The Effect of Enveloping Surface Shape and Size on the Determination of Sound Power

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ABSTRACT

This report describes an experimental programme designed to assess the effect of enveloping surface shape and size on the determination of sound power using procedures based on those described in ISO 3744. The programme focused on hemispherical and parallelepiped measurement surfaces since these underpin all of the sound-pressure based standards, but a conformal surface shape was also considered. All measurements were carried out in hemi-anechoic conditions. Three locations were used: two were outdoor sites that consisted of large flat surfaces covered with either concrete or steel plates, and one a hemi-anechoic room that satisfies the requirements of ISO 3745, for hemispherical surfaces with radii up to 1.5 m.

The sound power levels of four machines were determined using three hemispherical and three parallelepiped enveloping surfaces with radii and measurement distances that conform to the requirements of ISO 3744. The machines were reasonably acoustically complex noise sources and typical of the type that will be subject to compliance with noise labelling and noise limits set out in numerous EC Directives. In addition, a more detailed series of measurements were made using a reference sound source with enveloping surface areas ranging from 3 m^2 to 56.5 m^2.

For parallelepiped and hemispherical surfaces sound power level determinations were dependent on the surface area, becoming approximately constant when the radius of the hemisphere was at least three-times the characteristic dimension and the parallelepiped measurement distance was at least 0.5 m. For the conformal surface there was no systematic variation.

Sound power levels determined using a parallelepiped were higher than those for a hemisphere and those for a conformal surface were lower. To reduce measurement uncertainty, the use of a bias correction to account for variations resulting from the use of different enveloping surfaces should be considered.

Significant differences were observed between sound power levels determined in the three hemi-anechoic environments, indicating that the environmental correction factor should be experimentally determined for all measurement locations.

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1 INTRODUCTION

In recent years a large number of European Directives have been published, containing requirements for determining the sound power levels of machines. The forerunner was Directive 79/113/EEC[1], which included a general method of determining the sound power level of construction plant and equipment. This was implemented by Directive 84/532/EEC[2] and several subsequent related directives, which imposed sound power limits on a wide range of machines used on construction sites. Separately from these, Directive 86/594/EEC[3] made provision for labelling household appliances with their sound power level on a voluntary basis, and this was followed by Directive 92/75/EEC[4] which made the noise labelling mandatory. Directive 89/392/EEC[5] (the Machinery Directive) covers the safety of a wide range of machinery types, and it requires manufacturers to give information on the sound power level if the sound pressure level at the work station of a machine exceeds 85 dB(A). In addition to all these, there is another new directive now under consideration which will address the noise emitted by machinery used outdoors[6]. This is intended to supersede some of the earlier directives, it concerns some sixty machine types and will require that all machines are labelled with their sound power level and will include some new noise limits.

The Machinery Directive is one of the "new approach" kind, which allows manufacturers to refer to standards in order to demonstrate compliance with the requirements. The UK intends that the new directive on machinery used outdoors will similarly refer to published standards. In order to produce the necessary standard noise test specifications, CEN and ISO are working closely together on various methods of measurement, to suit different acoustical conditions. The standards of interest for present purposes are all type B within the CEN hierarchy, that is they apply in principle to the noise of a wide range of machinery types. Type C standards, giving detailed machinery-specific methods will be based on these, and they will select and refer to individual type B standards for the appropriate method of noise measurement.

The declared noise level (the value on the label) is defined in ISO 4871:1997[7] as a maximal statistical value that is not exceeded for a given confidence level. This standard requires the addition of an uncertainty value to measured noise levels. It may be that the increase in declared noise level resulting from the addition of this uncertainty will affect sales of a particular machine or, for machines that are subject to noise limits, it may result in the machine having to be withdrawn from the European market. Thus, it is of prime importance that the sound power level is accurately determined and the level of measurement uncertainty is carefully specified.

The measurement procedures called up in the proposed new Directive are taken from the series of international standards that are concerned with the determination of sound power and in particular those that determine sound power levels in approximately hemi-anechoic conditions from measurements of sound pressure level around the machinery by carrying out a series of measurements over a hypothetical surface surrounding the source. The Standard generally used as the basis for all sound power determinations is ISO 3744:1994[8]. This standard underpins all of the sound-pressure based standards and requires the use of hemispherical or parallelepiped measurement surfaces. Although the shape and size of the surface is defined in the standard there is some considerable choice offered to the user.

A recent study[9] has indicated that the choice of measurement surface may affect the magnitude of determined sound power levels. Because of the requirement to affix a level label to each machine that displays a maximum noise level that is guaranteed by the manufacturer and that will have to withstand the verification procedures defined in ISO 4871, it may be important that the determined sound power level is not affected by the choice of enveloping surface.

This report describes an experimental programme designed to assess the effect of enveloping surface shape and size on the determination of sound power using procedures based on those described in ISO 3744. The programme focused on hemispherical and parallelepiped measurement surfaces since these underpin all of the sound-pressure based standards; other measurement surfaces can be regarded as derivatives of these two basic types.

2 BACKGROUND TO RELEVANT INTERNATIONAL STANDARDS

The main series of international standards defining generic methods (B-type standards) of sound power level determination using sound pressure level measurements contains eight standards. The series dates back originally to the 1970s and is at present undergoing major revision.

The Standards that are of interest for the purposes of this study are ISO 3744[8], ISO 3745[10] and ISO 3746[11]. These form a group of standards which address free-field, hemi-free-field and approximately hemi-free-field test environments, using similar measurement methods in all cases.

ISO 3745 is the precision method, for laboratory anechoic and hemi-anechoic rooms constructed according to strict requirements, and the conditions achieved in the rooms have to be qualified experimentally; the atmospheric conditions in the rooms also have to be controlled. No environmental correction is made to the results because the performance of a room has to be demonstrably ideal, but a correction is imposed for atmospheric pressure and temperature where they differ from the reference values. Because of the stringent requirements on the acoustical environment ISO 3745 is not suitable for the measurements required by the various EU Directives.

ISO 3744 is an engineering-grade method based on ISO 3745 for a hemi-free field and forms the basis of methods used for the purposes of noise labelling. An environmental correction, K_2, is defined to allow for deviations of the test conditions from the ideal ones specified, and this is not allowed to exceed 2 dB. For open test sites consisting of a hard, flat ground surface, such as asphalt or concrete, and with no sound-reflecting objects nearby, the standard assumes that K_2 is less than or equal to 0.5 dB and is negligible. There are no restrictions, nor corrections for atmospheric conditions.

ISO 3746 is a survey-grade method based on ISO 3744, where the environmental requirements are substantially relaxed and a correction of up to 7 dB is allowed. This allows measurements to be made with machinery in situ in its working conditions.

The methods of measurement are essentially similar in all three standards, with more microphone positions required for the higher grades of accuracy. Microphones are arrayed over a measurement surface in the form of a sphere or hemisphere for ISO 3745, or over a hemisphere or parallelepiped for ISO 3744 and ISO 3746. The minimum number of microphone positions is twenty on a sphere for ISO 3745, ten on a hemisphere for ISO 3744 and four on a hemisphere for ISO 3746. There are now many laboratory rooms or outdoor test sites in the UK that conform with ISO 3744, but only a few complying with ISO 3745. While the application of the latter standard is restricted almost entirely to research, ISO 3744 and ISO 3746 are used to test a very wide range of machine types and together these methods are by far the most commonly used ones for sound power determinations, certainly in the UK and probably throughout the world.

3 GENERAL PROGRAMME DESIGN CONSIDERATIONS

3.1 OUTLINE OF THE EXPERIMENTAL WORK PROGRAMME

The objective of the experimental work programme was to assess the effect of the shape of the enveloping surface on the determination of sound power level. This experimental objective was achieved by an analysis of sound power level data obtained using outdoor and indoor hemi-anechoic environments (see Sub-section 3.2). Sound power levels of several machines and of a reference sound source were determined strictly according to ISO 3744. This Standard is an engineering (grade-2 accuracy) method and addresses hemi-free-field and approximately hemi-free-field test environments.

The sound power levels determined using techniques based on sound pressure measurements to ISO 3744 were evaluated, addressing hemispherical and parallelepiped surfaces. Sound power levels and associated random uncertainties obtained by repeat measurements, were determined strictly according to the Standard. The standard permits measurements to be made employing either a hemisphere or a parallelepiped as the enveloping surface. A wide range of surface sizes may be chosen. There is however, a minimum surface area which is governed by the dimensions of the machine. The machine dimensions are described in the standards in terms of the size of the "reference box" and d_0, the "characteristic dimension". The reference box is a hypothetical surface which is the smallest rectangular parallelepiped that just encloses the source and terminates on the reflecting plane. The characteristic dimension is half the length of the diagonal of the box consisting of the reference box and its images in adjoining reflecting planes. The radius, r of the hemispherical measurement surface must be greater than or equal to twice the characteristic dimension. For the parallelepiped surface the measurement distance, d (the perpendicular distance between the reference box and the measurement surface) must be at least 0.25 m. Typical measurement configurations for a parallelepiped surface and for a hemispherical surface are shown in Figures 1 and 2 respectively.

Initial assessments were carried out using a small number of machines (see Sub-section 3.3) that were considered as reasonably acoustically complex noise sources and typical of the type of machines that will be subject to compliance with noise limits and measurement procedures set out in numerous EU Directives.

There was some doubt as to the long term stability of the noise levels of the machines used so the initial assessments were followed by a more detailed series of measurements using a reference sound source (RSS). A reference sound source is a stable, calibrated, omnidirectional broad-band source that will permit an assessment of small changes in sound power determinations that are independent of source variability.

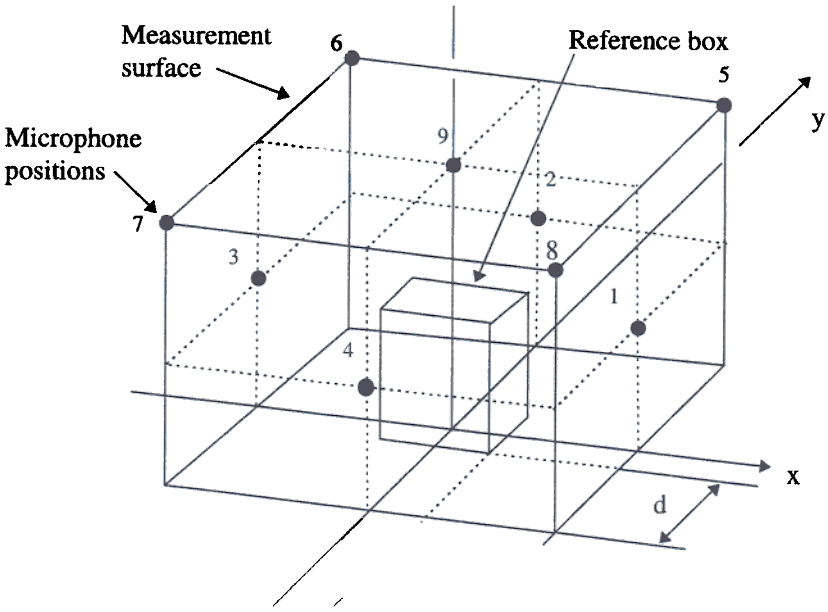

Figure 1. Typical parallelepiped measurement surface

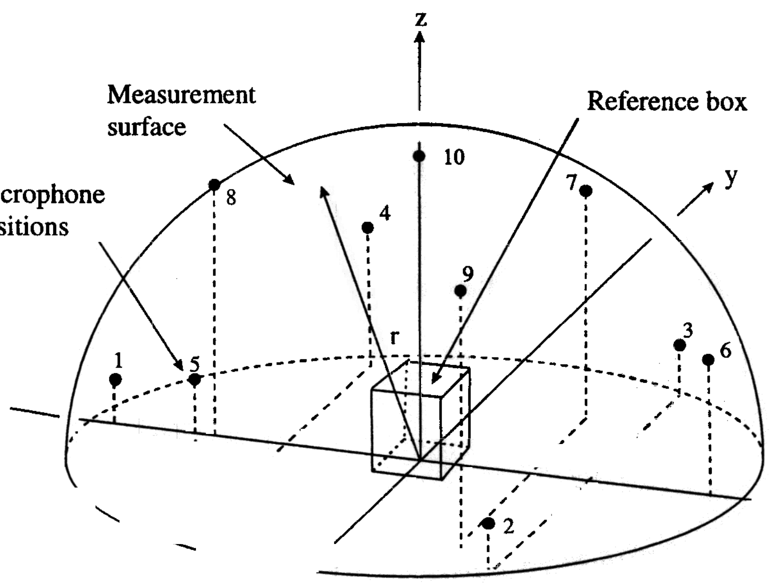

Figure 2. Typical hemispherical measurement surface

MEASUREMENT SITES AND INSTRUMENTATION

Measurement sites

The initial hemi-anechoic measurements (see Section 4) were carried out at two locations, one an outdoor hemi-anechoic site that consisted of a large flat surface covered with concrete to a depth of at least 0.2 m and approximately 50 m square with no sound-reflecting objects, and the other a hemi-anechoic room that satisfies the requirements of ISO 3745 for hemispherical measurement surfaces with radii up to 1.5 m. The hemi-anechoic room is an acoustically isolated asymmetrical chamber, with volume 91.5 m^3 and a mean height of 3.8 m, consisting of acoustically absorbent wedges on the walls and ceiling and a painted concrete reflecting floor of area 134 m^2.

The hemi-anechoic measurements using a reference sound source (see Section 5) were also carried out at two locations, one an outdoor site that consists of a large flat surface covered with 10 mm thick steel plate and approximately 15 m by 40 m with no sound reflecting objects and the other, the hemi-anechoic room described above.

Instrumentation

There is an inherent requirement for all instrumentation to adhere to the specifications described in the various standards under examination. The instrumentation used to carry out the basic noise measurements discussed in this report complied with these specifications and where necessary had current traceable calibration certificates. Brief details of the instrumentation used are listed below.

For sound power determination using measurements of sound pressure level:

dual channel frequency analyser	Brüel & Kjær	type 2144,
microphone(s)	Brüel & Kjær	type 4165,
microphone preamplifier(s)	Brüel & Kjær	type 2639,
pistonphone	Brüel & Kjær	type 4228.

For sound power determinations using a sound level meter:

sound level meter (with sound power software)	Norsonic	type 116,
microphone preamplifier	Norsonic	type 1201,
microphone	Norsonic	type 1220,
sound calibrator	Norsonic	type 1250.

The data was stored and processed on a pc using Lotus 1-2-3 release 4.

3.3 NOISE SOURCES.

Initial tests were conducted on four machines, comprising an electric drill, a diesel-engined electrical power generator, a two-stroke petrol-engined lawnmower, and a diesel-engined air compressor. The drill, which required a 240 V mains electrical supply, was provided with a mounting stand. The generator, lawnmower and air compressor were all used free-standing on the floor of the test area. Their approximate overall sizes and characteristic dimension are shown in Table 1. These sizes are also the dimensions of the reference box. The reference box is defined in ISO 3744 as, a hypothetical surface which is the smallest rectangular parallelepiped that just encloses the source and terminates on the reflecting plane. Brief details of each machine are given in sub-sections 3.3.1 to 3.3.5. In all cases the information given in the manufacturer's instruction book were followed. It must be stressed that the running conditions were not those required for tests according to EU Directives. Here the objective was to provide stable noise levels and so reported noise levels should not be compared with those that have been obtained according to the requirements of an EU Directive. Measurements were also carried out using a Brüel & Kjær type 4204 reference sound source.

Table 1 Approximate machine dimensions.

Machine	Dimensions (m)			
	Side-to-side	Front-to-back	Height	characteristic
Drill	0.3	0.05	0.3	0.34
Generator	0.5	0.7	0.7	0.78
Lawn mower	0.5	0.7	0.4	0.59
Compressor	1.2	1.6	1.2	1.56
RSS	0.3	0.3	0.3	0.37

3.3.1 Electric drill

Manufacturer: Black & Decker.
Power requirement: 240 volt, 50 Hz electrical supply.

The drill was fastened to a Black & Decker drill stand which was securely fixed to a wooden base plate of dimensions 300 mm x 250 mm x 20 mm. The drill was operated in the non-hammer mode with the speed trigger secured full in (maximum rpm).

Electrical power generator

Manufacturer: Lombardini (engine), Markon Engineering (generator), Clarke Power (rectifier).
Power requirement: diesel fuel, SAE grade 15/40 oil.

Some preparatory checks were carried out; check the oil level using the dip-stick and top up as required and, if necessary, clean the air filter. Before commencing measurements the engine was allowed to idle for a few minutes by keeping the throttle lever at its highest position. During measurements the engine was operated at the maximum power setting with the throttle lever fixed at its lowest position.

Two-stroke petrol-engined lawnmower

Manufacturer: Siag (lawnmower), Briggs and Stratton (engine).
Power requirement: Unleaded petrol in 50:1 ratio with a two stroke oil rated TC-W.

The lawn mower is a rotary mower with no forward drive as is usual with cylinder mowers. Two sets of notches were cut into the speed control lever housing and during measurements the speed control lever was positioned between them. This resulted in an engine speed of 2000 rpm. Trials showed that small variations (larger than would be expected due to human error) in control lever position around the "notches" did not significantly alter the engine speed.

Diesel-engined air compressor

Manufacturer: Atlas Copco.
Power requirement: diesel fuel, SAE 15/40 motor oil, hydraulic oil of ISO recommended viscosity of VG32

Several preparatory checks were carried out before use, the engine has an electric starter and once started it was left until it was running smoothly, the air outlet valve was closed and the engine given a couple of minutes to warm up.

3.3.5 Reference sound source

Manufacturer: Brüel & Kjær, type: 4204
Power requirement: 240 volt, 50Hz mains

4 INITIAL MEASUREMENTS ACCORDING TO ISO 3744

4.1 MEASUREMENT LOCATIONS

Sound power determinations made according to this standard may be carried out in a hemi-anechoic room or an outdoor space fulfilling the acoustic environment requirements of the standard. Because of the low noise level of the electric drill measurements were carried out in a hemi-anechoic room . The other three machines all produce exhaust gases and so were tested outdoors (see 3.2.1 above). The environmental correction factor for each environment was determined using a calibrated reference sound source. The value of K_{2A} was less than 0.5 dB.

4.2 MEASUREMENT SURFACES

Sound pressure levels were measured with frequency weighting A, on three hemispherical measurement surfaces of radii listed in Table 2, and on three parallelepiped measurement surfaces with the measurement distances listed in Table 3.

Table 2 Measurement radii, *r*, for the hemispherical surfaces.

Machine	r_1 (m)	r_2 (m)	r_3 (m)
drill	1.0	1.25	1.5
generator	2.0	4.0	6.0
lawn mower	2.0	4.0	6.0
compressor	4.0	6.0	8.0

Table 3 Measurement distances, *d*, and numbers of measurement positions for parallelepiped measurement surfaces.

Machine	Number of measurement positions			
	d_1 = 0.25 m	d_2 = 1.0 m	d_3 = 1.5 m	d_3 = 2.0 m
drill	14	9	9	-
generator	37	9	-	9
lawn mower	21	9	-	9
compressor	61	21	-	9

Ten measurement positions were used for each hemispherical measurement surface.

The ten positions chosen were those shown in Figure 2. These are described in ISO 3744 as "the key microphone positions" and are associated with equal areas of the measurement surface. Their coordinates in x, y, z form are listed as a function of the hemisphere radius in Table 4.

Table 4 Coordinates of microphone positions according to ISO 3744

microphone position	x/r	y/r	z/r
1	-0.99	0	0.15
2	0.50	-0.86	0.15
3	0.50	0.86	0.15
4	-0.45	0.77	0.45
5	-0.45	-0.77	0.45
6	0.89	0	0.45
7	0.33	0.57	0.75
8	-0.66	0	0.75
9	0.33	-0.57	0.75
10	0	0	1.0

4.3 EXPERIMENTAL RESULTS

For each machine three repeat determinations of sound power level were carried out for each enveloping surface in order to obtain data on repeatability uncertainty. An estimate of repeatability uncertainty is essential in order to assess the significance of differences between sound power levels determined using the various enveloping surfaces. The mean values of sound power levels determined using both hemispherical and parallelepiped enveloping surfaces for the four machines are shown in Figures 3a to 3d together with the associated repeatability uncertainties. Repeatability uncertainties are expressed as a standard deviation about the mean value and are displayed in the four figures as ± 2 standard deviation error bars representing a statistical confidence interval of 95%. For each enveloping surface, the sound power level is plotted against the corresponding area correction, C, in dB, which is given by:

$$C = 10 \lg (S/S_0).$$

Where S is the area of the enveloping surface in m^2 and S_0 is the reference area of 1 m^2.

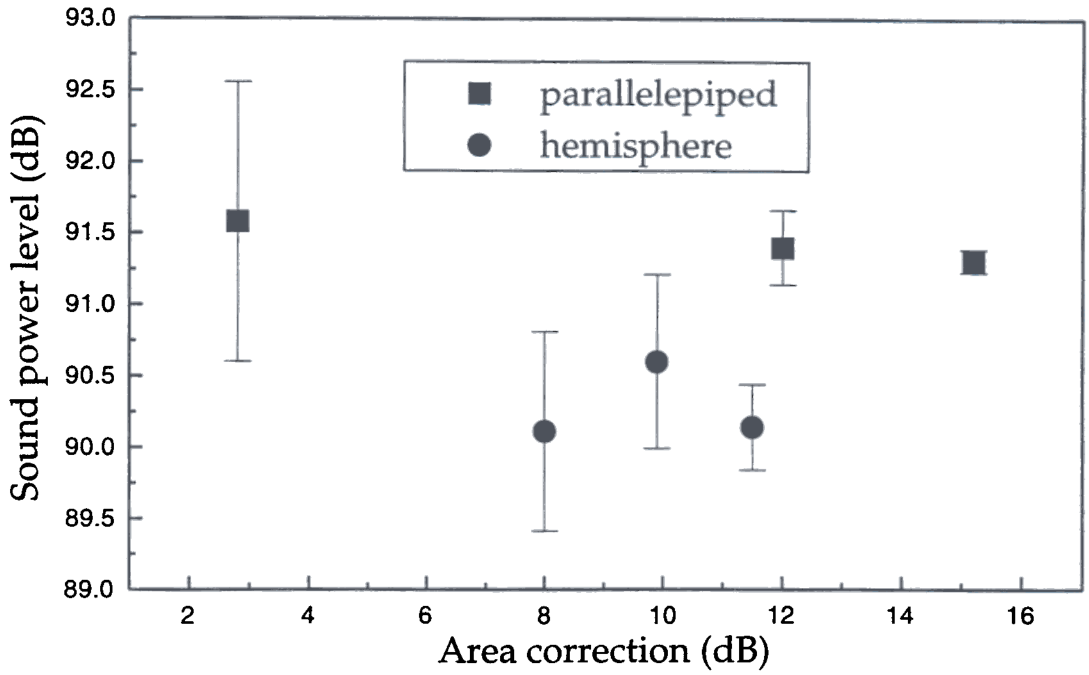

Figure 3a. A-weighted sound power levels and associated error bars for the electric drill

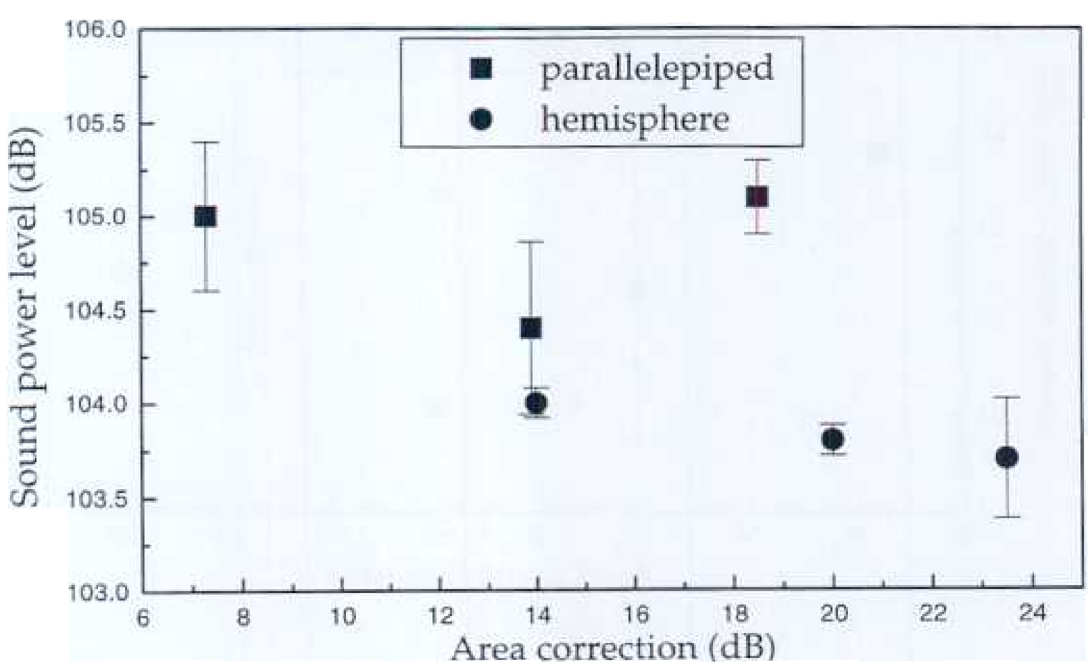

Figure 3b. A-weighted sound power levels and associated error bars for the generator

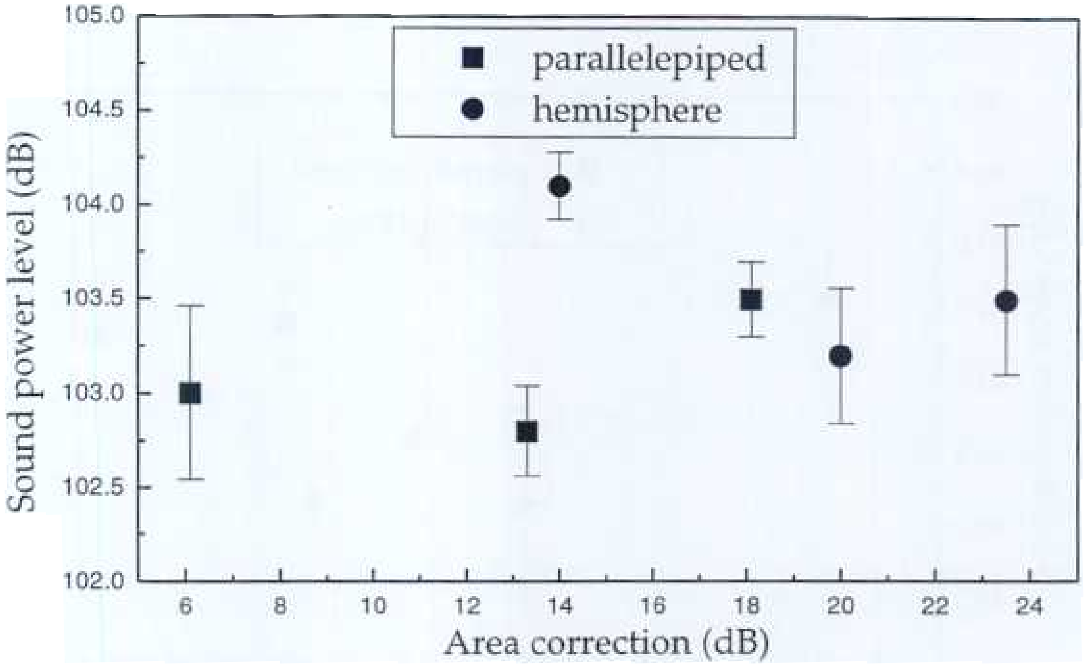

Figure 3c. A-weighted sound power levels and associated error bars for the lawn mower

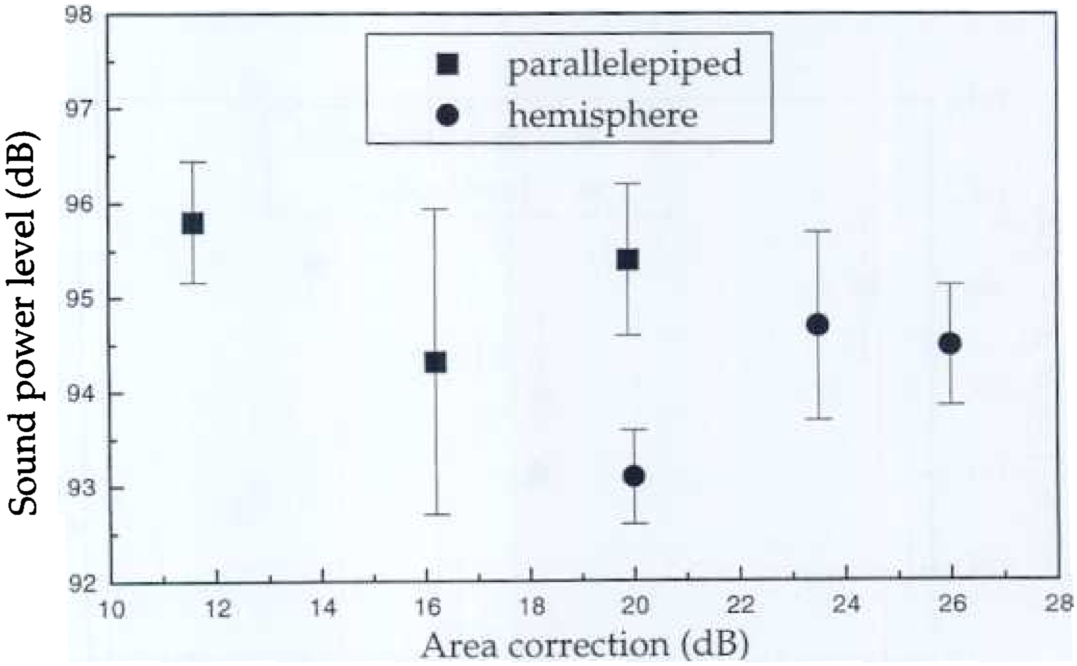

Figure 3d. A-weighted sound power levels and associated error bars for the compressor

It can be seen from the four figures that there is a variation of mean sound power level with both radius and measurement distance although because of the magnitude of the repeatability uncertainty this variation may not be statistically significant. An examination of the difference between sound power levels determined using hemispherical surfaces with those obtained using parallelepiped surfaces would seem to be machine dependant. For the drill and the generator there is clearly a significant difference with larger sound power levels obtained using the parallelepiped surfaces. A similar result is evident from the compressor data but the large values of repeatability uncertainty mean the difference will probably not be statistically significant. It is difficult to make any meaningful conclusion regarding the lawn mower results because of the data scatter and magnitude of the uncertainty levels. This may be a result of variations in noise emission, as despite efforts to ensure constant running conditions (see 3.3.3 above) it is possible that the sound power levels varied between determinations.

Although there is a possibility of a variation of sound power level determinations with both measurement distance and radius, it is interesting to average the mean values shown in Figure 3 and compare the values of sound power level obtained using hemispherical surfaces with those obtained using parallelepiped surfaces. The resulting average sound power levels for each machine are listed in Table 5.

Table 5 Average A-weighted sound power levels

Surface	Machine			
	Drill	Generator	Mower	Compressor
Parallelepiped	91.43	104.83	103.10	95.17
Hemisphere	90.28	103.83	103.60	94.10
Difference	1.15	1.00	-0.50	1.07

It can be seen that for the drill, the generator and the compressor the sound power levels determined using parallelepiped surfaces is approximately 1 dB higher than those determined using the hemispherical surfaces. For the lawn mower the sound power levels obtained using the parallelepiped surfaces are 0.5 dB lower. However, as discussed above, the significance of this result is in some doubt.

Although the repeatability uncertainty values prevent the calculation of a statistically significant difference between sound power levels obtained using parallelepiped surfaces with those determined using hemispherical surfaces, it is clear that there may be a difference of approximately 1 dB. If this is the case then the problem should be addressed by the appropriate Standards organisations when revising the current international standards describing methods to be used for sound power determination.

The repeatability standard deviations shown in Figure 3 vary with the shape and size of the enveloping surface and between machines. The values of standard deviations used for the error bars in Figure 3 are listed in Table 6.

Table 6 Repeatability standard deviations used in Figure 3

Machine	parallelepiped			hemisphere		
	d_1	d_2	d_3	r_1	r_2	r_3
Drill	0.98	0.26	0.08	0.70	0.61	0.30
Generator	0.40	0.46	0.20	0.08	0.08	0.32
Mower	0.46	0.24	0.20	0.18	0.36	0.40
Compressor	0.64	1.62	0.80	0.50	1.00	0.64

It can be seen that generally the uncertainty values for the hemispherical surfaces are less than those for the parallelepiped surfaces. For the parallelepiped surfaces values tend to reduce as the measurement distance is increased. For the hemispherical surfaces the variation with change in radius is not so clear. However, the uncertainties tend to be similar in magnitude to the difference between sound power levels obtained using the two types of surface. It is possible that these relatively large values of repeatability uncertainty may result from actual variations in sound power due to small short term changes in the noise emission of the machines. To assess this possibility the experimental programme continued with a series of measurements using a reference sound source. A reference sound source is a stable, calibrated, omnidirectional broad-band source that will permit an assessment of small changes in sound power determinations that are independent of source variability.

4.4 CONCLUSIONS FROM MEASUREMENTS ON MACHINES

There is a variation of mean sound power level with both radius and measurement distance although because of the repeatability uncertainties this variation may be not statistically significant.

The difference between sound power levels determined using hemispherical surfaces and those obtained using parallelepiped surfaces is machine dependent.

The difference between sound power levels obtained using parallelepiped surfaces and those determined using hemispherical surfaces is approximately 1 dB. However, because of repeatability uncertainties this variation may be not statistically significant.

5 MEASUREMENTS USING A REFERENCE SOUND SOURCE

5.1 SELECTION OF THE NOISE SOURCE

As discussed in Section 4, the conclusions from the results of the initial measurements carried out on several machine types according to ISO 3744 were somewhat confusing. Differences between sound power determinations obtained using hemispherical surfaces with those using parallelepiped surfaces were relatively small and were dependent on machine type and on the area of the surface. It was suggested that the confusion may be a result of actual variations in sound power due to small short term changes in the noise emission of the machines. To assess this possibility a series of measurements using a reference sound source were performed.

5.2 MEASUREMENT LOCATION

Measurements have been carried out under hemi-anechoic conditions at two locations: indoors in a hemi-anechoic room and outdoors over a steel ground surface. Both locations are described in sub-section 3.2.1. Initially measurements were carried out indoors where the room size limited the largest hemispherical enveloping surface radius to 1.5 m. In order to cover a wider range of enveloping surface areas a second (outdoor) site was used.

5.3 ENVELOPING MEASUREMENT SURFACES

As for the initial measurements discussed in Section 4, sound power levels have been determined using hemispherical and parallelepiped surfaces, in order to assess any possible variations within the ISO 3744 requirements. However, to further investigate the effect of the shape of the enveloping surface a conformal surface shape has also been used. The conformal shape is in effect similar to the parallelepiped but with the vertical corners rounded such that the distance from the surfaces of the enveloping surface from the machine are more constant. So, microphone positions 5, 6, 7 and 8 in Figure 1 will, relative to positions 1, 2, 3 and 4, be closer to the noise source and will therefore, be subjected to a higher sound pressure level. However, the area of the conformal surface will be less than that of the parallelepiped surface for a given value of measurement distance. This means that the area correction used in the determination of sound power will be less for the conformal surface. To obtain the same surface area for these two surface types the measurement distances used for the conformal surfaces was slightly larger than that used for the parallelepiped surfaces. Whilst conformal surface shapes are not used in the ISO 3740 series of standards that determine sound power from measurements of sound pressure level, they are an option in ISO 9614-1[12] and in ISO 9614-2[13], two standards that determine sound power from measurements of sound intensity level. The enveloping surface areas are shown below in Table 7.

It can be seen from Table 7 that enveloping surfaces with areas up to 14.1 m^2 were used indoors and areas up to 56.5 m^2 outdoors with an overlap for areas of 6.3 m^2 and 14.1 m^2. This overlap should allow a direct comparison between the two hemi-anechoic environments.

Table 7 Enveloping surfaces used with the reference sound source

Area		hemisphere	parallelepiped	conformal	location	
m^2	C (dB)	radius (m)	measurement distance (m)	measurement distance (m)	indoor	outdoor
3	4.8	*0.69*	0.30	*0.37*	✔	
4	6	0.80	0.38	0.45	✔	
6.3	8	1.00	0.51	0.62	✔	✔
14.1	11.5	1.50	0.88	1.02	✔	✔
25.5	14.1	2.00	1.25	1.43		✔
56.5	17.5	3.00	1.97	2.24		✔

The ISO 3744 requirement regarding the size of the radius or measurement distance is related to the characteristic dimension. The characteristic dimension is defined as half the length of the diagonal of the box consisting of the reference box and its images in the adjoining reflecting plane. The reference box is defined in ISO 3744 as a hypothetical surface which is the smallest rectangular parallelepiped that just encloses the source and terminates on the reflecting plane. ISO 3744 requires that the radius of a hemispherical enveloping surface is equal to or greater than twice the characteristic dimension and that the minimum measurement distance associated with a parallelepiped surface shall be 0.25 m. Furthermore, the number of microphone positions for a parallelepiped surface is dependent on the dimensions of the side under consideration such that if a dimension is greater that three times the measurement distance then the number of microphone locations has to be increased above the minimum requirement. For the reference sound source a measurement distance of less than 0.3 m will require extra microphone positions. To avoid adding another variable (number of microphone positions) in the comparison of sound power determinations it was decided that the minimum measurement distance would therefore be 0.3 m. The 3 m^2 area is calculated for this measurement distance. The characteristic dimension of the reference sound source is 0.37 m, so this means that the hemispherical surface with the same area as the smallest parallelepiped has a radius of 0.69 m and this is just outside the ISO 3744 requirement and so a hemispherical enveloping surface has not been used in this case.

5.4 RESULTS FROM MEASUREMENTS CARRIED OUT INDOORS.

Sound power determinations were carried out using three types of enveloping surfaces (see sub-section 5.3 above) with areas of 3 m^2, 4 m^2, 6.3 m^2 and 14.1 m^2. This range was limited at one end by the minimum measurement distance (0.3 m) and at the other by the maximum radius (1.5 m) for which the room meets the requirements of ISO 3744. Repeat determinations of sound power level were carried out for each enveloping surface in order to obtain data on repeatability uncertainty. An estimate of repeatability uncertainty is essential in order to assess the significance of differences between sound power levels determined using the various enveloping surfaces. The mean values of sound power levels determined using hemispherical, parallelepiped and conformal enveloping surfaces are shown in Figure 4 together with the associated repeatability uncertainties. For each enveloping surface, the sound power level is plotted against the corresponding area correction (see sub-section 4.3).

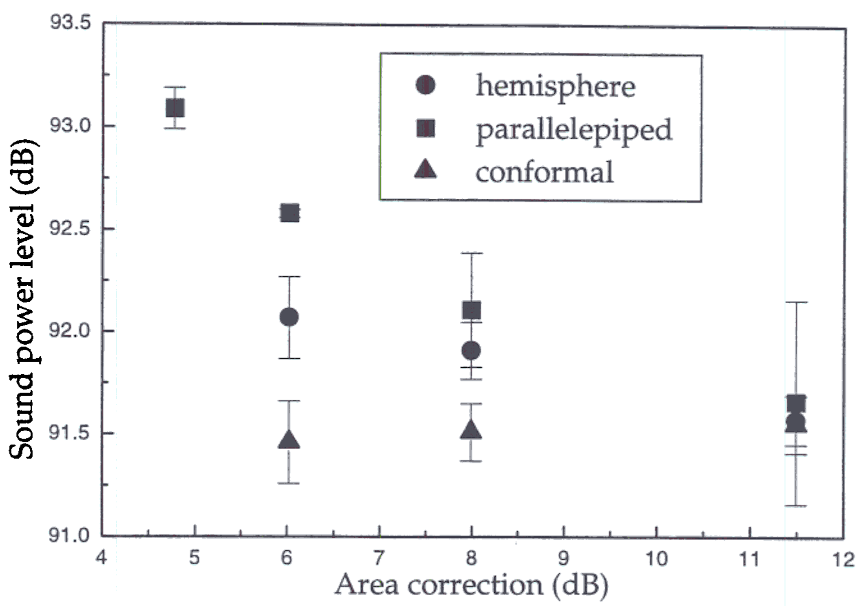

Figure 4. A-weighted sound power levels and associated error bars for the reference sound source, indoor measurements

It can be seen that for the parallelepiped surfaces there is a clear variation of sound power level with measurement distance with values reducing as the measurement distance is increased. It can also be seen that the rate of decrease reduces as the area increases. A similar observation can be made for the sound power levels obtained using a hemispherical measurement surface although in this case the variation and the rate of change is not so marked. For the conformal surface there is no systematic variation. The mean values are tabulated in Table 8 together with the associated repeatability standard deviations.

Table 8 Mean and standard deviations for the indoor measurements

Area		hemisphere		parallelepiped		conformal	
m^2	C (dB)	mean (dB)	sd(dB)	mean (dB)	sd (dB)	mean (dB)	sd (dB)
3	4.8	-	-	93.09	0.05	-	-
4	6.0	92.07	0.10	92.58	0.01	91.46	0.10
6.3	8.0	91.91	0.07	92.11	0.14	91.51	0.07
14.1	11.5	91.57	0.06	91.66	0.25	91.55	0.07

It was suggested in sub-section 4.3 that some of the variation observed in the determination of the sound power of the machines used may be a result of actual short term changes in the noise emission of the machines. A comparison of the standard deviations in Table 8 with the standard deviation data from Table 6 shows that the values for the reference sound source are considerably lower than those associated with actual machines. Thus as proposed in sub-section 4.3, the use of a reference sound source should permit an assessment of small changes in determined sound power that are not the result of source variability.

It can be seen from Table 8 that for parallelepiped surfaces sound power levels reduce by 0.92 dB when the area is increased from 4 m^2 to 14.1 m^2 ; for hemispherical surfaces the corresponding reduction is 0.50 dB and for the conformal surface there is an increase of 0.09 dB.

Because there is evidence of a variation of sound power level with the area of the enveloping surface, differences in determined sound power level between surface type will have to be examined for each area. It can be seen from Table 8 that the sound power levels determined using parallelepiped surfaces are 0.51 dB, 0.20 dB and 0.09 dB higher than those obtained using hemispherical surfaces for areas of 4 m^2, 6.3 m^2 and 14.1 m^2 respectively. For the conformal surface, determined sound power levels are lower than those for the hemispherical surface, the corresponding differences are, -0.61 dB, -0.40 dB and -0.02 dB. So, on average, when compared to sound power levels obtained using hemispherical surfaces, values determined using parallelepiped surfaces are 0.26 dB higher and those obtained using conformal surfaces are 0.34 dB lower. However, these average values may be misleading as sound power levels determined using the larger area are, as can be seen from Table 8, in fairly good agreement.

5.4.1 Conclusions from measurements performed indoors on the reference sound source

The enveloping surface areas considered ranged from 3 m^2 to 14.1 m^2.

For the parallelepiped and hemispherical surfaces there is a clear variation of sound power level with the area of the enveloping surface (with measurement distance and radius) with levels reducing as the area is increased, with the rate of decrease reducing as the area increases. For parallelepiped surfaces sound power levels reduce by 0.92 dB when the area is increased from 4 m^2 to 14.1 m^2. For hemispherical surfaces the corresponding reduction is 0.50 dB. For the conformal surface there is no systematic variation.

On average, when compared to sound power levels obtained using hemispherical surfaces, values determined using parallelepiped surfaces are 0.26 dB higher and those obtained using conformal surfaces are 0.34 dB lower.

5.5 RESULTS FROM MEASUREMENTS PERFORMED OUTDOORS.

Sound power determinations were carried out using the same three types of enveloping surfaces (see sub-section 5.3 above) with areas of 6.3 m^2, 14.1 m^2, 25.5 m^2 and 56.5 m^2. These areas extend the range used for the indoor measurements with 6.3 m^2 and 14.1 m^2 being repeats of the larger indoor areas. As for the indoor measurements, repeat determinations of sound power level were carried out for each enveloping surface in order to obtain data on repeatability uncertainty. The mean values of sound power levels determined using hemispherical, parallelepiped and conformal enveloping surfaces are shown in Figure 5 together with the associated repeatability uncertainties. For each enveloping surface, the sound power level is plotted against the corresponding area correction (see sub-section 4.3).

It can be seen that, unlike the variations observed from the indoor results (see sub-section 5.4), for the parallelepiped surfaces there is no systematic variation of sound power level as the enveloping surface area is increased. The level increases by 0.39 dB with an area change from 6.3 m^2 to 25.1 m^2 and then reduces by 0.25 dB for an area of 56.5 m^2, so is only 0.14 dB higher than the 6.3 m^2 value. A similar observation can be made for the sound power levels obtained using hemispherical measurement surfaces, although here the value at 56.5 m^2 is lower than the value at 6.3 m^2. For the conformal surface there is no systematic variation. The mean sound power levels are tabulated in Table 9 together with the associated repeatability standard deviations.

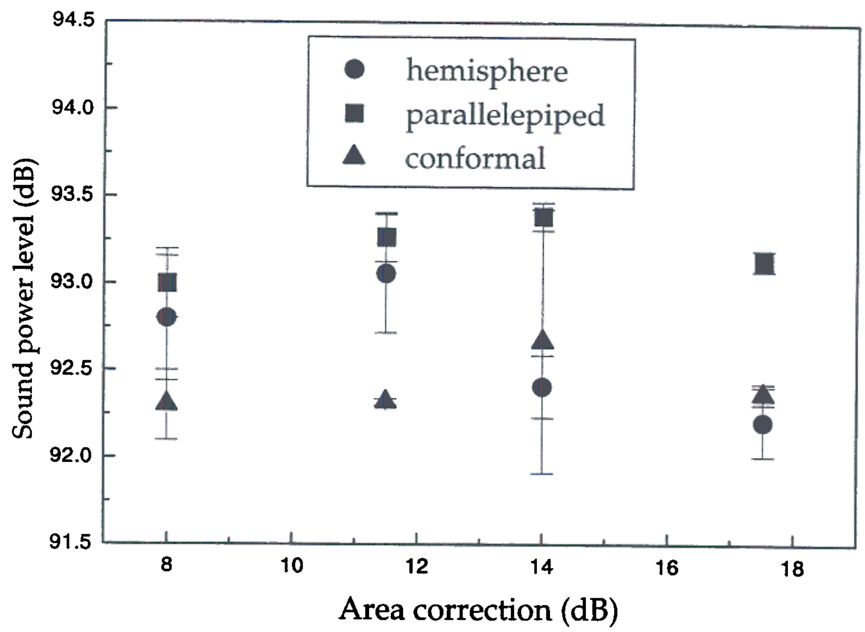

Figure 5 A-weighted sound power levels and associated error bars for the reference sound source, outdoor measurements

Table 9 Mean and standard deviations for the outdoor measurements

Area		hemisphere		parallelepiped		conformal	
m^2	C (dB)	mean (dB)	sd(dB)	mean (dB)	sd (dB)	mean (dB)	sd (dB)
6.3	8.0	92.80	0.18	93.00	0.10	92.30	0.10
14.1	11.5	93.06	0.17	93.27	0.07	92.32	0.01
25.1	14.1	92.41	0.09	93.39	0.04	92.67	0.38
56.5	17.5	92.21	0.10	93.14	0.03	92.37	0.06

It can be seen from Table 9 that the sound power levels determined using parallelepiped surfaces are 0.2 dB, 0.21 dB, 0.98 dB and 0.93 dB higher than those obtained using hemispherical surfaces for areas of 6.3 m^2, 14.1 m^2, 25.1 m^2 and 56.5 m^2 respectively. For the conformal surface, determined sound power levels are lower than those for the hemispherical surface for the two smaller areas and higher for the two larger areas, the corresponding differences values are, -0.50 dB, -0.74 dB and 0.26 dB and 0.16 dB. So, on average, when compared to sound power levels obtained using hemispherical surfaces, values determined using parallelepiped surfaces are 0.58 dB higher and those obtained using conformal surfaces are 0.21 dB lower. A comparison of these average values with those determined from the measurements carried out indoors (see sub-section 5.4) shows reasonable agreement. The corresponding differences are 0.26 dB higher for the parallelepiped surfaces and 0.34 dB lower for the conformal surfaces. However, the average outdoor values may be misleading as sound power levels determined using the smaller areas are, as can be seen from Table 9, in fairly good agreement.

Measurements were performed using the outdoor location in order to increase the range of hemisphere radius and parallelepiped measurement distance above those permitted in the hemi-anechoic room. A comparison of the sound power levels obtained outdoors with the indoor results is interesting as there seems to be a difference in determined sound power levels. This difference is particularly evident from an examination of the sound power levels determined using the two surface areas that were used both outdoors and indoors. A more detailed examination of the differences between outdoor and indoor results is described in sub-section 5.6.

5.5.1 Conclusions from measurements performed outdoors on the reference sound source

The enveloping surface areas considered ranged from 6.3 m^2 to 56.5 m^2.

There is no systematic variation of sound power level as the enveloping surface area is increased.

On average, when compared to sound power levels obtained using hemispherical surfaces, values determined using parallelepiped surfaces are 0.58 dB higher and those obtained using conformal surfaces are 0.21 dB lower.

5.6 COMPARISON OF INDOOR AND OUT DOOR MEASUREMENTS

As briefly discussed above in sub-section 5.5, the sound power levels determined in the two locations are not in good agreement. To illustrate this disagreement, the average sound power levels for both locations are shown in Figure 6. Here it is clear that the sound power levels determined on the outdoor location are greater than those determined indoors.

This is especially evident from an examination of the results for enveloping surface areas of 6.3 m^2 and 14.1 m^2 where data was obtained in both locations. The sound power levels for these two areas are listed in Table 10.

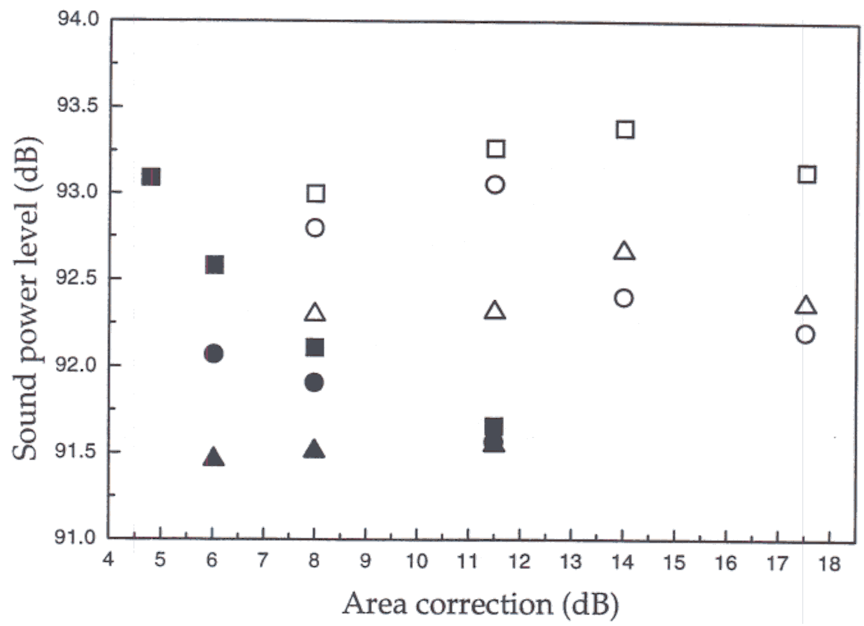

Figure 6 A-weighted sound power levels:
Indoors: ■ parallelepiped, ● hemisphere, ▲ conformal.
Outdoors: □ parallelepiped, ○ hemisphere, △ conformal.

Table 10 Comparison of outdoor and indoor results for the overlapping areas

		Sound power level (dB)	
		Surface shape	
Area m^2 or (C dB)	Location	Hemisphere	Parallelepiped
6.3 (8.0)	Outdoor	92.80	93.00
	Indoor	91.91	92.11
Difference (outdoor - indoor)		0.89	0.89
14.1 (11.5)	Outdoor	93.06	93.27
	Indoor	91.57	91.66
Difference (outdoor - indoor)		1.49	1.62

It can be seen from Table 10 that there is a difference of 0.89 dB between indoor and outdoor determinations using a surface area of 6.3 m^2 for both hemispherical and parallelepiped surfaces. For the 14.1 m^2 surface area this increases to 1.49 dB for the hemisphere and 1.62 dB for the parallelepiped. The good agreement of these sound power level differences between surface shape implies that there is a difference in the environmental correction factor, K_{2A} between the two measurement locations, with the outdoor location being least hemi-anechoic. Annex A of ISO 3744 describes methods of determining K_{2A} and states "For open test sites which consists of a hard, flat ground-surface, such as asphalt or concrete, and with no sound reflecting objects within a distance from the source equal to three times the greatest distance form the source centre to the lowest measurement points, it is assumed that the environmental correction K_2 is less than or equal to 0.5 dB and is, therefore, negligible.". It is clear from the large differences discussed above, that this assumption may not be correct and that it is vitally important to determine the K_{2A}-factor of each measurement location. Whilst the differences in K_{2A} shown in Table 9 are difficult to justify from a visual examination of the two measurement locations (bearing in mind the ISO 3744 requirements), it is interesting to re-examine the measured data with an environmental correction factor applied to the outdoor site results. ISO 3744 defines one method of determining K_{2A} using a hemispherical measurement surface and if a mean value of the two differences in Table 10 for the hemispherical surfaces were used the value of K_{2A} would be 1.19 dB. On the other hand, if K_{2A} were assumed to be the average value of all four differences listed in Table 10 the value would be 1.22 dB. Thus the way the data is averaged seems to make very little difference to the end result. The mean of all differences is used in this report. The sound power levels shown in Figure 6 are replotted in Figure 7 with a K_{2A} correction of -1.22 dB applied to the outdoor measurements.

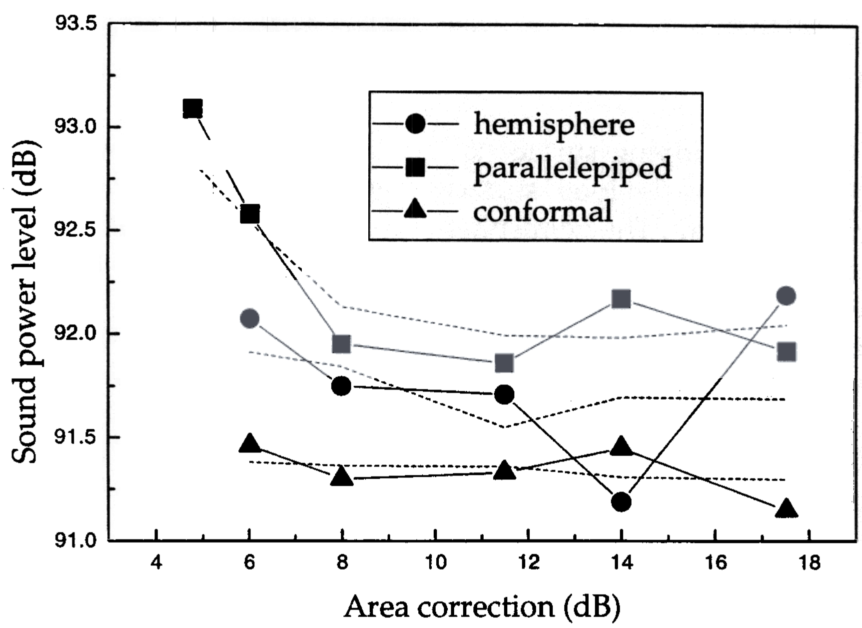

Figure 7 A-weighted sound power levels with adjacent averaging (dashed lines)

In Figure 7 the sound power levels obtained using enveloping surface areas of 6.3 m^2 and 14.1 m^2 are the average of the outdoor and indoor values. The solid lines in Figure 7 simply join the individual data points and only serve to give an indication of overall trends. It can be seen that the for the parallelepiped and hemispherical surfaces there is a clear variation of sound power level with measurement distance and radius with values reducing as either of these two parameters are increased, and that the rate of decrease reduces as they increase. These were the trends described in sub-section 5.4 where only data for smaller enveloping surface areas were considered. To obtain a more quantitative assessment of the variation of sound power determinations for each surface shape with the surface area, the data have been averaged. It was evident that a linear or polynomial curve fit would not be appropriate for these data and so an adjacent averaging procedure has been adopted. The dashed curves are the result of the adjacent averaging procedure and are, effectively, smoothed versions of the solid lines. The smoothed value at an area, a, is the average of the data points in the interval:

$$[a-(n-1)/2 \text{ to } a+(n-1)/2]$$

The number of data points, n, used to calculate each averaged result was 3.

It can be seen from Figure 7 that these averaged curves are approaching constant values approximately 0.3 dB apart with the sound power levels determined using parallelepiped surfaces the highest and those determined using conformal surfaces the lowest. These differences must be assessed in conjunction with the standard deviations of repeatability, which are, on average, approximately 0.1 dB for each surface. However, the uncertainties that should be considered here are those listed in Tables 8 and 9 which are based on these standard deviations multiplied by a coverage factor of 2, providing a level of confidence of approximately 95%. Hence, the resulting measurement uncertainties are approaching the same order as the differences in sound power level. The statistical implications are considered in more detail in sub-section 5.7.

As the area of the enveloping surface is increased the sound power levels for the hemispherical and parallelepiped surfaces become essentially constant for areas between 6.3 m^2 and 14.1 m^2. The hemisphere radius associated with these two areas is 1 m and 1.5 m for 6.3 m^2 and 14.1 m^2 surfaces respectively. These correspond to approximately three-times and four-times the characteristic dimension. The measurement distances associated with these two areas are approximately 0.5 m and 0.9 m for 6.3 m^2 and 14.1 m^2 respectively. The implication here is that the radius should be at least three-times the characteristic dimension (four-times for safety) and the measurement distance should be at least 0.5 m (0.9 m for safety). The current version of ISO 3744 requires a radius of twice the characteristic dimension and a measurement distance of at least 0.25 m.

5.6.1 Conclusions from measurements on the reference sound source

The enveloping surface areas considered ranged from 3 m^2 to 56.5 m^2.

For the parallelepiped and hemispherical surfaces there is a clear variation of sound power level with the area of the enveloping surface with levels approaching a constant value as the area is increased. Approximately constant sound power levels are determined using enveloping areas greater than approximately 6.3 m^2. For the conformal surface there is no systematic variation with surface area.

For the region of enveloping surface areas where there is negligible variation in sound power levels with changes in area, levels obtained using the three surface shapes are approximately 0.3 dB apart with the sound power levels determined using parallelepiped surfaces the highest and those determined using conformal surfaces the lowest.

It is vitally important to determine, experimentally, the environmental correction factor, K_{2A} for each measurement location.

The radius of a hemispherical enveloping surface should be at least three-times the characteristic dimension (four-times for safety) and the measurement distance for a parallelepiped enveloping surface should be at least 0.5 m (0.9 m for safety).

5.7 STATISTICAL ANALYSIS

In the previous two sub-sections the sound power levels determined using two hemi-anechoic locations have been considered. Differences in determined sound power levels resulting from the use of various enveloping surface shapes and sizes have been assessed by observation and by smoothing techniques. However, the statistical significance of these differences remains to be investigated in order to assess the implications for measurements made according to ISO 3744. For instance if the differences between measurements made using hemispherical surfaces and those made using parallelepiped surfaces is statistically significant then it may be possible to account for the variation in sound power level by the use of a correction factor or, a more probable outcome, to restrict measurements to a particular surface. A statistical assessment has been carried out using of an analysis of variance, which is one of the tools incorporated in the commercially available SPSS software package.

In order to determine statistical significance it is necessary to determine whether the observed differences in the sample means, described in previous sub-sections, resulting from different types of measurement configurations can be attributed to a natural variability between the sample means or whether they come from populations that have different means. The statistical technique used in this report is the SPSS procedure called one-way ANOVA. The technique examines the variability of measured data within each chosen group and the variability between the group means. Based on these two estimations of variability the F-ratio is computed and from a comparison with tabulated values of the F-distribution a statistical significance level, "F-prob" is obtained from which it is possible to draw certain conclusions about the group means. This is achieved by testing the null hypothesis, which in this case is that the data from the two groups are from the same population. F-prob (calculated from the ratio of the within-group and between-group mean squares) has a value between zero and unity. If the null hypothesis is true then these two mean squares are close to one another and F-prob will be close to unity which indicates no significant difference between the two groups.

In the analyses carried out in this report the data from two groups are considered to be significantly different if the value of F-prob is less than 0.05. This is equivalent to the 95% confidence interval which was assumed for the error bars shown in Figures 3, 4 and 5. A statistical analysis has been carried out on the data obtained using each surface shape and size considered in this report and results are discussed in the following three sub-sections.

5.7.1 Statistical analysis for the indoor measurements

Statistical analyses were carried out to examine the significance of differences between sound power determinations made using different surface sizes and also by using different surface shapes. To assess the statistical significance of differences in determined sound power resulting from the differing surface shape the analysis of variance was performed for each surface size (three) and for several data set combinations. All three shapes were considered together and in addition to assess the relationships between individual shapes three further combinations were considered, namely the difference between hemispherical and parallelepiped, the difference between hemispherical and conformal and the difference between parallelepiped and conformal. The resultant values of F-prob are shown for each in Table 11. Values of F-prob that indicate a statistical significance at the 95% level are shown in bold type. The table may, therefore, be used to estimate statistical confidence at other levels.

Table 11 Values of F-prob for the indoor measurements

		surface shape combination			
Area		all three	hemisphere - parallelepiped	hemisphere - conformal	parallelepiped - conformal
m^2	C (dB)				
4	6	**0.001**	**0.006**	**0.006**	**0.004**
6.3	8	**0.023**	0.236	**0.030**	**0.036**
14.1	11.5	0.729	0.557	0.849	0.605

From the analysis of variance performed on data from all three surface shapes, it can be seen from Table 11 that, there is a statistically significant variation between sound power levels determined using different shaped enveloping surfaces for surface areas of 4 m^2 and for 6.3 m^2 but not for 14.1 m^2. This confirms the observations detailed in sub-section 5.4, where it can be seen from Figure 4 that the sound power levels obtained using enveloping surfaces of 14.1 m^2 are similar for all three surfaces. An examination of F-prob for individual surface pairs shows that with the exception of the hemisphere/parallelepiped comparison, at 6.3 m^2 the differences between sound power determinations are all statistically significant. The non-significant F-prob for the 6.3 m^2 area is probably the result of the relatively high repeatability uncertainties associated with the parallelepiped measurements.

An analysis of variance was also performed to assess the statistical significance of the variation of sound power determinations resulting from using differing sizes of each surface shape. In this case there is a single value of F-prob for each surface shape. The values of F-prob for the hemisphere, parallelepiped and conformal shapes were **0.002**, **0.000** and 0.556 respectively. These values confirm the observations of sub-section 5.4 where it was concluded that there was a variation of sound power levels with the area of the enveloping surface used for hemispherical and parallelepiped shapes but not for the conformal surface.

5.7.2 Statistical analysis for the outdoor measurements

The statistical analyses described in sub-section 5.7.1, designed to examine the significance of differences between sound power determinations made using different surface sizes and also by using different surface shapes, were repeated for the outdoor measurements. For the outdoor measurements F-prob has been determined for the four surface sizes used. The resultant values of F-prob are shown in Table 12. Values of F-prob that indicate a statistical significance at the 95% level are shown in bold type. The table may, therefore, be used to estimate statistical confidence at other levels.

Table 12 Values of F-prob for the outdoor measurements

		surface shape combination			
Area		all three	hemisphere - parallelepiped	hemisphere - conformal	parallelepiped - conformal
m^2	C (dB)				
6.3	8	**0.002**	0.173	**0.014**	**0.001**
14.1	11.5	**0.000**	0.125	**0.003**	**0.000**
25.1	14.1	**0.004**	**0.000**	0.312	**0.030**
56.5	17.5	**0.000**	**0.000**	0.085	**0.000**

From the analysis of variance performed on data from all three surface shapes, it can be seen from Table 12 that, there is a statistically significant variation between sound power levels determined using different shaped enveloping surfaces for all surface areas. This confirms the observations detailed in sub-section 5.5. An examination of F-prob for individual surface pairs shows that for the parallelepiped/conformal comparison the differences between sound power determinations are statistically significant for all surface areas. For the other two surface comparison pairs, the results are mixed. The non-significant F-prob for the smaller areas in the hemisphere/parallelepiped comparison reflects the relatively small difference in sound power levels between those determined using the two surface shapes (see Table 9). A similar conclusion may be drawn regarding the non significant F-prob for the larger surface areas of the hemisphere/conformal comparison.

An analysis of variance was also performed to assess the statistical significance of the variation of sound power determinations resulting from using differing sizes of each surface shape. In this case there is a single value of F-prob for each surface shape. The values of F-prob for the hemisphere, parallelepiped and conformal shapes were **0.000**, **0.001**and 0.178 respectively. These values indicate a statistically significant variation for the hemisphere and parallelepiped surfaces but not for the conformal surface.

At first sight these statistically based conclusions would seem to conflict with the observations of sub-section 5.5 where it was concluded that there was no <u>systematic</u> variation of sound power levels with the area of the enveloping surface for all three surface shapes. However, the key word here is "systematic", which in this context implies that sound power levels either tend to continually increase or decrease as the area of the enveloping surface is increased. Although it can be seen from Figure 5 that determined sound power levels do not generally either increase or decrease with the size of the enveloping area it is clear that values do vary with area albeit in a somewhat random way.

In order to assess the degree of systematic variation of sound power level with surface area, a best fit line has been applied to data obtained using each surface and for both environments. A Pearson correlation coefficient has been calculated in order to assess how well the data fit these lines. This correlation coefficient will have a value between zero and unity and a value close to unity indicates that there may be a systematic variation. For the data obtained indoors correlation coefficients of 0.95, 0.98 and 0.57 were obtained for the hemispherical, parallelepiped and conformal surface shapes respectively. This indicates a systematic variation for the hemisphere and parallelepiped but not for the conformal shape. For the data obtained outdoors correlation coefficients were 0.77, 0.38 and 0.27, indicating that there is no systematic variation for all three surfaces. These results are in accord with the conclusions of sub-sections 5.4 an 5.5.

5.7.3 Statistical analysis of the difference between indoor and outdoor measurements

The value of F-prob when considering the difference between indoor and outdoor sound power determinations is shown in Table 13. As in previous tables, values of F-prob that indicate a statistical significance at the 95% level are shown in bold type. The table may, therefore, be used to estimate statistical confidence at other levels.

Table 13 Values of F-prob for the difference between indoor and outdoor sound power determinations

	surface shape		
Area m^2 or (C dB)	hemisphere	parallelepiped	conformal
6.3 (8)	**0.008**	**0.004**	**0.003**
14.1 (11.5)	**0.000**	**0.000**	**0.002**

It can be seen from Table 13 that all values of F-prob indicate that there is a statistically significant difference between sound power levels determined indoors and those determined outdoors. This is not a surprising outcome considering the input data, which is shown in Figure 6. This statistical confirmation serves to highlight the importance of an experimental determination of K_{2A} rather than rely on a visual assessment of the measurement site as permitted by ISO 3744.

5.7.4 Conclusions from the statistical analysis

The results of the statistical analyses using SPSS one-way ANOVA and the Pearson correlation coefficient confirm the observations summarised in sub-sections 5.4.1, 5.5.1 and 5.6.1.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS BASED ON THE MEASUREMENTS CARRIED OUT ON MACHINES OUTDOORS

There is a variation of mean sound power level with both radius and measurement distance although, because of the repeatability uncertainties, this variation may not be statistically significant.

The difference between sound power levels determined using hemispherical surfaces and those obtained using parallelepiped surfaces is machine dependent.

The difference between sound power levels obtained using parallelepiped surfaces and those determined using hemispherical surfaces is approximately 1 dB. However, because of repeatability uncertainties this variation may be not statistically significant.

6.2 CONCLUSIONS BASED ON THE MEASUREMENTS CARRIED OUT USING A REFERENCE SOUND SOURCE INDOORS

The enveloping surface areas considered ranged from 3 m^2 to 14.1 m^2.

For the parallelepiped and hemispherical surfaces there is a clear variation of sound power level with the area of the enveloping surface, with levels reducing as the area is increased, with the rate of decrease reducing as the area increases. For parallelepiped surfaces sound power levels reduce by 0.92 dB when the area is increased from 4 m^2 to 14.1 m^2; for hemispherical surfaces the corresponding reduction is 0.50 dB. For the conformal surface there is no systematic variation.

On average, when compared to sound power levels obtained using hemispherical surfaces, values determined using parallelepiped surfaces are 0.26 dB higher and those obtained using conformal surfaces are 0.34 dB lower.

6.3 CONCLUSIONS BASED ON THE MEASUREMENTS CARRIED OUT USING A REFERENCE SOUND SOURCE OUTDOORS

The enveloping surface areas considered ranged from 6.3 m^2 to 56.5 m^2.

There is no systematic variation of sound power level as the enveloping surface area is increased.

On average, when compared to sound power levels obtained using hemispherical surfaces, values determined using parallelepiped surfaces are 0.58 dB higher and those obtained using conformal surfaces are 0.21 dB lower.

6.4 OVERALL CONCLUSIONS BASED ON THE MEASUREMENTS USING A REFERENCE SOUND SOURCE

The enveloping surface areas considered ranged from 3 m^2 to 56.5 m^2.

For the parallelepiped and hemispherical surfaces there is a clear variation of sound power level with the area of the enveloping surface, with levels approaching a constant value as the area is increased. Approximately constant sound power levels are determined using enveloping areas greater then approximately 6.3 m^2. For the conformal surface there is no systematic variation with surface area.

For enveloping surface areas where sound power levels are approximately constant, levels obtained using the three surface shapes considered are approximately 0.3 dB apart with the sound power levels determined using parallelepiped surfaces the largest and those determined using conformal surfaces the lowest.

It is vitally important to experimentally determine the K_{2A}-factor of each measurement location.

The radius of a hemispherical enveloping surface should be at least three-times the characteristic dimension (four-times for safety) and the measurement distance for a parallelepiped enveloping surface should be at least 0.5 m (0.9 m for safety).

6.5 CONCLUSIONS OF THE STATISTICAL ANALYSIS OF MEASUREMENTS USING A REFERENCE SOUND SOURCE

The results of the statistical analyses using ANOVA and the Pearson correlation coefficient confirm the conclusions summarised above in sub-sections 6.1 to 6.4.

6.6 RECOMMENDATIONS

When current standards such as ISO 3744 are revised or when it becomes necessary to review the status of the ISO 3740 series of standards, careful consideration should be given to the requirements on measurement conditions. The experimental results discussed in this Report highlight three areas of where the recommendations given in current standards need to be reviewed:

- the environmental correction factor,
- the size of the enveloping surface,
- the shape of the enveloping surface.

On these three specific items, it is recommended that:

- the environmental correction factor should be experimentally determined for all measurement locations,

- the radius of a hemispherical enveloping surface should be at least three-times the characteristic dimension (four-times for safety) and the measurement distance for a parallelepiped enveloping surface should be at least 0.5 m (0.9 m for safety),
- the addition of a bias correction to account for differences in sound power determinations resulting from the use of different enveloping surfaces should be considered.

7 ACKNOWLEDGEMENTS

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