THE USE OF DAT RECORDINGS AND SOUND REPRODUCTION THROUGH A LOUDSPEAKER TO REPRODUCE A NOISE SOURCE

DJ Atkinson University of Derby, Kedleston Road, Derby, UK

1. INTRODUCTION

This paper is based upon a project submitted for the Diploma in Acoustics and Noise Control. The concept of the project was to use a digital audio tape (DAT) recording of a noise source and subsequent sound reproduction through a loudspeaker to reproduce the noise source at a different location and hence under different acoustic conditions. This was undertaken with a view to assessing the suitability of the proposed new location of the noise source, to ensure a Statutory Noise Nuisance did not arise.

An assessment is undertaken on the suitability of using DAT recordings and sound reproduction through a loudspeaker to simulate a noise source within a room. The sound power level of the source is determined along with a DAT recording taken within the direct field.

The directivity of the loudspeaker is ascertained allowing the calibration of the loudspeaker under free field conditions to ensure an equivalent sound power level as the original source. Reproduction of the DAT recording through a loudspeaker effectively simulates the reverberant sound pressure levels and frequency spectrum on the internal façade of a room. The determination of the room's acoustic parameters permits the comparison of the predicted and experimentally determined reverberant sound pressure levels within the room to validate the method.

The direct and reverberant sound pressure levels of the DAT-loudspeaker combination are predicted under a range of possible room acoustic parameters. This indicates the suitable conditions when it may be used to ensure the reverberant sound pressure level is dominant on the internal façade of the room.

2. ASSESSMENT OF THE NOISE SOURCE

2.1 DETERMINATION OF THE SOUND POWER LEVEL OF THE NOISE SOURCE

It was necessary to determine the sound power level[1] of the noise source, a weaving loom, in its current location. As the room in which the weaving loom was located was not anechoic or semi-anechoic a precision method[2] for determining the sound power level could not be used. However, it was felt that an engineering[3] or survey[4] method could be used instead, provided that the environmental test conditions could be achieved. BS ISO 9902:1993[5] was chosen as the method on which to base the assessment, as it is specific to determining the sound power level of textile machinery. Measurements were taken in accordance with BS ISO 9902:1993 and the sound power level of the noise source determined as being 116±2 dB(A).

2.2 METHOD FOR PRODUCING A DAT RECORDING OF THE NOISE SOURCE

The DAT recording was required to give an accurate representation of the weaving loom noise. The DAT microphone was located at a distance of 4.5 metres from the weaving loom. This was chosen to ensure that the microphone was relatively equidistant from all the noise generating sources within the machine, and hence ensure that dominant noises caused by the close proximity of the microphone to a particular part of the machine did not arise.

An $L_{Aeq,5\ second}$ of 88.2 dB(A) was determined at the DAT microphone location. The level determined at a distance of 1 metre from the machine was 100.3 dB(A). Distance correction of the sound pressure level taken at a distance of 1 metre to a distance of 4.5 metres, assuming direct field conditions only, results in a predicted level of 87.2 dB(A). The actual level at the DAT microphone location and the predicted level are within 1 dB(A).

A recording made in the reverberant field was not wanted, as the room may have been more reverberant at particular frequencies. Therefore the resulting recording may be frequency biased depending upon the room acoustics. The resulting frequency bias would be unlikely to be large, but may be significant to introduce errors and as such attempts were made to ensure this did not occur. It was therefore assumed that the DAT recording was taken within the direct field with, possibly, a relatively small contribution from the reverberant field.

3. CALIBRATION OF THE LOUDSPEAKER TO ENSURE AN EQUIVALENT SOUND POWER LEVEL

3.1 DETERMINATION OF THE DIRECTIVITY OF THE LOUDSPEAKER

In order to ensure that the loudspeaker would have the same sound power level as the weaving machine it was necessary to determine the directivity index (*D*). Using the directivity index it would be possible to take into account the fact that the loudspeaker is not omnidirectional and ensure that the sound power level would be equivalent to the weaving machine.

In order to determine the directivity index[6], sound pressure levels were taken at equal distances from the loudspeaker whilst the DAT recording was being reproduced. The loudspeaker was placed on a hard reflecting surface with no significant reflecting surfaces within 40 metres and sound pressure levels were taken at 13 points on an enveloping hemisphere at a distance of 2 metres. The measurement positions in relation to the loudspeaker are given in Figure 3.1.

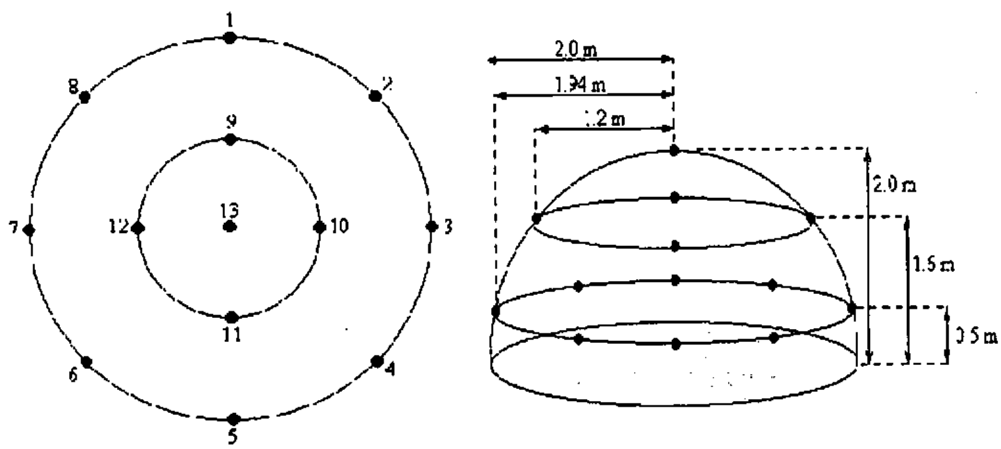

Figure 3.1
Measurement Positions for Determining the Directivity Index of the Loudspeaker

The residual noise level with the loudspeaker turned off was determined for a period of 5 minutes prior to taking the sound pressure levels around the loudspeaker. The $L_{Aeq,5min}$ determined was 42 dB(A), comparing this value with the 13 determined around the loudspeaker it was assumed that the background noise contribution was insignificant and therefore no correction was made.

Table 3.1
Sound Pressure Levels Determined at the Measurement Positions 1 to 13

Measurement Position	1	2	3	4	5	6	7	8	9	10	11	12	13
Lp / dB(A)	95.6	85.9	77.4	74.5	73.9	75.1	78.7	86.9	90.7	79.3	76.4	79.6	81.3

The loudspeaker was found to be very directional, as expected, and the associated sound pressure levels determined are given in Table 3.1, where position 1 is face on to the speaker cone.

The directivity index of the loudspeaker was determined using the following equation[6];

$$D = SPL - SPL_{av}$$

Taking the logarithmic average of all the sound pressure levels using;

$$SPL_{av} = 10 \text{ Log } \{(10^{[L1/10]} + 10^{[L2/10]} + \ldots + 10^{[Ln/10]})/n\}$$
$$SPL_{av} = 86.8 \text{ dB(A)}$$

Using the SPL value determined in position 1 of 95.6 dB(A), the directivity index (D) at position 1 is given by;

$$D = 95.6 - 86.8 = 8.8 \text{ dB(A)}$$

3.2 'CALIBRATION' OF THE LOUDSPEAKER

As the weaving loom was found to have a sound power level of 116 dB(A) it was necessary to determine a level at a specified distance from the loudspeaker under free field conditions that would ensure the loudspeaker would also have a sound power level of 116 dB(A).

The level at a distance of 2 metres at position 1 (0.5 metres high) was determined, using a sound power level of 116 dB(A).

$$Lp = Lw - 20 \text{ Log } r - 8 + D$$

As the loudspeaker will be on a hard reflecting surface the numerical factor 8 was used instead of 11.

$$Lp = 116 - 20 \text{ Log } 2 - 8 + 8.8 = 110.8 \text{ dB(A)}$$

Therefore, if the loudspeaker is positioned on a hard reflecting surface and the volume adjusted to result in a sound pressure level of 110.8 dB(A) at a distance of 2 metres from the speaker cone, it is anticipated that the loudspeaker will have a sound power level of 116 dB(A).

4. ASSESSMENT OF THE PROPOSED LOCATION FOR THE WEAVING LOOM

4.1 DETERMINATION OF THE ROOM REVERBERATION TIME

In order to determine the predicted sound pressure levels within the proposed new room it was necessary to experimentally determine the reverberation time. The reverberation times were determined in 1/3 octave band levels between 100 and 10,000 Hz. It was also necessary to determine the frequency spectrum of the weaving loom as comparison with the reverberation times would allow the identification of the dominant sound levels. Figure 4.1 shows the experimentally determined reverberation times and A weighted sound pressure levels versus the 1/3 octave band centre frequencies.

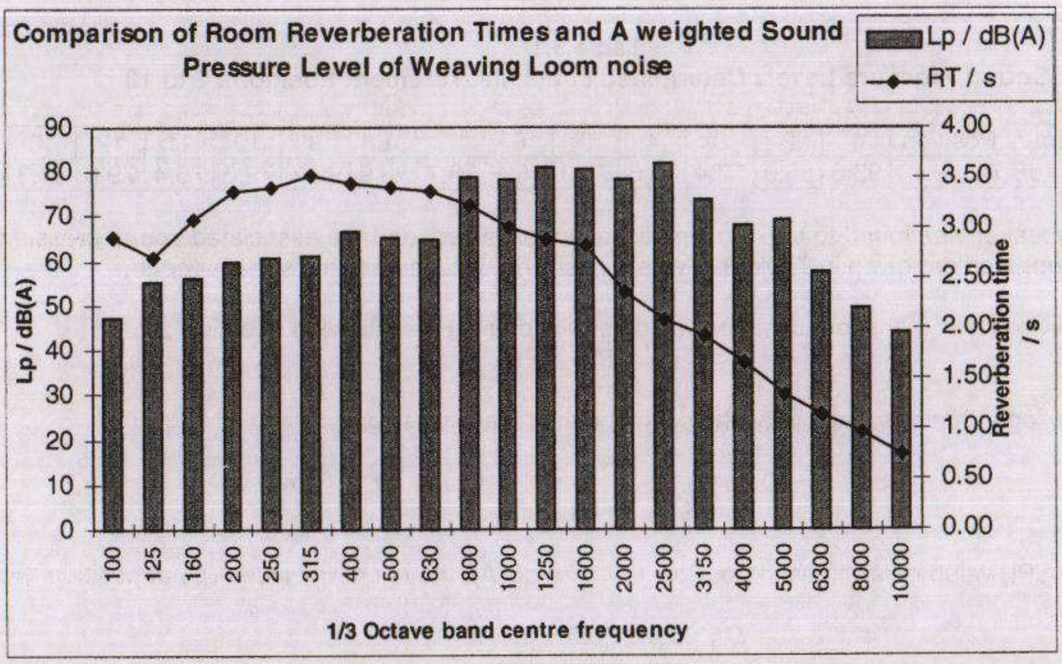

Figure 4.1
Comparison of the room reverberation times and weaving machine frequency spectrum in 1/3 octave band levels

It can be seen that the dominant 1/3 octave band levels, all above 70 dB(A), are from 800 to 3150 Hz. The dominant levels were used to select the reverberation times at the 1/3 octave band centres which would best represent the room acoustics for that particular noise. At the dominant levels, the reverberation times were averaged so that the room absorption, absorption coefficient, room constant, and hence the reverberant sound pressure level could be calculated. The dominant levels and reverberation times are given in Table 4.1.

Table 4.1
Dominant 1/3 octave band levels and associated room reverberation times

1/3 octave band centre frequency / Hz	Level / dB(A)	Reverberation time / Hz
800	78.1	3.21
1000	78.5	2.99
1250	81.4	2.88
1600	81.4	2.82
2000	79.5	2.36
2500	83.0	2.09
3150	75.1	1.92
	Average RT =	**2.61**

4.2 PREDICTED REVERBERANT SOUND PRESSURE LEVELS WITHIN THE ROOM

It was anticipated that the average absorption coefficient was < 0.2, as the room was empty with bare reflective walls, floors and ceilings, hence the use of the Sabine formula is appropriate. Using the average reverberation time from Table 4.1, the room absorption was calculated using the Sabine formula;

$$A = 0.16V/T$$

Using the calculated room volume $V = 270.31\ m^3$, and average reverberation time $T = 2.61$ s, then;

$$A = (0.16 \times 270.31)/\ 2.31 = 16.67\ m^2$$

As $A = \alpha S$, and the calculated total surface area is $283.93\ m^2$, then the average absorption coefficient is given by;

$$\alpha = A/S = 16.67\ /\ 289.93 = 0.058$$

It is then possible to determine the room constant using;

$$Rc = \alpha S/(1 - \alpha) = 16.67\ /\ (1 - 0.058) = 17.69\ m^2$$

The room constant was then used to determine the reverberant sound pressure level in the room, with the weaving machine in operation, using the equation;

$$Lp = Lw + 10\ Log\ (4/Rc)$$

Where $Lw = 116$ dB(A), and $Rc = 17.69\ m^2$, then;

$$Lp = 116 + 10\ Log\ (4\ /\ 17.69) = 109.5\ dB(A)$$

To ensure that the sound pressure levels at the internal walls of the room would be 109.5 dB(A) a noise map of the unit was produced, see Figure 4.2. The noise source was approximated to a point in the centre of the room and the predicted sound pressure levels were calculated to take into consideration both the reverberant and direct field contributions. No directivity correction was applied to the noise source as it was anticipated that the loudspeaker would be located face up within the room to attempt to eliminate any inherent directivity towards the room walls. The following equation was used;

$$Lp = Lw + 10\ Log\ \{\ (Q/4\pi r^2) + (4/Rc)\ \}$$

Where $Q = 2$ for a flat reflecting surface, $Rc = 17.69\ m^2$, and r was determined for a range of points within the room.

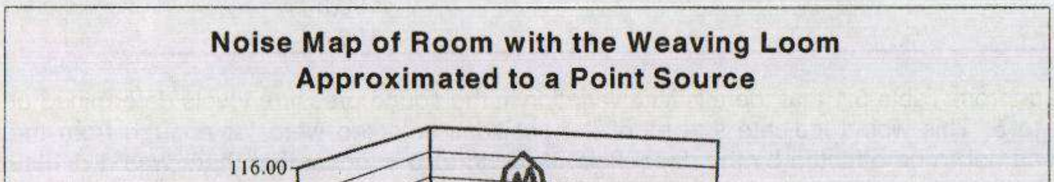

Figure 4.2
Noise Map of Room for the Proposed Housing of the Weaving Loom

It can be seen from Figure 4.2 that if the source was placed in the centre of the room, and approximated to a point source, then the levels at the boundary walls of the room will be effectively equal to the reverberant level only. The position of the weaving loom may have an impact on the noise on the boundary wall as the closer to the wall the source is then the greater the contribution from the direct field. Hence, the proximity of the source to the boundary walls may have an impact on the levels transmitted through the building structure. For the purposes of this paper the source will be considered to be at a great enough distance from any wall that purely the reverberant field level will act on all of the interior boundary walls.

It was therefore predicted that the reverberant field levels on the internal façade of the room would be 109.5 dB(A).

5. EXPERIMENTALLY DETERMINED REVERBERANT SOUND PRESSURE LEVELS WITHIN THE PROPOSED ROOM

The loudspeaker was 'calibrated' by adjusting the volume on a hard reflective surface to 110.8 dB(A) at a distance of 2 metres and a height of 0.5 m. A background L_{Aeq} of 43.5 dB(A) was obtained prior to the 'calibration' of the loudspeaker. This was deemed insignificant with respect to the 110.8 dB(A) that the loudspeaker would produce and, hence, no correction was taking into consideration when 'calibrating' the loudspeaker.

Once the loudspeaker was calibrated it was transferred to the proposed room where it was positioned to point into the corner of the room. This was to help ensure that a diffuse field was created. Sound pressure level readings were then taken at 5 positions around the room at a great enough distance to ensure only reverberant conditions existed.

The sound pressure levels recorded using a B&K Type 2231 sound level meter at the 5 positions are given in Table 5.1.

Table 5.1
Reverberant sound pressure levels determined within the room

Measurement position number	Sound Pressure Level / dB(A)
1	108.1
2	108.4
3	108.6
4	108.3
5	108.4

It can be seen from Table 5.1 that there is little variation in the sound pressure levels determined at positions 1 to 5. This would indicate that all of the positions selected were far enough from the speaker so as not to be effected by the direct field. It would also suggest that there was a diffuse sound field in the room and no focusing or standing waves were being set up.

The average reverberant level produced in the room was determined using the following equation;

$$SPL_{av} = 10 \text{ Log } \{(10^{[L1/10]} + 10^{[L2/10]} + \ldots + 10^{[Ln/10]})/n\}$$

Therefore using the reverberant sound pressure levels given in Table 5.1 the average level was given as;

$$SPL_{av} = 108.4 \text{ dB(A)}$$

It was established that the calculated reverberant sound pressure level within the room should be 109.5 dB(A). It can be seen that there is an error of 1 dB(A) between the predicted and determined levels. This is not considered significant and within the experimental errors that would have been incurred within the calculations and experimental work.

6. CONCLUSIONS

The sound power level of the weaving room was determined as being 116±2 dB(A) using BS ISO 9902:1993.[5]

The DAT recording produced of the weaving loom in operation was shown to be outside of the near field, and could be approximated to free field conditions. It was also assumed that the microphone position was equidistant from all noise sources of the machine, as dominant noises caused by the close proximity of the microphone to a particular part of the machinery was not wanted.

A limitation of the method for the production of a DAT recording may arise in very reverberant rooms. As the absorption coefficients of most materials are frequency dependant it could be assumed that the resulting reverberant field may not accurately reflect the frequency spectrum created by the machine. Although this affect is not expected to be significantly large, it may cause errors. This is especially the case, as the DAT recording was used for determining the frequency spectrum of the machine. In all cases the DAT recording should be taken as close to the machine as possible, but where free field conditions apply, ensuring an accurate as possible frequency spectrum of the noise is recorded. Consideration should also be given to the directivity of the noise source to be assessed. It is anticipated that if the noise source being assessed has a larger directivity index than the loudspeaker, used to reproduce the noise, this needs to be taken into account to ensure reverberant conditions will exist on the internal façade of the room. Otherwise the assessment may result in significant errors.

The directivity of the loudspeaker was determined using the DAT recording of the weaving room being replayed through the loudspeaker. The directivity face-on to the speaker cone, was determined as being 8.8 dB(A). It is acknowledged that only 13 measurement positions were used over a theoretical hemisphere enveloping the loudspeaker. Therefore it was expected that small errors might arise in the determination of the directivity. A more rigorous assessment, involving a larger number of measurement positions, would be needed to reduce any errors. However, the use of the directivity factor to 'calibrate' the loudspeaker at a known sound power level, and resulting reverberant sound pressure levels within the room were shown to be sufficiently accurate to the calculated expected levels.

It is acknowledged that the frequency spectrum of sound being replayed may result in a change in the directivity. A frequency spectrum weighted with low frequency sound may reduce the directivity face on to the speaker cone. High frequencies are not easily diffracted and tend to 'beam'. Low frequencies are more easily diffracted and hence cause a spreading of the wave-front leaving the speaker case. It is expected this effect alter the directivity. It is also acknowledged that reproduction of low frequencies may cause the speaker cabinet to resonate, again causing an increase in sound emitted from the rear and sides of the loudspeaker.

It is also important to note that loudspeakers do not reproduce low frequency sound as efficiently as mid to high range frequencies. It is expected that replaying DAT recordings may result in a frequency spectrum that will be biased towards the mid and high frequencies. This may become significant when assessing low frequency noise sources as the loudspeaker - DAT recording may not accurately reproduce the sound. As low frequency sound is the most easily transmitted through buildings structures, the resulting assessment may not be sufficiently accurate owing to poorly reproduced low frequencies by the loudspeaker.

The reverberant sound pressure levels within the room determined experimentally were shown to be accurate with respect to the calculated sound pressure levels. The use of the DAT and loudspeaker allowed an accurate reproduction of the sound source at another location, giving an equivalent sound power level, frequency spectrum and has resulted in an assessment to be made without the need to determine the sound reduction index of the buildings structure.

It was shown that the reverberant sound pressure levels within the room were of the expected magnitude. However, it is expected that the acoustics of the destination room will play an important factor for using the DAT - loudspeaker system. If one considers an anechoic room, which no reverberant field exists, thus clearly the DAT - loudspeaker would be unsuitable. Owing to the directivity of the loudspeaker the room is required to be sufficiently reverberant to ensure a diffuse field. This will result in a diffuse field acting on the internal walls of the structure and an accurate assessment of the noise breakout. In the case of an anechoic room the loudspeaker will project sound directly onto the internal wall of the building. It is felt that the directivity of the loudspeaker would need to accurately represent the directivity of the assessed sound source for an accurate representation under such conditions. Therefore, it is expected that the DAT - loudspeaker system will not be effective in rooms with high absorption.

In order to predict the suitability of the DAT loudspeaker combination under a range of possible room acoustics the following equation was used;

$$Lw + 10 \text{ Log } (Q/4\pi r^2) + 6 = Lw + 10 \text{ Log } (4/Rc)$$

The distance from the noise source was predicted under a range of possible room surface areas and average absorption coefficients to ensure the sound field was predominantly reverberant. This was undertaken by determining the distance from the noise source at which the reverberant field was 6 dB higher than the direct field. The predicted distances from the noise source are given in Figure 6.1.

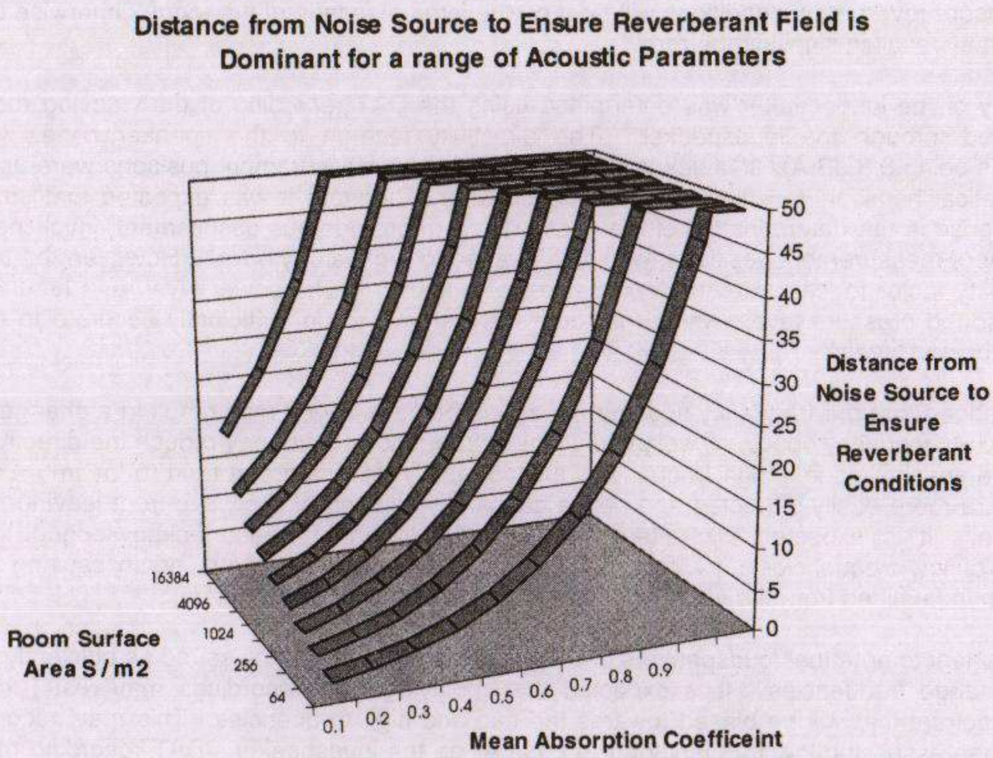

Figure 6.1
Distance from Noise Source to Ensure the Reverberant Field is Dominant for a range of Room Acoustic Parameters

It is evident that the DAT-loudspeaker combination is cannot be used in semi or totally anechoic conditions. However, there are a large range of conditions, depending upon the room shape, whereby the method could be used for accurately reproducing a noise source. An assessment of each room for which the DAT-loudspeaker is to be used would be required to ensure the room acoustics meet the necessary requirements to ensure the sound field is reverberant on the internal façade of the room.

7. REFERENCES

1. BS 4196:Part 0:1981 ISO 3740-1980 Sound power levels of noise sources – Guide for the use of basic standards and for the preparation of noise test codes.

2. ISO 3745:Part 5:1981 Precision methods for determination of sound power levels for sources in anechoic and semi-anechoic conditions.

3. ISO 3744:1994 BS EN ISO 3744:1995 Acoustics. Determination of sound power levels of noise sources using sound pressure. Engineering method in an essentially free field over a reflecting plane.

4. ISO 3744:1994 BS EN ISO 3744:1995 Acoustics. Determination of sound power levels of noise sources using sound pressure. Engineering method in an essentially free field over a reflecting plane.

5. BS ISO 9902:1993 Textile machinery acoustics – Determination of sound pressure levels and sound power levels emitted by textile machines – Engineering and survey methods.

6. Acoustics and Noise Control, 2nd edition, Smith BJ, Peters RJ, and Owen S, p.142