Measurement uncertainties associated with sound power level determination due to source operating conditions

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ABSTRACT

Manufacturers can demonstrate compliance with regulations by carrying out measurements in accordance with internationally standardised methods. The machinery industry 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". The implications of having this information are important, where 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.

The effect of noise source operating conditions on the determination of sound power level needs to be accounted for in the ISO 3740 uncertainty budgets. However, the discrete effect of operating conditions on the overall measurement uncertainty is unknown. An investigation has been conducted 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. The mean standard uncertainty for machines with a continuous steady noise output obtained from analysis of a range of sources was found to be 0.2 dB. Using a dataset of standard deviations of repeatability determined for machines tested with an activity type operation, the mean standard uncertainty was found to be 1.0 dB.

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Approved on behalf of the Managing Director, NPL
by Dr B Zeqiri, authorised by Director, Quality of Life Division

CONTENTS

1 INTRODUCTION

This report provides a summary of the work carried out in order to determine in real-time, repeatability uncertainties in sound power determinations resulting from source operating conditions. The report initially provides some background to the measurement of noise emission from machinery and goes on to present the rationale for conducting research on repeatability uncertainties due to operating conditions. Section 2 describes the methodology employed for the investigation and the results from an extensive series of measurements are presented and analysed in section 3. Section 4 sets out the project conclusions, and recommendations are given in section 5. A number of informative annexes have also been included.

1.1 BACKGROUND

Although noise in the environment and workplace has long been recognised as a problem, on a local, national, European and international scale, action to control and reduce it has not historically been successful. This was a finding of the 1996 European Commission Green Paper on Future Noise Policy(1), which recognised that up to 170 million citizens of the EU were living in areas where the noise levels were such as to cause serious annoyance during daytime. Furthermore, it has been reported by the Chartered Institute of Environmental Health (CIEH) that Local Authorities in England and Wales received five times as many complaints about noise in 2002/2003 than in 1982/1983. Since 1991, industrial/commercial noise complaints have risen by about 30%. The Green Paper accepted the misgivings of previous years and the Commission have since set out a vision for the year 2020 to "avoid the effects of noise exposure from all sources and preserve quiet areas". This has lead somewhat to an increase in legislative activities and a policy system driven by EC Directives.

Regulatory focus over the past 20 years has quite correctly tended to concentrate on the reduction of noise emission by sources, such as to both reduce the noise exposure of workers and limit industrial noise emitted into the environment. However, in the UK such regulation has not historically been enforced with stringency. In recent years the machinery industry has been subject to the implementation of a number of new and revised Directives, which are now enforced by independent regulators, requiring that manufacturers measure noise emission levels and declare the sound power levels of machines and products.

Directive 98/37/EC(2) , commonly known as the Machinery Directive is the most broad ranging of these, covering a wide range of machinery types, and requiring manufacturers to give information on the A-weighted sound power level if the sound pressure level at the work station of the machine exceeds 85 dB. Most recently, the machinery industry has had to comply with Directive 2000/14/EC(3), which deals with noise emitted by machinery used outdoors. Similarly, this Directive requires manufacturers to measure or have measured the sound power level of 57 categories of equipment, 22 of which have to meet limits. It further requires that labels be affixed to each item of equipment showing the guaranteed sound power level and that declarations of conformity be issued.

To demonstrate compliance with these and other Directives, industry must make reference to standardised test methods. For the machinery manufacturing industry there are a large number international measurement standards. Many of these, termed Type C standards under the hierarchy of international standards, set out details of machinery-specific test methods.

However, all such standards derive from Type-B standards, which generically define methods for determining the sound power level of machines.

In measuring noise from machines, manufacturers must therefore demonstrate compliance with these definitive Type-B standards. Most commonly in the machinery industry, reference is made to the methods set out in the ISO 3740 series of measurement standards.

1.2 RATIONALE

The ISO 3740 series(4-9), comprises six standards and sets out methods for measuring the sound power of machines and equipment by measuring the sound pressure level over a measurement surface enveloping the source, within different environments. This series of standards is currently under short-term revision, with research to assist in the development, being coordinated by ISO/TC43/SC1/WG28, the ISO Working Group charged with control of "Basic Noise Emission Standards". There are also proposals for longer-term revision, to simplify what is considered at present an excessively complicated and inflexible range of standards.

High on the agenda in respect to short term revision is the proposed introduction of full uncertainty budgets consistent with the ISO "Guide to the expression of uncertainty in measurement"(10). A considerable international research effort leading up to the production of draft standards has been focused on evaluating recognised errors and known uncertainties associated with test methods described in the ISO 3740 series.

In the recently revised ISO 3745(7), seven categories of uncertainty have been identified that could potentially effect the result of a sound power determination. It is proposed, at this stage that the general expression for the calculation of the sound power level, L_W, be given by the following equation:

$$L_W = \overline{L_p} + 10\lg\left(\frac{S}{S_0}\right) + \delta_{slm} + \delta_{rep} + \delta_{K2} + \delta_{mic} + \delta_{met} + \delta_{angle} + \delta_{imp} \quad \text{dB} \qquad (1)$$

where

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

S is the area of the measurement surface, in m^2,

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_{K2} is an input quantity to allow for any error in the environmental correction,

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, Note;

All of the uncertainties listed above have been identified by users and experts of the working group, as being important factors to consider when making a sound power measurement.

The effect of noise source operating conditions on the determination of sound power level is accounted for in the uncertainty budget (1) with the parameter δ_{rep}. However, currently there is no proposed value for δ_{rep} and the magnitude of the effect of operating conditions is unclear.

The main practical implication of not having evidential correlation between repeatability uncertainty due to operating conditions and the determined sound power level is that the level of stringency, set down in the specification requirements, is unknown. Some machinery manufacturers, especially those with an internal combustion-engined power source, have expressed concern about high values of repeatability uncertainty when using the enveloping surface method to determine sound power levels. The value of the standard deviation of repeatability is used in the assessment of uncertainty that is required to provide guaranteed or declared noise emission levels. These guaranteed levels are used to provide data for a label to be affixed to a noise source and may also be compared to a noise limit (see for example Directive 2000/14/EC[(3)]), it is important, therefore that values of repeatability uncertainty are not only accurate but are not excessively large.

On this basis, it was considered important that this component of uncertainty in sound power determination be investigated. The main objective of the project was to examine a range of machines, primarily with internal combustion-engined power source to provide data on the effect of operating conditions on the repeatability of sound power determination. The project set out to evaluate and provide typical repeatability uncertainty data for a range of machines which would assist both in the introduction of full uncertainty budgets to the ISO 3740 series[(4-9)] and the drafting of ISO C-type standards, which specific operating requirements for machinery requiring noise testing.

2 METHODOLOGY

Essentially, the investigation involved an extensive series of sound power determinations for a range of machinery, primarily with internal combustion-engine power sources, enabling evaluation of repeatability uncertainties.

2.1 OVERVIEW

Initially it was necessary to identify and acquire a range of machines for the experimental programme. Section 2.3 sets out the noise sources selected for the project. Where applicable, C-type standards were obtained for the noise sources to assess requirements for machine operating conditions.

Aligned with test source selection, it was necessary to select an appropriate measurement site. An outdoor site at NPL was assessed for suitability in accordance with the requirements given in ISO 3744(6). Section 2.4 sets out details of the method employed to assess the site performance. The site, as shown in Figure 1 was found to be acceptable for test requirements. Annex A provides the results of the site qualification measurement survey.

Having established the adequacy of the test site, an extensive series of noise emission measurements were conducted. Sound pressure levels were measured in terms of $L_{eq,1sec}$ for each machine over a six point microphone array, according to the coordinate system provided in ISO 4872(13), enabling determination of the sound power level. The same microphone array was used for all sources. The measurement equipment is described in section 2.5, and details of the measurement set-up are provided in section 2.6.

The results have been analysed, particularly to examine typical A-weighted repeatability uncertainties for a range of machines, and presented and discussed in section 3.

2.2 LIMITATIONS TO SCOPE

The project had practical and economic constraints, such that the range of machines tested had to be limited. In selecting the machines, the approach was to consider, as best as possible, different types of machinery with a range of operational characteristics, from machines which are generally operated in a relatively continuous mode (e.g. power generator) to actively operated machines (e.g. chainsaw). All machines examined were designed for use outdoors and considered to be small noise sources.

Different types of machinery to those examined, especially large assemblies may exhibit different levels of repeatability uncertainty due to operating conditions. The values determined from the measurements conducted under this project will not necessarily be appropriate to describe the repeatability uncertainty for all machines.

It is also noted that the machines employed for the investigation were not new and had been in service for varying degrees of time. It is acknowledged that the degree of repeatability determined for the selected machines may differ from machines tested straight off the production line. However, the machines used were determined to be in good working order and where appropriate had received regular servicing. It could be considered that the outcome of the investigation is representative of the worst-case repeatability.

Finally, it is noted that the scope of the investigation has been to consider only A-weighted values. This reflects the common requirements in practice, where for example, it is the single A-weighted value that is used for declaration purposes in accordance with Directive 2000/14/EC[3]. Frequency data was however acquired and could if required by analysed as part of a further investigation.

2.3 SELECTION OF NOISE SOURCES

In total nine machines were acquired for the investigation. Details of each machine are given in Table 1.

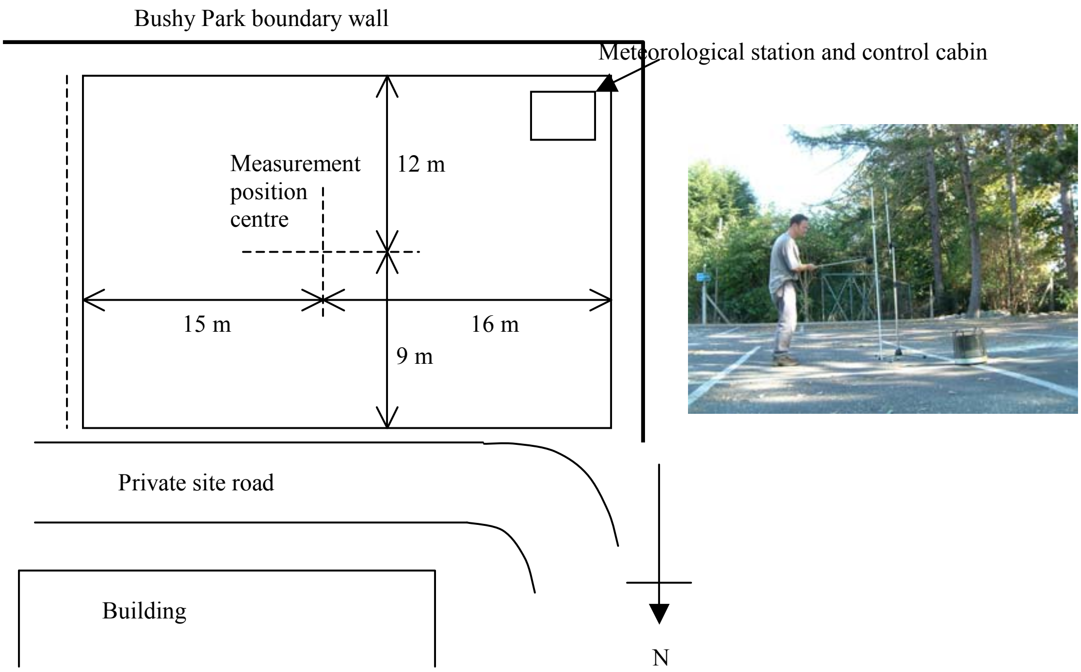
Table 1. Machines selected for investigation

Generic Description	*Details*	
Leaf blower	Description	Leaf blower GX240 'Billy Goat' 8 hp, SN:93098051
	Manufacturer:	Honda
	Power requirement:	Petrol
Grass trimmer (1)	Description	Grass trimmer FS200, id:PFI GARD0010
	Manufacturer:	STIHL
	Power requirement:	Petrol
Grass trimmer (2)	Description	Grass trimmer (Domestic) GL340C/H1E, id: 9843-7
	Manufacturer:	Black & Decker
	Power requirement:	Electrical, 240V
Hedge trimmer	Descriptions	Hedge trimmer H850, SN: 144539897
	Manufacturer:	STIHL
	Power requirement:	Petrol
Shredder/ chipper	Description	Shredder/ chipper (Domestic) SN: 4500178232
	Manufacturer:	Powerbase
	Power requirement:	Electrical, 240V
Chainsaw	Description	Chainsaw H580, SN: 144539897
	Manufacturer:	STIHL
	Power requirement:	Petrol
Lawnmower (1)	Description	Lawnmower HRH 365 PRO Roller, id: PFI:GARD 0009
	Manufacturer:	Honda
	Power requirement:	Petrol
Lawnmower (2)	Description	Two-stroke petrol engined lawnmower
	Manufacturer:	Siag (lawnmower), Briggs and Stratton (engine)
	Power requirement:	Unleaded petrol in 50:1 ratio with a two stroke oil rated TC-W
Power Generator	Description:	Electrical Power Generator
	Manufacturer:	Lombardini (engine) Markon Engirneering (generator), Clarke Power (rectifier).
	Power requirement:	Diesel fuel, SAE grade 15/40 oil.

2.4 MEASUREMENT SITE

An outdoor measurement site, with a flat and level asphalt ground plane was used for the investigation. Figure 1 shows the site indicating the dimensions and layout.

Figure 1. Outdoor test site used for sound power determinations



Prior to conducting measurements as part of the experimental programme, the hemi-anechoic performance of the test site was assessed. The criterion for acoustic adequacy of such sites requires that as far as is practicable, the test environment shall be free from reflecting objects other than the reflecting plane(s). ISO 3744[(6)] describes procedures for determining the magnitude of the environmental correction, K_2, to account for deviations of the test environment from the ideal condition. It is a requirement for K_{2A} to be numerically less than or equal to 2 dB for measurements to be considered valid. However, it is noted that in the revision of ISO 3744[(6)], it has been proposed that the K_2 criteria be increased from 2 dB to 4 dB.

2.4.1 Assessment using absolute comparison test

A reference sound source (RSS) meeting the requirements of ISO 6926[(14)] was mounted in the test environment, the same position to be used for testing each of the selected noise sources. The sound power level of the RSS was determined, (without the environmental correction K_2) over a 20-point hemispherical enveloping surface, in accordance with the procedures set out in ISO 3744[(6)].

The environmental correction, K_2, (A-weighted and in frequency bands) was evaluated using:

$$K_2 = L^*_W - L_{Wr} \qquad (2)$$

where;

L^*_W	is the environmentally uncorrected sound power level of the reference sound source, determined in accordance ISO 3744[6] when using the value 0 for K_2 (dB);
L_{Wr}	is the calibrated sound power level of the reference sound source (dB).

The outcome of the site qualification measurement survey is given in sub-section 3.1 and results are provided in Annex A.

2.5 MEASUREMENT EQUIPMENT

The equipment used to conduct the noise emission measurements discussed in this report complied with the instrumentation specifications set out in ISO 3744[6]. Brief details of the instrumentation are given in Table 2.

Table 2. Details of the instrumentation

Acoustical instrumentation used for sound power determination	
• Microphones	6 x Brüel & Kjær; type 4165
• Microphone preamplifiers	G.R.A.S. type 26AK
• Preamplifier extension cables	G.R.A.S. AA0020/X, Lemo 1B extension cable, 20m length
• Microphone Power Supply	Norsonic 'front end' type 335; providing signal conditioning, gain and microphone power.
• Windscreens	6 x Brüel & Kjær; type UA0237
• Calibrator	1 x Brüel & Kjær type 4231
NPL data acquisition and analysis system	
• Computer	DELL GX260 PC
• Signal and frequency analysis software	Sound Technologies 'SpectraRTA'. 1/1 octave and A-wt real time levels
• Multi-channel audio A/D converter	Aardvark 'Aark 24', PCI sound card with breakout box
• Measurement control and data storage	Microsoft VB6 programming language. NPL in-house developed software controlling SpectraRTA using DDE interface

The microphone sensitivity was checked before and after the measurements using a Brüel & Kjær; type 4231 calibrated calibrator,.

Recognising that environmental conditions, such as wind and temperature, can have an adverse effect on acoustic propagation, meteorological conditions were checked prior to carrying out noise measurements, at a specially set up monitoring station adjacent to the test site. In all cases the wind strength was negligible and temperature and pressure conditions were suitable for noise measurements.

2.6 MEASUREMENT SET-UP FOR SOUND POWER DETERMINATION

The main objective of the experimental measurement programme was to determine the typical repeatability uncertainty due to the operational conditions for a range of real machines. It was not a requirement that the sound power levels be determined in strict accordance with specification of particular noise test codes, as the absolute values were not to be used for declaration purposes. It was necessary to set up the measurement such that sound pressure levels could be monitored continuously over an enveloping surface, enabling evaluation of the variability of sound power level with time and for different operational activities. The method used to evaluate repeatability uncertainty is described in more detail in section 2.7.

2.6.1 Measurement Surface

In practice at least within the UK, it is common that for outdoor machinery, sound power levels are determined using the microphone coordinate system specified in ISO 4872[(13)], which has now been subsumed as a normative annex in ISO 3744[(11)]. The measurement surface comprises 12 microphones although this may be reduced to 6 if preliminary investigations for a particular family of machines show that, by using the reduced number, the surface sound pressure levels do not deviate by more than 0.5 dB from those determined over the whole ten or twelve positions. The "Noise emission in the environment by equipment for use outdoors" Directive 2000/14/EC[(3)] recommends the use of this coordinate system, and makes the point that generally the arrangement with six microphone positions will be used.

This being the case it was considered appropriate that for the purposes of the investigation the coordinates provided by the original ISO 4872[(13)] and Directive 2000/14/EC[(3)], be adopted for determining the sound power levels for each of the selected machines. As the aim was to enable analysis of source variability with time it was considered unnecessary to construct the full 12-point array, where the 6-point array would suffice to provide a relative indication of change in sound power level. A radius of 1.5 m was selected for all machines tested. It is acknowledged that for some of the machines the specific test codes recommend a larger radius. However, it was considered more time efficient to employ a single radius measurement surface allowing a greater number of machines to be examined within the constraints of the project. Reiterating the point made above, the aim was not to obtain precise absolute sound power levels, where the result could be used for declaration purposes, but to monitor noise emission levels continuously over an enveloping surface, enabling evaluation of the variability of sound power level with time and for different operational activities.

2.6.2 Operation of machinery for tests

The following describes the mode(s) of operation adopted for each machine in the determination of sound power levels for the investigation. In the overall analysis, machines have been considered in two distinct categories, as either (i) operating in fixed continuous mode or (ii) activity mode, (indicated below by *).

Leaf blower

Directive 2000/14/EC[(3)], which must be adhered for regulatory purposes, stipulates that the leaf blower shall be operated at its nominal speed, and that the period of observation shall be at least 15 seconds.

These operational requirements were adopted for the investigation and data were acquired to enable analysis over separate periods of 15 seconds duration.

Grass trimmer (1)

Guidance on appropriate operating conditions for determining the sound power level of grass trimmers could be sourced from two documents at the time of the investigation[3,15].

Directive 2000/14/EC[3] refers to grass trimmers specifying basic set up conditions and requires that the test be conducted under load.

ISO/DIS 22868.2-prEN[15], stipulates specific conditions for brush cutters and grass trimmers, and provides a test procedure. It requires that measurement be made for both idling and racing states, which are specified in terms of a work cycle. Essentially, it is required that four separate periods of noise data be obtained totalling at least 20 seconds. Measurements are accepted where the range of values is less than 2 dB.

For the purposes of the investigation, the two grass trimmers were used in the study where each was set up in a fixed position within the hemispherical measurement array and operated at both idling speed and in racing mode, where the throttle trigger was fixed on full power. Data were acquired to enable analysis over separate periods of 20 seconds duration.

Hedge trimmer

Directive 2000/14/EC[3] states that the test be carried out under load, requiring that the hedge trimmer is operated at nominal speed with the cutting device working, and that the period of observation shall be at least 15 seconds.

These operational requirements were adopted for the investigation and data were acquired to enable analysis over separate periods of 15 seconds duration.

Shredder / chipper *

At the time of the investigation it was found that there were two specification sources[3,16] providing information on the appropriate operating conditions for the determination of sound power levels of shredder/chippers.

Directive 2000/14/EC, which must be adhered to for regulatory purposes, requires that the shredder/chipper be tested chipping one or more pieces of wood. It states that the sample of wood should measure 1.5 m long with a diameter equal to the maximum that the machine is designed to accept. It is further stated that the period of observation shall end when there is no more material in the chipping area but it shall not exceed 20 seconds. If both operations are possible, the higher sound power level has to be given.

A noise test code in preparation at the time of the investigation, prEN 13683[16], requires that the machine be run until stable conditions are reached before the test is commenced. It states that the shredder/chipper shall be in the normal stationary position and shall be tested using 2 pieces of dry pine 12 x 24 x 200 mm for each test cycle, which should be no less than 10 seconds. It further requires that when measuring sound power level, tests shall be repeated until three consecutive A-weighted results give values within not more than 2 dB.

Acknowledging the specified operating conditions as referred to above, NPL conducted two separate tests to determine sound power levels with different size samples and work-cycles accordingly.

Chainsaw *

Guidance on appropriate operating conditions for determining the sound power level of chainsaws could be sourced from three documents at the time of the investigation[3,16,17].

Directive 2000/14/EC[3], which must be adhered for regulatory purposes, recommends that the sound power level sound be determined for "under load" conditions, where the chainsaw is on full load sawing wood, and for "free of load" condition, where the engine is powered at maximum revolution without load, commonly referred to as "racing". The Directive refers to ISO 9207:1995[17] for more detailed specification of operating conditions and measurement set up for particular types of chainsaw. Particularly of interest for the investigation, it states that a rectangular beam of non-dried timber be used, and that measurements be made during cross cutting with the throttle fully open.

ISO/DIS 22868.2-prEN[16], which incorporates ISO 9207:19959[17] provides a detailed test procedure giving specific conditions for chainsaws when determining sound power levels. Again, it is a requirement that measurements be carried out for different operating conditions, including full load, racing and idling. For the cutting operation, it requires that a test timber in the form of a rectangular log of depth 260 mm ± 10 mm, having a slot of width 40 mm ± 12 mm be used. It is required that the range of values for each operating condition be less than 2 dB and if this range is exceeded, then the tests should be repeated until four consecutive results fall within the range of 2 dB.

The investigation did not require measurements to be conducted in strict accordance with the test code, where the final result was not to be used for regulatory purposes. For this reason it was considered unnecessary to adopt the detailed specific requirements set out in ISO/DIS 22868.2-prEN[16]. Alternatively for the investigation, it was concluded that it would be appropriate to use a non-dried section of timber, which would require a cutting time of around 20 seconds. Measurements were also conducted for both idling and racing states over prolonged periods.

Lawnmower (1 & 2)

Directive 2000/14/EC[3], which includes requirements for lawnmowers refers to ISO 11094:1991[18] for specification of operating conditions for measurement of noise emission. This standard provides a test procedure for a range of lawnmower types and specifies detailed requirements for operation during the test.

It stipulates that immediately before the noise measurements are conducted, the machine shall be operated for a period of approximately 10 minutes for stabilizing. Measurements should be started immediately following this period. Requirements for both stationary and travelling conditions are given. For measurements with the machinery stationary it is required that no operator should be present, the ground drive be disengaged, and the maximum operating engine/motor speed be used.

Two lawnmowers were used in the study, and the operational requirements for stationary assessment were employed.

Power generator

Directive 2000/14/EC[3] requires that for regulatory purposes, power generators should be tested under load and refers to ISO 8528-10:1998[19] for more detailed specification. The Directive states that the period of observation shall be at least 15 seconds.

For the purposes of determining the relative variability of sound power level over an operational period for the selected power generator, the engine was operated at the maximum power setting with the throttle lever at fixed position. Data were acquired to enable analysis over separate periods of 15 seconds duration.

2.7 REPEATABILITY EVALUATION

The rationale for investigating repeatability uncertainties due to source operating conditions is set out in section 1.3. Essentially the project aimed to obtain an indication of the typical level of repeatability uncertainty for a range of real machines. The following describes the method by which repeatability uncertainty has been determined for this study.

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, 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.

The more repeat determinations that are made the better the estimate (S_r) will be.

To enable a determination of the standard deviation of repeatability for each of the selected machines listed in Table 1, sub-section 2.3, surface sound pressure levels were measured continuously for prolonged periods enabling determination of a large number of sound power levels (L_W) at select intervals. For example, sound power levels could be determined on the basis of 15-second time energy-averaged sound pressure levels, this providing a large sample size for evaluating the standard deviation of repeatability due to operating conditions for a particular machine. This information would however be machine specific describing the typicality of deviation from the true value for only the selected machine. The ultimate aim was, however, to derive values, which represent an estimation of the possibility of a single sound power level determination for categories of machine being different from the average sound power level by a given amount, due to operating conditions. As such it was necessary to consider collectively, repeatability values for different machines in defined categories. It was deemed reasonable to use the mean of calculated standard deviations to represent categories of the standard uncertainty for repeatability δ_{rep}.

This standard uncertainty could then be considered as an individual uncertainty contribution *u*, in the overall scheme of the measurement, where it would be combined with the other components of measurements uncertainty listed in equation 1. The value of combined total standard uncertainty, $u(L_W)$ is given by:

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

where
u_i is the ith uncertainty contribution.
n is the number of individual uncertainty contributions

$u(L_W)$ remains an expression in terms of standard deviation, describing how values typically differ from the average. However, the estimation of the probability of deviation will generally need to be expressed as a percentage of sound power level determinations that are expected to be outside a given range of sound power level. This percentage referred to as a “confidence level” indicates the likelihood of a sound power level determination falling within this range. For the purposes of inclusion in ISO standards a confidence level of 95% would most likely be adopted. As such, where the number of sound power level determinations in a set are very large (as is the case for this evaluation) it can be stated that 95% of sound power level determinations will be within a range of the average sound power level plus 1.96 (which is usually approximated to 2.0) times the standard deviation. This constant, 2.0 referred to as the coverage factor *k*, enables evaluation of the expanded uncertainty *U*, which is a requirement of the *Guide to the Expression of Uncertainties in Measurement*(10), L_W having the interval $[L_W-U, L_W+U]$ covers a range of the values of L_W that might reasonably be attributed to L_W. To that purpose, a coverage factor, *k*, is used (here it is assumed that the coverage factor is 2), such that $U=k.u$.

However, for the purposes of inclusion in an ISO standard only the value of combined total standard uncertainty is required as the value of δ_{rep} will be included in the combined total standard uncertainty for a sound power measurement that will, in turn, be expressed as an expanded uncertainty.

3 RESULTS & ANALYSIS

An extensive series of sound power determinations have been made for a range of machinery, primarily with internal combustion-engine power sources, enabling evaluation of repeatability uncertainties under controlled conditions. The results and analysis are presented and discussed briefly in the sub-sections 3.4.1 to 3.4.10 and are summarised in sub-section 3.5.

3.1 SITE QUALIFICATION

The site was evaluated using the absolute comparison test specified in ISO 3744(6), which is stated as the preferred qualification procedure. It was determined that the site was suitable for the investigation. The results of the site qualification measurement survey are provided in Annex A.

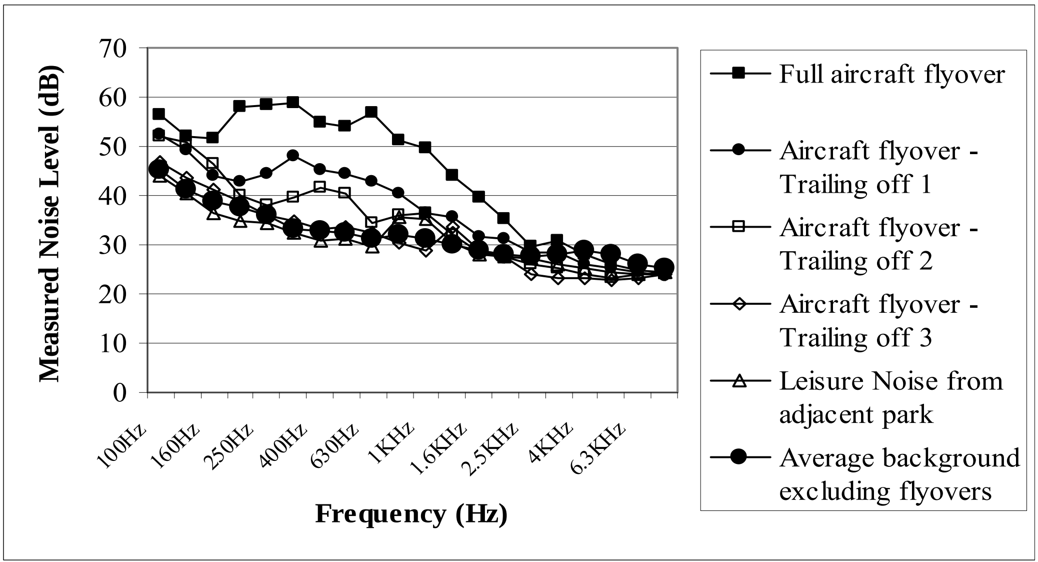
3.2 BACKGROUND NOISE

The test site is subject to a variety of ambient noise sources, mainly aircraft, due to the locality of Heathrow International Airport, and local road traffic due to an adjacent private road. In determining sound power levels of machinery, it is necessary that the sound pressure levels due to background noise (in frequency bands or A-weighted) be at least 6 dB and preferably more than 15 dB below the mean sound pressure level due to the noise source under test. Recognising the potential effect that extraneous noise could have on the experimental results, an initial background noise survey was carried out.

Relatively short background noise measurements were taken in terms of L_{eq} and $L_{n's}$ at a number of periods during the daytime with observations made as to the sources of noise occurring during the measurement. Subjectively it was clear that aircraft and local traffic passbys posed the most significant noise sources.

Data were acquired for particular noise events including a number of discrete aircraft flyovers, and leisure activities in the nearby park. Background noise levels were also measured without the contribution of aircraft noise or local traffic passby's to gain an indication of the likely lower range of noise levels occurring at the site. Figure 2 provides a summary of the typical background noise levels measured at the site in terms of L_{eq} from 100 Hz to 8 kHz.

Figure 2. Typical Noise Levels at NPL Test Site



The corresponding A-weighted average background noise level excluding flyovers was determined to be around L_{Aeq} 61 dB(A) at the test site during the daytime. It was considered likely that the machines selected for the study would generate significantly higher levels than prevailing background noise levels at the site, especially where aircraft flyovers and local traffic passby's could be avoided.

It is noted that the meteorological conditions during the survey were suitable for outdoor noise measurements, with negligible wind strength and temperatures within the range 19˚C to 21˚C, and were representative of the conditions selected for the experimental programme.

3.3 PRELIMINARY ASSESSMENT OF SELECTED MACHINE REPEATABILITY

Prior to carrying out comprehensive noise measurements to enable sound power determinations for each of the test machines, a preliminary examination of the noise emission characteristics of selected machines was conducted. Noise levels were measured at one fixed position. The resulting continuous time-level histories are provided in Annex B, Figure B.1.

The initial assessment determined that for machines operating in fixed continuous mode, the range of A-weighted sound power levels varied during an observation period of approximately 25 minutes from 0.5 dB to 1.3 dB, and the largest standard deviation was 0.2 dB. A chainsaw under load, considered as an activity type operation was also tested at the preliminary stage and was found to have a range of A-weighted sound power levels of 1.1 dB. The calculated standard deviation of repeatability was found to be 0.5 dB.

3.4 REPEATABILITY ANALYSIS FOR A-WEIGHTED NOISE EMISSION LEVELS

Section 2 sets out the experimental methodology, where sub-section 2.6.2 describes specifically how the selected machines where operated for the noise emission measurements. Section 2.6 describes, in general terms the method for evaluating repeatability uncertainty. This section provides a summary of the results obtained from the experimental programme, focussing on the A-weighted repeatability calculated for each machine, determined from an extensive database of measured values.

Figures B.2 to B.10 given in Annex B, show continuous time-level histories of the surface average L_{Aeq} or "sound power level"(L_w), determined over the measurement array described in sub-section 2.6.1. The period of observation is in most cases 15 seconds, ($L_{Aeq,15sec}$) with the exception of the grass trimmers, where the L_w has been determined on the basis of $L_{Aeq,20sec}$, and the chainsaw and shredder/chipper have been analysed in terms of event duration. The noise levels have been normalised relative to the start period.

The following provides a brief analysis for each machine, referring to detailed time-level history charts given in Annex B. A summary of the results is given in Table 6, section 3.5.

3.4.1 Leaf blower

Noise emission levels for the leaf blower were measured on three separate occasions, over different durations ranging from 10 minutes to 97 minutes. In each case there was a short period allowed for machine/engine stabilisation. In accordance with the requirements of Directive 2000/14/EC[ref], sound power levels where determined over 15 second periods of observation, in terms of L_{Aeq}.

Using the data presented in Figures B.2, the calculated range of L_{Aeq} and standard deviation were found to be 0.4 dB and 0.1 dB respectively.

3.4.2 Grass trimmer (1)

After a short period to allow for stabilisation, the petrol driven grass trimmer (1) was measured in racing mode as is required by ISO/DIS 22868.2-prEN[14].

Figure B.3 shows the time-level history of the sound power level (L_w) determined over a duration of 16 minutes, in terms of $L_{Aeq,15sec}$. The overall range of L_{Aeq} determined over this period was 0.3 dB, which is clearly significantly less than the required 2 dB. The standard deviation of repeatability calculated from the 15-second samples was 0.1 dB.

3.4.3 Grass trimmer (2)

Noise levels were monitored for this electrically powered grass trimmer over a period of 64-minutes from start up. Figure B.4 shows the time-level history of the sound power level (L_w) determined over this period, in terms of $L_{Aeq,15sec}$. It is apparent that over the first 30-minutes, there is a gradual decrease in level of around 1 dB. Calculating the standard deviation of the entire period, a value of 0.2 dB results. The corresponding range is 1.2 dB. If the period following the first 30-minutes is used, the standard deviation reduces to 0.1 dB and range reduces to 0.3 dB.

3.4.4 Hedge trimmer

Figure B.5a shows the time-level history of the sound power level (L_w) determined for the hedge trimmer in idling mode over a duration of 18 minutes. Although it is not generally necessary to determine hedge trimmer idling levels, the results have been included here as they clearly demonstrate the need for a warming up period, indicating a gradual increase in level of nearly 2 dB over about the first 10 minutes of operation. If the warm up period is not allowed for and the range and standard deviation are calculated over the full 18-minute period, the results would be 2.8 dB and 0.7 dB respectively. Acknowledging the warm up period, where the results are analysed for the period following the first 10 minutes, the values are significantly reduced, where the range was determined as 1.2 dB, less than 2 dB which is generally required by standardised methods, and the standard deviation of repeatability equalled 0.3 dB.

The hedge trimmer was measured in racing mode, as is required by Directive 2000/14/EC[3] on a separate day. From Figure B.5b, it can be seen that there is again a need to allow for a warm up period, although the increase in level is not as significant as for the idling condition. The machine was allowed to stabilise for 20 minutes, thereafter the measured results have been used. The range and standard deviation of repeatability were found to be lower than the idling condition, at 0.5 dB and 0.1 dB respectively.

3.4.5 Shredder / chipper

Acknowledging the specified operating conditions discussed in section 2.6.2, two separate tests were carried out to determine sound power levels with different size samples and work-cycles.

Sound power levels were determined using short timber samples, measuring 12 x 24 x 200 mm. Figure B.6a shows the time-level histories, in terms of $L_{Aeq,1sec}$ for 6 repeats. It is apparent that repeat 5 is significantly different to the other measurement results. Where the range and standard deviation are calculated using all 6 repeats, values of 13.1 dB and 5.0 dB result. These values are greatly reduced, if the fifth repeat is not considered, where the range is 2.6 dB and the standard deviation is 1.2 dB. However, as noted in 2.6.2, a determined sound power level can only be accepted where it has been confirmed that the range calculated from repeated determinations is within 2 dB. It was determined that the range over events 2 to 4 was 1.9 dB. Using this dataset, the corresponding standard deviation was found to be 1.1 dB.

Additionally, sound power levels were determined where the machine was loaded with timber sections measuring 1.5 m long. Figure B.6b shows the time-level histories, in terms of $L_{Aeq,1sec}$ for 5 repeats. Average sound power levels were determined for each repeat, lasting up to 20 seconds. The range over all the measurements was found to be 4.5 dB, and the corresponding standard deviation over the five repeats was found to be 1.7 dB. Again, however, the criteria of a maximum range of 2 dB had to be observed. It was determined that the range over events 3 to 5 was just slightly over 2 dB. Using this dataset, the standard deviation was recalculated and found to be 1.1 dB.

3.4.6 Chainsaw

Measurements were conducted for two modes of operation; racing (after an initial period of idling) and under full load, where a non-dried section of timber was cut.

Figure B.7a shows a time-level history for the chainsaw in idling and racing modes, although only data for the racing mode was used. The range value for operation in racing mode was determined to be 0.6 dB and the standard deviation equated to 0.2 dB.

Noise levels measured for the chainsaw under load for eight activity events are shown in Figure B.7b in terms of $L_{Aeq,1sec}$. The average sound power level was determined for each repeat for a select 20-second period, accounting for the sawing activity. The range and standard deviation were then calculated for each repeat, and found to be 2.6 dB and 1.1 dB respectively.

However, as noted in 2.6.2, a determined sound power level can only be accepted where it has been confirmed that the range calculated from repeated determinations is within 2 dB. It was determined that this criterion was achieved over events 3 to 6 and 4 to 7. Using these datasets, where the range equated to 2.0 dB, the standard deviation was re-calculated and found to be 0.9 dB.

3.4.7 Lawnmower (1)

The petrol driven lawnmower was operated for a period of around 20 minutes to allow for engine stabilisation. Figure B.8 shows the sound power levels determined over 15-second intervals for a period of around 40-minutes. The range of results was 0.8 dB and the standard deviation was calculated as 0.2 dB.

3.4.8 Lawnmower (2)

Figure B.9 shows the time-level history of the results obtained from operation of lawnmower (2) from the period of start-up, in terms of 15-second periods of observation. It is apparent that for the first 60-minutes, the absolute measured level increased steadily by around 2 dB. Clearly there was a need to allow for engine stabilisation. Allowing for 10 minute warm up period, which is nominally required for many machines, the range equates to 2.0 dB and the corresponding standard deviation is 0.6 dB. This test machine had not been used prior to the test for around 2 years, and although it was determined as being in proper working order, it may have benefited from an engineering service. If the increase over the first hour is accounted for and removed in the calculation, the range values and standard deviation are reduced significantly to 1.2 dB and 0.2 dB.

3.4.9 Power generator

Figure B.10 shows the time-level history of the results obtained from operation of the diesel power generator from the period of start-up. A steep rise in level with the first 5-minutes can been seen. Recognising this, a stabilisation period of 10-minutes was allowed for prior to calculation of the range and standard deviation. For the period around 25 minutes following stabilisation, the range was found to be 0.4 dB and standard deviation 0.1 dB.

3.4.10 Reference Sound Source

As a control measure, a calibrated reference sound source was examined for stability at the site. It was found that the standard deviation of repeatability calculated from 15-second samples over a period of a few minutes was less than 0.1 dB

3.5 RESULTS SUMMARY

The results as discussed in sub-sections 3.4.1 to 3.4.10 are summarised in Table 3. It should be noted that data provided in the summary table is that which has been used in the overall uncertainty analysis. These data are based on the principle of allowing for machine stabilisation and repeat measurements to ensure reasonably limited range values. The Table also includes a mean value for all machines, for fixed continuous machines and for activity machines.

Table 3 Results Summary

Machine Name	Operational category	Stabilsation period allowed (minutes)	Period of observation (Measurement averaging time)	Number of repeat Lw determinations	Range (dB)	Standard Deviation (dB)	Probability distribution	Distribution divisor	Uncertainty, u ± dB
Leaf blower	Fixed continuous	10 minutes	15	97	0.4	0.1	Normal	1	0.1
Grass trimmer (1)	Fixed continuous	10 minutes	15	65	0.3	0.1	Normal	1	0.1
Grass trimmer (2)	Fixed continuous	10 minutes	15	214	0.7	0.2	Normal	1	0.2
HedgeTrimmer - Idling	Fixed continuous	10 minutes	15	33	1.2	0.3	Normal	1	0.3
HedgeTrimmer - Racing	Fixed continuous	20 minutes	15	73	0.3	0.1	Normal	1	0.1
Shredder / chipper (Short timber) *	Activity	10 minutes	<=20	5	1.9	1.1	Normal	1	1.1
Shredder / chipper (Long timber) *	Activity	10 minutes	<=20	5	2.1	1.1	Normal	1	1.1
Chainsaw *	Activity	5 minutes	Event	8	2.0	0.9	Normal	1	0.9
Chainsaw	Fixed continuous	Following activity	15	10	0.6	0.2	Normal	1	0.2
Lawnmower (1)	Fixed continuous	20 minutes	15	158	0.8	0.2	Normal	1	0.2
Lawnmower (2)	Fixed continuous	10 minutes	15	299	1.2	0.2	Normal	1	0.2
Generator	Fixed continuous	10 minutes	15	105	0.4	0.1	Normal	1	0.1

Mean

All	0.37
Fixed continuous	0.15
Activity	1.02

Expanded Uncertainty

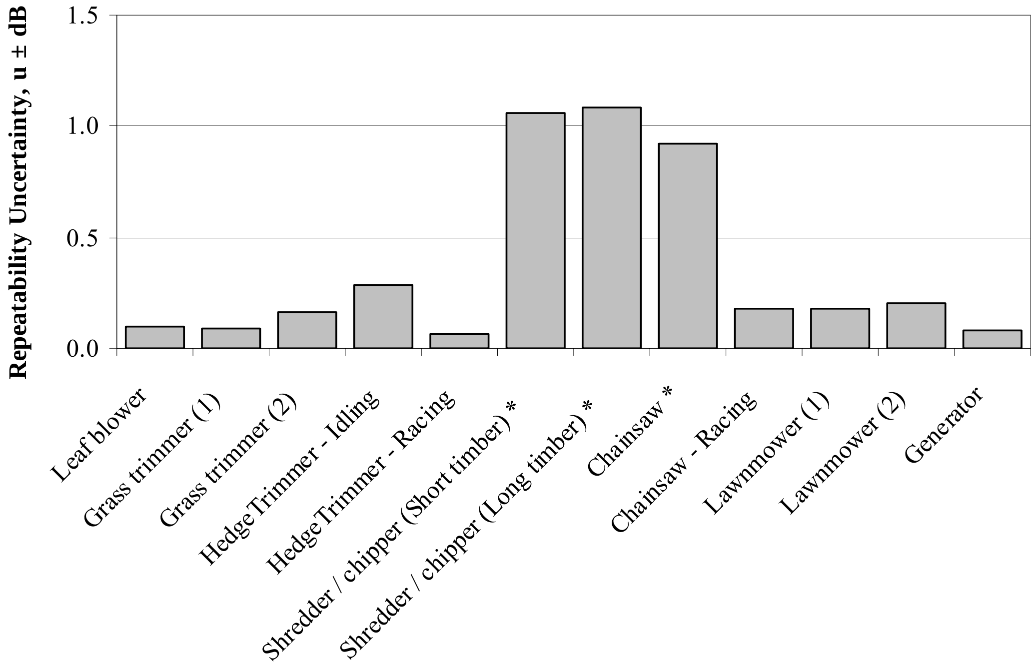
All	0.7
Fixed continuous	0.3
Activity	2.0

3.5.1 Summary Discussion

Further to a preliminary assessment, a large number of sound power determinations were made for a variety of different machines on the basis of an extensive series of controlled noise measurements at a qualified outdoor test site. Table 3 indicates the range values and standard deviations of repeatability calculated from data obtained. Operation of the machines has been considered in two distinct categories; (i) fixed continuous and (ii) activity. Using these data, mean values for the combined total uncertainty and for the expanded uncertainty have been evaluated and are given in Table 3.

It is clearly apparent that there is a distinct difference in repeatability between machines that are tested in a fixed continuous mode, and those, which require activity type operation. This is further illustrated in Figure 3.

Figure 3. Difference in repeatability between machines



Note: * Activity type mode

Standard deviations for machines operated in fixed continuous mode were generally found to be less than 0.2 dB, although the actual range of σ_r was from 0.1 to 0.3 due a slightly higher value resulting from the hedge trimmer when assessed in idling, which generally does not need to be considered for regulatory purposes. Accounting for a normal probability distribution in the evaluation of individual uncertainty for each machine, the mean uncertainty for fixed continuous machines was found to be 0.2 dB after rounding.

The standard deviations of repeatability determined for machines tested with an activity type operation were found to range from 0.9 dB to 1.1 dB. Again, accounting for a normal probability distribution in the evaluation of individual uncertainty for each machine, the mean standard uncertainty for machines assessed with repeated activities indicated a total standard uncertainty of 1.0 dB.

Although it is not necessarily a requirement at this stage to convert the total standard uncertainty to an expanded uncertainty, as the determined values will ultimately be combined with other the uncertainty parameters listed in equation 1, it is interesting to observe the potential magnitude of uncertainty due to repeatability resulting from operating conditions. If the value for fixed continuous mode machines is taken as 0.2 dB and activity type machines is 1.0 dB, the expanded uncertainty *U* associated with the measurement would be 0.4 dB and 2.0 dB.

The value for activity type operation, in terms of expanded uncertainty is clearly high when it is considered that the grade of accuracy applied to the measurement method as specified in ISO 3744, used to obtain the results is classified "engineering", which requires the standard deviation of reproducibility σ_R to be equal to or less than 1.5 dB. Indeed, even the value in terms of standard uncertainty could be considered high. The value is close to the limit of the required reproducibility value, which is a concern when it is considered that uncertainties due to repeatability must be combined with other measurement uncertainties as listed in equation 1, such as s_{lim} accounting for error in the measuring instrumentation, or δ_{K2} allowing for error in the environmental correction.

The findings bring into question the appropriateness of the engineering grade classification where the method is used for determining sound power levels of machines, which are tested by repeated individual activities.

To aid analysis of how repeatability due to operational conditions affects the measurement result, reference has been made to a previous study conducted at NPL[(20)], which involved a round robin assessment of selected machines as part of a development project to improve measurement rapidity. The output provided a reliable database of reproducibility data for a range of machines tested by the methods specified in the ISO 3740 series[(4-9)]. The machines used were, if considered under the categories used for this investigation, all operated in fixed continuous mode. All the machines used were also small. It determined that a value of 1.5 dB as specified for ISO 3744 accounting of reproducibility was reasonable for small machines tested in fixed continuous mode operation. The findings set out in this report indicate that for such machines the repeatability contribution to the overall reproducibility values is 0.2 dB, allowing over 1 dB for all other contributions. This confirms that the engineering grade of accuracy assigned to the method is appropriate where the method is used to quantify small machines operated in fixed continuous mode.

The same cannot confidently be concluded for machines tested by activity type operation. The validity of the engineering grade has been confirmed in the past for only a limited number of machines, which did not require activity type operation. It has been found that uncertainty due to repeated activity can result in levels close to the 1.5 dB values for reproducibility.

The implications of high uncertainty for machines tested by activity type operation are serious. Users of the standards are permitted to use the standard deviation of reproducibility provided by the B-Type standards to evaluate a guaranteed noise level. Hence, where ISO 3744[(6)] is employed, a value of 1.5 dB may be added to determined sound power level. However, this correction to account for measurement uncertainty may be below what the actual uncertainty is, and as such the level declared may be inaccurate. This is unacceptable where the noise level may be indicated on a noise label to assist consumers in decision-making, and even more so where the value declared is compared against a legal noise limit.

It should be made clear to the users of the standards that the uncertainty associated with a sound power level determined where the machine is tested by repeated activities events, can be large. It is further considered that users should not be permitted to use only the 1.5 dB for derivation of the guaranteed noise level. The problem should be assessed by those providing C-type standards. Options to address the problem include either (i) providing a clear definition of machine set-up and operating conditions allowing for example, a period of stabilisation or (ii) quoting reliable uncertainties for particular machines to be used in the derivation of the guaranteed noise level.

The focus of the analysis has been on the calculated standard deviations as these values provide a measure of the spread of sound power level datasets, describing how values typically differ from the average. However, it is apparent that the range of values determined has the potential to be significantly higher for select machines. The shredder/chipper for example, when tested repeatedly with long samples of timber resulted in a range of up 4.5 dB where all events were considered. For the machines operating in a fixed continuous mode, the range of values were generally lower than for activity type operations but the values were much larger than the standard deviations. Fixed continuous mode machines were generally found to have higher range values where the absolute noise level emitted by the machine had either increased or decreased over a prolonged period of time, see for example Figure B.9 in Annex B. It is noted that if range values were determined for select intervals during the prolonged period of time, say the first or last 10 samples of Lw, the range would be greatly reduced.

There are two important points to consider in assessing the implications of a resulting wide range value. Firstly, from a practical perspective it must be acknowledged that the absolute level determined for a particular machine may vary considerably depending upon when, in the duration of operation, the noise measurements have been taken. It may be possible to achieve a lower noise level if a machine is left to run for a certain amount of time. Conversely, it may be better to make the measurement as soon as possible after start up. The second point, which is not unrelated to the first, is that the potential variation in level over a prolonged period of operation is a source of uncertainty. A machine may be tested at one laboratory not long after start-up, and may be re-measured at another site at a different period in the duration of operation. The absolute levels determined could vary significantly purely due to operating conditions of the machine. This is important considering that the absolute values are often required for regulatory declaration purposes, where an appointed Notified Body may check guaranteed levels independently. This becomes especially relevant where noise limits are placed on the machines.

There are two possible approaches to deal with the issue of potentially wide range values. The first, which is currently implemented in some of the existing and proposed C-Type standards, is that limits be set on the operating conditions for the measurement, in the form of acceptable range values and/or, a measurement time window, allowing for example, a period of engine stabilisation. The effect of such limits will effectively control the repeatability and reproducibility uncertainty. The second more difficult approach would be to use the determined range of values in the overall uncertainty analysis. However, it is considered that this approach would be unreasonable, primarily because the higher range values can be avoided where operational conditions for the test are set to achieve the lower values.

Finally, in close to the discussion, it is recognised that there were limitations to the investigation. Most notably, only a small number of sources were examined relative to the potential number machines with different operating conditions. Other machines, particularly large assemblies may exhibit different repeatability due to operating conditions. It is also acknowledged that the set-up of the machines was not in strict adherence with the requirements of the C-Type standards. However, this is not a significant concern as the object of the study was to examine relative differences between repeat measurements, and not to determine the absolute emission level for particular machines.

4 CONCLUSIONS

An extensive series of sound power determinations have been conducted on a range of machinery, primarily with internal combustion-engine power sources, which enabled evaluation of actual repeatability uncertainties for real machines under controlled conditions. The primary aim was to provide data that would be a useful contribution to aid the introduction of full uncertainty budgets within the ISO 3740 series[(4-9)] of sound power standards.

In the overall data analysis, machines have been considered in two distinct categories, as either (i) operating in fixed continuous mode or (ii) activity mode. The mean standard uncertainty for fixed continuous machines obtained from an analysis of a range of sources was found to be 0.2 dB. Using a dataset of standard deviations of repeatability determined for machines tested with an activity type operation, the mean standard uncertainty was found to be 1.0 dB.

The findings bring into question the appropriateness of the "engineering" grade classification where the method is used for determining sound power levels of machines that are tested by repeated individual activities.

The absolute emission level or sound power level for particular machines may vary considerably where the machine is operated over a prolonged period. Large range values were particularly observed for machines tested with an activity type operation.

5 RECOMMENDATIONS

It is recommended that categorised values be made available to account for δ_{rep} in the uncertainty budget set out in equation 1, which is now included in ISO 3744[(6)].

As a preliminary estimate, it is proposed that the following categorised values given in Table 4 be used for the uncertainty budget included in ISO 3744[(6)].

Table 4. Proposed values for δ_{rep} according to category.

Category of operation for small machines	δ_{rep}
Fixed continuous mode	0.2 dB
Activity mode	1.0 dB

It is considered that the categories offered are appropriate only for small machines. It is therefore recommended that further work be carried out to evaluate the influence of operating conditions on measurement repeatability for other machines, especially large assemblies.

Recognising the potential for variation in the absolute noise level emitted by a machine where the output may either increase or decrease over a prolonged period of time, the principle of defining the specific operation conditions and setting limits on range values in C-Type standards is supported.

6 ACKNOWLEDGEMENTS

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ANNEX A: SITE QUALIFICATION SURVEY

This annex provides information and results obtained from the site qualification measurement survey carried out 11/07/2003, in accordance with methods summarised in sub-section 2.4.1.

Absolute comparison test

Table A.1 indicates the environmental correction K_2 for 1/3-octave frequency bands and overall A-weighting, determined from the measurements made at the NPL site.

K_{2A} was found to be 0.4 dB(A). ISO 3744[(6)] specifies that for engineering grade measurements, where K_{2A} must be numerically less than or equal to 4 dB. It was concluded that the site was suitable for the determination of sound power levels for the purposes of experimental investigation.

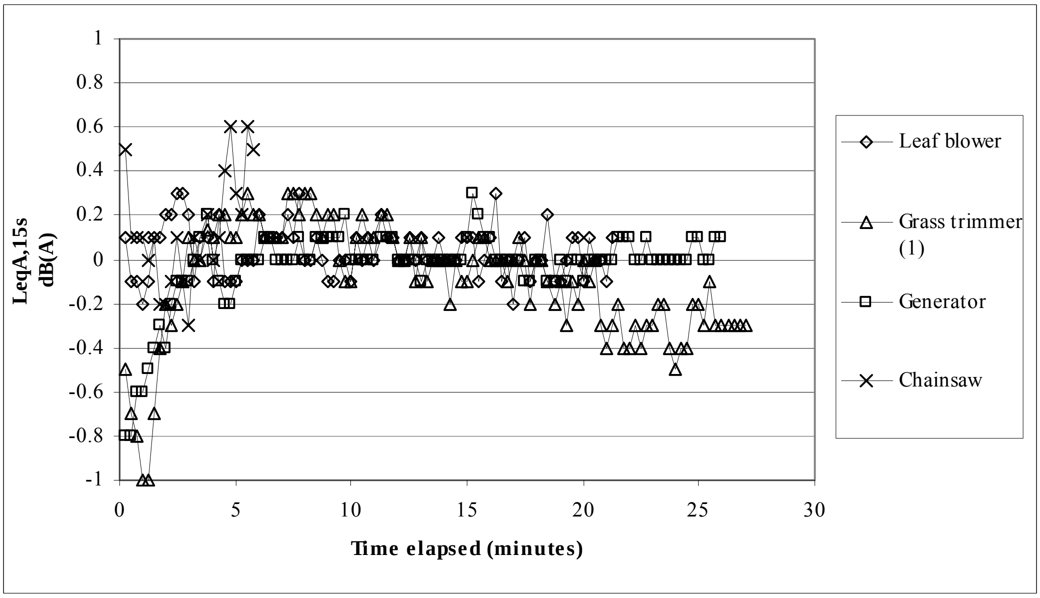
Table A.1 Results from absolute comparison test.

1/3 Octave Frequency band (Hz)	**RSS L_w determined from site measurements. (dB)**	**Calibrated L_w values for RSS. (dB)**	**K_2**
100	75.1	77.0	-1.9
125	74.9	75.5	-0.5
160	74.8	75.6	-0.8
200	75.7	76.4	-0.6
250	76.8	77.3	-0.6
315	76.7	77.3	-0.6
400	75.9	76.9	-1.0
500	76.4	77.0	-0.6
630	76.9	77.4	-0.5
800	79.0	79.3	-0.3
1000	80.1	80.4	-0.3
1250	82.0	82.0	0.0
1600	81.3	81.6	-0.4
2000	80.5	81.1	-0.5
2500	78.5	77.6	0.9
3150	80.0	78.2	1.8
4000	81.0	79.3	1.7
5000	80.2	78.9	1.3
6300	79.2	76.9	2.3
8000	77.9	74.8	3.2
10000	74.1	72.9	1.2
A wtg	**91.4**	**91.0**	**0.4**

ANNEX B: TIME-LEVEL HISTORY RESULTS

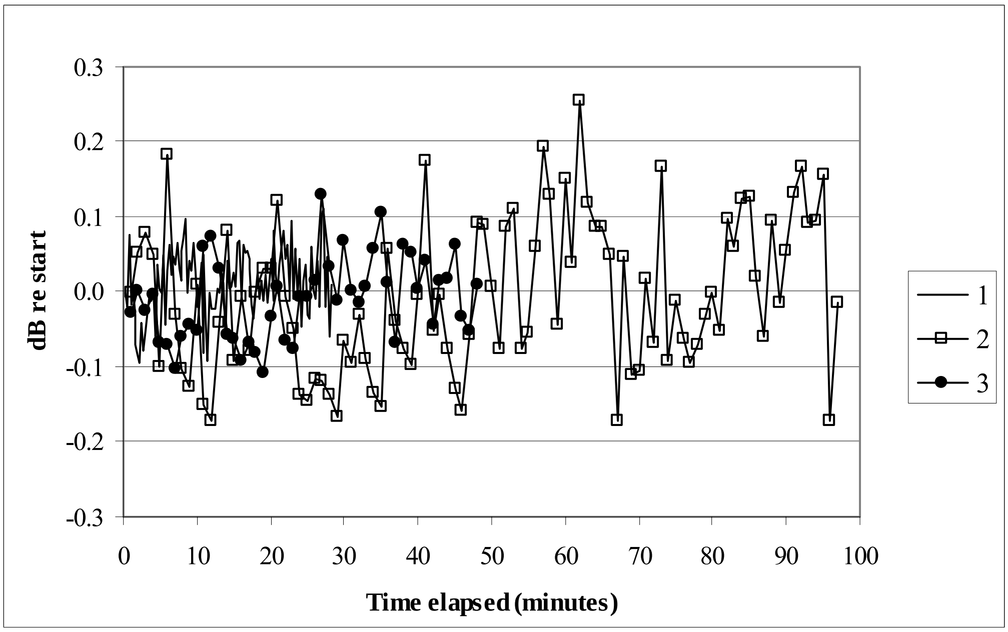
Results of preliminary assessment

Figure B.1 Normalised time-level history for range of machines measured at single position



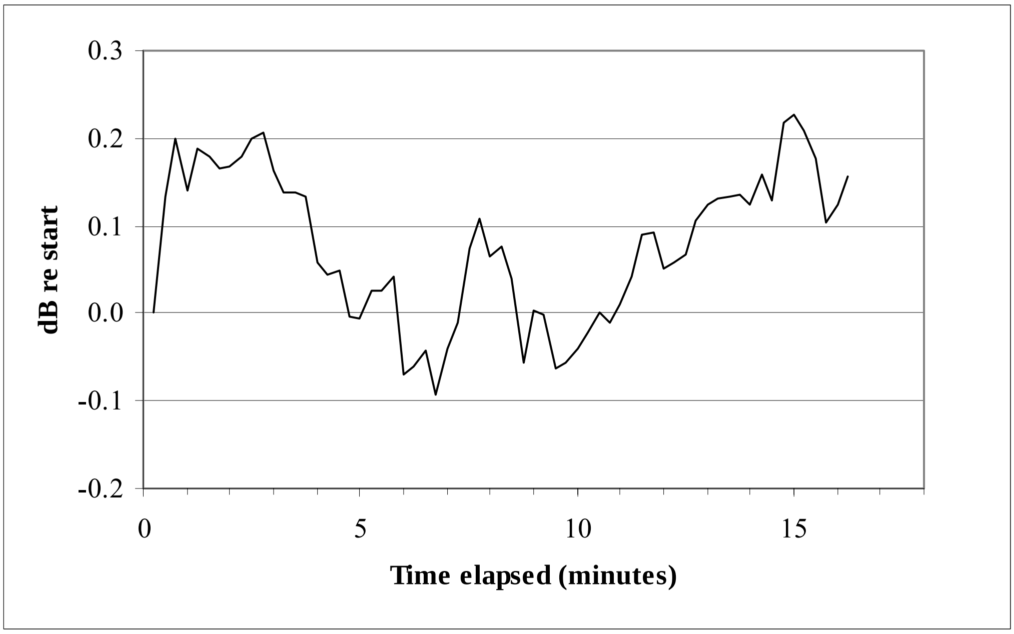
Leaf blower

Figure B.2 Sound Power Levels determined over 15-second periods for Leaf blower ***(3 repeats, normalised for initial throttle setting)***



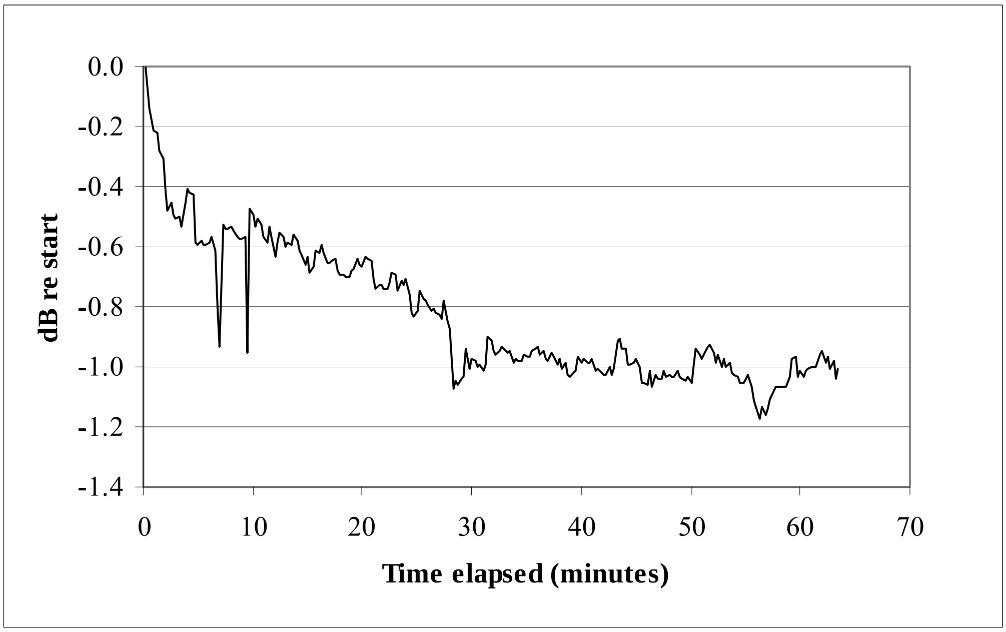
Grass trimmer (1)

Figure B.3 Sound Power Levels determined over 15-second periods for Grass trimmer (1) - Petrol



Grass trimmer (2)

Figure B.4 Sound Power Levels determined over 15-second periods for Grass trimmer (2) – Electric



Hedge trimmer

Figure B.5a Sound Power Levels determined over 15-second periods for Hedge trimmer - Idling

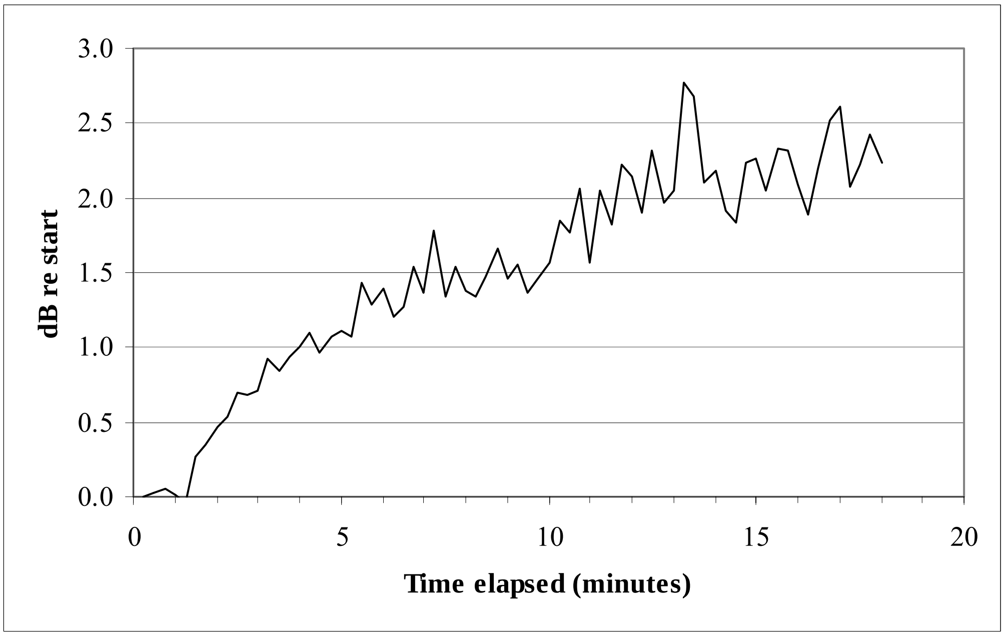
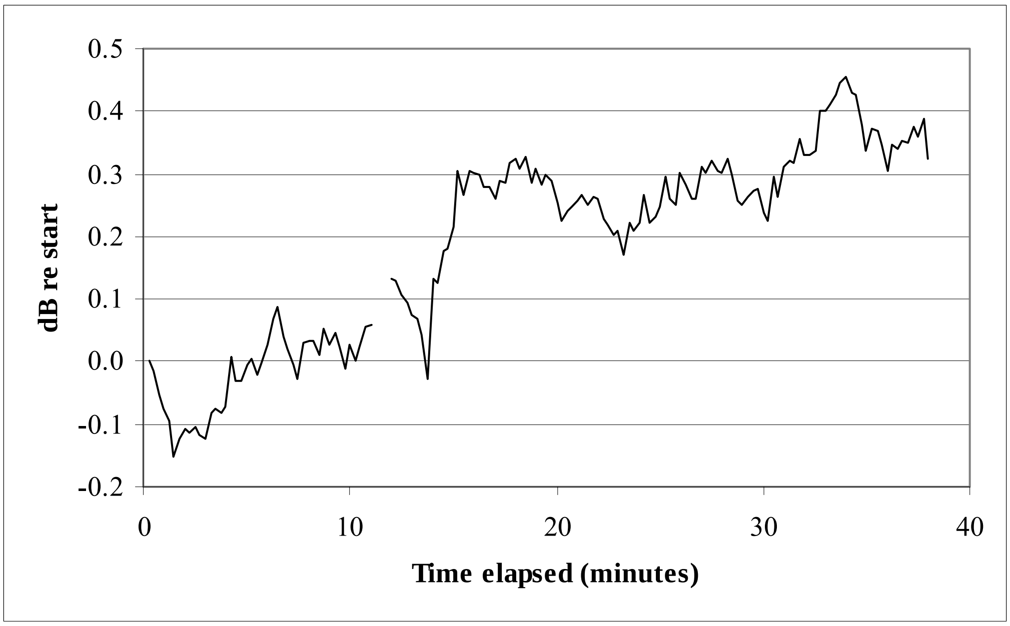


Figure B.5b Sound Power Levels determined over 15-second periods for Hedge trimmer - Racing



Shredder / chipper

Figure B.6a Sound Power Levels determined over 1-second periods for Shredder/chipper (short timber samples)

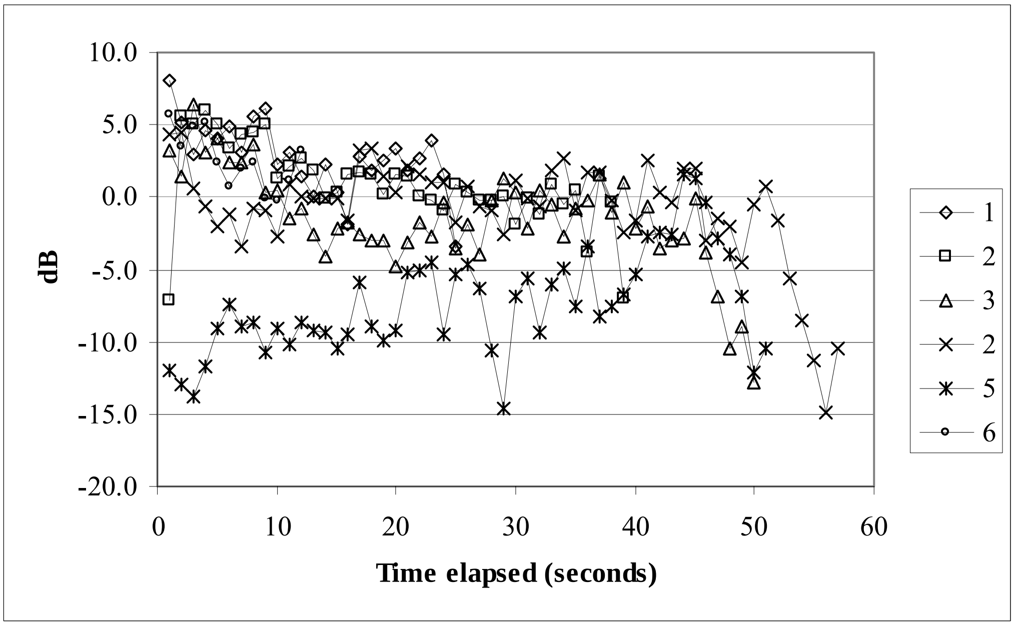
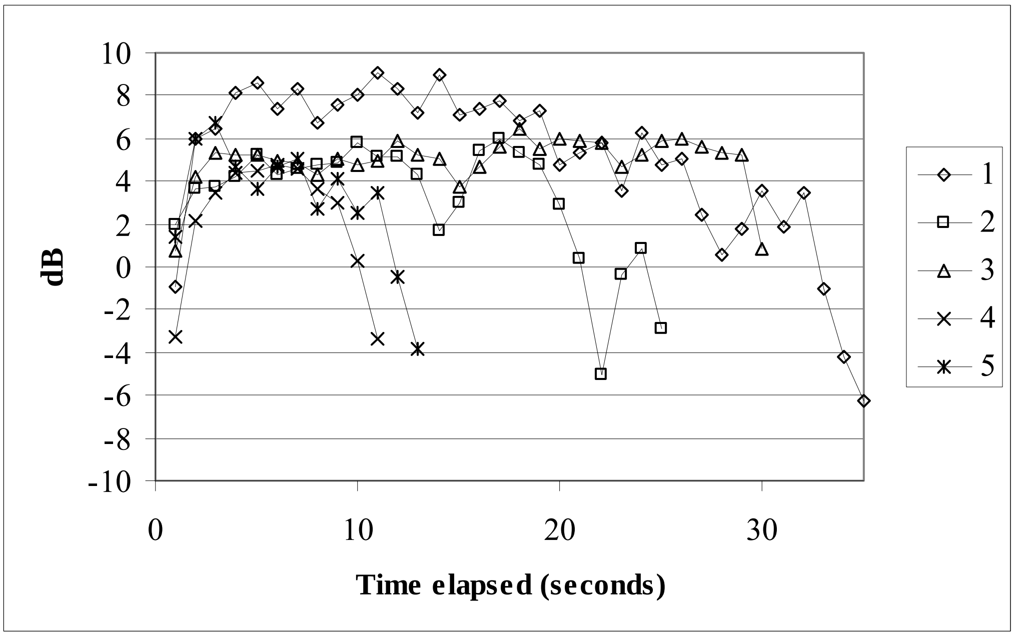


Figure B.6b Sound Power Levels determined over 1-second periods for Shredder/chipper (Long timber samples)



Chainsaw

Figure B.7a Sound Power Levels determined over 15-second periods for Chainsaw in Idling then racing mode

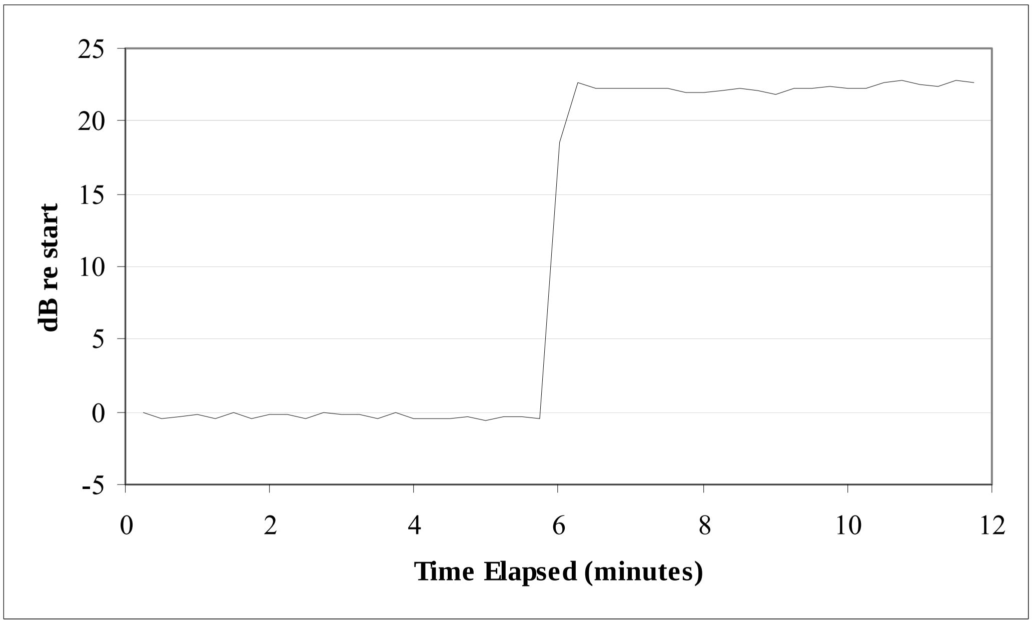
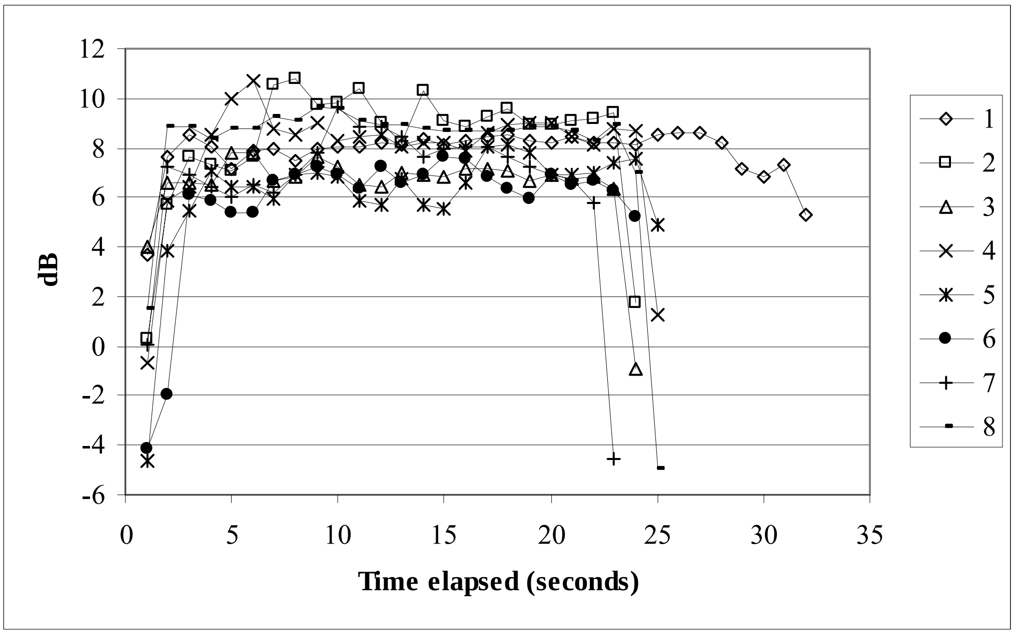
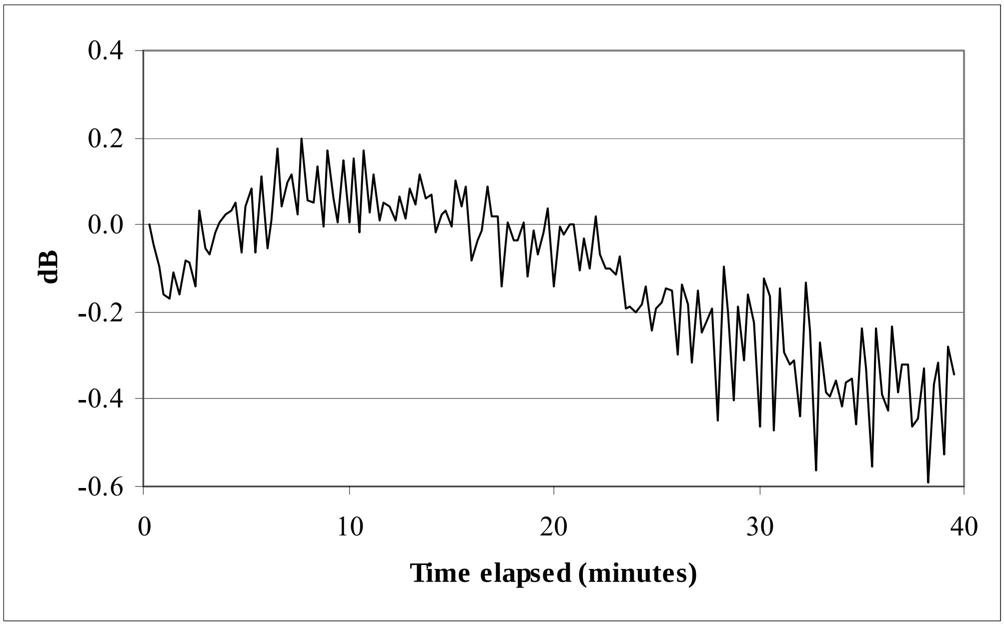


Figure B.7b Sound Power Levels determined over 1-second periods for Chainsaw under load



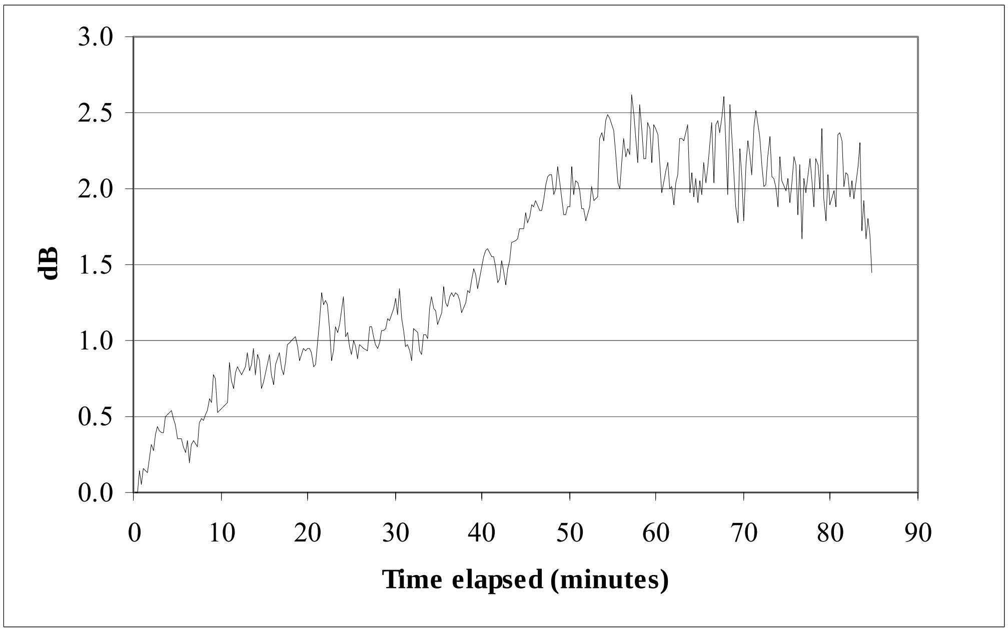
Lawnmower (1)

Figure B.8 Sound Power Levels determined over 15-second periods for Lawnmower (1) stationary



Lawnmower (2)

Figure B.9 Sound Power Levels determined over 1-second periods for Lawnmower (2)



Power generator

Figure B.10 Sound Power Levels determined over 1-second periods for Power Generator