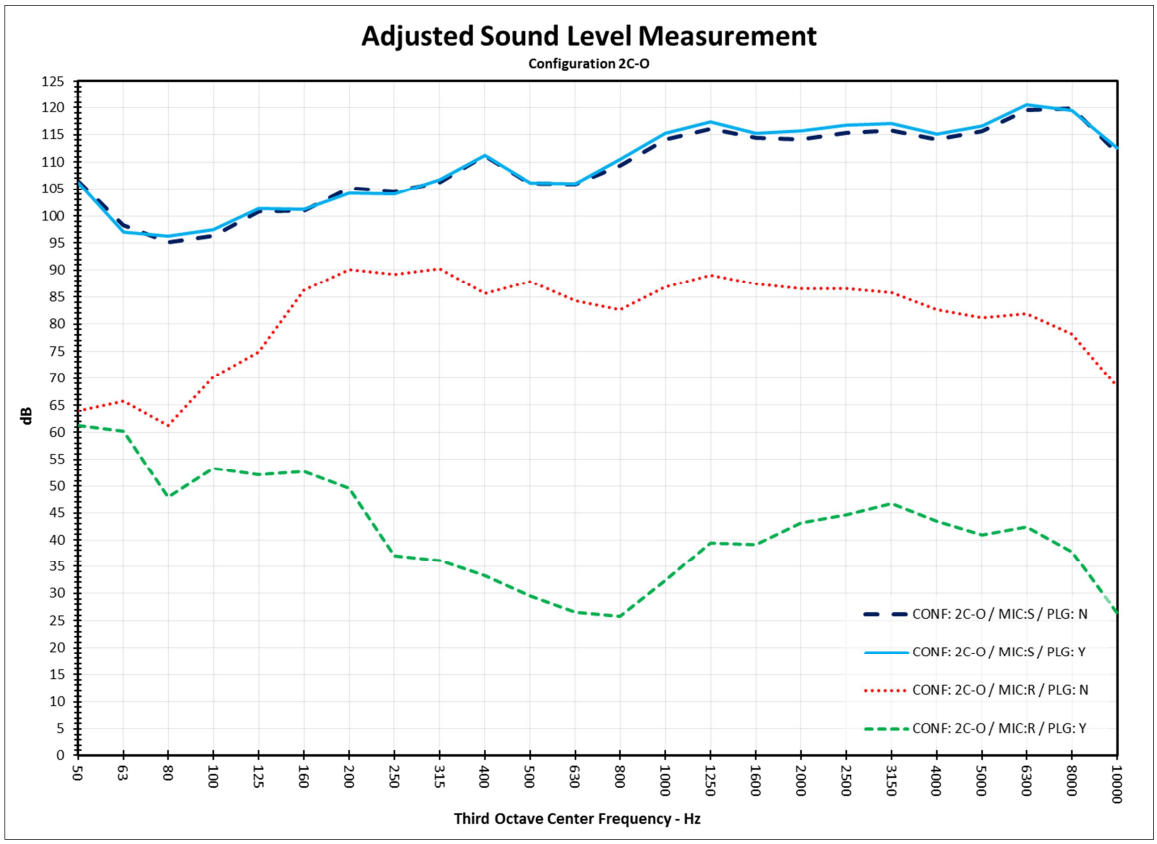

Figure C.1 - Adjusted Sound Pressure Level from Configuration 2C-O

Table C.3 - Sound Pressure Level Data from Configuration 2C-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.9	96.6	102.6	102.7	102.1	105.1	108.1	105.4	108.1	105.5	104.3	105.2	107.4	114.5	118.5	116.1	115.6	116.9	118.7	119.0	120.4	122.7	120.8	114.7
S	N	N	43.8	39.7	36.7	36.0	38.0	36.6	35.0	34.5	35.0	35.2	35.5	35.6	34.7	34.6	36.0	35.6	36.6	40.8	38.6	39.7	41.1	42.3	44.7	46.3
R	Y	N	63.9	65.7	61.3	70.2	74.9	86.3	90.1	89.2	90.3	85.7	87.9	84.3	82.6	86.8	89.1	87.4	86.6	86.5	85.8	82.7	81.2	81.9	78.2	68.4
R	N	N	39.1	37.3	34.5	30.7	45.4	34.1	30.1	31.6	27.6	26.6	27.7	23.1	18.6	17.0	17.9	17.5	17.2	20.2	18.4	19.2	20.4	21.4	23.7	25.3
S	Y	Y	100.5	97.2	104.1	103.6	102.9	106.1	109.2	105.1	107.5	104.3	103.1	103.6	106.1	114.6	118.9	116.3	116.0	117.6	119.2	119.0	120.7	123.4	121.5	115.7
S	N	Y	44.2	40.0	36.4	36.1	38.5	36.3	35.1	35.0	34.9	35.1	35.6	35.6	34.5	34.6	35.9	35.6	36.5	40.8	38.6	39.7	41.2	42.3	44.6	46.3
R	Y	Y	61.3	60.2	48.2	53.4	52.4	52.8	49.7	38.3	36.8	34.5	32.3	28.8	26.9	32.6	39.5	39.2	43.2	44.7	46.7	43.5	41.0	42.5	37.9	28.9
R	N	Y	41.0	39.9	35.5	31.1	39.2	32.3	31.0	32.5	28.2	28.6	29.1	24.9	20.2	18.4	19.0	18.1	18.0	19.7	18.8	19.2	20.4	21.5	23.7	25.3
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

Table C.4 – Adjusted Sound Pressure Level Data from Configuration 2C-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	100.9	96.6	102.6	102.7	102.1	105.1	108.1	105.4	108.1	105.5	104.3	105.2	107.4	114.5	118.5	116.1	115.6	116.9	118.7	119.0	120.4	122.7	120.8	114.7
R	Y	N	63.9	65.7	61.3	70.2	74.9	86.3	90.1	89.2	90.3	85.7	87.9	84.3	82.6	86.8	89.1	87.4	86.6	86.5	85.8	82.7	81.2	81.9	78.2	68.4
S	Y	Y	100.5	97.2	104.1	103.6	102.9	106.1	109.2	105.1	107.5	104.3	103.1	103.6	106.1	114.6	118.9	116.3	116.0	117.6	119.2	119.0	120.7	123.4	121.5	115.7
R	Y	Y	61.3	60.2	48.0	53.4	52.2	52.8	49.6	37.0	36.2	33.2	29.5	26.5	25.9	32.4	39.5	39.2	43.2	44.7	46.7	43.5	41.0	42.5	37.7	26.4
MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF																										

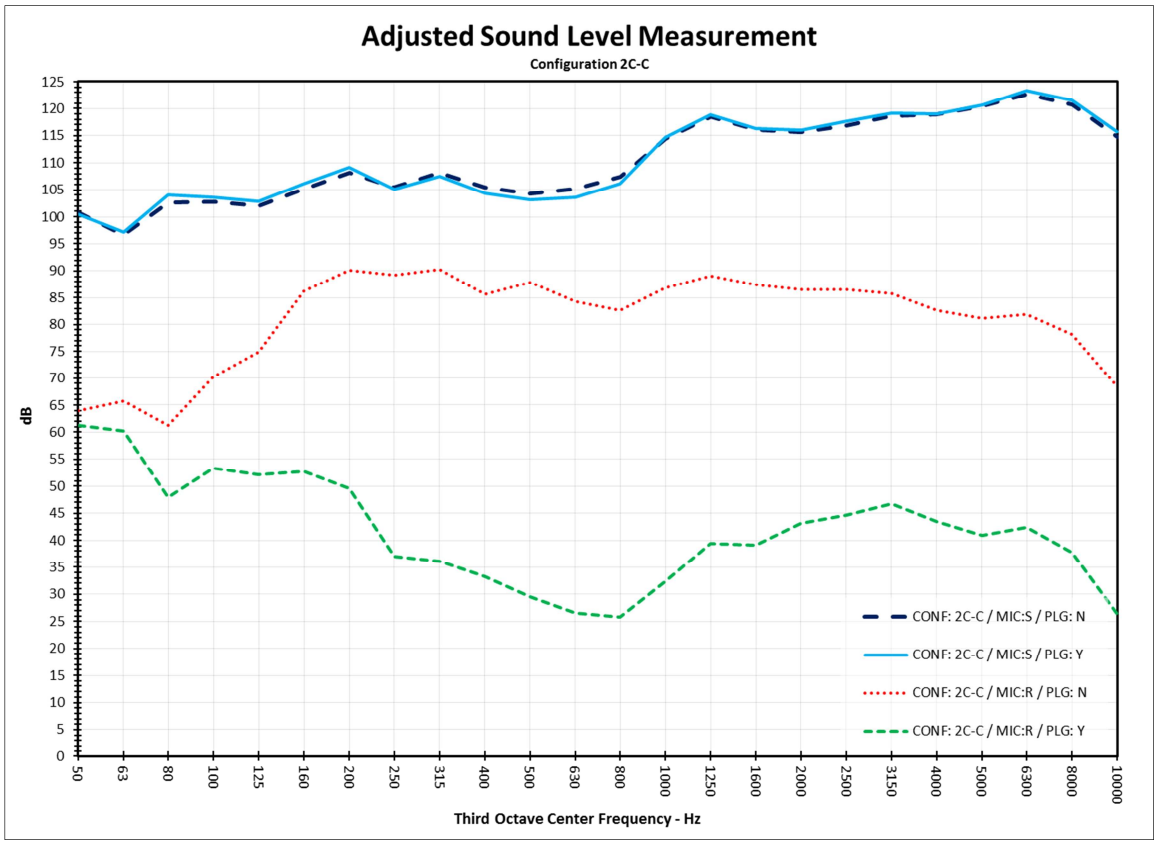

Figure C.2 - Adjusted Sound Pressure Level from Configuration 2C-C

Table C.5 - Sound Pressure Level Data from Configuration 3C-D

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.8	105.7	109.1	106.7	103.3	110.3	111.6	109.1	105.5	105.8	109.5	103.3	103.4	116.8	113.7	115.1	113.0	114.3	113.2	112.2	114.7	120.8	122.3	115.6
S	N	N	39.2	42.9	41.1	38.8	40.1	37.8	35.4	34.5	34.7	35.1	35.7	35.7	34.4	34.6	35.8	35.5	36.6	40.9	38.6	39.6	41.1	42.3	44.6	46.3
R	Y	N	56.3	64.2	70.8	74.5	79.3	92.9	94.8	89.9	88.6	90.6	89.3	85.1	85.2	87.6	90.1	87.6	86.9	86.9	86.5	83.7	81.7	82.7	79.0	69.2
R	N	N	39.7	38.4	34.7	30.6	45.8	33.9	30.2	31.7	27.7	26.6	27.9	23.0	18.5	17.0	17.7	17.0	16.6	19.8	18.2	19.0	20.3	21.4	23.6	25.2
S	Y	Y	97.4	104.9	108.9	106.5	103.1	109.8	111.2	109.3	103.6	106.6	110.2	101.8	104.6	113.9	114.6	113.3	112.6	112.6	113.2	113.3	116.9	122.5	121.9	114.8
S	N	Y	38.4	43.0	40.7	38.4	41.4	36.7	35.3	34.5	34.6	35.1	35.6	35.7	34.7	34.5	35.9	35.6	36.6	40.7	38.6	39.7	41.2	42.3	44.7	46.3
R	Y	Y	56.3	50.3	52.1	58.3	56.3	60.3	54.0	40.6	35.5	35.8	32.8	28.8	28.1	33.0	40.3	39.1	42.2	46.8	48.1	44.8	42.3	42.3	38.8	29.5
R	N	Y	40.6	40.3	36.4	32.1	39.5	33.0	31.1	32.3	27.7	27.7	28.6	23.7	19.1	17.3	18.2	17.2	17.1	19.9	18.3	19.1	20.4	21.6	23.8	25.4

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

Table C.6 – Adjusted Sound Pressure Level Data from Configuration 3C-D

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.8	105.7	109.1	106.7	103.3	110.3	111.6	109.1	105.5	105.8	109.5	103.3	103.4	116.8	113.7	115.1	113.0	114.3	113.2	112.2	114.7	120.8	122.3	115.6
R	Y	N	56.2	64.2	70.8	74.5	79.3	92.9	94.8	89.9	88.6	90.6	89.3	85.1	85.2	87.6	90.1	87.6	86.9	86.9	86.5	83.7	81.7	82.7	79.0	69.2
S	Y	Y	97.4	104.9	108.9	106.5	103.1	109.8	111.2	109.3	103.6	106.6	110.2	101.8	104.6	113.9	114.6	113.3	112.6	112.6	113.2	113.3	116.9	122.5	121.9	114.8
R	Y	Y	56.2	49.8	52.0	58.3	56.2	60.3	54.0	39.9	34.7	35.1	30.7	27.2	27.5	32.9	40.3	39.1	42.2	46.8	48.1	44.8	42.3	42.3	38.7	27.4

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

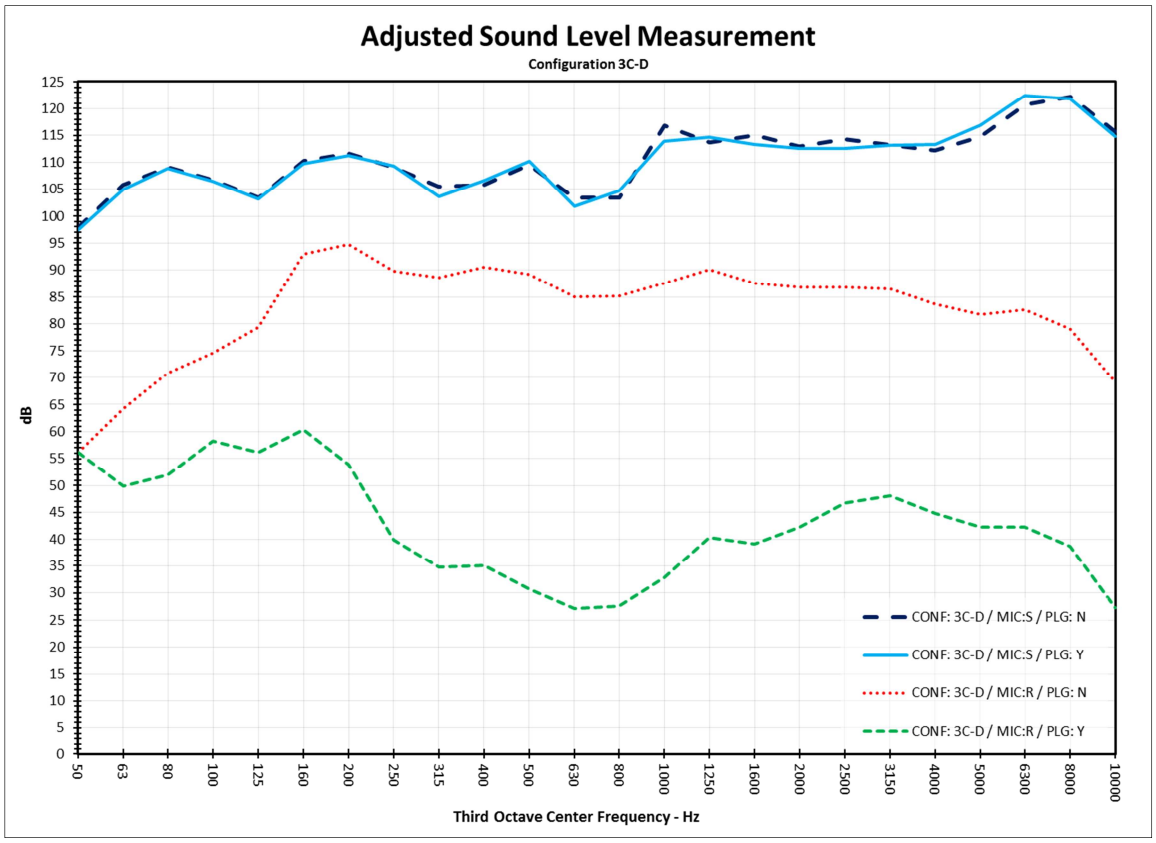

Figure C.3 - Adjusted Sound Pressure Level from Configuration 3C-D

Table C.7 - Sound Pressure Level Data from Configuration 3C-C

Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.7	108.5	111.5	107.5	103.7	113.2	113.4	108.4	104.8	112.6	112.7	109.4	110.8	115.6	118.9	116.7	116.5	117.6	119.6	118.9	119.9	123.3	120.3	114.1
S	N	N	39.2	42.9	41.1	38.8	40.1	37.8	35.4	34.5	34.7	35.1	35.7	35.7	34.4	34.6	35.8	35.5	36.6	40.9	38.6	39.6	41.1	42.3	44.6	46.3
R	Y	N	56.3	64.2	70.8	74.5	79.3	92.9	94.8	89.9	88.6	90.6	89.3	85.1	85.2	87.6	90.1	87.6	86.9	86.9	86.5	83.7	81.7	82.7	79.0	69.2
R	N	N	39.7	38.4	34.7	30.6	45.8	33.9	30.2	31.7	27.7	26.6	27.9	23.0	18.5	17.0	17.7	17.0	16.6	19.8	18.2	19.0	20.3	21.4	23.6	25.2
S	Y	Y	97.8	108.8	111.6	108.0	104.5	113.8	114.1	108.7	104.4	112.7	112.1	109.2	110.0	114.3	117.7	115.6	115.1	117.4	118.8	117.4	118.7	121.8	120.0	114.0
S	N	Y	38.4	43.0	40.7	38.4	41.4	36.7	35.3	34.5	34.6	35.1	35.6	35.7	34.7	34.5	35.9	35.6	36.6	40.7	38.6	39.7	41.2	42.3	44.7	46.3
R	Y	Y	56.3	50.3	52.1	58.3	56.3	60.3	54.0	40.6	35.5	35.8	32.8	28.8	28.1	33.0	40.3	39.1	42.2	46.8	48.1	44.8	42.3	42.3	38.8	29.5
R	N	Y	40.6	40.3	36.4	32.1	39.5	33.0	31.1	32.3	27.7	27.7	28.6	23.7	19.1	17.3	18.2	17.2	17.1	19.9	18.3	19.1	20.4	21.6	23.8	25.4

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

Table C.8 – Adjusted Sound Pressure Level Data from Configuration 3C-C

Adjsuted Sound Pressure Levels																										
MIC	**SRC**	**PLG**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10K**
S	Y	N	97.7	108.5	111.5	107.5	103.7	113.2	113.4	108.4	104.8	112.6	112.7	109.4	110.8	115.6	118.9	116.7	116.5	117.6	119.6	118.9	119.9	123.3	120.3	114.1
R	Y	N	56.2	64.2	70.8	74.5	79.3	92.9	94.8	89.9	88.6	90.6	89.3	85.1	85.2	87.6	90.1	87.6	86.9	86.9	86.5	83.7	81.7	82.7	79.0	69.2
S	Y	Y	97.8	108.8	111.6	108.0	104.5	113.8	114.1	108.7	104.4	112.7	112.1	109.2	110.0	114.3	117.7	115.6	115.1	117.4	118.8	117.4	118.7	121.8	120.0	114.0
R	Y	Y	56.2	49.8	52.0	58.3	56.2	60.3	54.0	39.9	34.7	35.1	30.7	27.2	27.5	32.9	40.3	39.1	42.2	46.8	48.1	44.8	42.3	42.3	38.7	27.4

MIC: Microphone | **S:** Source | **R:** Reverberation | **SRC:** Sound Source | **PLG:** Plug | **Y**: ON | **N**: OFF

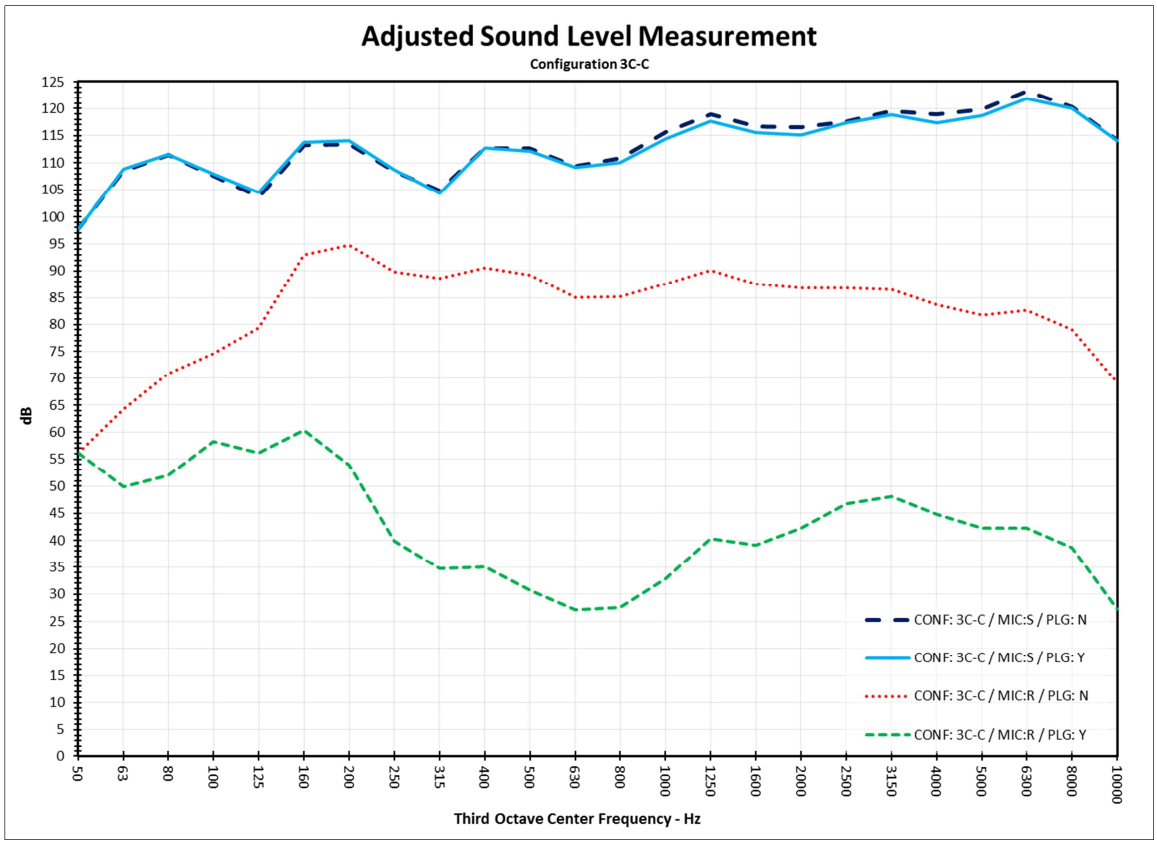

Figure C.4 - Adjusted Sound Pressure Level from Configuration 3C-C

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