The influences of changes in international standards on performance qualification and design of anechoic and hemi-anechoic chambers

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ABSTRACT

Historically, anechoic and hemi-anechoic chamber qualification has been defined in ISO 3745 Annex A. In 2012 an independent standard for anechoic and hemi-anechoic chamber qualification, ISO 26101, was initially released. The latest revision of ISO 3745 was also released in 2012. ISO 3745 is currently under revision to adopt the procedures outlined in ISO 26101 for chamber qualification. ISO 26101 is also under revision to improve the method of the standard.

The presentation will compare and contrast the two standards and their current states. The impact of the changes on existing chambers and future chamber design will be presented. Actual chamber data will be analyzed using both methods to show how these different fitting methods impact chamber performance.

Keywords: Anechoic, Qualification, Standards I-INCE Classification of Subjects Number(s): 73.1

1. INTRODUCTION

Historically, anechoic and hemi-anechoic chamber qualification has been defined in ISO 3745 Annex A. The first version ISO 3745 was published in 1977. It was the first of the ISO 3740 sound power standard series and the precision-level sound power standard. As the precision-level standard, the measurements for ISO 3745 occurred in anechoic and hemi-anechoic chambers and the need for qualification of these chambers was defined in Annex A of the standard.

The fact that anechoic and hemi-anechoic chamber qualification requirements existed only in the annex of a standard led to the formation of ISO TC 43 WG 8 to provide a stand-alone document for anechoic and hemi-anechoic chamber qualification. ISO TC 43 WG 8 published ISO 26101 in 2012. ISO 26101 makes qualification of anechoic chambers more readily available for audio, automotive, military, and other users that are not interested in sound power measurements.

ISO 26101 improved many areas of chamber qualification including removing the acoustic center collinear offset, changing the number of required traverse directions, and removing octave band measurements in favor of one-third octave band measurements at certain frequencies of interest. However, 26101 created an unnecessary requirement in that traverses must extend to one-half wavelength and did not address the impact on the qualification tolerances created with measuring high frequencies inside the free-field.

This paper highlights the issues with ISO 3745 and ISO 26101. It presents test data from anechoic chambers showing how some requirements in ISO 26101 are too stringent and offers suggestions on how to alleviate these issues.

2. ISO 3745 Annex A

2.1 Measurement Overview

The qualification procedure defined in ISO 3745 Annex A uses five microphone traverses that

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move a microphone away from a sound source located in the center of the measurement area. Data is acquired at discrete points or continuously along the traversed path. For a discrete traverse, at least 10 measurement points with spacing of 0,1m must be evaluated.

The sound source must be a device qualified under section A2.2.2 for source directivity. A source that is compliant with A2.2.2 will radiate spherically for full anechoic chambers or hemispherically for hemi-anechoic chambers. The 2012 revision to ISO 3745 mandated the use of pure tone signals as the primary signal method instead of broadband signals during qualification.

After a traverse is completed, the measurement levels at each point are compared to the inverse square law levels for a free-field. Table 1 lists the allowable deviations between the measured data points and inverse square law. The allowances differ based on frequency band. After all traverse paths have been measured, the chamber's qualified performance is determined by the maximum distance that falls within the allowable deviations along all the paths and at all frequencies of interest.

Table 1 — Maximum allowable deviation of measured sound pressure levels from theoretical levels using the inverse square law (1)

Type of test room	**One-third-octave band frequency** Hz	**Allowable deviation** dB
Anechoic (free-field)	≤630	±1,5
	800 to 5 000	±1,0
	≥6 300	±1,5
Hemi-anechoic (hemi-free-field)	≤630	±2,5
	800 to 5 000	±2,0
	≥6 300	±3,0

2.2 Annex A Curve Fit

ISO 3745 estimates the sound pressure levels of each traverse based on inverse square law with the following equations. "The sound pressure level at the *i*th position with the region to be qualified, $L_p(r_i)$, is given by…

$$L_p = (r_i) = 20Log\left(\frac{a}{r_i - r_0}\right) dB \tag{1}$$

where

$$a = \frac{Mr_0^2 + \sum_{i=1}^{M} r_i^2 - 2r_0 \sum_{i=1}^{M} r_i}{\sum_{i=1}^{M} r_i q_i - r_0 \sum_{i=1}^{M} q_i} \tag{2}$$

r_i is the distance of the *i*th measurement position from the center of the measurement sphere or hemisphere;

r_0 is the collinear offset of the acoustic center along the axis of the microphone traverse — it is a measurement of the separation between the acoustic center of the source and the origin of the microphone traverse, whose apparent position is given by:

$$r_0 = \left(\frac{\sum_{i=1}^{M} r_i \sum_{i=1}^{M} r_i q_i - \sum_{i=1}^{M} r_i^2 \sum_{i=1}^{M} q_i}{\sum_{i=1}^{M} r_i \sum_{i=1}^{M} q_i - M \sum_{i=1}^{M} r_i q_i}\right) \tag{3}$$

in which

$$q_i = 10^{-0.05L_{pi}} \quad (4)$$

where L_{pi} is the sound pressure level of the ith position in decibels;

M is the number of measurement positons along each microphone traverse within the region where the inverse square law is followed (assumes the data points neat the end of the traverse may be discarded).”(1)

The curve fitting equation in ISO 3745 Annex A allows the measured collinear acoustic offset location to be adjusted to create the best fit for the data. In practice, this allows the fitted measurement line to be adjusted away from the inverse square law line so that the data is only compared to deviations from itself instead of the inverse square law response. By using this fitting method, a chamber can fully comply with ISO 3745 at certain frequencies while not exhibiting free-field performance at those frequencies. This typically serves to extend the qualified chamber performance down to a lower frequency where a larger chamber size would be needed to demonstrate true inverse square law performance.

Besides the problem that a movable acoustic offset creates, there is no limit to the distance of the acoustic offset in the fitting equation. The standard says that the offset “should” fall within 200 mm of the actual center of the sound source. 200 mm places the acoustic center outside the volume of many sound sources used for room qualification and the “should” instead of “shall” language creates an ambiguity that can be used to drastically remove the fitted data from the actual inverse square law performance.

3. ISO 26101

3.1 Key Changes from ISO 3745

The qualification procedure of ISO 26101 generally follows the procedure of ISO 3745. Several key changes were implemented to improve and update the procedure. The changes create more stringent requirements for chambers and erase the ambiguities present in ISO 3745. The main body of ISO 26101 lists requirements of all chamber qualifications and Annex A lists the requirements for a general purpose anechoic chamber without an overriding noise code or specific repeated item of testing.

3.1.1 Traverse Paths

The number of traverse paths necessary to qualify a chamber differs between the ISO 3745 and ISO 26101. In ISO 3745, only five traverse paths are required for all chambers. In ISO 26101, a minimum of five paths must be run with additional paths necessary for unique geometries or chamber additions that break the uniform acoustic treatment. For standard chambers, this does not create any differences in testing but it necessitates additional traverse paths for chambers with abnormalities incorporated into the design.

3.1.2 Curve Fit

The curve fit of ISO 26101 follows inverse square law and shows the chamber performance versus true free-field performance.

“From the sound pressure levels measured at positions specified in 5.1.4.3, the estimation of sound pressure levels based on the inverse square law shall be determined for each measurement traverse from the following equation:

$$L_p(r_i) = b - 20\lg\left(\frac{r_i}{r_0}\right) dB \quad (5)$$

where

$L_p(r_i)$ is the sound pressure level at distance *ri* estimated by the inverse square law, expressed in decibels (dB);

r_i is the distance of measurement point i from the acoustic centre of the sound source, expressed in metres (m);

r_0 is the reference value, $r0$ = 1 m;

b is a parameter that is adjusted to optimise the fit of the measured sound pressure levels into the tolerance range, to maximise the qualified distance from the test sound source.

$$b = \frac{\sum_{i=1}^{N} 20lg\left(\frac{r_i}{r_0}\right) dB + \sum_{i=1}^{N} L_{pi}}{N} \tag{6}$$

where

L_{pi} is the measured sound pressure level (corrected for source stability) at measurement point i, expressed in decibels (dB);

N is the number of measurement points along the measurement traverse." (2)

The fitting equation is modified by a parameter included to determine the number of analysis points necessary to maximize the fitting distance given the measured data points. The allowable deviations from this curve fit are the same as those from ISO 3745 as shown in Table 1. The curve fit procedure in ISO 26101 does not allow for acoustic center adjustment of the source as allowed in ISO 3745.

3.1.3 **Qualification Bandwidth**

ISO 26101 requires the measured data to be analyzed at all contiguous one-third octave band frequencies that compose the frequency range of interest. ISO 3745 allows octave band analysis of frequencies between 125 Hz and 400 Hz and requires one-third octave band analysis at all other points.

ISO 3745 also requires the chamber to be qualified from 100 Hz to 10 kHz to be in full conformity with the standard. ISO 26101 allows chambers of a reduced frequency range to be qualified in full conformity with the standard.

3.1.4 **Spatial Resolution and Starting Point**

ISO 26101 requires at least one-tenth wavelength measurement spacing at frequencies below 1 kHz and 25 mm at frequencies above 1 kHz. ISO 3745 allows measurement spacing up to 100 mm. Both standards require at least 10 measurement points per traverse path.

ISO 26101 traverses can be started up to one-quarter wavelength of the lowest frequency of interest away from the acoustic center of thee sound source. ISO 3745 traverses all start at 0,5 m away from the acoustic center of the sound source.

When testing according to both standards, a reference microphone is used to monitor the output of the sound source. This microphone is stationary throughout the test. In ISO 26101, the levels measured by the reference microphone are required to be used to correct the measured traverse data for source stability. In ISO 3745, the use of these reference levels for correction is optional.

3.1.5 **Traverse Length**

ISO 26101 requires the traverse path distance to extend out to one-half wavelength of the lowest frequency of interest in order to qualify the chamber. ISO 3745 requires only the minimum number of measurement points as discussed above. The one-half wavelength requirement of ISO 26101 impacts the design of anechoic and hemi-anechoic chambers because the ability to traverse to this distance must now be considered when designing a chamber. In practice, this requirement is not necessary to determine inverse square law performance and, if left in the standard, will require future chambers to unnecessarily grow larger while reducing the frequency range of existing chambers based on geometry and not acoustical performance.

In the following section, it will be shown that measured data from existing chambers exhibit compliance or noncompliance with inverse square law well before the required one-half wavelength distance. The increased chamber sizes needed to comply with the one-half wavelength traverse requirement impacts the design and implementation of future chambers from both logistical and budgetary perspectives.

4. Case Studies

4.1 Low frequency data

Chamber size and wedge depth is driven by the wavelength of the lowest frequency of interest. In large chambers, the difference in qualification between ISO 3745 and ISO 26101 will not have a major effect on chamber size. However, the required qualification distances of ISO 26101 will require chambers that once qualified to ISO 3745 to now qualify to a reduced frequency range simply because the required ISO 26101 traverse distances could not be met. This reduced frequency range is not a function of the chamber's ability to provide inverse square law performance but a function of geometry. It will be shown that the revised curve fit method of ISO 26101 corrected the errors of ISO 3745 and the minimum traverse length of one-half wavelength is not necessary.

4.1.1 Large Hemi-anechoic Chamber

Figure 1 represents an operational hemi-anechoic chamber originally designed and qualified from 100 – 20 kHz to a distance of 2,0m by ISO 3745:2012 with internal dimensions of (L x W x H) 7,8 x 6,3 x 5,2m. The measured data was reanalyzed using the qualification procedures of ISO 26101 from section 3.1.2. Both figures show the measured data for the nearest wall traverse which is the traverse path expected to perform the worst in a rectangular chamber. Figure 1 shows the chamber following inverse square law to further than the half-wavelength distance of 1,7m at 100Hz. This chamber performs as designed using both qualification methods.

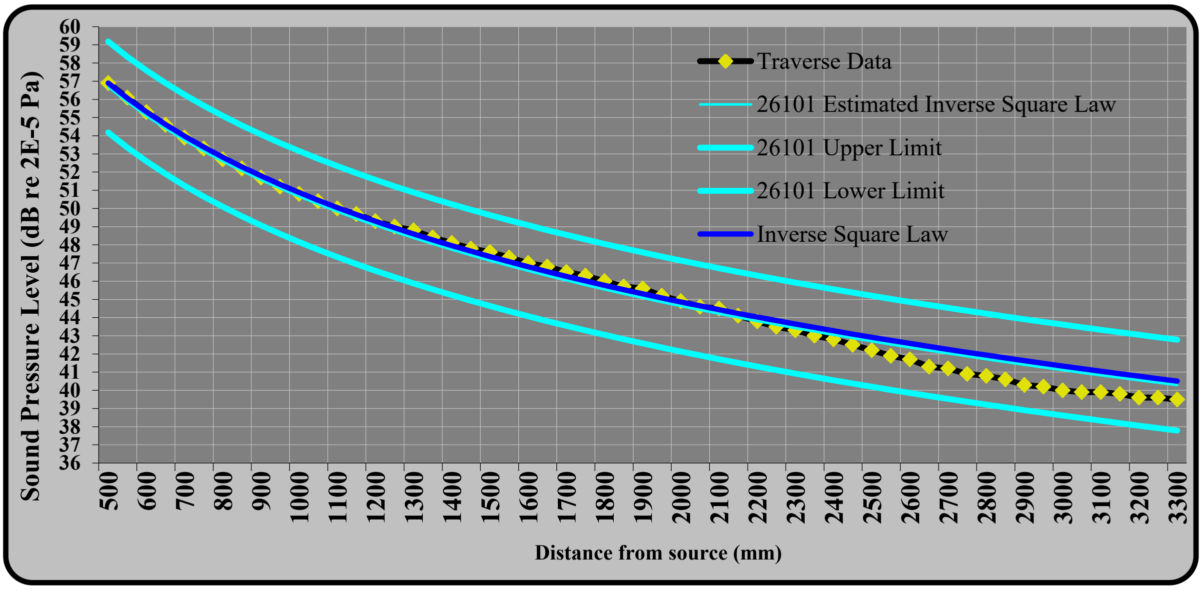

Figure 1: Large Hemi-Anechoic Chamber – ISO 26101 Curve Fit to 100 Hz

4.1.2 Small Anechoic Chamber

Figures 2, 3, and 4 represent an operational anechoic chamber constructed for audio and telephone testing with internal dimensions (L x W x H) – 3,35 x 3,05 x 2,74m and specified ISO 3745 qualification range from 160 Hz to 20 kHz to a distance of 1m. The ISO 26101 qualification range of this chamber is 214 Hz – 20 kHz where the low frequency performance is limited due traverse distance requirements not actual chamber performance. Figure 2 shows the chamber analyzed to ISO 3745 at 160 Hz using the ability to calculate an abnormal acoustic offset. Figure 3 shows the chamber analyzed to ISO 26101 at 160 Hz with the deviation from inverse square law performance clearly seen before the half-wavelength distance of 1.1m. Figure 4 shows this chamber very closely following inverse square law performance at 200 Hz to 1.0 m where the ISO 26101 half-wavelength traversing distance limits the chamber to 214 Hz due to geometry constraints.

The range under which the chamber follows inverse square law and where it begins to deviate from inverse square law is obvious without employing either curve fit methodology. This performance is evident well before the one-half wavelength traverse distance required by ISO 26101. At 160 Hz, the chamber does not perform to inverse square law when analyzed according to ISO 26101. This corrects the problem associated with ISO 3745 as intended. The chamber follows inverse square law to a distance of 1 m at 200 Hz as designed, but the current requirements of ISO 26101 invalidate this claim because the required traverse distance could not be performed. The required one-half wavelength traverse distance is not needed because the curve fit methodology of ISO 26101 corrects the error of ISO 3745 on its own.

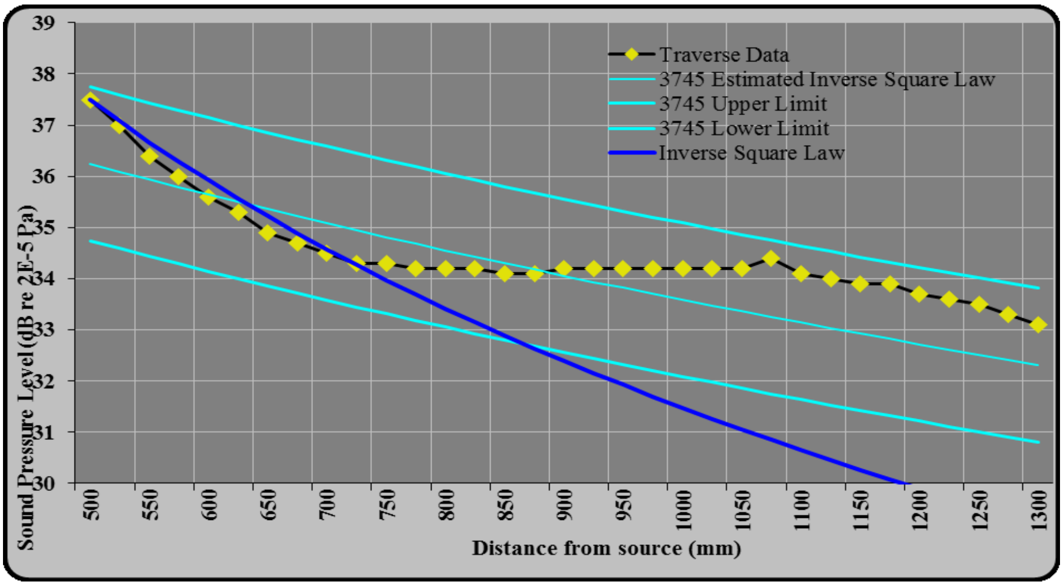

Figure 2: Small Anechoic Chamber – ISO 3745 Curve Fit at 160 Hz

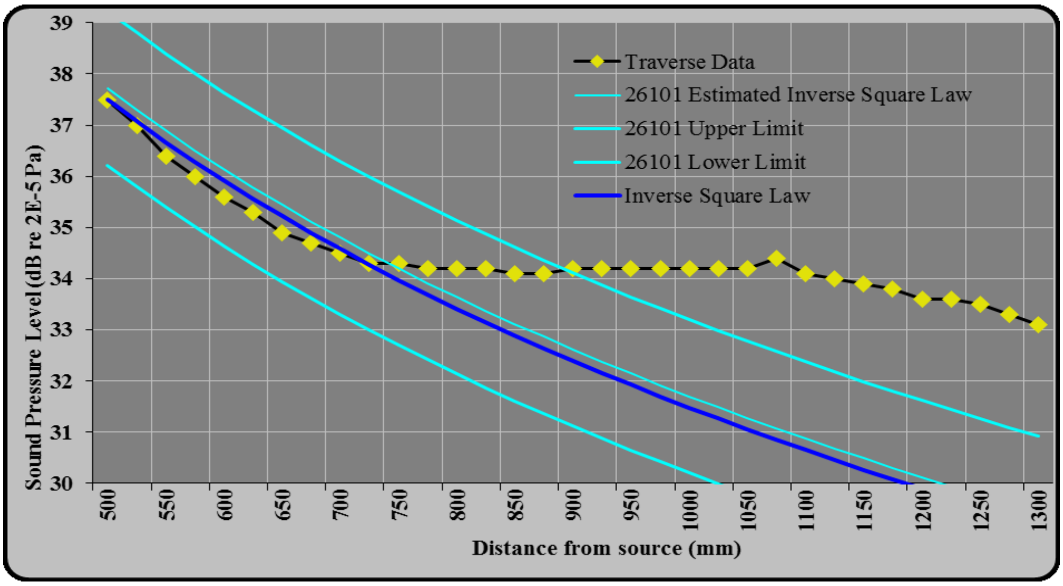

Figure 3: Small Anechoic Chamber – ISO 26101 Curve Fit at 160 Hz

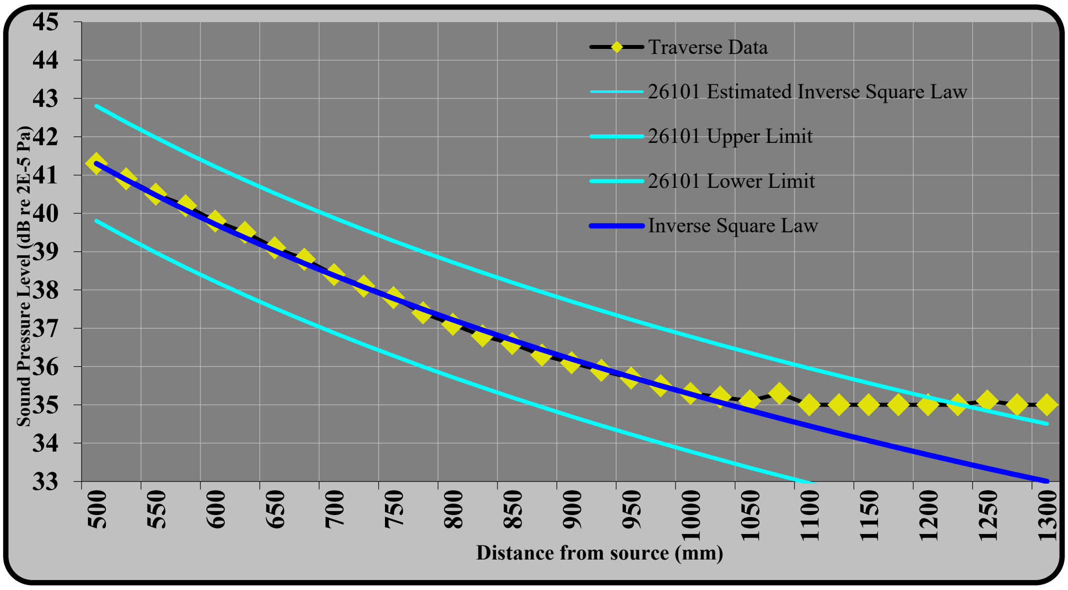

Figure 4: Small Anechoic Chamber – ISO 26101 Curve Fit at 200 Hz

4.2 High Frequency Chamber Performance

Using ISO 26101 qualification methods and sound sources fully compliant with the directivity of both standards, the high frequency traverses end up as the determining factor for chamber qualification distance instead of low frequency traverses in large chambers. This is counter-intuitive for uniform chambers constructed without reflecting areas or measurement apparatuses. This situation occurs during pure tone qualifications and is not present in broadband qualifications due to signal averaging and is especially pronounced in frequencies above 10 kHz as seen in Figure 6.

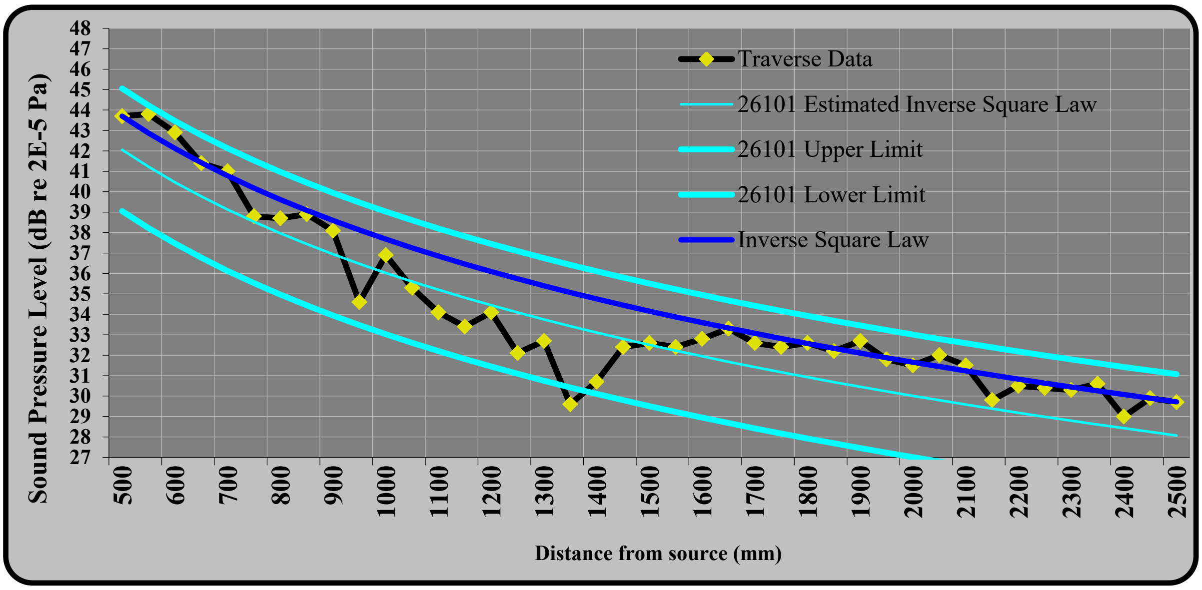

Figure 6: Large Hemi-Anechoic Chamber – ISO 26101 Curve Fit to 16 kHz

The most likely factor is the influence of the measurement system inside the free-field creating reflections that do not appear at lower frequencies. A testing stand or rig is required to qualify most anechoic chambers without built in anchoring points or a center floor cavity. The introduction of these apparatuses in the free field causes small deviations to appear in the measurements. The ISO 3745 curve fit method allowed more flexibility in fitting this data even though it was often times difficult. When using the ISO 26101 curve fit method, it is often impossible to fit the high frequency data. More research is needed to fully explore situation. To account for this effect while research is ongoing, the deviation window in frequencies above 10 kHz may need to be expanded to fall more in line with the expanded allowable deviations in source directivity above 10 kHz as seen in Table 2.

Table 2 — Allowable deviation in directivity of the test source (1,2)

Type of test room	One-third-octave-band frequency Hz	Allowable deviation in directivity dB
Anechoic (free-field)	≤630	±1.5
	800 to 5,000	±2.0
	6,300 to 10,000	±2.5
	>10,000	±5.0
Hemi-anechoic (hemi-free-field)	≤630	±2.0
	800 to 5,000	±2.5
	6,300 to 10,000	±3.0
	>10,000	±5.0

5. CONCLUSIONS

ISO 26101 is an improvement of the anechoic and hemi-anechoic chamber qualification methods of ISO 3745 Annex A and assures that chambers are designed and built in ways that will more closely follow inverse square law performance. The qualification distances and frequency ranges of many previously built small anechoic and hemi-anechoic chambers will be reduced by this standard. While this ultimately will provide more accurate free-field results it will also cause chamber sizes to increase unnecessarily. The ISO 26101 half-wavelength traversing requirement is not necessary and should be reduced or eliminated. Additionally, the allowable deviations for high frequencies need to be adjusted to reflect the parameters allowed for the sources. Unless this change to the high-frequency requirements is implemented, chambers will be unnecessarily limited in performance by the method and apparatuses used instead of by the actual acoustic performance of the chamber.

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