Dearborn, Michigan
NOISE-CON 2008
2008 July 28-30

Sound source near field and directionality impacts on hemi-anechoic chamber qualification

Ankit Chadha[a]
Douglas F. Winker[b]
Einar Ristroph[c]
ETS-Lindgren Acoustic Research Laboratory
1301 Arrow Point Drive
Cedar Park, Texas 78613

ABSTRACT

Hemi-anechoic chamber provides a free-field environment for the purpose of precision grade sound power level determinations of devices with tonal emissions. Qualification of hemi-anechoic chambers is of critical concern for both the chamber manufacturers and the end user as it determines free-field performance of the chamber and also yields the largest volume inside the chamber within which a measurement surface can be chosen. ISO 3745:2003 Annex A outlines the procedure for chamber qualification and also provides requirements for omni-directional sound sources that can be used for performing qualification testing. The standard suggests starting measurements at a distance of 0.5 m from the acoustic center of the qualification source in order to be outside of the "near field". The purpose of this paper is to: a) compare the deviations from inverse square law using a source that qualifies according to ISO3745 Annex A.2.2.2 with a source that does not meet the standard requirements, b) and to study the effects of near field on deviations from inverse square law. Near field effects will be evaluated by using sources of different size and shapes (Point source to a source having a largest dimension of about 0.5m).

1. INTRODUCTION

Hemi-anechoic chambers provide an acoustic environment which approximates the operating and mounting conditions for many noise sources. This acoustical environment (i.e. a free-field) over a perfectly reflecting plane is of great importance for acoustic testing of computers, loudspeakers, microphones, aerospace components; for doing various types of studies like speech intelligibility, sound quality analysis, directionality response, frequency response; and finally for the determination of sound power from various noise emitting products. These chambers provide a hemispherical region of space that can be used for setting up the microphone arrays for sound pressure level measurements that is finally used for the calculation of sound power. ISO 3745:2003(E) Annex A[1] outlines the procedure for qualification of hemi-anechoic chambers. Qualification of a hemi-anechoic chamber is a way to evaluate the quality of free-field inside the chamber, to determine the maximum hemispherical measurement surface radii for setting up the microphone arrays and finally to determine the frequency range in which sound

[a] Email address: ankit.chadha@ets-lindgren.com
[b] Email address: douglas.winker@ets-lindgren.com
[c] Email address: einar.ristroph@ets-lindgren.com

pressure level measurements can be conducted for precision grade sound power level determination of devices with tonal emissions. ISO 3745 also outlines the directionality requirements on the sources that can be used for the purpose of chamber qualification. The standard requires performing five (5) radial traverses from the geometrical center of the measurement hemisphere. The sound pressure level measurements should be started at a distance of about 0.5 m from the source and ending at or beyond the radius that has to be qualified. The reason for starting the measurements at about 0.5 m form the acoustic center of the source is to be away from the near-field of the source.

The key objective of this paper is to a) study the effects of using different types of excitation signal used for the purpose of assessing the free-field performance of the chamber, b) compare the deviations from inverse square law using a source that qualifies according to ISO3745 Annex A.2.2.2 with a source that does not meet the standard requirements c) to study the near-field effects on deviations from ISL and also to show that ISO 3745 analysis routine can lead to misleading results if not employed in the proper way.

2. HEMI-ANECHOIC CHAMBER QUALIFICATION

A. ISO 3745 Qualification Procedure

ISO 3745:2003 Annex A describes a method for qualifying hemi-anechoic chambers to determine their acceptability for use in precision-grade sound power level determinations in accordance with the standard. The standard requires performing radial traverses starting from the geometric center of the measurement hemisphere and going towards each upper trihedral corner of the chamber and one (1) traverse extended towards the wall of the chamber. Sound pressure levels are measured at small incremental distances starting 0.5 m from the sound source (r=0) and ending at least or beyond the expected qualifying radii of the chamber (r_i). The deviations from inverse square law were calculated using the following equation:

$$\Delta L_{pi} = L_{pi} - L_p(r_i)\ \mathrm{dB} \tag{1}$$

where

ΔL_{pi} is the deviations from inverse square law;

L_{pi} is the sound pressure level measured at ith measurement position along the traverse line;

$L_p(r_i) = 20\log\left[\dfrac{a}{r_i - r_0}\right]$ dB, is the sound pressure level at distance r_i estimated by inverse square law, where a is the source strength; r_i is the distance from the source along the traverse line at the ith measurement position (mm); r_0 is the collinear offset of the acoustic center of the source from its actual physical location.

$$a = \frac{\left(\sum_{i=1}^{N} r_i\right)^2 - N\sum_{i=1}^{N} r_i^{\,2}}{\sum_{i=1}^{N} r_i \sum_{i=1}^{N} q_i - N\sum_{i=1}^{N} r_i q_i} \tag{2}$$

$$r_0 = -\left[\frac{\sum_{i=1}^{N} r_i \sum_{i=1}^{N} r_i q_i - \sum_{i=1}^{N} r_i^2 \sum_{i=1}^{N} q_i}{\sum_{i=1}^{N} r_i \sum_{i=1}^{N} q_i - N \sum_{i=1}^{N} r_i q_i} \right] \tag{3}$$

where $q_i = 10^{-0.05 L_{pi}}$

B. Data Acquisition Hardware & Software

An automated microphone traverse mechanism was used to move a microphone along a linear traverse path away from the source and measure sound pressure levels. A LabVIEW-based data acquisition system was used for sound pressure level measurements and for controlling the stepper motor that moves the microphone away from the source. Table 1 shows a list of hardware and software used for the purpose of this study

Table 1: Testing Equipment and Software

Item	Description
Data acquisition hardware	National Instruments (*NI*) PXI-1033 chassis and NI PXI-4462 DAQ card interfaced to x86 computer running Microsoft Windows XP OS
Data acquisition software	"Acoustic Systems Traverse Control 02Nov 2006.vi"
Reference microphone system (used for monitoring source stability)	G.R.A.S. Type 40HF low-noise microphone system
D.C. motor for moving the traverse microphone	Controlled by LabVIEW through serial port
Traverse microphone pre-amplifier	G.R.A.S. Type 26CF (*+20 dB* gain setting , *linear* filter setting)
Traverse microphone	G.R.A.S. Type 40AE
Microphone calibrator	B&K Type 4231 single-frequency calibrator
Sound Sources	ISO 3745 qualified sources
Signal Generator	NCH Tone Generator software
Power Amplifier, Equalizer	110 watt Power amplifier connected to a band equalizer
Data analysis software	"Acoustic Systems ISO 3745 Qualification Analysis Software v211.xls"

C. Excitation Signal: Broadband or Pure Tones

The free-field performance of the chamber can be examined by playing different excitation signals through the qualified omnidirectional sound source. The standard suggests using pure tone as the excitation source signal only if the chamber has to be used for conducting measurements on sources that radiate predominantly pure tones. However, it is the general understanding that many daily used products (computers, hard drives, cell phones and servers) can be more closely approximated by a source emitting different tones. Hence the qualification done by employing pure tones would be a better way of evaluating the free-field inside the chamber.

An experiment was designed to collect the inverse square law data inside a hemi-anechoic chamber at a frequency which is below the cut-off frequency of the chamber. This experiment was conducted inside a chamber which was designed such that it qualifies according to ISO 3745 up to a radius of 2.0 meters and a frequency range of 200 Hz – 20 k Hz. The deviations from inverse square law were compared from a single source subjected to two different excitation signals: broadband pink noise and a computer generated signal consisting of pure tones at each one-third octave band center frequency. It should be noted that the signal emitting pure tones at one-third octave band center frequency is a mix of pure tones separated at each particular frequency band. The standard suggests using this type of signal rather than doing a single traverse with each single tone. The standard provides no criteria for validating the fidelity of the source signal while playing pure tones, but still it was verified by looking at the narrow-band spectrum. The acquisition bandwidth was maintained at one-third octave band center frequency. Figure 1 shows the results obtained by playing two different source signals. The data shown in figure 1 clearly indicates that the broadband provides lesser information about the type of the free-field present inside the chamber. It should be noted that the data-acquisition bandwidth was same through out this experiment. The drop in the field was completely missed by the broadband excitation. Some recent studies[2] suggest that if the broadband noise is filtered in narrow-band corresponding to the pure tones at one-third octave band center frequency, then both of the signals will yield similar deviations from inverse square law. In other words these studies demonstrate that the bandwidth of the input signal and the data acquisition will have a stronger influence on the observed response. In this case the acquisition bandwidth was maintained the same but the input signal was: a) one discrete frequency (pure tones), and b) a mixture of different frequencies with in each one-third octave band (pink noise).

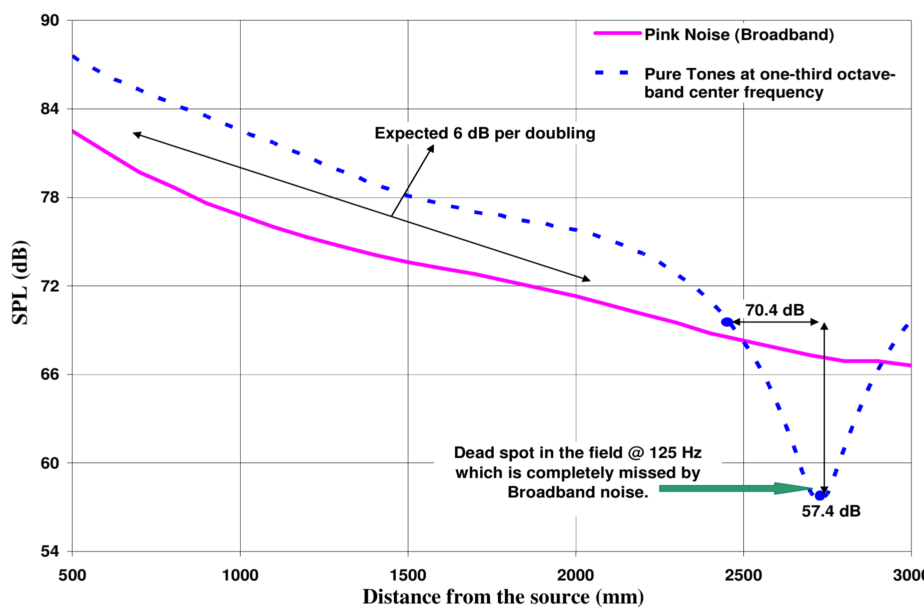

Figure 1: Sound Pressure Levels (SPL) measured from a source (starting from 0.5 m and ending at 3.0 m). Excitation Signal: Blue dotted line shows the levels measured while playing pure tones at one-third octave band center frequency, Pink solid line shows the levels measured while playing Pink Noise. Levels displayed were measured @ 125 Hz one-third octave band center frequency.

Additional work is planned in near future to provide experimental data comparing the inverse square law deviations obtained by broadband excitation with a selected acquisition bandwidth of a discrete frequency and the deviations determined by playing pure tones at the same analysis bandwidth. The effect of reflections on the deviations from inverse square law decreases with an increase in the band width of the input signal. In light of these considerations, the excitation signal selected for the purpose of evaluating the effects of sound source directionality, and the effects of near field on chamber qualification has been restricted strictly to pure tones.

3. SOUND SOURCE DIRECTIONALITY

A. ISO 3745 Sound Source Directionality Requirements

ISO 3745 A.2.2.2 “Test Sound Source Directionality" outlines requirements on the sources that can be used for performing chamber qualification. The standard requires that the sound source used should be omnidirectional, i.e., it should radiate equal sound energy in all directions, within specified tolerances. The standard requires 32 sound pressure level measurements with the source placed at the center of the room selected as $r = 0$, and with $\phi = 90°$, representing the plane corresponding to the rigid floor. Four (4) microphones are placed at $r = 1.5$m at an angle $\varphi = 80°, 60°, 40°, 20°$, where $\varphi=0°$ represents a position directly above the source. These 32 measurements are used for computing the maximum and minimum deviations from the mean. Table 2 shows the allowable deviations for the sound sources that can be used for the purpose of draw away testing.

Table 2: Allowable deviation in directionality of the test source per ISO 3745

Type of test room	One-third-octave band frequency Hz	Allowable deviations in Directionality dB
Hemi-anechoic	≤ 630 800 to 5000 6300 to 10 000 > 10 000	± 2,0 ± 2,5 ± 3,0 ± 5,0

B. Effects of Sound Source Directionality on deviations from ISL

This section compares the deviations from inverse square law determined using two different sources. Figure 2 shows all the possible cases. Fig 2a shows the comparison of deviations from inverse square law when both the sources qualify at that particular frequency. Fig 2b presents the case where only one source qualifies according to the ISO 3745 Annex A.2.2.2 and the other source does not meet the directionality requirements. In this case the deviations from ISL obtained from the non-qualified source are outside the allowed deviations for ISO 3745 chamber qualification. Figure 2c demonstrates the case where again only one source qualifies according to the standard, nonetheless the chamber still seems qualified. The excitation signal employed for all these studies was pure tones at one-third octave band center frequencies. The data presented in Figure 2 was obtained using two sources: a) Norsonic Type-250 Hemi-Dodecahedron, S/N 23283 and b) another hemi-dodecahedron source identified as ETS-HAS01. The directivity of each source was measured in accordance with ISO 3745. Table 3 summarizes the ISO 3745 qualified frequency range for these two (2) sources. The work presented here is an extension of the study conducted by Chadha *et al*[3,4].

Table 3: ISO 3745 qualified frequency range for Norsonic Type 250 (NOR-250) & ETS-HAS01. Excitation signal: Pure tones @ one-third octave band center frequency.

Source	ISO 3745 qualified frequency range
Norsonic Type-250 Hemi-Dodecahedron	100-630 Hz
ETS-HAS01(hemi-dodecahedron source)	200-1250 Hz

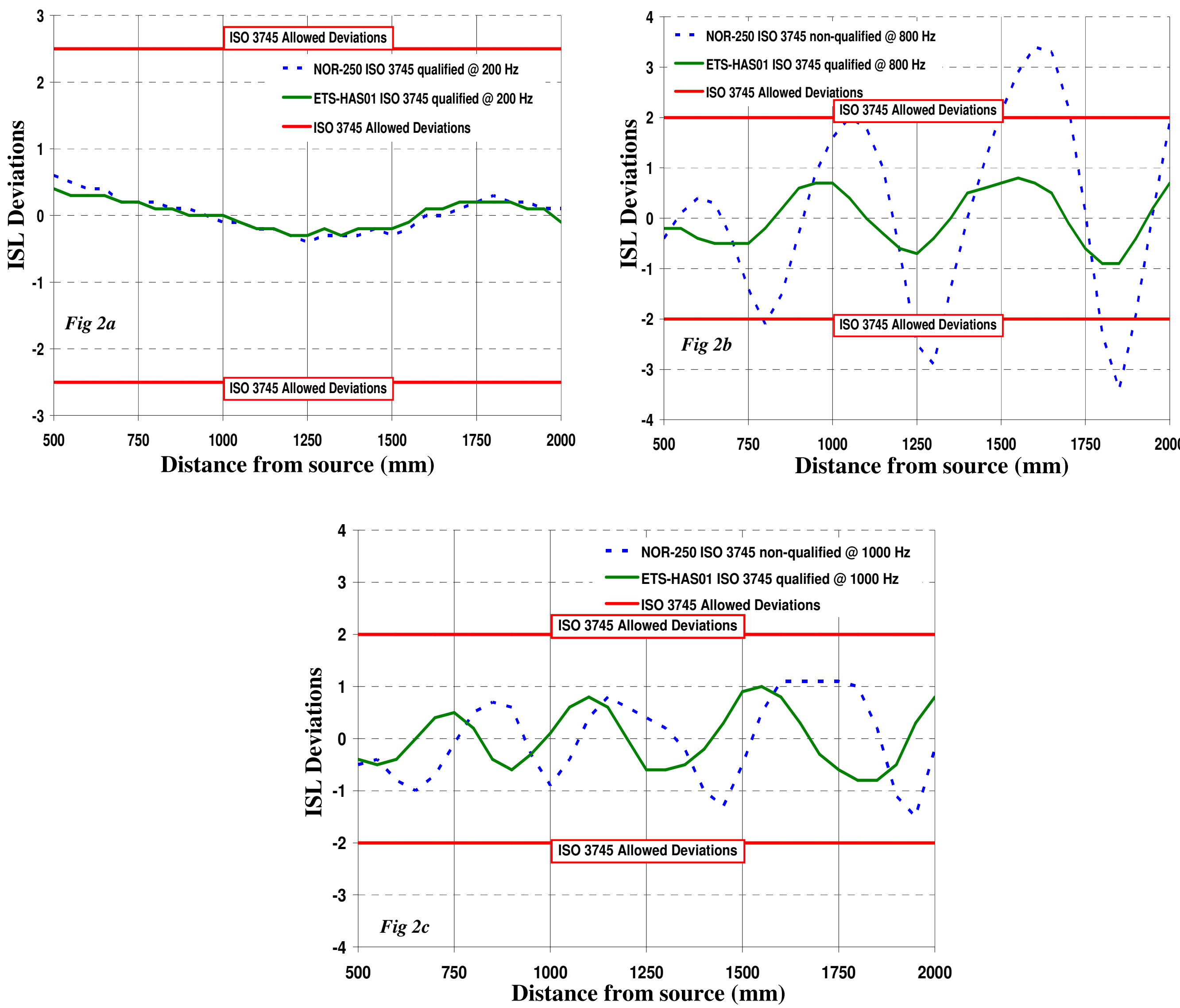

Figure 2: Comparison of deviations from inverse square law in dB obtained by two different sources: 2a.) both the sources qualify according to the standard. 2b) only one source qualifies according to the standard and chamber only qualifies with the qualified source. 2c) only one source qualifies according to the standard but the chamber still qualifies with both the sources.

The above figure clearly demonstrates that the deviations determined from two different sources only match up when the two sources qualify according to ISO 3745 directionality requirements. However, it has also been observed that even when a source which does not qualify at a particular frequency might still yield results that indicate the acceptability of the internal acoustic field. It can be concluded that the ISO 3745 qualified sources provide the best results while conducting chamber qualification. The evaluation of the free-field inside the chamber is a very complex phenomenon involving too many test variables, and a good practice while performing such test is to make sure that as a scientist we are not trying to test too many things at the same time. This can be fully accomplished by using ISO 3745 qualified sources for the purpose of draw away testing.

3. NEAR FIELD: DEFINITION & EFFECTS ON ISL DEVIATIONS

A. Near Field: Definition

Near field of a source is defined as the region around the source where the particle velocity is not necessarily in the direction of travel of the wave, and an appreciable tangential velocity component may exist at any point. It is also characterized as appreciable variations in sound pressure with position even when the sound source is placed in anechoic space. The distance from the source to which the near field exists is considered to be a function of: a) frequency, b) characteristic source dimension and c) phase of the radiating parts on the surface of the source. For the purpose of chamber qualification, ISO 3745 suggests to start the measurements of sound pressure level at a distance of 0.5 m away from the acoustical center of the source in order to be outside the near field of the source. It has been observed that if the data collected from close to the source is included in ISO 3745 fit range, it may or may not show deviations greater than the allowed limits. This inconsistency in the data obtained with in the close vicinity of the source can be explained by the presence of near field. An experiment was designed to study the effect of near field on deviations from inverse square law and specifically the deviations which are assumed to be present inside the near field of the source.

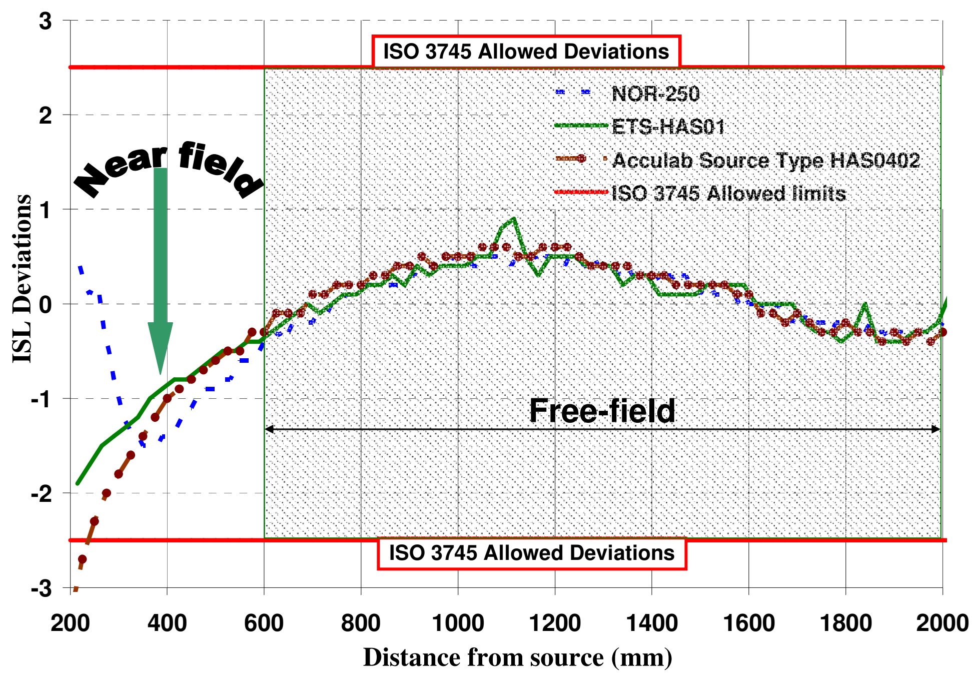

Figure 3: Comparison of inverse square law deviations obtained by using three different sources Norsonic Type 250, ETS-HAS01, Acculab Source Type HAS0402. Frequency: 100 Hz. Excitation signal: Pure tones.

Figure 3 shows the inverse square law deviations determined by using three different sources. All the deviations are closely matching each other at approximately starting at a distance of 0.5 – 0.6 m from the geometric center of the measurement hemisphere showing the presence of a free-field. The deviations in the region close to the acoustic center of the source have less similarity which can be explained by the presence of the near-field. It has also been observed that even within the near field the two sound sources Norsonic Type 250 and ETS-HAS01 show that the field is acceptable due to the standard. However, the third source Acculab Type HAS0402 shows larger deviations which are outside the allowable limits of the standard.

B. Is it really Near-field or improper use of ISO 3745 fit routine?

This section discusses the careful approach needed while using ISO 3745 Annex A analysis routine for the purpose of determining the maximum qualified radius inside a chamber and deviations from inverse square law. While setting up a microphone traverse system for data acquisition, all data points are normally gathered that the microphone traverse system can physically achieve and for which the sound source can meet signal-to-noise requirements. The ISO 3745 Annex A analysis routine is then applied on incrementally smaller subsets of all the measured data points, in order to determine a radius of hemispherical measurement surfaces that qualifies for determination of precision-grade sound power levels. This study demonstrates that if the data contaminated due to the reflections is selected within this fit range, the deviations from inverse square law might appear to be failing at the beginning of the traverse.

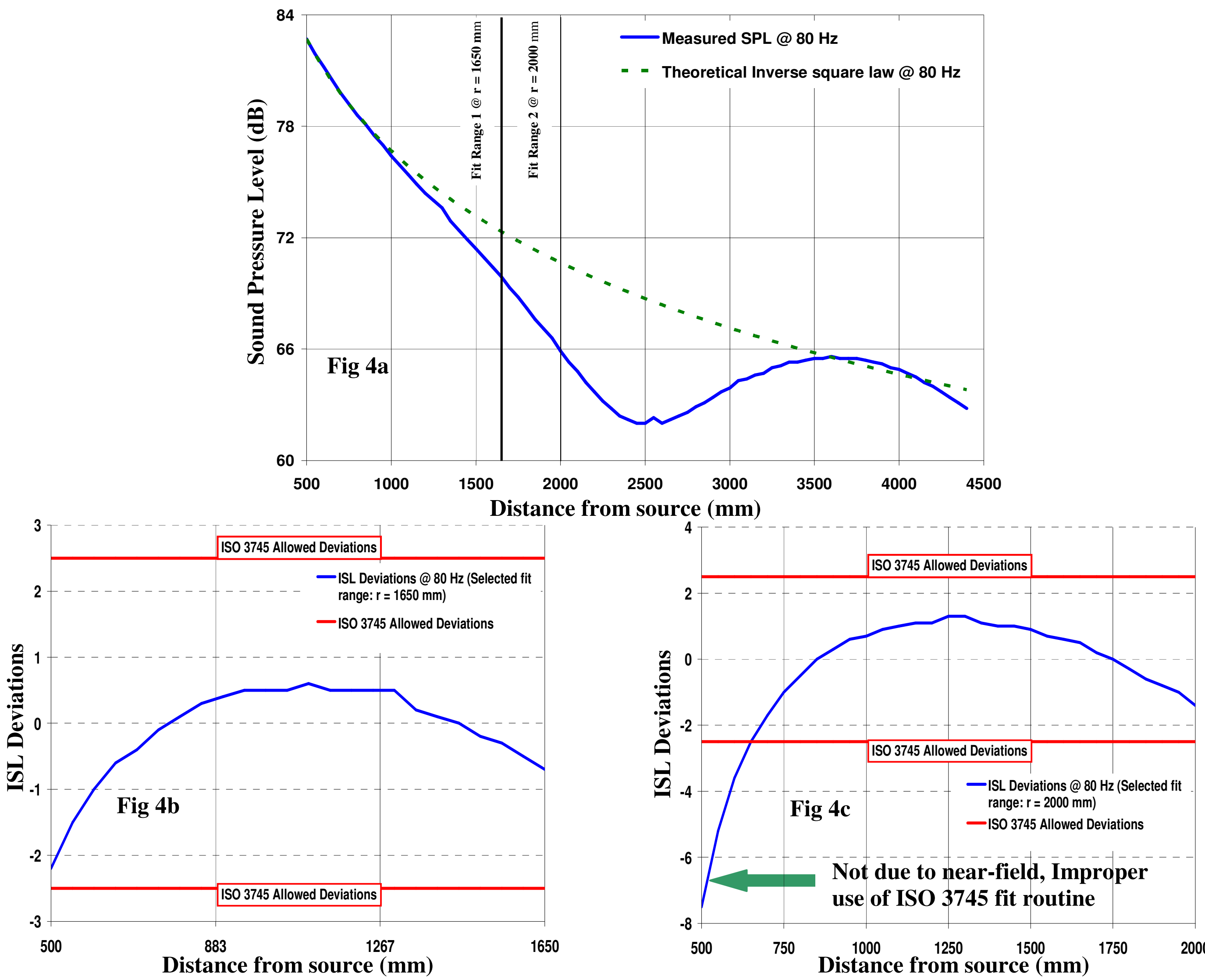

Figure 4: 4a) Sound Pressure Levels (SPL) measured from a source (starting from 0.5 m and ending at 4.4 m). Excitation Signal: Pure tones at one-third octave band center frequency. Levels displayed were measured @ 80 Hz one-third octave band center frequency. 4b) deviations from ISL obtained by fitting the acquired data up to a selected fit range of 1650 mm. 4c) deviations from ISL obtained by fitting the acquired data up to a selected fit range of 2000 mm.

Figure 4a shows the sound pressure levels measured at 80 Hz one-third octave band. This data was collected inside a chamber which was designed to qualify according to ISO 3745 up to a radius of 2.0 meters and a frequency range of 100 Hz – 20 k Hz. The dip observed in the field shows that there is an effective cancellation from the reflected signals at that particular observation point. It can be clearly seen that this drop occurs beyond the free-field region of the room at 80 Hz. But ISO 3745 does not provide any guidelines for selecting the fit range for the purpose of calculating deviations from inverse square law. If the selected fit range is up to 1.65 meters the actual and ideal deviations from inverse square law are shown in Figure 4b. However if the same data set is employed with a selected fit range of 2.0 meters the deviations from inverse square law obtained are shown in Figure 4c. In this case the deviations at about 0.5 – 0.6 meters away from the geometric center are outside the allowable ISO 3745 chamber qualification limits. These larger deviations should not be misinterpreted as the deviations caused because of the near field effects of the source. In fact these deviations are caused by the improper use of ISO 3745 analysis routine by including the contaminated data. This can be easily avoided by looking at the graph showing sound pressure level drop with increase in distance and ensuring that the data selected for ISO 3745 analysis routine does not include any reflections coming off from the chamber boundaries.

4. CONCLUSIONS

The broadband traverses provide lesser information about the type of free-field inside a chamber as compared to the deviations obtained from the pure tone traverses. Future work is planned to compare broadband and pure tone traverses with a selected analysis bandwidth of a discrete frequency (narrow band). The work presented here also demonstrates that a source that meets the ISO 3745 directivity requirements will provide a better picture of the chamber performance. However, it has also been observed that a source which does not qualify at a particular frequency according to the standard might still yield acceptable results.

It has also been shown that deviations from inverse-square obtained within close vicinity of different sources may not match with each other due to the presence of near-field of each individual source. The amplitude of deviations matches starting from an approximate distance of about 0.5 – 0.6 meters away from the source validating the presence of free-field.

Finally, the work presented here also indicates that a very careful approach is needed while using the ISO 3745 fit routine and while determining the maximum qualified radius of a chamber at its lowest usable (cut-off) frequency. It has been observed that if the data contaminated due to the reflections is selected within the fit range, the deviations from inverse square law might appear to be failing at the beginning of the traverse. It should be clearly understood that these deviations should not be considered as failures caused due to the near-field of the source.

ACKNOWLEDGEMENTS

We are very grateful to ETS-Lindgren Acoustic Research Laboratory, for supporting this work. We also want to thank Michael C. Black, John A. Phillips, and Jeff G. Schmitt for being a constant source of guidance and motivation throughout this work.

REFERENCES

[1] ISO 3745:2003 “Acoustics — Determination of sound power levels of noise sources -- Precision methods for anechoic and hemi-anechoic rooms,” International Standard (International Organization for Standardization, Geneva, Switzerland, 2003).

[2] Kenneth A. Cunefare, Jeff Badertscher, Volker Wittstock , “On the qualification of anechoic chambers; Issues related to signals and bandwidth “The Journal of the Acoustical Society of America -- August 2006 -- Volume 120, Issue 2, pp. 820-829

[3] Ankit Chadha, Einar Ristroph, Douglas Winker, “Effect of source directionality on deviations from inverse square law in a hemi-anechoic chamber typically used for product noise emission testing “ in Proceedings of Noise-Con 2007, Reno, Nevada (2007).

[4] Douglas Winker, Ankit Chadha, Einar Ristroph, “Source design considerations for qualifying hemi-anechoic chambers in compliance with ISO 3745,” in Proceedings of Noise-Con 2007, Reno, Nevada (2007).