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Problems in the industrial application of procedures for measurement of machinery noise emission

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Problems in the industrial application of procedures for measurement of machinery noise emission

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ABSTRACT

This report examines the methods used by industry both for diagnostic measurements of noise emission of machinery and for measurements to existing current specification standards. It reviews the validity of using existing air-borne noise emission measurement methods, as specified in current specification standards for certain applications, identifying the failings and gaps in knowledge. The data analysis demonstrates particular practical measurement problems for various methods and source types, and identifies main failures of the standards and gaps in knowledge for the generic area, which require further measurements to be performed in order to identify reasons for failure.

Views and experiences of industry, on particular problems they have encountered, were sought verbally, by email and interactively using a custom-designed web page. Findings were summarised, and categorised into 'problem areas'. It turned out that there were five main areas that cover the comments received from the survey and are grouped under, the environment (meteorological conditions); uncertainties (especially when providing guaranteed noise levels); operating conditions (load or no-load and assessment of work place noise levels); test site (size and background noise); number of measurement positions (requirement to increase or the possibility of reducing). All five areas are assessed and recommendations are provided for future research.

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1. INTRODUCTION

1.1 MAIN AIMS AND OBJECTIVES

Consultations with industry and organisations involved with noise measurements have revealed that there are concerns about accuracy and effort required when measuring noise emission from machines using current techniques. Existing methods such as sound pressure and sound intensity can lead to large uncertainties for certain situations, particularly large sources. There are practical difficulties where, for example, extraneous noise can be a problem with the measurement result contaminated by unwanted contributions from other component noise sources. The size, shape and emission characteristics of machines cause problems when measuring noise levels at limited discrete nearby positions. The ability to measure noise emission accurately is essential for manufacturers and UK industry as a whole to demonstrate compliance with regulations, which exist to protect both the workforce and the community. It is also important that industry have available accurate, and efficient, source characterisation technology to encourage innovative solutions to further reduce the noise output of machines and products in line with EC noise policy. The main objective of this project is, therefore, to identify the limitations, failings and gaps in knowledge of current specification standard methods for machinery noise measurement. To achieve this objective, views and experiences of industry, on particular problem areas they have encountered, were sought verbally, by email and interactively using a custom-designed web page. Findings are summarised and various problem areas identified.

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2. THE SURVEY

2.1 SURVEY SCOPE

Views of industry were elicited via a survey. The aim of this survey was to contact areas of UK industry that are involved with noise emission measurement of machines and products with special attention to measurement of sound power. The survey was therefore aimed mainly at manufacturers of machines but it also included acoustics consultants, noise measurement equipment manufacturers and suppliers, and test laboratories. Also trade associations representing appropriate industrial sectors were contacted.

Contact details for manufacturers and trade associations were collated from searches on Internet based ‘online’ business directories, and from the NPL database of customers and contacts. Contact information for consultants and individuals in noise related organisations were sourced from other directories such as the membership list of the Institute of Acoustics (IOA).

In addition to these searches, an advertisement was placed on the NPL Acoustics home page and in the NPL machinery noise guide, and a news item was placed on the IOA website. The item remained on the IOA website for approximately 3 months. The guide front page with the included advert is reproduced as Figure A1.1 I Annex 1.

A total of 204 organisations or individuals were identified. Direct contact was made with 156 of these and difficulty was experienced in contacting the remaining 48 as they were found to be unavailable or no longer had sufficient interest in noise measurement. A brief summary of the 156 contacted is listed below.

In all, 24 trade associations from 17 manufacturing sectors were contacted. The general interest areas of each association listed in alphabetical order are:

Agricultural machinery,	Air conditioning,	Compressed air,
Construction equipment,	Domestic appliances,	Fans,
Hydraulic tools,	Industrial cleaning,	Industrial trucks,
Loading and elevating,	Manufacturing technology,	Marine engines,
Power generation systems,	Process automation,	Pumps.

A total of 71 machinery manufacturers were contacted. The manufacturing area, together with the number of manufacturers in each area (in parenthesis), listed in alphabetical order are:

Construction equipment (15)	Domestic appliances (2)
Engines (2)	Heating ventilation air conditioning (5)
Information Technology and office (1)	Lifting & handling machinery (5)
Machine and construction power tools (16)	Paper (3)
Power and power conversion (3)	Process automation (1),
Pumps (18).	

From the IOA register, 54 organisations or consultancies that were involved with machinery noise measurement were contacted. In addition to these, contact was made with 3 Government organisations, 2 major noise measurement instrumentation suppliers, 1 supplier of acoustics facilities and 1 business assurance organisation.

It must be remembered, however, that the total number of manufacturers that were aware of the survey will be greater than the above total of 156 direct contacts as some trade associations also made sure that their members were aware of the survey.

2.2 SURVEY QUESTIONNAIRE

A survey questionnaire was designed with the aim of eliciting the views from industry. The survey was designed to be quick to complete and simple to understand. It was divided into two sections, the first section, consisting of six questions, requested contact details from the recipient, and the second section asking four open questions relating to the type of measurements they carry out and any problems that they have encountered. The survey was distributed in two formats, which are outlines below:

Firstly, a specially designed set of web pages incorporating an online survey was produced, (see Figure A1.3a, and A1.3b of Annex1). Upon completing the form using the provided text fields, the recipient electronically submits the form. The form is sent as an automatically generated e-mail containing the content of the fields to a dedicated e-mail account.

Secondly, batches of printed A4 sized colour fliers were produced (see figure A1.2a in Annex 1). This included the survey questionnaire that followed a similar format and content as the online survey form, on it's reverse side (see Figure A1.2b). The flier was circulated in the July 2005 issue of the IOA Acoustics Bulletin. It was also distributed at the IOA Autumn Conference in the same year, and was also included with a mail-shot of a major supplier of acoustics facilities.

The survey replies were collated and analysed to obtain not only a list of individual problems, but to obtain an overview of general problem areas.

2.3 METHODS OF CONTACTING INDUSTRY

Once the details of the organisation had been obtained, see sub-section 1.1, a variety of contact methods were used. In the case of manufacturers this involved a preliminary telephone call requesting contact details of the individual responsible for noise measurement or an equivalent post. Where necessary, this call would also confirm that the product was produced or developed within the UK. A standard E-mail was then sent to the named contact. The content of this E-mail is reproduced in Annex 2. Care was taken in drafting this message to ensure that it was concise and easy to respond. This e-mail contained a web link to the survey questionnaire shown in Figure A1.3 in Annex A2.

In the case of trade associations, the preliminary telephone call requesting contact details of the individual responsible for noise measurement or an equivalent post was made. This was followed by sending the individual the E-mail message but in addition enquiries were made as to the possibility of including the NPL flier in the appropriate trade journal or posting it on the association web site perhaps with a short news item. In most cases the individual offered to forward the E-mail to association members via their internal mailing lists.

2.4 SURVEY RESPONSE

The organisations listed above that replied to the survey, were contacted by telephone in order to discuss in detail their particular concerns. These discussions resulted in the formulation of a list of more general problem areas, which are outlined below.

Very little actual measurement data was offered in support of reported problems and furthermore, the problems did not lend themselves easily to some form of collaboration on measurement effort to examine particular problems in more detail. However, it became clear that the reported problems could be grouped and considered as "problem areas". It turned out that there were five main areas that cover the comments received from the survey and these are briefly summarised below (not in order of importance) in sub-sections 2.5.1 to 2.5.5 and are examined in more detail in Sections 3 to 7.

2.5 SUMMARY OF ISSUES IDENTIFIED

2.5.1 The environment

ISO provide a series of specification standards for the determination of sound power level of machinery. This is otherwise known as the 3740 series of basic standards for the measurement of machinery noise emission(1 - 7). Some of the standards in the 3740 series have restrictions on temperature and wind speed and atmospheric pressure. In some cases a measurement cannot be made and in others measurements may be made in what could be considered as adverse meteorological conditions. The question that needs to be addressed is, what is the effect of meteorological conditions on the determination of sound power level? Concerns have also been expressed regarding meteorological conditions as to the potential difference between measurements carried out indoors under steady, controlled conditions and those made outdoors where large variations occur as a result of seasonal variation and geographical location. This is of especial concern to companies that carry out measurements in expensive facilities where conditions are carefully controlled, who experience a financial penalty when competing with organisations that use relatively inexpensive outdoor measurement sites whose measurement results are subject to higher measurement uncertainties.

In Section 3, the effect of atmospheric temperature and atmospheric pressure on sound power determination is assessed using a theoretical approach(5). Small variations about ambient conditions are examined as well as larger variations due to seasonal variations or geographical location. Variations in sound power level due to changes in pressure or temperature are dependent on the type of noise source and this is also considered in Section 3.

2.5.2 Uncertainties

Concern has been expressed regarding the assessment of uncertainties associated with noise emission measurements. The uncertainty may be required to accompany a measurement or to demonstrate compliance for some form of regulatory purpose or to provide a guaranteed level as required by European Directive 2000/14/EC[8] "*on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors*", otherwise commonly known as the 'outdoor directive', for example. In the latter case uncertainty due to the measurement procedure and variations resulting from a production process need to be considered. It is usual for uncertainties to be expressed initially in the form of a standard deviation and then to be the subject of some form of statistical procedure to assess the risks associated with guaranteeing a noise emission level.

In Section 4, a brief introduction to the currently accepted format for expression of uncertainties generally associated with methods of measurement as given in the *Guide to the Expression of Uncertainties in Measurement*[9] (commonly known as GUM) is provided. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, from which the combined total uncertainty can be obtained. In addition, some measured data supplied by organisations that replied to the survey are used to assess uncertainty using procedures that are currently under consideration by various standardisation authorities[10,11,12]. Consideration is also given on the use of values of measurement uncertainty detailed in ISO 3744[4] using data from round-robin experiments carried out by NPL.

2.5.3 Operating conditions

A number of problems were raised regarding operating conditions, these are summarised in the following three paragraphs.

The first relates to the problem of potential differences between load and no-load measurements. A number of regulatory requirements specify a no-load sound power level determination. A no-load measurement is sufficient when used to obtain guaranteed levels according to various regulatory instruments or for comparing the noise levels of machines from different manufacturers, but may not be adequate for the purposes of assessing workplace noise levels where the machine is in use. Section 5 assesses the possibility of some form of simple correction using a table that equates a correction factor to a description of the room to enable a conversion from sound power level to emission sound pressure level. This kind of approach is used in Annex A of ISO 3744 where room description is equated to the mean sound absorption coefficient of a room.

Regarding load measurements, it has been pointed out by a number of survey replies that load measurements are dependent on a number of factors such as the precise job undertaken, the specific type of work piece and also on the quality of the tool (e.g. the sharpness of the tool will effect the noise level). This is a problem that should be addressed by the ISO Committees producing machine specific test codes (C-type standards in ISO parlance) and so is not considered further in this Report.

Another problem loosely related to operating conditions occurs when demonstrating conformity with, for instance, the requirements of 2000/14/EC when there are a large number of variants of a machine that are all very similar to each other. To carry out measurements on each variant is a very expensive process, so the possibility of assessing a number of machines as a "family group" is considered in Section 5.

2.5.4 Test site

Problems have been raised regarding finding a site that complies with the requirements of ISO standards, usually because of the size, and sometimes due to background noise.

Regarding site size, in Section 6, a brief description of some sound power level determinations carried out by NPL is provided. The data from these measurements is analysed to assess the possibility of using a smaller site or one with the requirements on obstacle proximity relaxed. The possibility of using a non-compliant site by increasing the measurement uncertainty is also considered.

A number of organisations had experienced problems resulting from high background noise levels and asked if it would be possible to carry out measurements even though the requirements of a number of ISO standards were not met. The possibility of accepting poorer background noise requirements, by applying corrections or by increasing measurement uncertainties is considered in Section 6. The possibility of using sound power determination based upon intensity measurement is considered although this is not an option accepted in Directive 2000/14/EC.

Questions have also been posed regarding the reflecting ground plane for measurements carried out in hemi-anechoic conditions, usually when it is required to approximate some kind of real floor covering. The assessment of the reflecting (or absorption) properties of a floor is complicated and usually requires the use of a reverberation chamber and hence, the financial cost associated with such a facility. In Section 6 the possibility of defining a simpler measurement procedure that will describe the reflection properties in a clear and simple way by measuring the environmental correction factor, 'k_2 ' is assessed. Here a computer model is used to calculate an estimation of k_2 from values of sound absorption coefficient.

2.5.5 Number of microphones

Several organisations have asked if it would be possible to use fewer microphone positions than specified in ISO standards when carrying out sound power level determinations.

Section 7 describes work that has been carried out at NPL where the measurement uncertainty is shown to be dependent on the number of microphone positions and on the directivity of the noise source. It is proposed that there should be a 'floating' uncertainty procedure where the measurement uncertainty reduces with increased effort. Procedures based on this principle would allow the user to exercise control over the balance between accuracy and effort.

A similar problem has been raised regarding the requirement to increase the number of microphone positions for directional noise sources. ISO 3744, for instance, requires that the number of microphone positions on a hemispherical surface be doubled from 10 to 20 if the difference between the minimum and the maximum sound pressure levels from the 10 positions is greater than 10 dB (i.e. the number of positions). Cases have been cited where the difference is 11 dB. Is the result using 20 positions instead of 10 sufficiently enhanced and with a significantly reduced measurement uncertainty to warrant the considerable extra effort? In fact not all standards have this ISO 3744 requirement to double the number of microphone positions if the source is highly directional. Perhaps they all should, or, maybe the requirement should be removed from ISO 3744? Answers to these questions are considered in Section 7 where measurements carried out at NPL on a directional source are examined to assess the magnitude of the error involved if the number of microphones is not increased.

3. METEOROLOGICAL CONDITIONS

3.1 THE EFFECT OF TEMPERATURE AND PRESSURE ON SOUND POWER LEVEL

Currently the ISO 3740 series of standards is undergoing a revision process. The seven standards in the series provide a variety of related methods of determining the sound power levels of noise sources. Currently, numerous machine specific noise emission measurement standards (ISO ‘C type’ standards) refer to these basic standards. These ‘C type’ standards are used extensively by manufacturers, consumers, regulatory authorities and others, for purposes of trade, declaring and verifying noise emission values, research, product development and so on. The original standards in the series were published during the 1970s and 1980s and were all revised during the 1990s and early 2000s. These revisions were treated piecemeal and during the process some differences of approach became apparent which now need to be rectified. Some standards in the series include methods for determining sound energy levels and others do not. Knowledge of, and experience in, dealing with measurement uncertainties has grown, and this topic has assumed greater importance in relation to both legal and contractual requirements concerning noise emission. The purpose of the current revision is to take care of all these concerns, based on existing knowledge. Care is being taken to retain the present structure of the series of standards, by which each standard is identified with a particular acoustic environment and grade of precision. In summary, the scope of the revision is based on the following purposes:

- to edit the seven standards so as to unify their structure, terminology and definitions;
- to add clauses covering determination of the sound energy level for noise sources which emit bursts of sound;
- to unify the treatment of measurement uncertainties and to add guidance showing how the uncertainties can be expressed in a manner consistent with the ISO Guide to the Expression of Uncertainties in Measurement;
- to incorporate a method of correcting sound power levels to those for standard atmospheric conditions.

It is the last bullet point that is of interest for the purposes of this Report. So, the proposed expressions included in the current revision of ISO 3744, for correcting values to standard atmospheric conditions, are summarised below. These expressions are used to examine the problems highlighted in sub-section 2.5.2 above.

The sound power level under reference meteorological conditions of barometric pressure 1,01325 x 10^5 Pa and atmospheric temperature 23.0 °C, $L_{W\mathrm{ref,atm}}$, may be calculated using the following equation (13) :

$$L_{W\,\mathrm{ref,atm}} = L_W + C_1 + C_2 \tag{1}$$

where

L_W is the sound power level under the meteorological conditions, which occurred at the time and place of the test, in decibels;

$$C_1 = -10\lg\frac{B}{B_0}\,\mathrm{dB} + 5\lg\left[\frac{(273.15+\theta)}{\theta_0}\right]\mathrm{dB}; \qquad (2)$$

$$C_2 = -10\lg\frac{B}{B_0}\,\mathrm{dB} + 15\lg\left[\frac{(273.15+\theta)}{\theta_1}\right]\mathrm{dB}; \qquad (3)$$

B is the barometric pressure at the time and place of the test, in Pascal;
B_0 is the reference barometric pressure, 1.01325×10^5 Pa;
θ is the air temperature at the time and place of the test, in degrees Celsius;
θ_0 = 314 K;
θ_1 = 296 K.

The air temperature, θ, may be estimated, and the barometric pressure, B, may be calculated using the following equation:

$$B = B_0(1-ah)^b \qquad (4)$$

where

a = $2.2560\cdot10^{-5}$ m^{-1};
b = 5.2553;
h is the elevation of the test site above mean sea level, in metres.

The value given for θ_0 leads to a characteristic impedance of air of 400 Ns/m² at the reference static pressure of $1{,}01325\times10^5$ Pa (14., 15):

$$\theta_0 = 273{,}15\ \mathrm{K}\cdot\left[\frac{331.45\,\mathrm{m/s}\cdot1.2929\,\mathrm{kg/m^3}\cdot1\mathrm{pW}}{(20\,\mu\mathrm{Pa})^2\cdot1\mathrm{m}^2}\right]^2 = 314\ \mathrm{K} \qquad (5)$$

Equation 1 has been evaluated for a temperature range of –10 ºC to +35 ºC and for atmospheric pressures from 800 mbar to 1100 mbar. The resultant values of the correction C_2 (which may also be viewed as a change on sound power level) are shown in Figure 1 as a function of temperature with pressure as a parameter.

Considering atmospheric pressure, it can be seen that there is a variation with pressure change amounting to approximately 0.8 dB for a pressure change from 800 mbar to 900 mbar and 0.7 dB for a pressure change from 900 mbar to 1000 mbar and 0.6 dB for a pressure change from 1000 mbar to 1100 mbar. So, it may be assumed that a change of 0.7 dB in sound power level will result from a pressure change of 100 mbar. To put these variations in context, consider the annual change in pressure throughout the year in the UK and also the change in pressure resulting from altitude above sea level. During 2005 the atmospheric pressure at London Heathrow varied from 980 mbar to 1040 mbar, a range of 60 mbar. Assuming a change in sound power level of 0.7 dB per 100 mbar, this change in atmospheric pressure corresponds to a change in sound power level of approximately 0.4 dB. While this may be considered as significant it must be remembered that this is associated with an annual change and so, it is likely that this will not occur during a particular measurement. However, it is clear that care must be taken when comparing data from measurements carried out with a significant time difference.

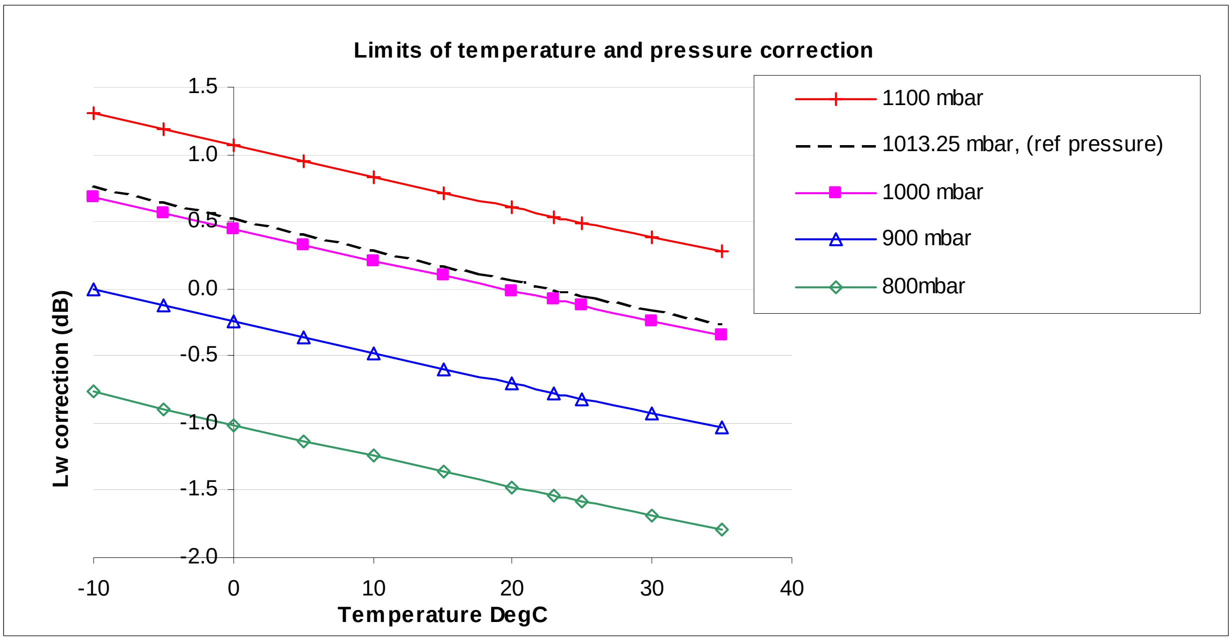

Figure 1 values of the correction to account for meteorological conditions

Atmospheric pressure decreases with altitude at approximately 50 mbar per 200 m. Using the approximate value of a change in sound power level of 0.7 dB for a change in pressure of 100 mbar, this altitude dependence corresponds to a sound power level change of 0.35 dB per 200 m or approximately 1.75 dB per 1000 m. Clearly if sound power level determinations are to be carried out at measurement sites that are significantly above sea level then the effects of atmospheric pressure needs to be taken into account.

Considering temperature change it can be seen from Figure 1 that the change in sound power level of approximately 0.1 dB results from a temperature change of 5 ºC and this is independent of atmospheric pressure. A 5 ºC variation in temperature is unlikely to occur during a measurement on a particular machine so the effect of temperature variations on sound power level is likely to be negligible. However, to assess the potential variations it is necessary to consider the annual temperature variations. During 2005 the maximum temperature at London Heathrow ranged from 4 ºC to 32 ºC and the minimum from –4 ºC to 22 ºC a potential range of 36 ºC, which will result in a sound power level change of approximately 3.6 dB. It is unlikely that measurements will be permitted over such a large range and so this should be taken as an upper value. However, it is clear that variations in sound power level resulting from temperature changes should be considered when carrying out measurements on particular types of machine at different times of the year.

An alternative display of the magnitude of the constant C is shown in Table 1, where values are listed relative to that at the standard conditions of 23 ºC and 1013 mbar. The shaded area in the table is an illustration of the "weather window" where sound power determinations are within ± 0.5 dB of those that would be obtained at standard meteorological conditions.

Table 1 variations in A-weighted sound power level resulting from variations in atmospheric conditions

Temp	Atmospheric pressure x 10^5 Pa																	
C degs	0.920	0.930	0.940	0.950	0.960	0.970	0.980	0.990	1.000	1.010	1.013	1.020	1.030	1.040	1.050	1.060	1.070	1.080
0	-0.61	-0.49	-0.38	-0.26	-0.15	-0.03	0.08	0.19	0.30	0.40	0.44	0.51	0.62	0.72	0.83	0.93	1.03	1.13
2	-0.65	-0.53	-0.42	-0.30	-0.19	-0.07	0.04	0.15	0.26	0.36	0.40	0.47	0.58	0.68	0.79	0.89	0.99	1.09
4	-0.69	-0.57	-0.45	-0.34	-0.23	-0.11	0.00	0.11	0.22	0.33	0.36	0.43	0.54	0.64	0.75	0.85	0.95	1.05
6	-0.73	-0.61	-0.49	-0.38	-0.27	-0.15	-0.04	0.07	0.18	0.29	0.32	0.39	0.50	0.60	0.71	0.81	0.91	1.01
8	-0.77	-0.65	-0.53	-0.42	-0.30	-0.19	-0.08	0.03	0.14	0.25	0.28	0.35	0.46	0.57	0.67	0.77	0.87	0.97
10	-0.80	-0.69	-0.57	-0.46	-0.34	-0.23	-0.12	-0.01	0.10	0.21	0.24	0.32	0.42	0.53	0.63	0.73	0.84	0.94
12	-0.84	-0.73	-0.61	-0.49	-0.38	-0.27	-0.16	-0.05	0.06	0.17	0.21	0.28	0.38	0.49	0.59	0.70	0.80	0.90
14	-0.88	-0.76	-0.65	-0.53	-0.42	-0.31	-0.19	-0.08	0.02	0.13	0.17	0.24	0.35	0.45	0.55	0.66	0.76	0.86
16	-0.92	-0.80	-0.68	-0.57	-0.46	-0.34	-0.23	-0.12	-0.01	0.10	0.13	0.20	0.31	0.41	0.52	0.62	0.72	0.82
18	-0.96	-0.84	-0.72	-0.61	-0.49	-0.38	-0.27	-0.16	-0.05	0.06	0.09	0.16	0.27	0.38	0.48	0.58	0.68	0.79
20	-0.99	-0.88	-0.76	-0.64	-0.53	-0.42	-0.31	-0.20	-0.09	0.02	0.06	0.13	0.23	0.34	0.44	0.55	0.65	0.75
22	-1.03	-0.91	-0.80	-0.68	-0.57	-0.46	-0.34	-0.23	-0.12	-0.02	0.02	0.09	0.20	0.30	0.41	0.51	0.61	0.71
24	-1.07	-0.95	-0.83	-0.72	-0.60	-0.49	-0.38	-0.27	-0.16	-0.05	-0.02	0.05	0.16	0.26	0.37	0.47	0.57	0.67
26	-1.10	-0.99	-0.87	-0.75	-0.64	-0.53	-0.42	-0.31	-0.20	-0.09	-0.05	0.02	0.12	0.23	0.33	0.43	0.54	0.64
28	-1.14	-1.02	-0.91	-0.79	-0.68	-0.56	-0.45	-0.34	-0.23	-0.13	-0.09	-0.02	0.09	0.19	0.30	0.40	0.50	0.60
30	-1.18	-1.06	-0.94	-0.83	-0.71	-0.60	-0.49	-0.38	-0.27	-0.16	-0.13	-0.05	0.05	0.16	0.26	0.36	0.46	0.57

3.2 THE EFFECT OF MACHINE TYPE ON THE EFFECT OF TEMPERATURE AND PRESSURE ON SOUND POWER LEVEL

In formulating Equation 3, used in sub-section 3.1, the value of the constants associated with the logarithmic terms are dependent on the type of noise generation process. In reference 16 it is shown that in assessing a value for these constants a multiplying factor, m is involved in the first logarithmic term and a multiplying factor n is involved in the second logarithmic term. Theoretically the value of m is 1 for all kinds of noise sources, but values of 1.4 and 0.7 have been determined [17]. However the variation in the value of C_2 associated with this potential variation is considered negligible by reference 17 and so the theoretical value of m=1 is assumed for the purposes of this current report. The value of n may vary between 1 and -5 depending on the type of noise source. Theoretically n can be expected to be –5 for quadrupoles, -3 for dipoles, -1 for monopoles and 1 for vibrating surfaces. The precise value of n is still the subject of some discussion, for instance even for a well defined source such as an aerodynamic reference sound source, values of –3 and –5 have been determined (see reference 15). A value of $n = -1$ has been used in the expression for C_2 in Equation 3 above to obtain the value of -15 in the second logarithmic term. This value of n is the result of statistical considerations and as such is subject to some uncertainty. In order to assess the potential error involved in these assumptions, Equation 3 has been evaluated for a small range of atmospheric conditions for the theoretical values of $n = 1$ and $n = -5$. For convenience Equation 3 is reproduced below.

$$C_2 = -10\lg\frac{B}{B_0}\ \mathrm{dB} + 15\lg\left[\frac{(273.15+\theta)}{\theta_1}\right]\ \mathrm{dB}\ ;$$

It can be seen that it is only variations in temperature, θ, that give rise to variations in C_2 resulting from differing values of n. So, for simplicity the case where the ambient atmospheric pressure, B is equal to the reference value, B_0, is considered. Evaluating Equation 3 for a range of temperature from 5 ºC to 30 ºC will give a range of values of C_2 of 0.8 dB for a temperature of 5 ºC and 0.3 dB for a temperature of 30 ºC. It can be seen that the potential error in C_2 is temperature dependent and may result in errors of up to 0.8 dB for the temperature range considered. Because of the assumptions made in the calculation procedure, these errors should only be considered as an indication of the potential magnitude that may exist but nevertheless do indicate a need for a more reliable assessment of the values of n to be used for particular, or perhaps groups, of machine. These potential errors should be considered as an uncertainty associated with the meteorological correction discussed in sub-section 3.1.

3.3 SUMMARY AND FURTHER WORK FOR METEOROLOGICAL CONDITIONS

It has been shown in sub-section 3.1, that variations in both temperature and atmospheric pressure (due to either meteorological variations or altitude) may result in significant variations in sound power level determinations. It is important, therefore, that such changes in conditions are considered when carrying out noise measurements or when assessing sound power levels determined at different locations or under different meteorological conditions.

It is clear that the value of the constant, n (see sub-section 3.2 above) is an important factor in accounting for changes in sound power level resulting from varying meteorological conditions. It is important, therefore, to validate the value of n for real machines. This could be done experimentally by determining the effect of ambient temperature and pressure and sound power level over a period of a year, for a selection of representative machines and then carrying out the calculations described in sub-section 3.1 with various values of n to obtain the best agreement, although clearly this would involve a limited range of conditions.

TREATMENT OF MEASUREMENT UNCERTAINTY

3.4 INTRODUCTION TO CURRENT REQUIREMENTS

When reporting the result of a measurement of a physical quantity, some quantitative indication of the quality of the result must be given. Without such an indication, measurement results cannot be compared either amongst themselves or with values given in a specification or standard. This indication is normally in the form of a (bilateral) value of measurement uncertainty. This could be stated in the form of a standard deviation (standard uncertainty). Alternatively, it could be in the form of expanded uncertainty, which is derived from the standard uncertainty multiplied by a coverage factor relating to the desired statistical confidence interval. A primary need for values of uncertainty is to demonstrate compliance with noise emission level declaration as required for numerous regulatory purposes, for example the European Directive 2000/14/EC. This Directive requires that machinery is labelled with a guaranteed A-weighted sound power level. In this case the guaranteed sound power level takes into account uncertainties due to production variation and measurement procedures.

Quantities commonly used to express standard uncertainty when dealing with the determination of sound power levels is standard deviation of reproducibility, and standard deviation of repeatability.

To obtain repeatability uncertainties it is necessary for the noise emission levels of a particular noise source to be measured:

- by the same method,
- by the same laboratory in the same locations,
- by the same personnel,
- using the same measurement apparatus,
- within a short time period.

To obtain reproducibility uncertainties it is necessary for the noise emission levels of a particular noise source to be measured;

- by the same method,
- by different laboratories (in different locations),
- by different personnel,
- using different measurement apparatus,
- at different times.

Ideally, reproducibility standard deviations should be derived from extensive round robin exercises. However, because of the expense and time involved in carrying out such an exercise values are usually, in practice, taken from the ISO standard that is being followed. ISO standards are generally described as ‘survey‘, ‘engineering’- or ‘precision’-grade and are associated with reproducibility uncertainties of 4 dB, 1.5 dB and 0.5 dB, for A-weighted sound power levels, respectively. Practical values of reproducibility are discussed in sub-section 4.3.

An alternative approach, that is gradually being introduced into ISO documents as they become due for revision, is to derive an overall uncertainty from analysis of individual components of uncertainty using the ISO guide to the expression of uncertainties in measurement. This is described in more detail in sub-section 4.2 below.

In addition to the requirement to provide values of uncertainty associated with a measurement, it is usual that some form of statistical treatment is used to assess levels of confidence that can be associated with these data. EU Directive 2000/14/EC for instance requires that a declared sound power level has an associated statistical confidence level and compliance with Directive requirements is assessed by market surveillance, which involves an independent verification. This statistical treatment raises a number of problems which are outlined in sub-section 3.7, below.

3.5 ASSESSMENT OF UNCERTAINTY USING GUM

3.5.1 Introduction to GUM

Information on measurement reproducibility given in current International Standards relating to the determination of sound power level can be helpful towards the derivation of measurement uncertainties, but it is incomplete. In particular, it does not give an analysis of the various components of measurement uncertainty and their magnitudes. The accepted format for expression of uncertainties generally associated with methods of measurement is that given in the GUM. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, from which the combined total uncertainty can be obtained. The data necessary to enable such a format to be adopted in the case of the International Standards relating to sound power are not currently available. However, an indication, taken from ISO 3745:2003, is given below of the sources of uncertainty that are thought to be associated with the methods and equipment described in the standards.

3.5.2 Application of GUM to ISO 3745

The general approach to calculation of uncertainties appropriate to the determination of sound power level for methods based on free-field over reflecting plane is detailed in ISO 3745:2003 and is reproduced below.

The general expression for the calculation of the sound power level, L_W, is given by the following equation:

$$L_W = \overline{L_p} + 10\lg\left(\frac{S}{S_0}\right) + \delta_{slm} + \delta_{rep} + \delta_{boun} + \delta_{mic} + \delta_{met} + \delta_{angle} + \delta_{imp} \quad \text{dB} \qquad (6)$$

where,

$\overline{L_p}$ is the surface sound pressure level,

S is the area of the measurement surface, in square metres,

S_0 = 1 m^2,

δ_{slm} is an input quantity to allow for any error in the measuring instrumentation,

δ_{rep} is an input quantity to allow for any error in the operating conditions of the noise source under test,

δ_{boun} is an input quantity to allow for any error in the influence of the test room boundaries,

δ_{mic} is an input quantity to allow for any error in the finite number of microphone positions,

δ_{met} is an input quantity to allow for any error in the meteorological conditions,

δ_{angle} is an input quantity to allow for any difference of angle between the direction in which the sound is emitted by the source and the normal to the measurement surface,

δ_{imp} is an input quantity to allow for any error in the impedance of the surroundings into which the source is emitting sound energy.

The input quantities included in equation 6 to allow for errors are those thought to be applicable in the current state of knowledge, but further research could reveal that there are others.

A probability distribution (normal, rectangular or triangular) is associated with each of the input quantities to allow for errors. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values, termed uncertainty. It is presumed (in Reference 10) that the mean values of all of the input quantities for errors given in equation 6 are equal to zero. This presumption may not be valid for some input quantities and so an allowance has to be made to account for a potential bias in results. It is a requirement of Reference 9, that the errors considered in Equation 6 are relative to values that have been taken to represent 'true' (or correct) values. Thus, when considering the input quantities listed above it may be necessary to take account not only of variations about mean values (quantified as standard deviations) but also the possibility that mean values may be different from the adopted 'true' values. However, in any particular determination of a sound power level of a noise source under test, the uncertainties do not vanish and they contribute to the combined uncertainty associated with values of the sound power level.

The contributions to the combined total standard uncertainty associated with the value of the surface sound pressure level depend on each of the input quantities to allow for errors, their respective probability distributions and sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how values of the surface sound pressure level are affected by changes in the values of the respective input quantities. The contributions of the respective input quantities to allow for errors to the overall uncertainty are then given by the products of the standard uncertainties, u_i and a factor corresponding to their probability distribution.

The combined total standard uncertainty of the determination of the sound power level, $u(L_W)$, from the n individual contributions is given by the following equation:

$$u(L_W) = \sqrt{\sum_{i=1}^{n} (c_i u_i)^2} \qquad (7)$$

where u_i is the ith uncertainty contribution.

The GUM requires an expanded uncertainty, U, to be specified, such that the interval [L_W-U, L_W+U] covers e.g. 95% of the values of L_W that might reasonably be attributed to L_W.

To that purpose, a coverage factor, *k*, is used, such that *U=ku*. The coverage factor depends on the probability distribution associated with the measurand.

3.6 ASSESSMENT OF REPRODUCIBILITY UNCERTAINTIES GIVEN IN ISO 3744

Uncertainties arise in part from variations between test sites, changes in atmospheric conditions if outdoors, the geometry of the test room or outdoor environment, the acoustical properties of the reflecting plane, absorption at the test room boundaries if indoors, background noise, and the type and calibration of instrumentation. They are also due to variations in experimental techniques, including the size and shape of the measurement surface, number and location of microphone positions, sound source location, integration times, and determination of environmental corrections, if any.

Information from round-robin testing shows that determinations of the sound power level of a noise source under test made in accordance with this International Standard, result, with few exceptions, in standard deviations of reproducibility equal to or less than the values shown in table 2.

Table 2 – Maximum standard deviations of reproducibility of sound power levels determined in accordance with ISO 3744

Octave band frequency (Hz)	One-third-octave band frequency (Hz)	Reproducibility (dB)
125	100 to 160	3
250	200 to 315	2
500 to 4000	400 to 5000	1.5
8000	6300 to 10000	2.5
A-weighted, for noise sources which emit sound with a relatively 'flat' spectrum		1.5

It should be noted that the standard deviations of reproducibility given above are associated with the test conditions and procedures defined in ISO 3744 and are not dependent upon the noise emission characteristics of the source under test.

The values of reproducibility listed in Table 2 encompass the various shapes and sizes of measurement surfaces allowed by ISO 3744 and are, therefore, generally accepted as an overestimate in cases where measurements are conducted in accordance with a machine specific test code that prescribes microphone locations and measurement surface shape and size.

A-weighted sound power level data obtained during an NPL managed round robin exercise [18] found that values of reproducibility for ISO 3744 were machine dependent varying from 0.7 dB to 1.7 dB with an average value of 1.1 dB (*cf* 1.5 dB in Table 2 above). A re-analysis of these data to obtain reproducibility for particular surface shapes and sizes for a number of small machines produced average reproducibility values of

0.7 dB for both hemispherical and parallelepiped measurement surfaces, considerably less than the value of 1.5 dB quoted in ISO 3744.

Similar results have been published by and Carletti [(19)] where values of reproducibility have been assessed from results of a round robin exercise carried out on two large machines, namely an excavator and a crawler dozer. Reproducibility values of 0.453 dB and 0.701 dB are quoted for the excavator and the dozer respectively - significantly lower than those given in ISO 3744 and similar to the NPL data. A paper produced by the Work Group of European Notified Bodies 2000/14/EC[(11)] contains suggested values for reproducibility for use in sound power level determination according to EU Directive 2000/14/EC. Values of reproducibility are provided for all the 57 machine types covered by the Directive. For the 45 machines that have steady noise emission characteristics values of reproducibility range from 0.4 dB to 0.8 dB with 37 of these machines having a value of 0.5 dB. For the 12 machines running in an activity mode, values of reproducibility range from 0.8 dB to 1.0 dB with the exception of mobile waste containers, which have a suggested value of 1.5 dB. These values are in general accord with the NPL data above.

It is interesting to consider these data when examining the steady noise emission characteristic uncertainty of 0.2 dB discussed below in sub-section 5.2 when assessing variations resulting from operating conditions. In sub-section 5.2 a value of 1.0 dB is assumed for machines running in an activity mode. A comparison with the data above indicates that for these machines the uncertainty is primarily a result of variations due to the activity.

3.7 UNCERTAINTIES CALCULATED USING VARIOUS METHODS

As discussed in sub-section 4.2, the GUM requires an expanded uncertainty, *U*, to be applied to sound power level, L_W, such that $L_W \pm U$ covers the measurement uncertainty at the required confidence level (*e.g*. 95%), where U is calculated from standard uncertainty, *u*, multiplied by coverage factor k.

At the time of writing this report, a sub-committee drawn from technical experts from EC member states has been tasked with producing a harmonised method for determining guaranteed noise emission level that takes uncertainty into account. The proposed methods, which are based on statistical procedures specified in ISO 7574, are designed to be suitable for the purposes of verification of sound power level as well as its declaration. These procedures propose alternative methods for calculating expanded uncertainty U.

Article 3(f) of EU Directive 2000/14/EC relating to the noise emission in the environment by equipment for use outdoors, defines the guaranteed sound power level as a quantity that includes an allowance for uncertainties due to production variation and measurement procedures. The estimated value of a standard deviation will become closer to the “true” value as the number, n, of repeat measurements carried out for the purpose of obtaining a standard deviation for measurement procedure uncertainty, or the number of machines used for the purpose of obtaining a standard deviation for production variation, is increased. The value of the expanded uncertainty, *U* (a value to be added to a measured sound power level to provide a guaranteed level) is dependent on these standard deviations and on the sample size, n. In this sub-section three methods for evaluating *U* that have been proposed to the EU sub-committee are considered. The three methods are described in references 10, 11 and 12 and emanate from the UK Department of Trade and Industry (DTI), the work group of European Notified Bodies (NB) and from Belgium market surveillance authority, (Bel). In fact, the European Notified Bodies have supplied two methods that they refer to as 2005 and 2006. The 2006 method (NB6), is a modification to the 2005 method (NB5) and is their preferred method.

The quantity, *U,* has been evaluated for n=5 and n=13 with a standard deviation of reproducibility of 0.5 dB and for a range of production standard deviations (prod sd) from 0.2 dB to 1.4 dB. The method of reference 10 has been evaluated using the standard deviation of reproducibility and for a standard deviation of repeatability of 0.2 dB. Values of *U* are shown in Table 3 with results for reference 10 listed under DTI_R for reproducibility and DTI_r for repeatability, results for reference 11 listed under NB5 for the 2005 method and NB6 for the 2006 method and those for reference 12 under Belgium.

Table 3 Evaluations of expanded uncertainty, *U*

	method									
Prod sd	NB6	NB5	Bel	DTI_R	DTI_r	NB6	NB5	Bel	DTI_R	DTI_r
	n = 5					n = 13				
0.2	0.8	0.8	0.9	1.1	0.6	0.8	0.8	0.8	0.9	0.5
0.4	1.1	1.0	1.2	1.4	1.0	1.0	1.0	1.0	1.1	0.8
0.6	1.5	1.2	1.5	1.7	1.4	1.2	1.2	1.2	1.4	1.1
0.8	2.0	1.4	2.0	2.0	1.8	1.5	1.4	1.4	1.6	1.5
1.0	2.4	1.7	2.4	2.4	2.2	1.8	1.7	1.7	1.9	1.8
1.2	2.8	2.0	2.8	2.8	2.6	2.1	2.0	2.0	2.2	2.1
1.4	3.2	2.2	3.2	3.2	3.0	2.4	2.2	2.2	2.6	2.4

It can be seen from Table 3 that all methods give similar results apart from NB5 (not the preferred method) at higher values of production uncertainty with n=5. The results for DTI_r are smallest at lower values of production uncertainty, this is due to the relatively small value of repeatability uncertainty. However, production uncertainties are unlikely to be below about 0.5 dB and so it may be concluded that all methods provide similar results. It is assumed that the EU sub-committee will eventually provide guidance on the evaluation of the expanded uncertainty but it would seem that their main consideration would lie in the mathematical robustness of the method and not necessarily on the final result. The considerable extra effort and associated costs involved will probably prohibit the use of large sample sizes and so here coverage factors evaluated with n=5 are considered. Experience has shown that production uncertainties can be typically in the order of 0.7 dB and so it may therefore be assumed that the value of *U* will be approximately 2 dB. It is proposed that the value of U for the purposes of noise declaration is set at 2 dB.

3.8 SUMMARY AND FURTHER WORK FOR TREATMENT OF UNCERTAINTY

Information on measurement uncertainty given in current International Standards relating to the determination of sound power level[1 to 7] can be helpful towards the derivation of measurement uncertainties, but it is incomplete. In particular, it does not give an analysis of the various components of measurement uncertainty and their magnitudes. The accepted format for expression of uncertainties generally associated with methods of measurement is that given in the GUM. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, from which the combined total uncertainty can be obtained. The data necessary to enable such a format to be adopted in the case of the International Standards relating to sound power are not currently available and it is clear that effort needs to put into research projects aimed at the evaluation of the individual uncertainty components.

A-weighted sound power level data obtained from numerous sources indicate that values of reproducibility for use in ISO 3744 were machine dependent but for machines that have steady noise emission vary from 0.4 dB to 0.8 dB with a value of 0.5 dB being most frequent. These values are significantly less than the 1.5 dB currently quoted on ISO 3744. For machines running in an activity mode, values of reproducibility range from 0.8 dB to 1.0 dB. The origin of some of these data is not clear and so it is therefore important that a series of round-robin exercises are performed to ensure that these values of reproducibility are acceptable for the purposes of noise declaration

The problems associated with the statistical assessment of correction factors required in the provision of declared noise levels are currently under consideration. However, the considerable effort and associated costs involved with the use of large sample sizes needs to be assessed to ensure that the end result is justified. It is suggested that using currently available practical values of uncertainty and sample sizes that as a guide, for noise declaration purposes, 2 dB will need to be added to measured values.

4. OPERATING CONDITIONS

4.1 BACKGROUND TO SOURCE OPERATING CONDITIONS ISSUE

As discussed above in Sections 3 and 4, manufacturers can demonstrate compliance with regulations by measuring in accordance with internationally standardised methods. The machinery manufacturing industries commonly refer to the ISO 3740 series of standards, which specify various methods for determining sound power levels of machines, equipment and their assemblies over a measurement surface enveloping the source, within different environments. This series of standards is currently under short-term revision, and high on the agenda is the introduction of full uncertainty budgets consistent with the ISO "Guide to the expression of uncertainty in measurement"(9). This has important implications since uncertainty values are used in practice to derive the final guaranteed sound power level, which is used as an absolute indicator on noise labels affixed to machines. One contributor to measurement uncertainty is the effect of noise source operating conditions. However, the discrete effect of operating conditions on the overall measurement uncertainty is unknown.

4.2 SOURCE STABILITY

In reply to the web-based survey, a number of organisations were concerned as to how source stability should be expressed. An investigation has been conducted by NPL(20) involving an extensive series of sound power determinations for a range of machinery, primarily with internal combustion-engine power sources, enabling evaluation of repeatability uncertainties.

Essentially the NPL project was designed to obtain an indication of the typical level of repeatability uncertainty for a range of real machines. The following brief summary describes the method by which repeatability uncertainty was determined for the project. Repeatability uncertainty can be described as a measure of the closeness of agreement between mutually independent sound power level determinations obtained under repeatability conditions. These are where mutually independent sound power level determinations are obtained using the same method on a single machine at the same measurement site by the same operator(s) using the same equipment within a short interval of time. The quantity that needs to be obtained is the standard deviation, σ_r of repeatability uncertainty. This is a parameter of dispersion of the distribution of the sound power level determinations under repeatability conditions and describes how different, in a set of sound power level determinations, individual sound power level determinations typically are from the average of the set.

The 'true' value of σ_r can only be found from a very large (infinite) set of sound power level determinations. From a smaller number, *n* of sound power level determinations an estimate of sample standard deviation of repeatability, S_r can be obtained using the expression:

$$S_r = \sqrt{\frac{\sum_{i=1}^{i=n}\left(x_i - \bar{x}\right)^2}{n-1}}$$

where,

n is the number of repeated sound power level determinations

x_i is the sound power level determination of the *i*th repeat determination

$\bar{x}$ is the arithmetic mean of the *n* repeat determinations.

Greater number of repeat determinations (*n*), will result in a better estimate of repeatability, (S_r).

Sound pressure levels over the measurement surface were measured simultaneously and continuously for prolonged periods enabling determination of a large number of sound power levels (L_w). This provided a large sample size for evaluating the standard deviation, S_r.

The mean standard deviation for machines that performed ‘continuous’ operation, was found to be generally approximately 0.2 dB, and for those types of machines performing an ‘activity’ type of operation, the mean standard uncertainty was found to be generally approximately 1.0 dB. To put these values in context, the value of reproducibility standard deviation assumed by ISO for engineering grade measurements (see sub-section 4.3 above) is 1.5 dB.

4.3 LOAD OR NO LOAD MEASUREMENTS

There are potentially large differences between sound power level determinations made under load conditions and those under no-load conditions. A number of regulatory requirements specify a no-load sound power level determination. A no-load measurement may be adequate when used to obtain guaranteed levels according to various regulatory instruments or for comparing the noise levels of machines from different manufacturers, but it is not very useful when there is a need to assess workplace noise levels where the machine is in use. Unfortunately the noise level difference between load and no-load conditions will depend on the particular machine in question and on the task undertaken. While the no-load data may be expected to be reasonably repeatable it is not the case for measurements made under load. Here noise levels will be dependent on a number of factors such as the precise job undertaken, the specific type of work piece and also on the quality of the tool (e.g. the sharpness of the tool will affect the noise level). If there are requirements to assess workplace noise then measurements under load must be specified in the standard that is to be followed. In such cases the standard will be in the form of a noise test code which addresses the problems of a particular machine (C-type standards in ISO parlance). It can only be suggested that if there are particular problems then manufacturers should contact the relevant trade association to put pressure on ISO to provide suitable documentation.

4.4 SOUND PRESSURE LEVEL ESTIMATION

If data is available for noise sources under load then predicting sound pressure levels at a particular location in the workplace, from a sound power level determination, could be a simple process involving the distance between the noise source and the work. It is suggested that it may be possible to provide some form of simple correction probably using a table that equates a correction factor to a description of the room to enable a conversion from sound power level to emission sound pressure level. This kind of approach is used in Annex A of ISO 3744 where room description is equated to the mean sound absorption coefficient of a room. The Table is reproduced below as Table 4. It is feasible that a similar table could be provided with the column headings changed to something similar such as "work place correction" and "workshop description". The corrections would all be relative to free-field data as it is assumed that this would be the environment for any regulatory measurements, and as such will be positive with values ranging from zero to around 8 dB. Providing values of "work place correction" that correspond to various workshop descriptions will require considerable experimental effort and corresponding financial funding and so such a scheme will only emerge if there is impetus from industry.

Table 4 Absorption coefficients for various rooms

Mean sound absorption coefficient α	Description of room
0.05	Nearly empty room with smooth hard walls made of concrete, brick, plaster or tile
0.10	Partly empty room; room with smooth walls
0.15	Room with furniture; rectangular machinery room; rectangular industrial room
0.20	Irregularly shaped room with furniture; irregularly shaped machinery room or industrial room
0.25	Room with upholstered furniture; machinery or industrial room with sound-absorbing material on part of ceiling or walls
0.30	Room with sound absorbing ceiling, but no sound absorbing materials on walls
0.35	Room with sound absorbing materials on both ceiling and walls
0.50	Room with large amounts of sound-absorbing materials on ceiling and walls

4.5 MEASUREMENTS ON MANY MACHINES

Another problem loosely related to operating conditions occurs when demonstrating conformity with, for instance, the requirements of EU Directive 2000/14/EC when there are a large number of variants of a machine that are all very similar to each other. To carry out measurements on each variant could be a very expensive process, so the possibility of assessing a number of machines as a 'family group' may be considered. It is likely that this will require a measurement programme to assess potential differences between machines so that the total manufacturers output may be divided into a small number of groups. One approach that has been used by some manufacturers is to work through their particular trade association and offer one of their machines, that is considered to be a worst case when considering noise levels, and have measurements conducted by a third party and arrive at an overall worst case noise level. All manufacturers then use this worst-case noise level as the guaranteed value. This approach does of course mean that there may be some variants that have actual sound power levels that are considerably lower that the labelled value. An alternative is to carry out measurements on many variants to obtain information on what particular differences affect the sound power level. For instance, a difference may be the routing of an exhaust system that may, for example, be horizontal or vertical. If this does not affect the sound power level, then such differences may be ignored in future variants.

4.6 SUMMARY AND FURTHER WORK FOR OPERATING CONDITIONS

The ultimate aim regarding source repeatability uncertainties (see sub-section 5.2) is to derive values that represent an estimation of variability of a single sound power level determination resulting from operating conditions, for categories of machines. The measurements carried out by NPL involved a limited range of machines. To ensure the values quoted for machines with a steady noise emission characteristic and those with an activity type operation are comprehensive, measurements need to be carried out on more machines including those that may be described as ‘large’.

Regarding the problems relating to differences between load and no-load sound power level determinations (see sub-section 5.3), it can only be suggested that if there are particular problems then U.K. manufacturers, or their trade association, should contact the British standards institute (BSI). The BSI can then put pressure on ISO to address the issue when the relevant standards are revised.

There is a need to provide values of “work place correction” that correspond to various workshop descriptions (see sub-section 5.4). This will require considerable experimental effort and corresponding financial funding, and so may only happen if it is considered to be a high priority by industry.

5. TEST SITE

Problems have been raised regarding finding a site that complies with the requirements of ISO standards, usually because of the size, high background noise and in special cases, providing a reflecting surface that is to represent some kind of real floor. These three issues will be examined in sub-sections 6.1, 6.2 and 6.3.

5.1 TEST SITE SIZE

NPL have carried out a limited series of measurements where sound power level determinations were obtained according to ISO 3744 with a hemispherical measurement surface. ISO 3744 requires that the radius of the hemisphere shall be approximately twice the maximum dimension of the noise source but not less than 1 m. The source used for these initial measurements was a reference sound source, with a maximum dimension of 0.3 m, so a radius of 1 m was used. ISO 3744 requires that the reflecting plane shall extend at least half a wavelength (of sound), $\lambda/2$, at the lowest frequency of interest beyond the projection of the measurement surface on the plane. If the lowest frequency of interest is assumed to be 50 Hz, where $\lambda/2$ is approximately 3.5 m, then the reflecting plane must be at least 9 m in diameter. Two repeat sound power level determinations were carried out with a reflecting plane diameter of 9 m and 8 m. There are no specific distance limits relating to obstacles, only comments such as “As far as practicable, the test environment shall be free from reflecting objects other than a reflecting plane so that the source radiates into a free field over a reflecting plane”. It is assumed that the intention is that large reflecting objects should not be located close to the reflecting plane. To test this assumption, large reflecting obstacles were located directly at the edge of the reflecting plane. The data from these measurements were analysed to assess the possibility of using a smaller measurement surface and also with closer obstacles than those permitted by ISO 3744. The results are shown in Figure 2 below.

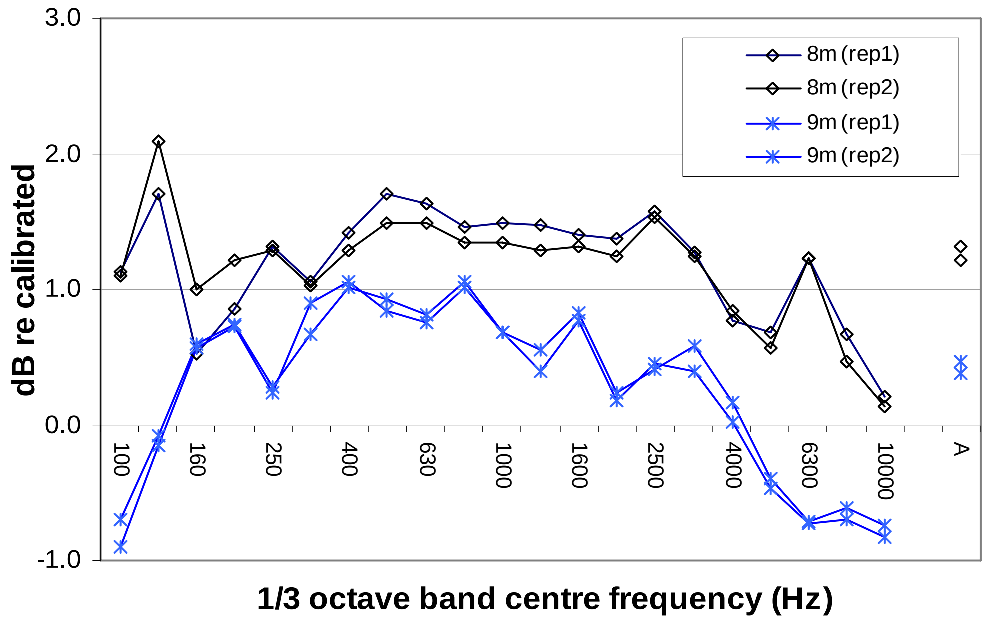

Figure 2 Sound power levels relative to calibrated values

It can be seen from Figure 2 that there is a significant difference between the two repeats of the measurement at 8 m distance, (8m rep1, 8m rep2), and measurement at 9 m distance (9m rep1, 9m rep2), with almost 1 dB between A-weighted levels. The difference is such that the levels obtained using the smaller radius (obstacles closer) are the larger, as would be expected if reflected energy is making a contribution. These data indicate that the criterion in ISO 3744 needs to be complied with, although it is not clear whether it is the site size or the presence of an obstacle that is causing the problem. However, the A-weighted values are all larger than the calibrated level. This is difficult to explain and so it is clear that more measurement data is required before a definitive conclusion can be drawn.

It is interesting to note that the permissible size of the reflecting plane is dependent on the lowest frequency of interest. So, it may be assumed that if only A-weighted levels are required then the lowest frequency of interest may be that which just begins to make a contribution, which may be considered as any one third octave level that is greater than say, 20 dB below the A-weighted level. To examine this possibility consider a noise source with a flat spectrum, then by applying the A-weighting corrections, the lowest frequency of interest is 100 Hz. Here the value of $\lambda/2$ results in a measurement surface size that is approximately 1.7 m larger than the hemisphere radius. For the measurements described above this would mean a surface that is only 5.4 m in diameter. The reference sound source, used in the measurements above, has a frequency spectrum that rises to a maximum at 1 kHz and then falls at higher frequencies. Applying the A-weighted corrections to this spectrum results in a lowest frequency of interest of 160 Hz. Here the value of $\lambda/2$ results in a measurement surface size that is approximately 1 m larger than the hemisphere radius. For the measurements described above, this would mean that a surface that is only 4 m in diameter could be used. It is clear that, if this is the intention of ISO 3744, then much smaller sites than would at first seem to be a requirement may be used. However, the data shown in Figure 2 exhibit differences for all one-third-octave-bands which would tend to be in conflict with the notion of a lowest frequency of interest concept. ISO 3744 is currently undergoing revision and it is clear that some clarification of the requirements regarding measurement sites is required.

5.2 BACKGROUND NOISE

A number of organisations had experienced problems resulting from high background noise levels and wondered if it would be possible to carry out measurements even though the requirements of ISO standards were not met. The possibility of accepting poorer background noise requirements, by applying corrections and perhaps limiting the application of the result is considered below. However, the possibility of using intensity level measurement (which will be used more and more in the future as instrumentation improves) could be considered although, at the moment, this is not an option accepted in, for example, Directive 2000/14/EC. The current requirement of ISO 3744 regarding background noise is that it shall be at least 6 dB below the noise level to be measured. Corrections are applied to levels between 6 dB and 15 dB and no corrections for values greater than 15 dB. However, there is a provision to apply a correction of plus 1.3 dB to sound power levels determined where background noise levels are less than 6 dB above the noise level to be measured. The correction of 1.3 dB is that calculated for a 6 dB difference and so will represent an upper value of sound power level. So, as regards providing levels for regulatory purposes such as Directive 2000/14/EC, it will be a "safe" overestimate. However, in the case of A-weighted levels, there may be scope here to assess the contribution of the particular noise band that has high background noise levels and if it is in excess of 15 dB less than the A-weighted level it may be neglected and a definitive result may be provided. This may at present be something that has to be agreed with the regulator but it is something that should be considered in the ISO 3744 revision.

5.3 GROUND ABSORPTION

Questions have also been posed regarding the reflecting ground plane for measurements conducted in hemi-anechoic conditions, especially, in connection with its approximation to acoustic characteristics of 'real' floors The assessment of the reflecting (or absorption) properties of a floor is complicated and usually requires the use of a reverberation chamber and the financial costs associated with such a facility. Here the possibility of defining a simpler measurement procedure that describes the reflection properties in a clear and simple way by measuring the environmental correction factor, K_2 is assessed. A computer model is used to calculate k_2, for various values of sound absorption coefficient. Several assumptions are made in the simple model, the most significant are that the model assumes that the absorption coefficient of the ground surface is independent of frequency and also that the source is omni-directional and may be represented by a series of pure tone signals, and so the computed data should only be used as a guide. The calculated values of K_2 for various values of absorption coefficient are shown in Table 5 together with some brief descriptions of surface types.

Table 5 Calculated values of K_2 for various values of absorption coefficient

Brief description	Absorption coefficient	K_2 (dB)
perfect reflector	0	0
wood / concrete	0.06	- 0.14
	0.1	- 0.23
	0.2	- 0.47
	0.3	- 0.74
grass	0.4	- 1.04
	0.5	- 1.38
	0.6	- 1.77
carpet	0.7	- 2.23
	0.8	- 2.81
	0.9	- 3.64
perfect absorber	1.0	- 6.00

The brief descriptions[21] are only intended as an indication of the sort of surface that is associated with the values of absorption coefficient. However, it can be seen that if the requirement were to simulate a grass surface, for example, then a relatively simple assessment of K_2 to ensure a value of approximately 1 dB would be sufficient.

5.4 SUMMARY AND FURTHER WORK FOR TEST SITE

It is clear that more experimental data is required before definitive recommendations regarding test site size can be made (see sub-section 6.1). Initially it is suggested that these would concentrate on data obtained using a reference sound source with measurements being carried out on a number of different sized sites and then expanded to use real machines. The measurement effort would then need to be extended to assess the effect of obstacles. ISO 3744 is currently under going revision and it is clear that some clarification of the requirements regarding measurement sites is required.

Regarding the problems related to background noise, in the case of A-weighted levels it is suggested in sub-section 6.2, that there may be scope to assess the contribution of the particular noise band that has high background noise levels. If it is in excess of say, 15 dB less than the A-weighted level, it may be neglected and a definitive result may be provided. This may require a short experimental programme to assess the feasibility when considering real machines but for the present it may be something that has to be agreed with the regulator but it certainly should be considered in the ISO 3744 revision.

The table proposed in sub-section 6.3, to simplify the problems related to measurement of ground reflection coefficient, is the result of calculations made with a number of serious limitations and as such is only intended as a guide. It is clear that if such a scheme is to be used then a measurement programme to correlate K_2 with ground absorption is a prime requirement.

6. NUMBER OF MICROPHONES

6.1 PROBLEMS RELATED TO HIGHLY DIRECTIONAL SOURCES

A potential problem was raised in the survey regarding the requirement to increase the number of microphone positions for directional noise sources. ISO 3744, for instance, requires that the number of microphone positions on a hemispherical surface be doubled from 10 to 20 if the range of the sound pressure levels (Δ_{Lp}) from the 10 positions is greater than 10 dB (i.e. the number of positions). Similarly when using parallelepiped surfaces the requirement is to sub-divide all faces, resulting in an increase in the number of microphone positions from 9 to 21. Cases have been cited where the difference is only just above 10 dB for a hemisphere (or 9 dB for a parallelepiped) and it is suggested that the value of the result obtained by doubling the number of positions is not significantly different and, for measurements on this type of noise source, does not have a significantly reduced measurement uncertainty.

Two examples have been supplied, firstly measurements carried out on a domestic DVD player/recorder unit. Here the source under test is a unit typical of a modern consumer electronics product including noise sources such as hard disk drive, and one or more cooling fans. This category of product is commonly installed in quiet domestic environments and there is increasing consumer demand for these products to operate 'silently'.

Where it is not possible to adopt the 1m radius hemisphere because of a low signal to noise ratio (a result of the quiet operation of the product) a closer measurement distance using a parallelepiped surface with a measurement distance, (d), 0.25 m may be adopted. Using a measurement distance d = 0.25m for a parallelepiped measurement surface with 9 microphone positions produced an A-weighted Δ_{Lp} of 10.0 dB, with a range of 5.6 dB to 14.8 dB when considering one-third octave-band levels - hence there is a requirement to increase the number of microphone positions from 9 to 21. When using a single microphone system this represents a doubling of measurement time and the associated financial penalty. The A-weighted sound power level determined was 38.3 dB. The measurements were repeated using a measurement distance of d = 1m which provided a maximum Δ_{Lp} of 8.8 dB (so the measurement surface faces do not need to be sub-divided) and an A-weighted sound power level of 38.5 dB. It is interesting to note that according to ISO 3744 the 0.25 m measurement is invalid and the 1 m measurement conforms even though the difference between the two A-weighted sound power levels is only 0.2 dB.

The second example deals with measurements on a 'Personal video recorder (PVR)' set-top-box. This is similar in construction and dimensions to the DVD recorder used in the first example. Measurement were conducted using a parallelepiped with a measurement distance d= 0.5m. The sound power level was determined as 37.9 dB. The A-weighted value of Δ_{Lp} was 10.0 dB with one-third octave-band values ranging from 16.3 dB and 5.0 dB. Therefore the measurement surface was required to be sub-divided again to increase the number of microphone positions from 9 to 21. However, in this case, the 21-position array was not used but instead measurements were repeated using a hemispherical surface with a radius of 1 m and the 10 key measurement positions from ISO 3744. The A-weighted sound power level was determined as 38.1 dB and the maximum value of Δ_{Lp} of

6.6 dB. Since the value of Δ_{Lp} was less than the number of microphones the measurement is considered valid. The measurements using the parallelepiped however did not conform even though the difference between the two sound power evaluations is only 0.2 dB. It is concluded therefore that the requirement to double the number of microphones should be investigated to ensure that undue restrictions are not being imposed.

6.2 THE EFFECT OF REDUCING THE NUMBER OF MEASUREMENT POSITIONS

In sub-section 7.1 above, the requirement to increase the number of measurement positions was discussed. An associated problem relates to the effect of reducing the number of measurement positions. Cases have been reported where sound power level measurements carried out using fewer measurement positions than specified in the relevant ISO standard have provided results having adequate accuracy. In sub-section 3.1 the current revision of the ISO 3740 series of standards was discussed. The seven standards in the series are all being revised in what ISO Working Group 28 describe as a 'short-term' revision. In the long term it is the intention that a new series of international standards will be proposed, to replace the current ISO 3740 series. The new series would cover the same variety of test environments, but comprise only four standards instead of the present seven. Two will require the use of qualified reverberant and free-field rooms. The others will be for use *in situ*, intended to give working methods for engineering or industrial use in declaring and verifying sound power levels. The latter two will provide information on how to optimise the measurement for the desired balance between measurement effort and measurement uncertainty, (e.g. choice of the number of measurement positions).

In order to assess the effect of varying the number of measurement positions, NPL(22) has carried out a programme of inter-laboratory measurements designed to obtain estimates of the standard deviation of reproducibility associated with sound power level determinations. The primary objective of the project was to acquire data on uncertainties in determination of sound power levels, expressed in terms of standard deviations of reproducibility. Sound power determinations were carried out using several microphone arrays with differing distribution on a hemispherical enveloping surface for noise sources encompassing a wide range of acoustic complexity and covering a directivity Index (DI) range from 0.8 dB to 6.9 dB. The magnitude of reproducibility standard deviations was found to be dependent on the number of microphone positions in the array, the DI of the noise source and the distribution of the microphone positions. For A-weighted sound power levels, a procedure was proposed that, for a given value of DI, will enable the user of a sound power standard to easily assess how many microphone positions are required in an array to obtain a required value of reproducibility, or, to assess the reduction in reproducibility that will be achieved by increasing the number of microphone positions. The resultant standard deviations of reproducibility are shown in Table 6 below as a function of DI and number of measurement positions.

In order to put the values of DI in context, if a machine has a particularly low value of DI (e.g. a reference sound source) then reproducibility values corresponding to a DI of 1 dB may be assumed. If upon visual inspection, the noise emission of a machine is not obviously highly directional (the case for the vast majority of machines) then a nominal value of reproducibility corresponding to a DI of 3 dB may be assumed. If the noise emission of the machine is obviously highly directional then high reproducibility values corresponding to a DI of 5 dB may be assumed. So, it can be seen that for the vast majority of machines (a DI of 3 dB) reducing the number of measurement positions from 10 (as specified in ISO 3744) to 4 only increases the standard deviation of reproducibility from 0.7 dB to 1.2 dB.

Table 6 Values of reproducibility as a function of DI and measurement positions

measurement positions	Directivity Index (dB)		
	1	3	5
10	0.4	0.7	1.0
7	0.4	0.8	1.1
6	0.5	0.9	1.3
4	0.6	1.2	1.8
3	0.9	1.8	2.7
1	1.3	2.3	3.3

6.3 SUMMARY AND FURTHER WORK FOR NUMBER OF MICROPHONE POSITIONS

Currently, ISO3744 specifies an increase in the number of microphone positions for directional noise sources, such that, for instance, the number of microphone positions on a hemispherical surface be doubled from 10 to 20 if the difference between the minimum and the maximum sound pressure levels from the 10 positions is greater than 10 dB, or when using parallelepiped surfaces to sub-divide all faces resulting in an increase in the number of microphone positions from 9 to 21. It is not clear where this requirement originated but it is clear that it needs to be validated to ensure that undue restrictions are not being imposed.

The seven standards in the ISO 3740 series are all being revised in what ISO Working Group 28 describe as a short-term revision. In the long term it is the intention that a new series of international standards will be proposed, to replace ISO 3740 series. The new series would cover the same variety of test environments, but comprise only four standards instead of the present seven. Two will require the use of qualified reverberant and free-field rooms. The others will be for use *in situ*, intended to give working methods for everyday use in declaring and verifying sound power levels. The latter two will give information on how to tailor the reproducibility of the results to the amount of measurement effort (i.e. the number of measurement positions). It is important that this long-term revision progresses with some urgency especially regarding a “floating uncertainty” working standard and may require an extension of the previous NPL measurements to encompass a greater machine range.

7. SUMMARY AND CONCLUSIONS

Methods used by industry both for diagnostic measurements of noise emission of machinery and for measurements to existing current specification standards have been examined. The validity of using existing air-borne noise emission measurement methods, as specified in current specification standards for certain applications has been reviewed using a web based information gathering survey. The data analysis demonstrated particular practical measurement problems for various methods and source types, and identified main failures of the standards and gaps in knowledge for the generic area, which require further measurements to be performed in order to identify reasons for failure. Problems were grouped into five general areas, the environment, uncertainties, operating conditions, the test site and the number of measurement positions. Where possible solutions to problems have been offered but in most cases it was clear that there was a need for more experimental investigations and for revision of the existing ISO standards in the noise area. Suggestions for further work are briefly outlined below.

It has been shown in sub-section 3.1, that variations in both ambient temperature and atmospheric pressure (due to either annual variations or of altitude) may result in significant variations in sound power level determinations. It is important, therefore, that such changes in meteorological conditions are considered when carrying out noise measurements or when assessing sound power levels determined at different locations or under different meteorological conditions.

It is clear that the value of the constant, n (see sub-section 3.2) is an important factor in accounting for changes in sound power level resulting from variation in meteorological conditions. It is important, therefore, to validate the value of n for real machines. This could be done experimentally by determining the effect of ambient temperature and pressure and sound power level over a period of a year, for a selection of representative machines and then carrying out the calculations described in sub-section 3.1 with various values of n to obtain the best agreement, although clearly this would involve a limited range of conditions.

Information on measurement uncertainty given in current International Standards relating to the determination of sound power level can be helpful towards the derivation of measurement uncertainties, but it is incomplete. In particular, it does not give an analysis of the various components of measurement uncertainty and their magnitudes. The accepted format for expression of uncertainties generally associated with methods of measurement is that given in the GUM. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, from which the combined total uncertainty can be obtained. The data necessary to enable such a format to be adopted in the case of the International Standards relating to sound power are not currently available and it is clear that effort needs to be applied into research projects aimed at the evaluation of the individual uncertainty components.

A-weighted sound power level data obtained from numerous sources indicates that values of reproducibility for use in ISO 3744 were machine dependent but for machines that have steady noise emission vary from 0.4 dB to 0.8 dB with the most frequent value being approximately 0.5 dB. These values are significantly less than the 1.5 dB currently quoted by ISO 3744. For machines that normally operate in activity mode, values of reproducibility range from 0.8 dB to 1.0 dB. The origin of some of these data is not clear and so it is important that a series of round-robin exercises are performed to ensure that these values of reproducibility are acceptable for the purposes of noise declaration

Issues associated with statistical treatment of measurement uncertainty for the purposes of noise declaration and verification is currently under consideration. However, the effort and costs associated with sample size needs to be assessed to ensure that the end result is justified. It is suggested that using currently available practical values of reproducibility, as a guideline for noise declaration purposes, 2 dB should to be added to measured values.

The ultimate aim regarding source repeatability uncertainties (see sub-section 5.2) is to derive values of standard uncertainty that represent variation due to operating conditions, for each category of machine. The measurements carried out by NPL involved a limited range of machines. To ensure the values quoted for machines with a steady noise emission characteristic and those with an activity type operation are comprehensive, measurements need to be conducted on more machines including those that may be described as large.

Regarding problems related to differences between load and non-load sound power level determinations (see sub-section 5.3), it is suggested that if there are particular problems then manufacturers should contact the relevant trade association to put pressure on ISO to provide suitable documentation.

There is a need to provide values of “work place correction” that correspond to various workshop descriptions (see sub-section 5.4). This will require considerable experimental effort and corresponding financial funding and so such a scheme will only emerge if the impetus is there from industry.

It is clear that more experimental data is required before definitive recommendations regarding test site size can be made (see sub-section 6.1). Initially it is suggested that these would concentrate on data obtained using a reference sound source - measurements being carried out on a number of different sized sites and then expanded to using real machines. The measurement effort would then need to be extended to assess the effect of obstacles. ISO 3744 is currently undergoing revision and it is clear that some clarification of the requirements regarding measurement sites is required.

Regarding the problems related to background noise, in the case of A-weighted levels it is suggested in sub-section 6.2, that there may be scope to assess the contribution of the particular noise band that has high background noise levels and if it is in excess of say 15 dB less than the A-weighted level it may be neglected and a definitive result may be provided. This may require a short experimental programme to assess the feasibility when considering real machines but for the present it may be something that has to be agreed with the regulator but it certainly should be considered in the ISO 3744 revision.

The table proposed in sub-section 6.3 to simplify the problems related to measurement of ground reflection coefficient, is the result of calculations made with a number of serious limitations and as such is only intended as a guide. It is clear that if such a scheme is to be used then a measurement programme to correlate the environmental correction factor, K_2 with ground absorption is a key requirement.

Currently, ISO3744 specifies an increase in the number of microphone positions for directional noise sources. For instance, for a hemispherical surface, there is a requirement that the number of microphone positions is doubled (from 10 to 20) if the difference between the minimum and the maximum sound pressure levels from the 10 positions is greater than 10 dB. Likewise, when using parallelepiped surfaces to sub-divide all faces resulting in an increase in the number of microphone positions from 9 to 21. Assurances are therefore needed to ensure that undue restrictions are not being imposed.

The seven standards in the ISO 3740 series are all being revised in what ISO Working Group 28 describe as a 'short-term' revision. In the long term it is the intention that a new series of international standards will be proposed to replace ISO 3740 series. The new series would cover the same variety of test environments, but comprise only four standards instead of the present seven. Two will require the use of qualified reverberant and free-field rooms. The others will be for use *in situ*, intended to give working methods for everyday use within industry. The latter two will give information on how to tailor the reproducibility of the results to the amount of measurement effort (i.e. decision on the number of measurement positions). It is important that this long-term revision progresses with some urgency especially regarding a "floating uncertainty" working standard and may require an extension of the previous NPL measurements to encompass a greater machine range.

8. ACKNOWLEDGEMENTS

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10. ANNEX 1: WEB PAGES AND QUESTIONNAIRE

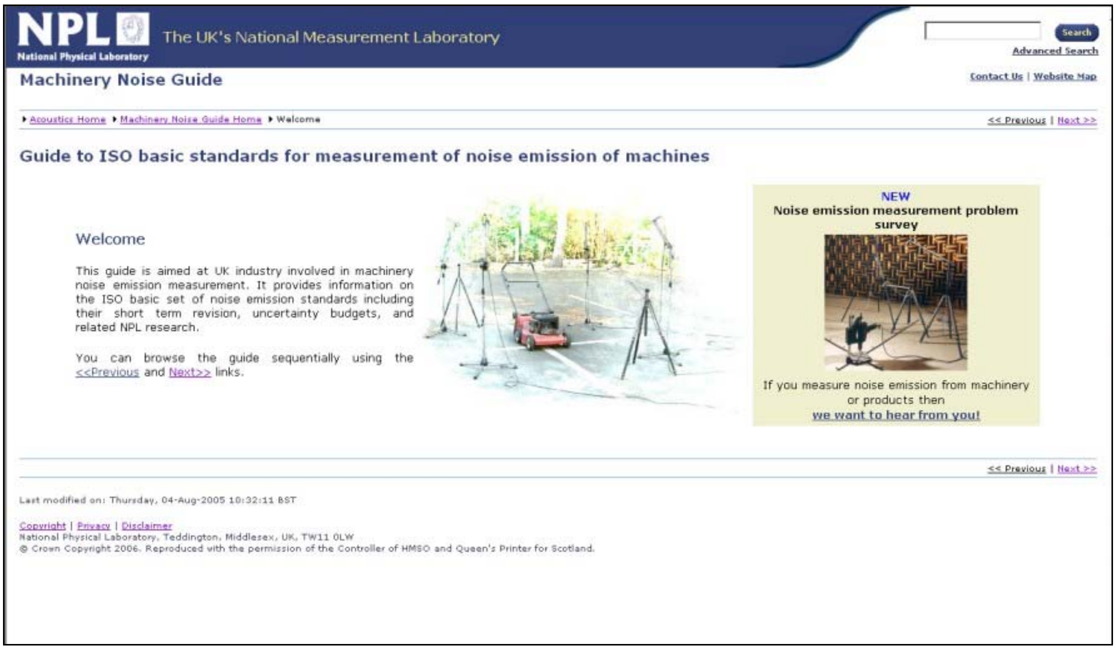

Figure A1.1 front page of Machinery noise guide

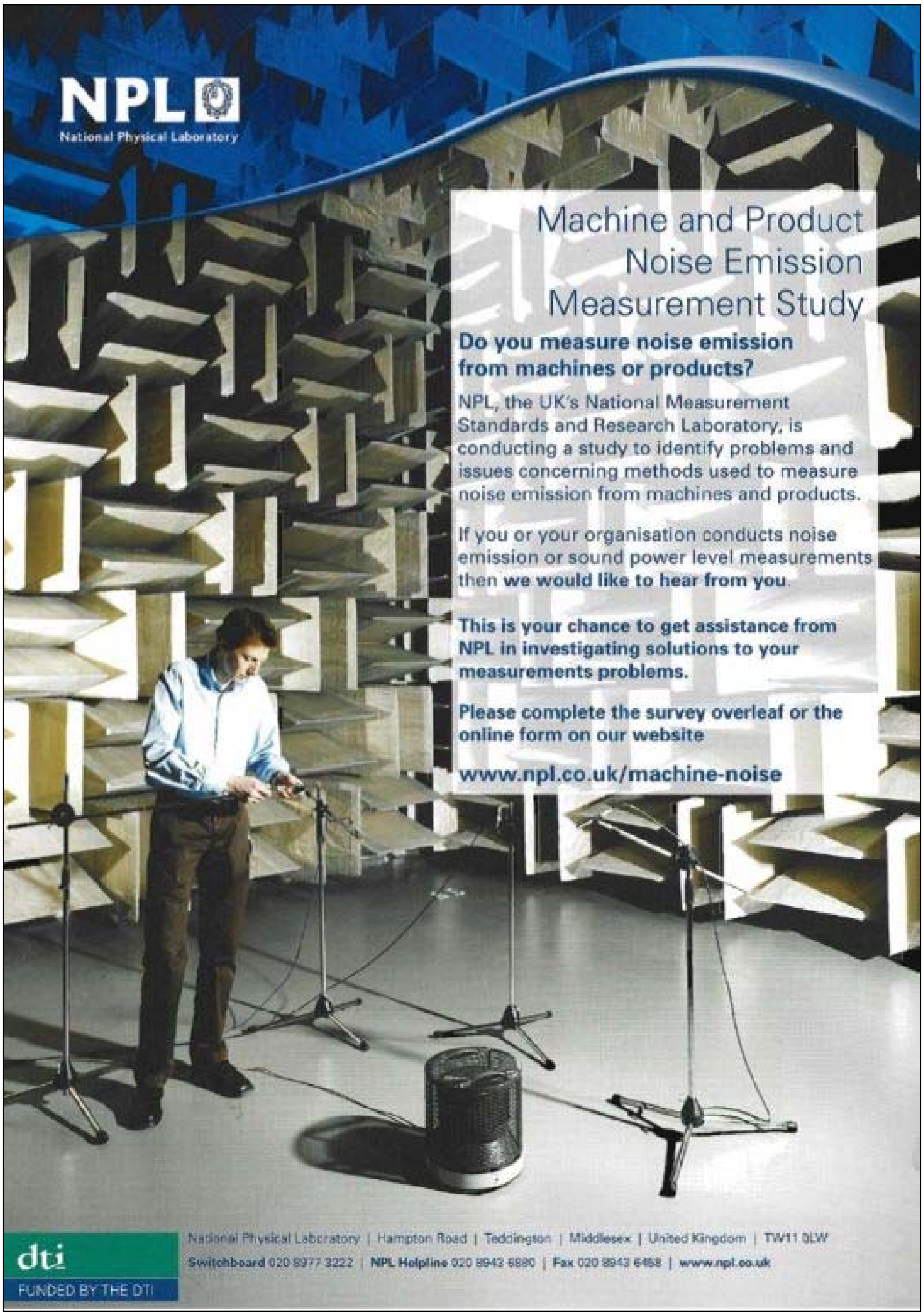

Figure A1.2a flier (front)

NPL
National Physical Laboratory

Survey Form
Machine and Product Noise
Emission Measurement Study

First name ....

Surname ....

Company name ....

Position within Company: ....

Phone number: ....

E-mail: ....

Q1. What measurement standards or procedures are you using: e.g. ISO 3744 for the sound power measurements and ISO 3744 Annex A 'two surface method' to qualify test sites

Q2. What is your measurement configuration: e.g. Using hemispherical measurement surface within a hemi-anechoic room, using the 10 key microphone positions at a radius of 2 m etc

Q3. What category of product or machine are you measuring:

Q4. Description of any measurement problem(s) or issue(s):

☐ I would like to receive information on the results of this NPL study, when available

☐ I would like to receive regular acoustics measurement information from NPL

Please return this form to:
Machinery Noise Survey | Bldg 59/Rm 201 | National Physical Laboratory | Hampton Road | Teddington | Middlesex | TW11 0LW
Tel: 020 8943 6593 Fax: 020 8943 6217

Figure A1.2b Flier - reverse side

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The UK's National Measurement Laboratory

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Noise emission measurement issues - Overview

Acoustics Home ▸ Noise emission ▸ Overview

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Background to the project

NPL is conducting an assessment of methods used for noise emission measurement of machines and products. The investigation, funded by the DTI, will focus on any problems and issues in the practical application of current measurement methods. We are especially interested in issues such as the trade off between measurement accuracy and effort.

We aim to achieve this by finding out the views and experiences from a wide area of UK industry that is concerned with noise emission measurement.

The results of this study will be published in an open report and will also help influence the development of the next generation of ISO noise emission measurement standards.

How you can help us

If your company is involved with noise emission measurement, in particular the determination of sound power level of machinery or products, then we would like to hear from you.

This is your chance to get assistance from NPL, in investigating the sources of problems that you have identified, and help improve measurement procedures.

Please spend a few minutes completing the machinery noise survey Online form on the next page.

If you have any queries regarding this survey please contact Machnoise@npl.co.uk

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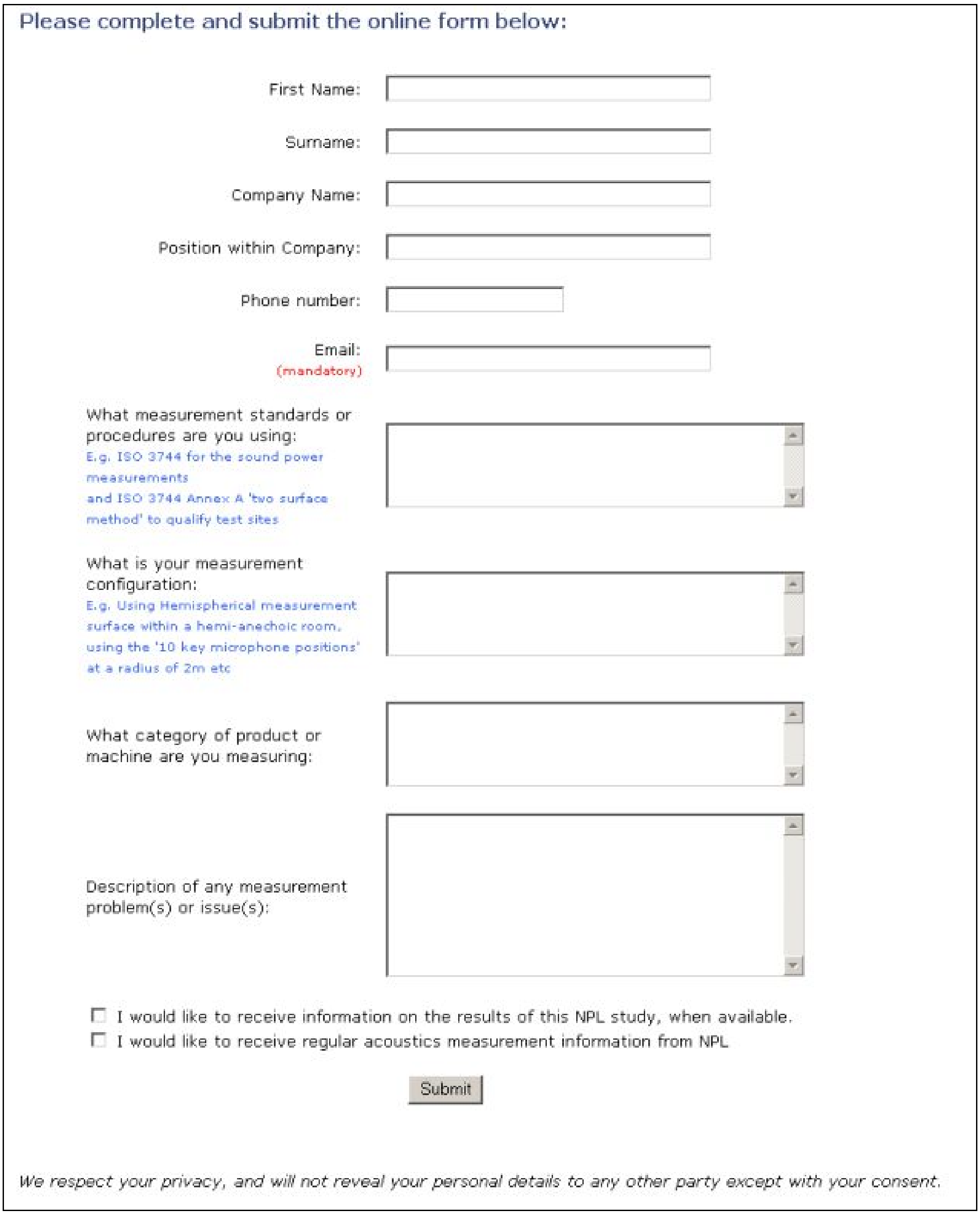
Figure A1.3a Online survey form (first page)



Please complete and submit the online form below:

First Name:

Surname:

Company Name:

Position within Company:

Phone number:

Email:
(mandatory)

What measurement standards or procedures are you using:
E.g. ISO 3744 for the sound power measurements
and ISO 3744 Annex A 'two surface method' to qualify test sites

What is your measurement configuration:
E.g. Using Hemispherical measurement surface within a hemi-anechoic room, using the '10 key microphone positions' at a radius of 2m etc

What category of product or machine are you measuring:

Description of any measurement problem(s) or issue(s):

☐ I would like to receive information on the results of this NPL study, when available.
☐ I would like to receive regular acoustics measurement information from NPL

Submit

We respect your privacy, and will not reveal your personal details to any other party except with your consent.

Figure A1.3b Online survey form (second page)

11. ANNEX 2: E-MAIL LETTER TO MANUFACTURERS

Dear Mr *********,

Machine and Product Noise Emission Measurement Study

NPL, the UK's National Measurement Standards and Research Laboratory, is conducting a study to identify problems and issues concerning methods used to measure noise emission from machines and products. We are carrying out an assessment of current measurement methods as they are used in practice.

If you or your organisation conducts noise emission or sound power level measurements then **we would like to hear from you**.

This is your chance to get assistance from NPL in investigating the sources of problems that you may have identified.

Please take a look at our website to find out more about participating in our project. The online survey form will only take a few minutes to complete.

http://www.npl.co.uk/acoustics/research/soundpower/survey/

Thanks for your help.

Regards