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Development of an in-service noise testing procedure for motorcycles

by G J Harris and P M Nelson

Unpublished Project Report
PR/PR/SE/037/94
S030L/VB

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No 7

TRANSPORT RESEARCH LABORATORY
An Executive Agency of the Department of Transport

PROJECT REPORT
PR/SE/037/94

DEVELOPMENT OF AN IN-SERVICE NOISE TESTING PROCEDURE FOR MOTORCYCLES

by G J Harris and P M Nelson

This report has been prepared for:

Project Record: S030L/VB In-Service Noise Testing
Customer: Vehicle Standards and Engineering Division, DOT (Mr A Brown)

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1994

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EXECUTIVE SUMMARY

This Project Report was produced as part of work carried out under Project SO30L/VB, 'In-Service Noise Testing', for Mr Andrew Brown of Vehicle Standards and Engineering Division (VSE2) of the Department of Transport.

The Department of Transport have commissioned TRL to carry out a programme of research and testing to evaluate procedures appropriate for the assessment of in-service vehicle noise. This Project Report describes the work carried out as part of Phase 1 of this project which is concerned with the development of in-service test procedures for motorcycles and mopeds. The Report considers the implications of testing noise emissions from motorcycles in both outdoor and an indoor environment such as a MOT test workshop and gives the results of measurements taken in different test locations on a range of motorcycles selected to be representative of the current motorcycle population in the UK. The Report also considers the use of low cost, industrial grade instrumentation, in order to provide information on the additional errors which may be introduced due to the use of test equipment with lower specification tolerances.

The results of the study confirmed that the in-service motorcycle noise test procedure described in the European Union Directive 78/1015/EEC was a relatively simple test to perform which could be carried out without the need for complex instrumentation.

The results of measurements taken in workshop locations indicated, that the in-service test procedure did not give measured noise levels which were consistent with the test levels obtained at the standard outdoor test site. The errors were particularly noticeable when the motorcycles were positioned in the centre position in each workshop where differences between the correct test levels and those measured in the workshops were found to be in the range 0 – 6 dB(A) depending upon the motorcycle under test and the test site location. The higher noise levels found in the workshops have been attributed to the reverberation characteristics of the enclosed spaces and to the production of standing waves in the vicinity of the measurement position. Since different indoor test locations will have different acoustical characteristics over the frequency range of interest, and the range of motorcycles that will need to be tested will also provide a broad range of noise sources with widely differing frequency characteristics, it has been concluded that it is not possible to conceive of a practical in-service test procedure based on measurements taken inside an enclosed space such as a garage test bay or workshop.

Although there are considerable reservations associated with using the close proximity test procedure with the motorcycle located inside an enclosed space, the errors associated with this test location were reduced when the motorcycle was positioned in an open doorway with the exhaust pointing outwards and were virtually eliminated when the motorcycles were tested outdoors but under non-standard site conditions. This indicates that provided motorcycles can be tested outdoors, virtually any location will be suitable provided the ambient noise levels produced by other sources are not excessively high. It follows that tests carried out on garage forecourts, outside workshops and at the roadside, would, with few exceptions, all be suitable for in-service testing.

The measurements taken with the low cost instrumentation produced close proximity noise levels which were systematically 1 to 2 dB(A) higher than the corresponding noise levels obtained using the precision grade equipment. These differences were attributed to differences in the tolerances associated with the averaging time circuitry in the two instruments. Further work in this area is indicated to provide a better understanding of the range of results obtained with low cost instrumentation and to determine whether improvements can be made to the equipment tolerances without affecting the overall cost.

Using the results of this study possible limit values for close proximity noise levels have been suggested. It was found that with the close proximity limits for small (i.e. <80cc) motorcycles set at 91 dB(A), and the corresponding limits for the medium and large capacity machines set at approximately 94 dB(A) and 99 dB(A) respectively, there would be a low probability that a motorcycle would fail to meet the close proximity limits and then would subsequently pass the drive-by type approval test.

1. INTRODUCTION

The noise emitted by road vehicles is controlled in many countries by regulations and test procedures which limit the noise from new vehicles prior to their registration and entry into service. Prominent among these are the member countries of the European Union where test methods and limit values for different vehicle categories have been imposed since the early seventies. These limits have been progressively lowered, following a series of amendments to the original Directives. In addition, changes to the test procedure have meant that, for some vehicle types, the level of permissible noise has been effectively reduced by more than 9 dB(A) since the limits were first introduced. Further substantial reductions in vehicle noise have been adopted by the Council of Ministers which will be brought into effect in the UK for most new vehicle types by October 1996.

While the noise limits and test procedures introduced provide a means of controlling and monitoring the noise emission performance of new vehicle types, prior to their entry into service, the question arises as to whether further checks are needed during the lifetime of the vehicles to ensure that they continue to conform to the standards achieved at type approval. In-service checking and test procedures have been introduced in some countries but, as yet, there is no international agreement on the preferred method of testing or to the limit values that would be applied to different vehicle categories.

At present, roadside checks are mainly limited to visual or aural inspections of exhaust systems for mechanical defects, or in controlling the manner of use of vehicles to reduce the nuisance caused. Clearly, the full environmental benefit of reduced type approval noise limits will not be realised until it can be assured that vehicles, when in service on public roads, are so maintained that their noise emission remains at or near the type approval levels.

Various regulatory standards have been imposed by different countries as a means of controlling the noise emitted by road vehicles in-service. These are summarised in the TRL Working Paper WP/NVU/05 'The control of noise from vehicles in-service (A review of test methods and enforcement practice'). The main conclusions reached in this review were that regulations governing the in-service noise generated by motorcycles and mopeds could be introduced in the UK fairly quickly and the exhaust noise test specified in ISO 5130 or EEC 1015 could form the basis of a suitable test.

For cars and trucks, it was recommended that it was necessary to measure the noise both from the power unit and the exhaust system by taking measurements midway between the engine centre and exhaust outlet. The vehicle's engine would be accelerated from idle to governed speed for diesel powered vehicles and to 4000 rpm for petrol engined vehicles before deceleration and noise measurements. In the latter case there was a danger of over-speeding and consequential engine damage and so simple, low cost instrumentation would be needed to cut the engine at just above the required speed or to control the maximum rpm in some other way.

Having considered the results of this earlier review the Department of Transport have commissioned TRL to carry out a further programme of research and testing to evaluate suitable test procedures for in–service noise testing of road vehicles suitable for introduction in the UK.

The programme of work is divided into three phases. The first phase is concerned with the development of in–service test procedures for motorcycles and the second and third phases are concerned with similar studies for diesel and petrol engined vehicles respectively.

This Project Report describes the work carried out as part of the first phase of this project.

2. EXPERIMENTAL DESIGN CONSIDERATIONS

An in–service test of vehicle noise would need to be inexpensive and simple to carry out and have the following characteristics:–

i) Allow checks to be carried out in a variety of ambient noise situations including roadside locations and, possibly, indoors (eg. a MOT test centre or garage space).

ii) Require the measurement microphone to be placed so that it is sensitive to exhaust system failures as well as faults with the power unit.

iii) Ideally, ensure that the vehicle is operated such that the noise produced during the test was reasonably correlated with the noise it would produce during the standard type approval test procedure.

In arriving at the detailed study design it is necessary to examine the various test procedures that could be used, and the locations where in–service noise testing might be carried out. In particular, it is important to identify the basic test site requirements that are required so that in–service measurements of motorcycle noise can be carried out simply at low relative cost and, as far as is practicable, in a manner which is representative of the noise generated when the motorcycle is driven normally in traffic.

This section of the Report is concerned, therefore, with establishing the most relevant test protocol to adopt for this study (Section 2.1), the identification of test site locations which are representative of the types of site conditions where in–service noise testing might be carried out in practice (Section 2.2), and the selection of motorcycle types which would, collectively, represent the current motorcycle population in–service in the UK (Section 2.3).

2.1 Standard test procedures for the measurement of noise from in–service vehicles

Various regulatory standards have been imposed by different countries as a means of controlling the noise emitted by road vehicles in–service. Many such regulations are based either wholly or, in part, on domestic or international standards.

The standards which have relevance for the testing of vehicles in service have tended to rely on the measurement of noise in close proximity to a stationary vehicle. This approach enables tests to be carried out in a variety of non–ideal acoustic environments without the results obtained being affected by noise other than that produced by the vehicle under test.

These standard test procedures have been reviewed in an earlier study produced by TRL (Nelson and Tobutt, 1992). In this previous work it was concluded that " Regulations governing the in–service noise generated by motorcycles and mopeds could be introduced in the UK fairly quickly. The exhaust noise test specified in ISO 5130 (International Standards Organisation, 1978) or European Community Directive 1015 (European Economic Community, 1981) could form the basis of a suitable test".

This conclusion was based, in turn on a measurement programme reported by Nelson and Ross (1985). This study showed that the close proximity test specified in either the EEC or ISO standards was a relatively simple test which produced both repeatable and reproducible results. In addition, the close proximity noise results obtained were closely correlated with the noise produced by the vehicles during the type approval test thereby satisfying the fundamental requirement (iii) listed above. Since the two test procedures were essentially the same in both standards it was decided, for the purpose of this study, to use the test procedure and interpretation requirements described in EEC Directive 78/1015. The essential details of both methods of measurement and interpretation are described in the following section.

2.1.1 ISO 5130

The International Standard ISO 5130 "Acoustics - Measurement of noise emitted by stationary road vehicles - Survey method" (1982) lays down requirements for an in-service testing scheme (International Organisation for Standardisation, 1982).

Sections 1-3 of the Standard deal with such matters as the field of application and instrumentation for acoustical measurements. Section 4 defines the test site conditions and section 5 deals with the background noise level, stating that the level of background noise at each measurement position shall be at least 10 dB less than the levels measured during the tests.

Section 6 of the Standard deals with the procedures required for the testing of exhaust noise and an annex deals with the testing of engine noise. For the exhaust noise test the Standard requires the measurement of the maximum noise level at a point 0.5m from the exhaust outlet, while the engine speed is allowed to rapidly decelerate from a specified engine speed. The initial engine speed is defined as a fraction of the engine speed, n, at which maximum power is produced. For motorcycles the initial engine speed for the test should be $n/2$ if $n > 5000$ rpm or $\frac{3}{4}n$ if $n < 5000$ rpm. The microphone used for this is required to be placed with its most sensitive axis parallel to the ground and pointing at the exhaust making an angle of 45 degrees with the vertical plane containing the direction of the gas flow.

Although ISO 5130 was developed as a technical standard for the measurement of noise in close proximity and, as such, has general application for vehicle noise testing, it is also clearly intended that the method should be considered for in-service testing of road vehicles. So far, however, it has not been used widely and the OECD suspect that this is due to technical difficulties associated with the operation of the test (Organisation for Economic Cooperation and Development, 1988).

A particular problem in using the method for in-service testing is to obtain reliable measurements of the engine speed. Not all vehicles are fitted with accurate tachometers and, for those that are, the question arises as to whether it is implicitly correct, in a regulatory test where prosecutions may result, to use the vehicle's instrumentation to set the initial engine speed condition or whether it is necessary to use a remote system designed specifically for conformity checking and which can be calibrated independently. A further concern over the use of the method arises because it is not clear whether the mode of operation of the vehicle will give rise to noise levels, at the prescribed measurement positions, which are well correlated with the noise generated by vehicles undergoing the type approval test. In fact the

Standard clearly states that "the values obtained using the method are not representative of the total noise emitted by vehicles in motion".

2.1.2 Directive 78/1015/EEC

EEC Directive 78/1015/EEC deals specifically with "the permissible sound level and exhaust system of motorcycles" (European Economic Community, 1978). The Directive is primarily concerned with specifying the type-approval noise testing procedure and limit values for motorcycles of different categories. It also prescribes a method for the measurement of noise in the proximity of the exhaust outlet(s).

(i) Type approval measurements

Full details of the test procedure can be obtained by consulting the Directive. Briefly the type approval measurement method requires the motorcycle to be driven in low gear at full acceleration from a steady initial speed. The test surface used shall be a hard and flat conventional road surface located in an open site where there are no reflecting objects or obstacles within a 50m radius drawn from the centre of the test area. During the acceleration, noise levels are measured and the maximum noise is recorded at a microphone located 7.5m from the centre-line of the trajectory of the vehicle under test. The approach speed chosen for the test is set as the lower of 50km/h or 75% of the maximum power speed of the engine. The gear selected (either 2nd or 3rd gear) depends upon the capacity of the motorcycle and the number of forward gears. The maximum noise levels recorded are rounded to the nearest whole decibel and the highest of four readings (two for each side of the vehicle) are then taken to represent the test level.

(ii) Close proximity measurements

The measurement of noise in the proximity of the exhaust is carried out with the vehicle stationary and using a mode of operation of the motorcycle engine and measurement method identical to that described in ISO 5130. However, the result is taken as the maximum of a number of repeat tests whereas the method described in ISO 5130 takes the average of the repeat tests as the result. To obtain the test noise level a minimum of four repeat tests are carried out and each measured level is rounded to the nearest decibel. The test result is the highest noise level obtained.

The Directive requires that the test site is a hard flat surface and that all edges are at least 3m from the vehicles extremities. No reflective objects should be within the 3m zone. It is also stipulated that the engine speed indicator should have an accuracy of better than 3%.

In addition the Directive also requires that:-

(i) The silencer is marked with a clearly legible and indelible reference to its make and type. (NB: This is clearly intended as an aid to the enforcement authorities when checking compliance in-service.)

(ii) Fibrous absorbent material may not be placed in those parts of the silencer

through which the gases pass.

(iii) Suitable devices must ensure that the fibrous absorbent material is kept in place for the whole time that the silencer is being used.

(iv) The fibrous absorbent material must be resistant to a temperature at least 20% higher than the normal operating temperature of the silencer.

2.2 Consideration of the choice of test sites

It is anticipated that the main difficulty in determining a suitable in-service test procedure for any vehicle is to establish a method which is independent, as far as can be made possible, of the test environment. If a suitable test procedure is to be introduced, then, in practice, in-service noise checking will be done under a range of different test conditions. Some vehicles may be tested in an open space whilst others will be tested indoors where the acoustic and ambient noise conditions may vary greatly from site to site. For these reasons it is necessary to examine carefully the test site conditions adopted to ensure that any variance introduced by differences in the test locations are minimised and that the minimum requirements for testing are clearly and simply stated.

2.2.1 Theoretical considerations

Sound radiated in an enclosed space is likely to be amplified relative to a free field situation by the effect of multiple reflections particularly from the walls ceiling and floor. The noise level at a given receiver position within the enclosed space will then be the summation of the direct sound component and sound reflected from surfaces located in the enclosed space, ie. the reverberant contribution. The relative proportions of these components is a function of the reverberance of the space and the distance of the measurement microphone from the source of noise being measured.

Clearly, the closer the receiver position is to the source of noise the greater the contribution of direct sound. As the microphone position is moved further away, the reverberant contribution will tend to increase relatively, depending upon the reverberance of the enclosed space, until a point is reached where the reverberant sound contributes significantly to the total measured sound level. At this position the measured noise level will not be equivalent to that measured under free field conditions at the same distance.

The reverberant sound pressure level (SPL) in a room is a function of the sound power level of the source and direct and reverberant sound energy components. The following expression applies:-

$$Total\ SPL = PWL + 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R_c} \right] \qquad (1)$$

where PWL is the sound power level of the source, Q is a term which accounts for the directional characteristics of the source, and r is the distance from the source in metres. (N.B. In the case of an omnidirectional point source positioned in free space, the directivity factor, Q = 1. For the same source positioned on a hard, acoustically reflecting, floor Q = 2).

R_c is the room constant which can be related to the amount of acoustic absorption present in the room and is given by the expression:-

$$R_c = \frac{S\bar{\alpha}}{1-\bar{\alpha}} \tag{2}$$

where S is the surface area of the room in m^2 and $\bar{\alpha}$ is the average absorption coefficient in the room. The room constant is measured in m^2 units.

The average acoustic absorption of the room can be derived from the room reverberation time (T) according to the expression[1]:-

$$\alpha = \frac{0.16V}{TS} \tag{3}$$

where V is the volume of the room in m^2 .

Consequently, by measuring the reverberation time over the frequency range of interest the average acoustic absorption can be determined using equation 3 and the room constant R_c can then be determined using equation 2. By substituting the value of R_c in equation 1 the SPL can be determined from the sound power level of the sources and measurement distance r.

Figure 2.1 illustrates the relationship between the attenuation of noise level with distance from a point source located on a hard acoustically reflecting surface in an enclosed space. The attenuation characteristics for different rooms giving a range of R_c values are shown in the Figure. The Figure also includes the theoretical attenuation with distance function expected in an open site situation where there are no significant reflecting surfaces. This is represented as a dashed line on the Figure. This line therefore represents the attenuation with distance of the 'direct' sound field only.

Equation 1 was used to determine the attenuation with distance characteristics in each case by assuming a value of 100 dB for the sound power level of the source. It should be noted that for the open site calculation it was necessary to assume that R_c becomes infinitely large

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[1] The reverberation time of a room is defined as the time in seconds for the sound level of an interrupted source to decay by 60 dB (Sound Research Laboratories, 1988). As the reverberation time varies with frequency it is necessary to measure in appropriate frequency bands across the frequency range of interest.

so that the second term in the brackets of equation 1 reduces to zero and the attenuation then reverts to the familiar inverse square law indicated by the equation.

The relationships given in Figure 2.1 can be used to gauge the importance of room reverberation characteristics on the close proximity noise measurement method. The close proximity procedure described in ISO 5130 for stationary testing of motorcycle noise specifies a measurement position 0.5 metres from the exhaust outlet. It can be seen from the Figure that at a receiver position located this close to the source it would be expected that the reverberant sound would not significantly contribute to the dominant direct component for rooms with a high value of R_c, say greater than 16. However, for values lower than 16 measurements taken in close proximity can be expected to increase significantly according to the absorption and reverberation characteristics of the enclosed space.

In practice the influence of the room acoustics on the measured noise levels will depend greatly on the frequency characteristics of the source and the values of R_c at dominant frequencies in the source spectrum. Consequently a room with a low room constant value at a particular frequency or band of frequencies will tend to have a strong amplification effect on sounds generated at these frequencies. If these frequencies coincide with the dominant frequencies in the source spectrum the overall noise level of the source will be significantly enhanced. If the dominant source frequencies do not match the reverberant peak frequencies of the room the overall level will be less affected.

A further point that needs consideration is the proximity of reflecting surfaces to the measurement microphone. Such reflecting surfaces could cause the measured noise levels to increase if the component of reflected noise is of similar magnitude to the direct component.

As a reasonable approximation it can be shown that, for a point source, provided the distance from the source to any acoustically reflecting wall, screen etc is greater than twice the source to receiver distance, the reflected contribution at the receiver will not be significant (Beranek, 1960).. Clearly, however, care must be exercised in avoiding locating a vehicle close to a reflecting surface.

Finally, it is important to recognise that there are other effects associated with room acoustics which may be difficult to resolve completely in this case. If a fundamental dimension of the room happens to match a multiple of the source frequency half wavelength, a standing wave may be generated (Sound Research Laboratories, 1988). The effect of this is to reinforce sound pressure at certain locations in the room and decrease it at others. If these room modes occur, they are widely spaced at low frequencies, becoming more numerous at higher frequencies. Standing waves tend to be most distinct at low frequencies in small rooms with highly reflective, parallel walls. Even close proximity measurements may be affected by this phenomenon depending on the room dimensions and the dominant source frequencies. If this proves to be an important factor the effect might be eliminated by placing acoustically absorbing screens around the motorcycle to help break up the potential for the generation of standing waves and to reduce the contributions from reflected sound.

It may be concluded from these considerations that noise measurements taken using the 0.5m microphone position in an enclosed space may be influenced by the dimensions of the room and the reverberation conditions encountered. Much will depend, however, on the sound

sources themselves and on whether normal test spaces give rise to room resonances. Clearly, these aspects need to be addressed in the design of the study to establish whether indoor testing, even in close proximity, can be carried out with acceptable error.

2.2.2 Test site selection rationale

A fundamental consideration in establishing the experimental design is to provide a means of determining the influence of non-standard test site conditions on the noise levels generated in close proximity to the vehicle under test. Clearly, in order to establish baseline noise levels for each motorcycle studied, each motorcycle should be tested initially under ideal 'open site' conditions. The results obtained for this test condition would then be able to be used to establish differences in the measured levels when the same motorcycles were tested in non-standard site conditions.

Initially, the non-standard tests should be undertaken outdoors but in a non-ideal location where, for example, there was a wall or building near to the measurement site which could give rise to reflections of sound energy. Such conditions should be chosen to simulate the conditions existing outside a test station (Garage forecourt, car park etc) or at a roadside (eg a lay-by) where the in-use test might be carried out by enforcement authorities.

For measurements taken inside a building, such as a garage space or MOT test bay, the theoretical considerations discussed in the previous section need to be considered. Essentially, there are two potential problems associated with the acoustics of the measurement site when the site is in an enclosed or semi-enclosed space. The first is concerned with possible errors caused by reverberation of sound in the enclosed space. It was shown earlier that theoretically rooms with little acoustic absorption could have an influence on the measurements taken in close proximity particularly if the dominant frequencies of the source spectrum coincide with the most reverberant frequencies of the room. (NB. Generally, highly reverberant rooms have hard reflecting surfaces and no significant absorbing features such as benches or partitions). Secondly, in some rooms, resonances could occur at important frequencies in the noise source spectrum which could also have an influence on the noise levels measured in close proximity to the test vehicle. Such rooms are likely to be small rooms where the test vehicle has to be located in relatively close proximity to the walls of the room.

Clearly, to evaluate fully the influence of both these conditions on the noise levels measured at the close proximity position, the motorcycles studied should be tested in a range of rooms with different room dimensions. In addition, in each of the rooms, the tests should be repeated with the vehicles located in different parts of the rooms in order to examine the importance of standing wave effects. Unfortunately, with this experimental design, a large number of measurements on each vehicle would need to be taken at considerable cost. A less expensive alternative which still achieves the objectives of the study would be to carry out tests for approximate 'worst case' conditions with the test vehicle located at a limited number of positions chosen to represent the most likely measurement positions in practice. With this design of experiment, it should be possible to establish the likely maximum differences between the results of standard condition measurements taken at an open site under controlled laboratory conditions and non-standard measurements taken indoors for a wide range of different types of motorcycles. If the results then showed that the errors involved were not

significant then a test procedure could be developed where motorcycles were tested inside a building such as a MOT test bay. Alternatively if the results showed large differences in the measured noise levels then the test method would not be viable unless some form of site calibration were introduced.

2.3 Vehicle selection

A further aspect of the study is to ensure that the test results obtained from in–service noise test procedure adopted correlate reasonably well with the noise generated by the test vehicles during the standard type approval test and that vehicles which are obviously exceeding the limit due to poor maintenance etc., are clearly identified. To achieve this objective it is important to identify a suitably representative sample of motorcycles for testing so that the results obtained can be generalised to the motorcycle population in–use in the UK. The following sections detail the information obtained on motorcycle registrations in the UK and give the selection rationale employed in arriving at the sample of vehicles selected for study.

2.3.1 Sales and trends

Motorcycles from 21 different world manufacturers are available for sale in the UK. Only four of these are British. Each maker produces a range of models with engine capacities in the range 49 to 1520 cc giving a total of about 200 different types of motorcycles registered in the UK.

To support the selection rationale, the Motor Cycle Industry Association (MCI) has provided TRL with information on new registrations (MCI, 1993). Table 2.1 shows the sales (registrations) of motorcycles in the UK for 1992 and 1993 categorised in terms of engine capacity. It can be seen that over this period there was a fall in sales for motorcycles at the lower end of the engine capacity range with a general increase in registrations noted for the more powerful motorcycles over 500cc.

The fifteen most popular (highest sales) motorcycles in the UK (1993) in order of sales figures are listed in Table 2.2.

2.3.2 Motorcycle selection rationale

The project requires that tests are performed on a representative sample of fifteen different motorcycles selected from the vehicle fleet. In considering the selection of motorcycles, due account would need to be taken of the relative sales (registrations) of the various engine capacities, makes and styles given in the previous section with the need to obtain selections of motorcycles in each of the three categories specified for type approval testing by the EU. These categories are classified in terms of engine capacity in the EC Directive 87/56/EEC as:–

Category 1 $\leq$80cc

Category 2 >80 – ≤175cc

Category 3 >175cc.

Additional requirements for the project are that the sample should include motorcycles which cover the range in–use as well as the most popular types. The sample should also contain examples of motorcycles fitted with replacement silencers and should include 2–stroke mopeds which can be simply modified to affect their noise emission. In addition, it was considered that the sample should include trail bikes which are also used on the road and have little shielding of the engine, road/sport machines, with both air and water cooling and touring machines with large, low revolution engines.

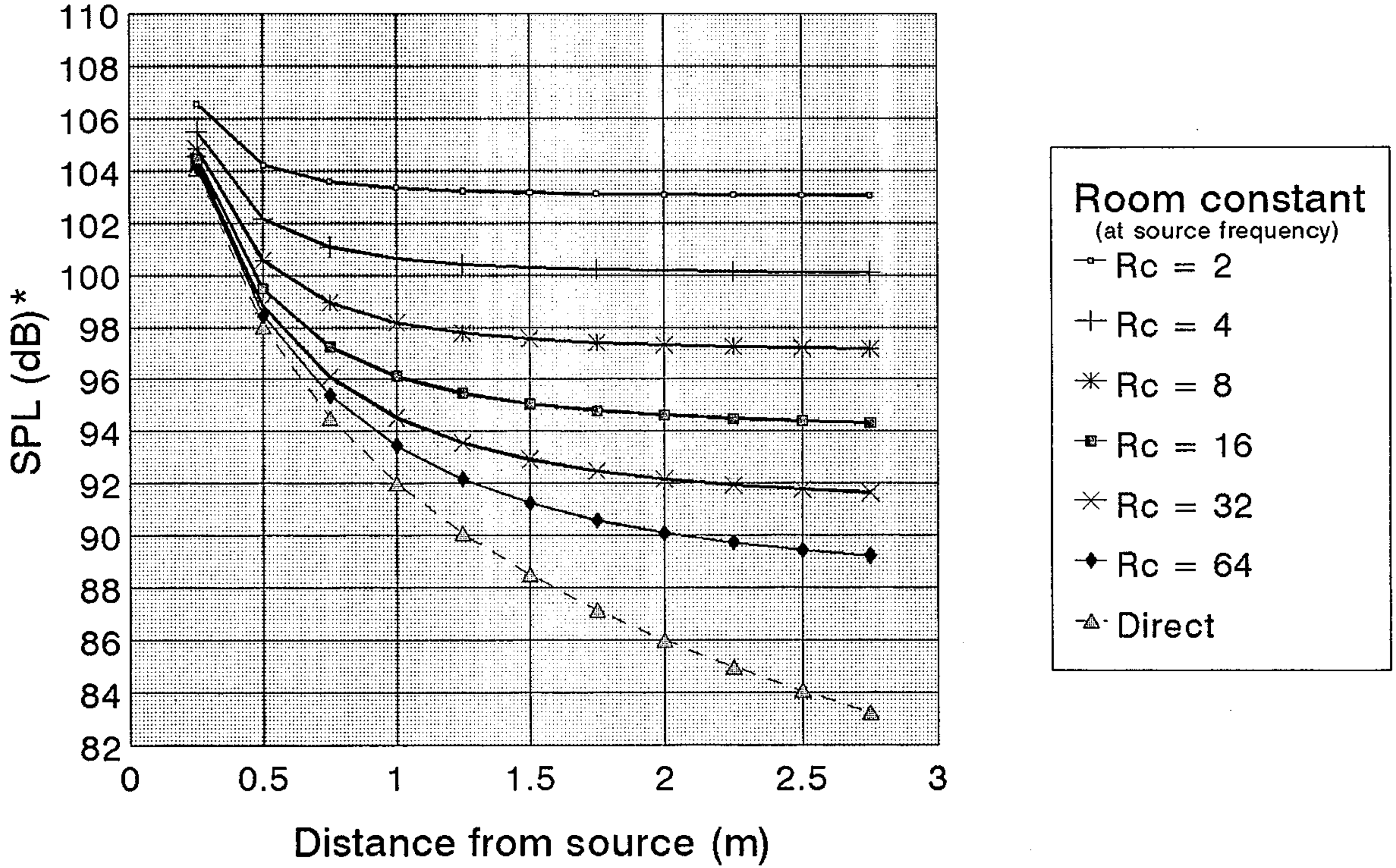
Engine capacity cc	Year end 1992	Year end 1993	Per cent change
0 -100 inc mopeds	14,314	10,143	-29
101 - 200	9,306	6,718	-28
201 - 500	7,030	6,020	-14
501 - 900	15,375	17,024	+11
901 - 1050	1839	1541	-19
Over 1050	4531	5287	+16

Table 2.1: Registrations of motorcycles by engine capacity

	Make	Model	Engine type	Engine cap. (cc)/no. of cylinders
1	Honda	C90	air cooled	85,single 4-stroke
2	Honda	SA50J	air cooled	49,single 2-stroke
3	Yamaha	XV535	air cooled	535,V-twin, 4-stroke
4	Kawasaki	ZX600E2 (ZZ-R600)	water cooled	498,4 cylinder 4-stroke
5	Kawasaki	EX500A6 (GPZ500S)	water cooled	498,parallel twin,4-stroke
6	Triumph Trident	T309 Road Sport	water cooled	885,transverse, 4-stroke
7	Suzuki	GSX100WP	water cooled	1127,4cylinder 4-stroke
8	Ducati 900	Super Sport	water cooled	904,V-twin 4-stroke
9	Piaggio moped	SFERA	air cooled	49,single 4-stroke
10	Yamaha	CW50	air cooled	49,single 2-stroke
11	BMW	RS1100RS Road Sport	oil cooled	1085,flat twin 4-stroke
12	Piaggio moped	TS125	air cooled	124,single, 4-stroke
13	Jawa Economy	Jazz Step Thro.	air cooled	49,single, 2-stroke
14	Harley Davidson	XLH1200 Custom	water cooled	1200,V twin, 4-stroke
15	CZ	Commuter	air cooled	125, single, 2-stroke

Table 2.2 Rank Order of Motorcycle Sales in UK (MCI, 1993)

Figure 2.1 Theoretical relation between noise level and distance for indoor spaces with different amounts of acoustic absorption



* Assuming omnidirectional point source with sound power level of 100 dB

3. METHOD

3.1 Test sites selected for the study

3.1.1 Outdoor testing

(i) ISO vehicle noise test track

The main location chosen for the outdoor noise tests was the TRL vehicle noise test site. This test site is located on the central area of the TRL test track facility. The surface of the test track is covered with a standard surface which has been specially designed by the International Organisation for Standardisation (ISO) for vehicle noise testing (International Standards Organisation, 1993)[2]. The site is located in an open space, as required by vehicle noise type approval testing standards, with no significant reflecting objects such as buildings within 50 metres of the centre of the test site.

(ii) Non standard outdoor location

In addition to the standard test site a further outdoor measurement site was used. This was located outside one of the test areas used for the indoor measurements (See section 3.1.2) and in close proximity to the wall of the building. The site was chosen to be representative of measurement conditions that might exist in a garage forecourt or roadside location where it would not be possible to achieve the ideal testing conditions described in the previous paragraph. Further details of the sites and measurement set up are given in section 3.3.

3.1.2 Indoor testing

In order to satisfy the experimental design conditions specified above, two rooms were located at TRL for the indoor tests. The rooms were selected following a small survey of motorcycle MOT test workshops. Both rooms had wide door openings suitable for motorcycle access. The rooms chosen were:-

(i) A large garage-workshop (approximately 11m deep x 6m wide and with a floor to ceiling height of 3.9m) with hard, acoustically reflecting walls, floor and ceiling.

(ii) A small garage/workshop (approximately 4.95m deep x 2.4m wide with a floor to ceiling height of 2.15m). This room also had no significant absorbing features and the walls were acoustically reflecting.

It was considered that the larger space would represent a typical measurement bay for a large garage/workshop but would represent the 'worst case' conditions for this type of space since

[2] This surface has been adopted by the European Commission as a standard surface to be used on all EU vehicle noise type approval test sites. Its specification has now been incorporated in the latest European Community Directive dealing with vehicle noise type approvals and is likely to feature in the Directive currently under discussion for 2 and 3 wheeled vehicles.

the room was empty (i.e. no significant sound absorption) and had highly acoustically reflecting solid concrete walls. A room of this size with no significant absorbing elements would be expected to have long reverberation times and hence low values of the room constant R_c. The smaller space chosen for the study represented potentially the smallest garage space that could be used in practice according to Vehicle Inspectorate specifications. Again the space was highly reverberant with solid acoustically reflecting walls, ceiling and floor. Further details of the test sites and measurement set up are given in section 3.3.

3.2 Motorcycles selected for the study

Taking into account all available information on motorcycle registrations and sales presented in section 2.3 above, a final selection of machines used for this study was obtained. The list of motorcycles used are summarised in Table 3.1 together with information on mileage, type of machine, engine capacity, stroke and general condition.

In all cases the motorcycles were secondhand but judged to be in either fair or good condition. Most of the bikes tested were less than two years old and none had excessive mileage. It can be seen that the final sample includes 16 motorcycles of which 14 were fitted with standard original equipment silencers. One of the GPZ500 Kawasaki motorcycles was fitted with a non standard single silencer box. In addition, the RXS100 Yamaha motorcycle was tested with the standard silencer fitted and then re-tested with the silencer baffles removed. This particular test was included to simulate a motorcycle with an inadequate or faulty silencer.

The overall grouping of the sample by engine capacity was:-

<80cc	2 mopeds; both with 2-stroke engines.
>80 - ≤175cc	5 machines; three with 2-stroke and 2 with 4-stroke engines. (NB In one of the 2 stroke machines the exhaust baffle was removed to simulate a machine with a poor condition silencer)
>175cc	9 machines; a selection of air and water cooled, trail, sport custom and touring motorcycles with different engine configurations.

3.3 Noise measurements

Noise measurements were taken on each motorcycle at each of the test site locations using the close proximity test procedure described in the European Union Directive 78/1015/EEC. The test procedure was described earlier in section 2.1.2. In addition to these tests each motorcycle was tested using the drive by type approval test procedure which was also described earlier in Section 2.1.2. The following sections give details of the measurement method employed, the layout of each test site, including the equipment used, and the method of analysis employed.

3.3.1 Type approval measurements

Drive-by type approval noise tests were conducted on each motorcycle using the type approval test site located on the TRL test track. A plan of the test site showing the position of the measuring microphone is given in Figure 3.1(a). As required by the standard, the noise measurements were taken at a microphone located 7.5 metres from the centre of the test track and at a height of 1.2m above the track surface. A type 1[3] one-third octave real time analyzer, set to maximum hold, was used for all drive-by measurements. The microphone and calibrator used with the analyzer were also of type 1 classification. With this setting, the instrument holds and displays the maximum A-weighted sound pressure level generated by the motorcycle during the test. This enables the operator to stand well clear of the microphone position during the test thereby avoiding the possibility of the errors occurring due to noise being reflected from the operator. The approach speed of the motorcycle was measured using portable radar instrumentation which had been calibrated prior to its use in this study.

In all cases the test motorcycle was warmed up to normal operating temperatures prior to testing. Normally four repeat runs were taken with the vehicle running in both directions over the test surface. The maximum noise levels were interpreted according to the procedures laid down in the Directive. In this way a single noise level value, rounded to the nearest decibel, was obtained for each motorcycle.

3.3.2 Close proximity

Close proximity noise measurements were carried out on each motorcycle at the ISO type approval test track site and at two locations in each of the indoor locations. The method of testing used the procedure described in the European Directive 78/1015/EEC which was described earlier. In addition, a further 'outdoor' close proximity test was carried out on each motorcycle with the vehicle located just outside the doors of the large workshop.

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[3] Type 1 refers to the precision classification of the instrument according to BS 5969 (British Standards Institution, 1981). The classification describes the accuracy of sound level meters in terms of a number of criteria such as frequency response and the time weighting characteristics of the detector. For each type classification the instrument must match a range of characteristics of an 'ideal' instrument within a specified tolerance. The allowable tolerance increases with type number. For example, a type 2 meter would be less accurate under certain conditions than a type 1 meter; accordingly the type 2 instrument would cost less.

Figure 3.1(b) shows a photograph of a close proximity measurement on the type approval test site. Plans of the layout of the large and small workshops are shown in Figure 3.2 and photographs of both workshops are shown in Figure 3.3. It should be noted that the photograph of the large workshop also shows some acoustic barriers in position around the microphone. The use of the barriers is discussed in section 3.4 below. The site layout used for the 'non standard' outdoor location is shown in Figure 3.4.

It should be noted that in each workshop, close proximity measurements were taken with each motorcycle in two positions; (i) with the motorcycle at the centre of the workshop with its exhaust outlet pointing towards the doors (i.e. position 1), and (ii) at the doorway position with the exhaust outlet in line with the doorway (i.e. position 2). The approximate position of the motorcycle for each of these tests is shown in Figure 3.2(a) for the large workshop and for the centre position only in Figure 3.2(b) for the small workshop.

In all cases where measurements were taken inside or close to the workshops, the workshop doors were left open. This was clearly necessary as a means of ventilating the test area and also was considered to be consistent with the normal operation of a garage or workshop where testing might be carried out.

The noise measurements were taken with a type 1, one–third octave real time analyzer set to maximum hold as before. In this case the analyzer was used to provide automatic measurement of the maximum noise level during each test, according to the requirements of the Directive, together with additional information on frequency spectra.

In addition to the measurements taken using this instrumentation a second series of measurements were taken on about 10 of the 16 motorcycles studied using an industrial grade, i.e. type 2, instrumentation (see footnote 3 on previous page - IEC 651, 1979). This instrument included a microphone, sound level meter and acoustic calibrator. The measurements were conducted in both the small and large workshops with the motorcycles in positions 1 and 2 only. The purpose of this aspect of the study was to evaluate the use of low cost instrumentation when compared with precision grade equipment. (N.B. The cost of the type 2 instrumentation used was approximately £500 whereas the costs of similar instrumentation, meeting type 1 IEC 651 specification cost in the region of £1000 in 1994.)

For all the close proximity measurements taken, engine speeds were measured using an electromagnetic tachometer. This device consisted of a probe which was placed near to a spark plug or high tension lead and instrumentation which gave a direct readout of engine speed in revolutions per minute (rpm). This instrument was calibrated prior to testing by TRL. It provided an accurate reading of engine speed with a precision of typically less than 2% and therefore fully met the requirements for engine speed measurements stipulated in the Directive 78/1015/EEC.

3.4 Close proximity measurements with sound absorptive panels

In order to reduce the potential effects of reverberation and standing waves in the enclosed spaces some of the close proximity tests were repeated with absorptive panels placed in the

vicinity of the measurement microphone. It was felt that the presence of the panels would help to reduce the possibility of standing waves being generated by reducing reflections between the walls.

Portable commercially available sound absorptive panels (2.5m long x 0.5m tall) were obtained for the purpose of this experiment. The panels had been initially used at TRL's noise barrier test facility. A sketch showing a section through one of the panels is shown in Figure 3.5a. It can be seen that the panels were essentially a hollow aluminium box, 12.5cms thick, with a fibre board mounted internally. A perforated sheet on one side allowed sound to enter the box where it was absorbed by the fibre board. Absorption measurements on the panels had shown from previous experiments that they gave high absorption coefficients (i.e. greater than 0.8) over a broad range of frequencies in the range 200 Hz to 5 kHz (Watts, Crombie and Hothersall, 1994). Figure 3.3a shows a photograph of the experimental set up in the large workshop.

Figure 3.5b shows a plan of the large workshop with the panels in position. It can be seen that the panels were initially located on both sides of the motorcycle and were parallel to the longitudinal axis of the bike. The panels were equidistant from the motorcycle and set 1m from the microphone position. Two panels were used each side to give a barrier height of 1m. In this way it was anticipated that the panels would act as a barrier to reflected noise from the walls whilst producing minimal additional refections of noise to the measurement microphone.

With this configuration, close proximity noise measurements were taken using the method described earlier. The tests were repeated for three different motorcycles chosen from the sample to represent examples of small, medium and large capacity machines. Each motorcycle was tested in both large and small workshops.

A further set of close proximity noise measurements were also taken with one of the motorcycles with the panels placed at 45° to the axis of the motorcycle. This configuration was examined in order to determine whether altering the precise location and configuration of the panels affected the measured noise levels at the close proximity position.

3.5 Measurements of reverberation time

Measurements of the reverberation times (RT's) of both the small and large workshops were taken in order to assist with the interpretation of the close proximity noise data. For both spaces, the measurements were taken with the doors fully open. In this way the RT's of both rooms were determined for the same conditions as for the close proximity noise measurements.

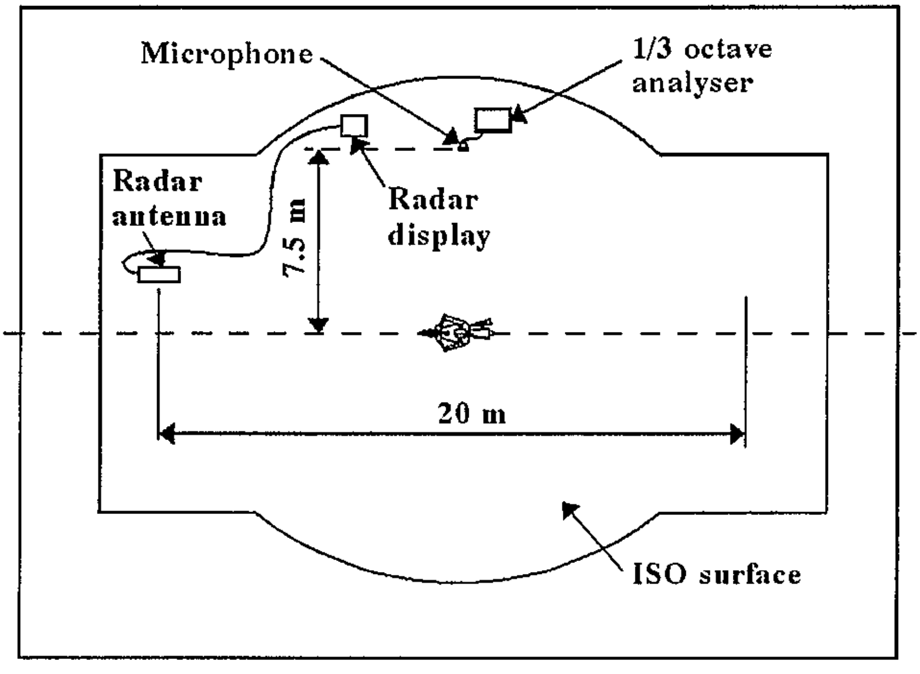
Measurements were carried out according to the method described in BS 5363 (BSI, 1976). Briefly, the method of measurement requires the determination of the time for a sound level, generated in the enclosed space, of known magnitude and frequency to decay by 60 dB. The measurement equipment consisted of a sound source amplifier and loudspeaker connected to a signal generator and a sound level meter with its output fed to a level recorder. Broad-band noise was played through the speaker at high level (ie. at least 40 dB above background noise). Once a stable noise field had established in the room the noise source was abruptly

switched off and the decaying sound field recorded on the level recorder. In order to generate sufficiently high noise levels across all frequencies the signal generator was switched to produce noise in individual 1/3 octave bands across the range 100 Hz to 4 kHz. Successive measurements of reverberation decay were then taken at each frequency band using a 1/3 octave filter set connected to the sound level meter to isolate the frequencies of interest. Two measurements were taken in each frequency band at three positions in the rooms. The average of these measurements at each frequency was taken to produce reverberation time spectra for the large and small workshops.

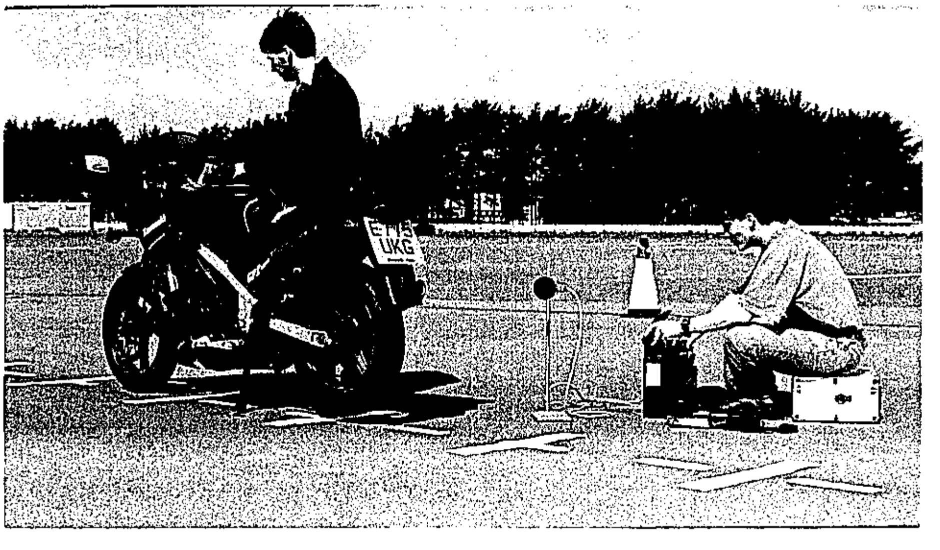
Make and model	Mileage	Type of machine	Engine capacity c.c. and stroke	Cooling system/ no. of cylinders	Condition of machine
Group 0–80cc					
Honda SA50J	987	moped	49 2–stroke	air/ single	good (original silencer)
Yamaha CW50	1,810	moped	49 2–stroke	air/ single	good (original silencer)
Group 80–175cc					
Honda C90G	3,045	small motor cycle	85 4–stroke	air/ single	good (original silencer)
Yamaha RXS100	7,917	small motor cycle	124 4–stroke	air/ single	fair (original silencer)
Yamaha RXS100	7,966	small motor cycle	124 4–stroke	air/ single	fair (baffle removed)
Honda CG125	5,198	small motor cycle	125 4–stroke	air/ single	good (original silencer)
Yamaha TDR125	6,025	small motor cycle	125 2–stroke	water/ single	good (original silencer)
Group over 175					
Yamaha XT350	7,495	trail bike	349 4–stroke	air/ single	good (original silencer)
Yamaha XV535	10,531	sport/custom	534 4–stroke	air/V–twin	good (original silencer)
Kawasaki GPZ500S	12,978	sport touring	500 4–stroke	water/ parallel twin	fair (original silencer)
Kawasaki GPZ500S	29,764	sport/touring	500 4–stroke	water/ parallel twin	fair (replacement silencer)
Kawasaki ZZ–R600	6,866	sport/touring	599 4–stroke	water/ 4 in–line	good (original silencer)
Triumph Trident 750	8,335	road/sport	749 4–stroke	water/ transverse triple	good (original silencer)
Ducati M900	3,257	sports	904 4–stroke	water/ V–twin	good (original silencer)
Suzuki GSX–R1100RS	1,813	race replica	1127 4–stroke	water/ 4–in line	good (original silencer)
BMW K1100RS Road Sport	937	road/sport	1085 4–stroke	oil/ flat twin	good (original silencer)

Table 3.1 Details of the motorcycles selected for the study

Figure 3.1 ISO type approval test site.

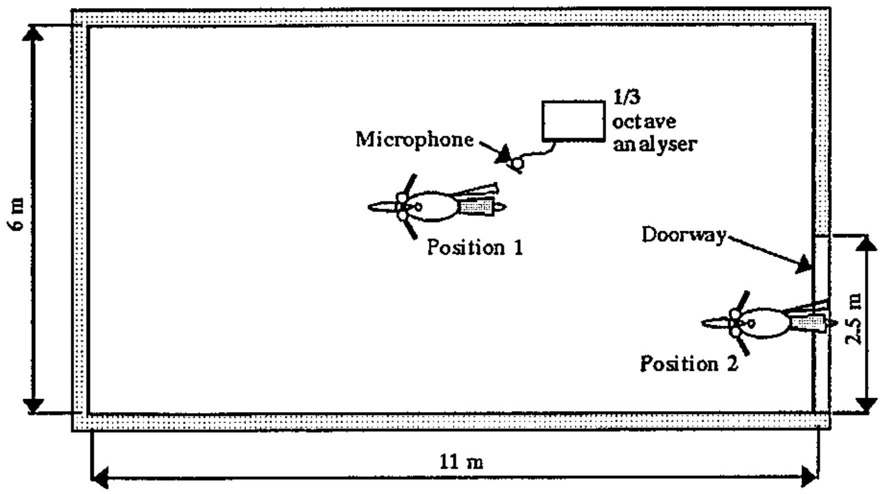


(a) Site layout and drive by microphone position

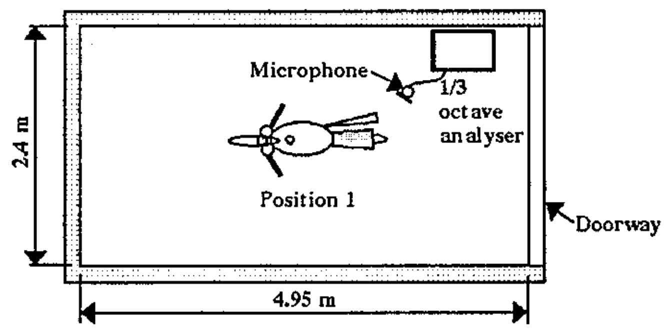


(b) View of test site showing close proximity measurement set up.

Figure 3.2 Layout of both large and small workshops.

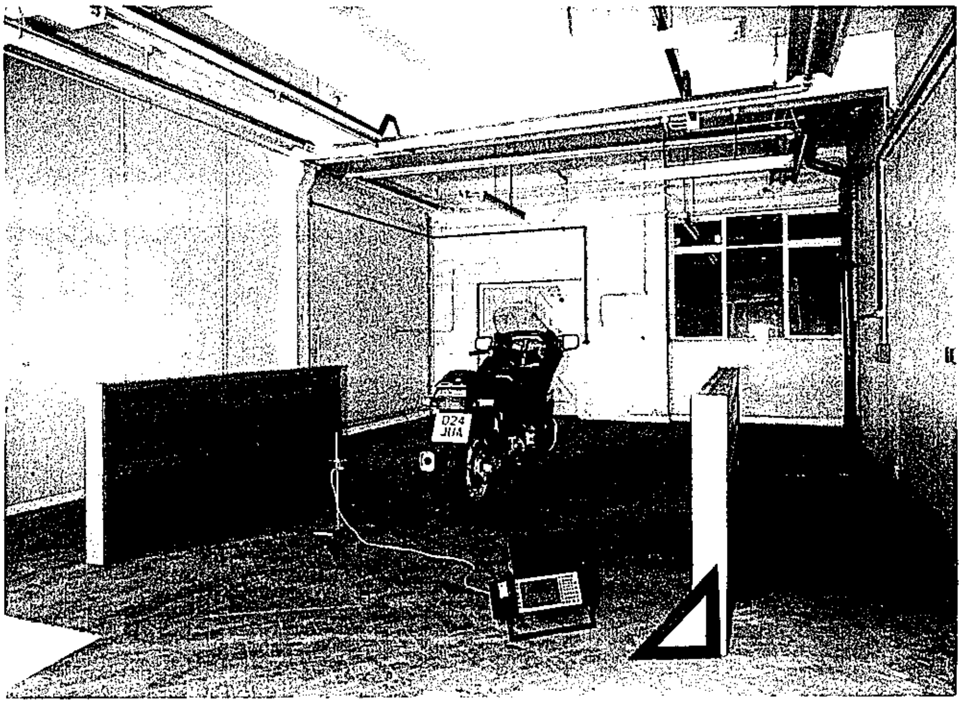


(a) Large workshop.



(b) Small workshop.

Figure 3.3 Close proximity measurements in the large and small workshops.



(a) Large workshop.

(b) Small workshop.

Figure 3.4 Layout for 'Non-standard' outdoor test site.

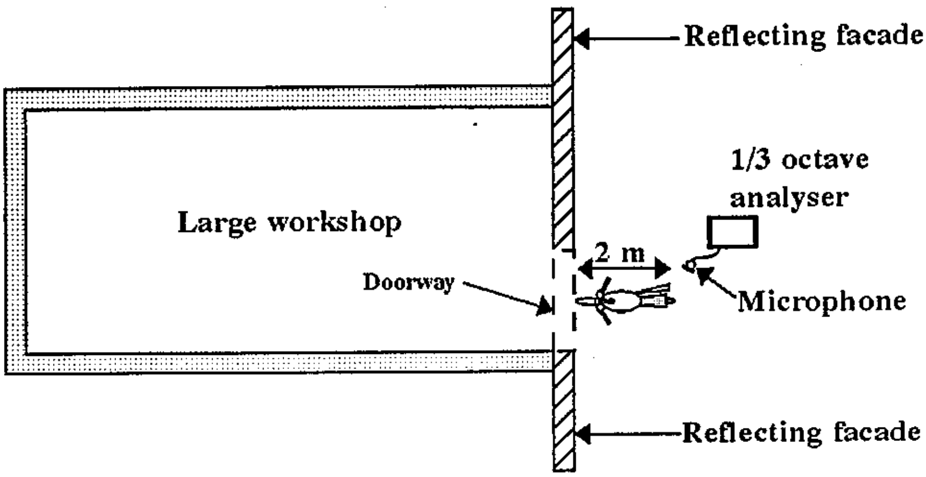
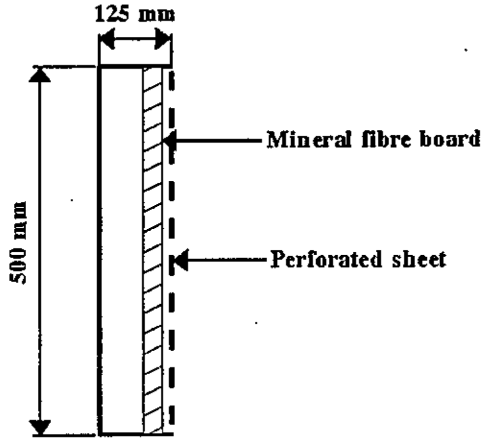
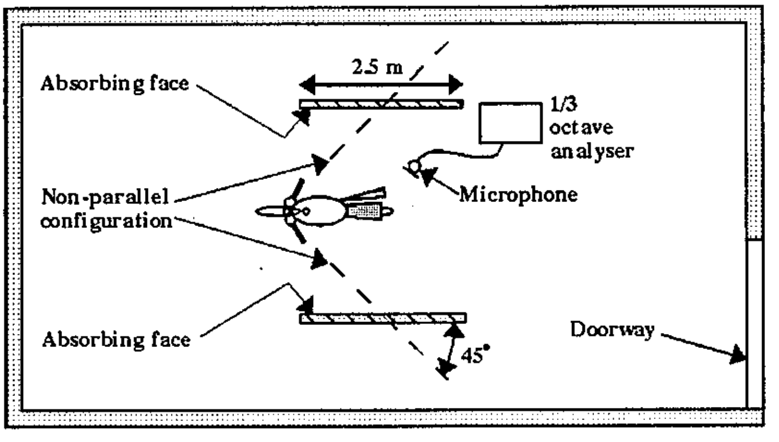


Figure 3.5 Absorbing panels used in the enclosed spaces.



(a) Section through absorbing panel.



(b) Plan of large workshop showing positions of the two panels.

4. RESULTS

The results of the noise measurements taken on the test track under drive-by type approval conditions are given in Table 4.1. and the results of the measurements taken in close proximity obtained with the type 1 and type 2 instrumentation are given in Tables 4.2 and 4.3 respectively.

The following sections examine the results in more detail.

4.1 Comparison of drive by and close proximity noise levels obtained on the test track

A comparison of the drive-by noise levels and the close proximity noise levels obtained on the TRL's standard ISO vehicle noise test site is given in Figure 4.1. Also included on the Figure are the current type approval noise limits for different classes of motorcycle. It can be seen that both of the small (<80cc) motorcycles tested gave noise levels which are at or below the current limit for this category of motorcycle. For the intermediate category, (i.e >80 - ≤175 ccs) three of the five motorcycles gave noise levels which were at or below the limit. It should be noted that the motorcycle in this category which gave the very high noise level of 94 dB(A) under drive-by conditions was the motorcycle fitted with a silencer with the baffles removed. For the large capacity machines (i.e. >175ccs), seven of the nine motorcycles tested gave noise levels which were either at or below the type approval limits for this category of vehicle.

A linear regression analysis of all the data showed that there was a significant correlation (r=0.85) between the drive-by type approval noise levels and the close proximity noise levels obtained on the test track. The regression line obtained is given on the figure together with the 95% confidence boundaries. However, it can be seen that within a particular group of motorcycles there is considerable scatter in the data points. The large correlation coefficient resulting from the analysis of all the data is partly explained by the outlying point at the right hand edge of the graph.

4.2 Comparison of close proximity noise levels

4.2.1 Type 1 Instrumentation

Figures 4.2 to 4.4 compare the close proximity noise levels obtained at the different positions in the large workshop, small workshop and non-standard outdoor location respectively. In each case the close proximity noise levels obtained on the test track, i.e. under ideal measurement conditions, have been included on the Figures for each motorcycle to aid the comparison between the different measurements.

The data clearly shows that measurements taken inside both the large and small workshops gave systematically higher close proximity noise levels than the measurements taken at the 'ideal' test track site. The differences between the results obtained can be easily seen by considering the average values listed in Table 4.2. For example, the close proximity noise levels obtained at position 1 (i.e. central position) in the large and small workshops were, on average, 2.6 dB(A) and 3.6 dB(A) higher respectively than the corresponding average levels

obtained for the motorcycles tested at the 'ideal' test track site. At position 2 (i.e. doorway position) the corresponding differences were 0.6 dB(A) and 1.5 dB(A) for the large and small workshops respectively. However, it can be seen from the data given in Figure 4.4 that the close proximity measurements obtained at the 'non-standard' outdoor measurement site were closely similar to the corresponding noise levels obtained at the 'ideal' test track site. In this case, the average difference between the close proximity noise levels obtained at the two sites was only 0.2 dB(A).

4.2.2 Type 2 instrumentation

Figure 4.5 compares the close proximity noise levels obtained at the centre workshop position in the large workshop with the type 1 and type 2 instrumentation. It can be seen that the results obtained with the type 2 instrumentation gave systematically higher close proximity noise levels than the levels obtained with the precision grade (type 1) instrumentation. On average the type 2 results were 1.2 dB(A) higher then the type 1 results. Similar differences were also observed when comparing measurements at position 2 in the large workshop and in positions 1 and 2 in the small workshops with average differences amounting to 1.5 dB(A) in the large workshop and 1.3 dB(A) and 2.6 dB(A) in the small workshop respectively. The results obtained using the type 2 instrumentation are shown in Table 4.3.

4.3 Effectiveness of sound absorptive panels

Table 4.4 summarises the results of the measurements taken in the large and small workshops using the sound absorptive panels with the panels arranged either parallel to the axis of the motorcycle under test or at an angle of 45° to the axis as described earlier in section 3.4. Included in the Table are the corresponding noise levels obtained for the same motorcycles but without the panels in position.

It can be seen from the results that the absorptive panels were responsible for reducing the close proximity test noise levels in each case by between 1 to 3 dB(A) depending upon the motorcycle and test location. For the one condition tested with the panels orientated at an angle of 45° to the axis of the motorcycle under test, there was no additional reduction indicating, as expected, that reflections of noise from the panels were not significantly affecting the close proximity test levels.

4.4 Reverberation time measurements

Reverberation time measurements were carried out in the large and small workshops using the procedure described earlier in section 3.5.

The one-third octave band spectra of reverberation time obtained for both workshops are given in Figure 4.6. It can be seen that, as expected, the reverberation times in the large workshop were significantly higher over the whole of the frequency range studied than the corresponding values obtained in the small workshop. Typically, the differences in reverberation time in the two rooms were about 1 - 1.5 seconds although greater differences were noted at low frequencies in the range 125 - 175 Hz where the differences in

reverberation time exceeded 2 seconds.

By substituting the measured values of reverberation time into equations 2 and 3 given earlier in section 2.2.1, the room constant, R_c, at each band centre frequency have been obtained. These values have then been substituted into equation 1 to obtain the sound pressure level for a given source power level in the two workshops over the frequency range measured. Figure 4.7 shows the calculated differences in the sound pressure level (SPL), deduced from the measured reverberation times, between the indoor (position 1) and outdoor (free field) measurement locations for both workshops. Note that the source power levels assumed in these calculations does not affect the result.

By comparing the two spectra it can be seen clearly that the measurements of reverberation time indicate that the acoustical characteristics of the small workshop will give rise to greater enhancements of the source noise levels than the large workshop which is consistent with the measured differences in the close proximity test levels presented earlier in section 4.2. which clearly showed that the test levels were higher in the small workshop.

From Table 4.2 the average increase in level due to the reverberant conditions in the large workshop was 2.6 dB(A). This is larger than the theoretical increase of approximately 1 dB(A) and is likely to be due to standing wave effects. Theoretical and measured differences are smaller for the small workshop.

Motorcycle	SPL dB L_{Amax}
Honda SA50J	75
Yamaha CW50	73
Honda C90G	81
Yamaha RXS100	79
Yamaha RXS100[1]	94
Honda CG125	75
Yamaha TDR125	78
Yamaha XT350	81
Yamaha XV535	82
Kawasaki GPZ500S	79
Kawasaki GPZ500S[2]	81
Kawasaki ZZ-R600	79
Triumph Trident 750 Road Sport	82
Ducati M900	84
Suzuki GSX-R1100WP	80
BMW K1100RS Road Sport	82

Table 4.1 Drive-by type approval noise levels for different motorcycles

[1] Baffle removed from exhaust silencer.
[2] Fitted with '2 into 1' replacement exhaust silencer

Motorcycle	SPL dB L_{Amax} (Type 1* instrumentation)					
	Test track-type approval test site	Non-standard outdoor location	Large workshop		Small workshop	
			Position 1	Position 2	Position 1	Position 2
Honda SA50J	**79**	79	79	77	80	79
Yamaha CW50	**76**	76	79	77	80	78
Honda C90G	**79**	79	81	79	82	81
Yamaha RXS100	**83**	84	86	83	88	84
Yamaha RXS100[1]	**109**	110	111	110	112	111
Honda CG125	**82**	81	85	84	86	84
Yamaha TDR125	**80**	81	84	82	85	82
Yamaha XT350	**85**	82	86	83	86	84
Yamaha XV535	**88**	88	92	89	91	89
Kawasaki GPZ500S	**87**	87	89	89	91	90
Kawasaki GPZ500S[2]	**92**	92	94	92	95	94
Kawasaki ZZ-R600	**90**	91	93	92	95	93
Triumph Trident 750 Road Sport	**91**	92	94	92	96	94
Ducati M900	**91**	93	95	92	96	94
Suzuki GSX-R1100WP	**93**	93	97	94	97	95
BMW K1100RS Road Sport	**95**	95	97	95	97	96
Average	**87.5**	**87.7**	**90.1**	**88.1**	**91.1**	**89.2**

Table 4.2 Close proximity noise levels for different motorcycles using Type 1 instrumentation

* Precision classification of measurement instrument
[1] Baffle removed from exhaust silencer
[2] Fitted with '2 into 1' replacement exhaust silencer

Motorcycle	SPL dB L_{Amax} (Type 2* instrumentation)			
	Large workshop		Small workshop	
	Position 1	Position 2	Position 1	Position 2
Honda SA50J	82 (79)**	80 (77)	81 (80)	80 (79)
Yamaha CW50	81 (79)	79 (77)	80 (80)	79 (78)
Honda C90G	82 (81)	80 (79)	84 (82)	82 (81)
Yamaha RXS100	88 (86)	- (83)	89 (88)	86 (84)
Honda CG125	87 (85)	86 (84)	- (86)	- (84)
Yamaha TDR125	85 (84)	83 (82)	85 (85)	84 (82)
Yamaha XT350	85 (86)	84 (83)	87 (86)	86 (84)
Yamaha XV535	92 (92)	90 (89)	92 (91)	91 (89)
Kawasaki GPZ500S	91 (89)	- (89)	93 (91)	- (90)
Kawasaki ZZ-R600	94 (93)	92 (92)	96 (95)	94 (93)
Triumph Trident 750 Road Sport	96 (94)	94 (92)	97 (96)	95 (94)
Ducati M900	96 (95)	94 (92)	98 (96)	97 (94)
Suzuki GSX-R1100WP	98 (97)	96 (94)	99 (97)	98 (95)
BMW K1100RS Road Sport	98 (97)	96 (95)	99 (97)	98 (96)
Average	**89.6** (90.1)	**87.8** (88.1)	**90.8** (91.1)	**90** (89.2)

Table 4.3 Close proximity noise levels obtained for different motorcycles using Type 2 instrumentation

* Precision classification of measurement instrument

** Numbers in brackets represent noise levels obtained using type 1 instrumentation (values taken from table 4.2).

	Close proximity SPL dB L_{Amax}				
	Large workshop			Small workshop	
Motorcycle	Without panels	With panels (parallel*)	With panels (non-parallel)	Without panels	With panels
Yamaha RXS100 (100cc single cyl.)	86	85	-	87	85
Kawasaki GPZ500S (500 cc twin cyl.)	91	89	89	92	90
BMW K100 (1000cc 4 cyl)	96	94	-	96	95

Table 4.4 Comparison of close proximity noise levels obtained with and without noise absorbing panels

* Alignment either side of motorcycle

Figure 4.1 Relation between close proximity and acceleration test noise levels

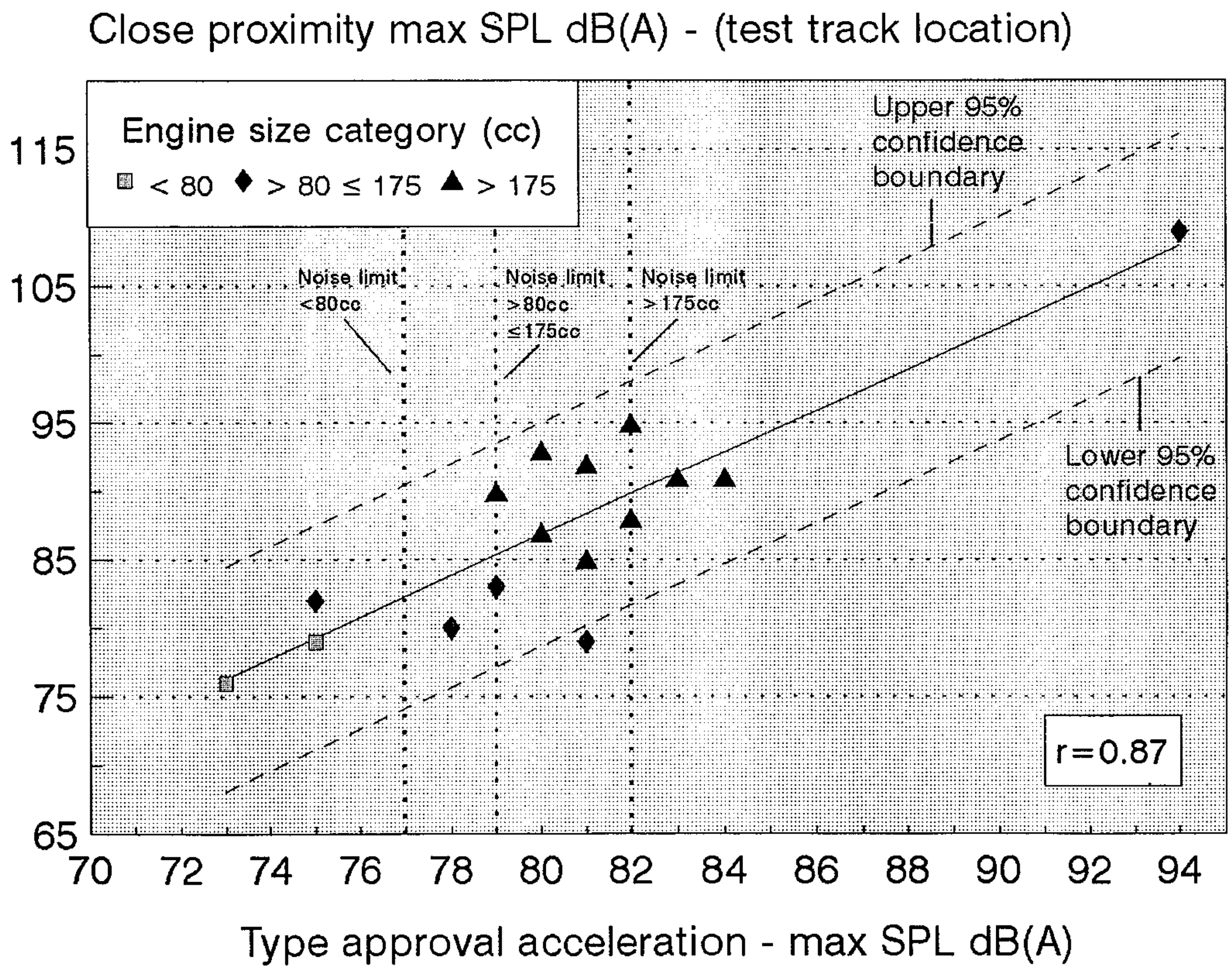
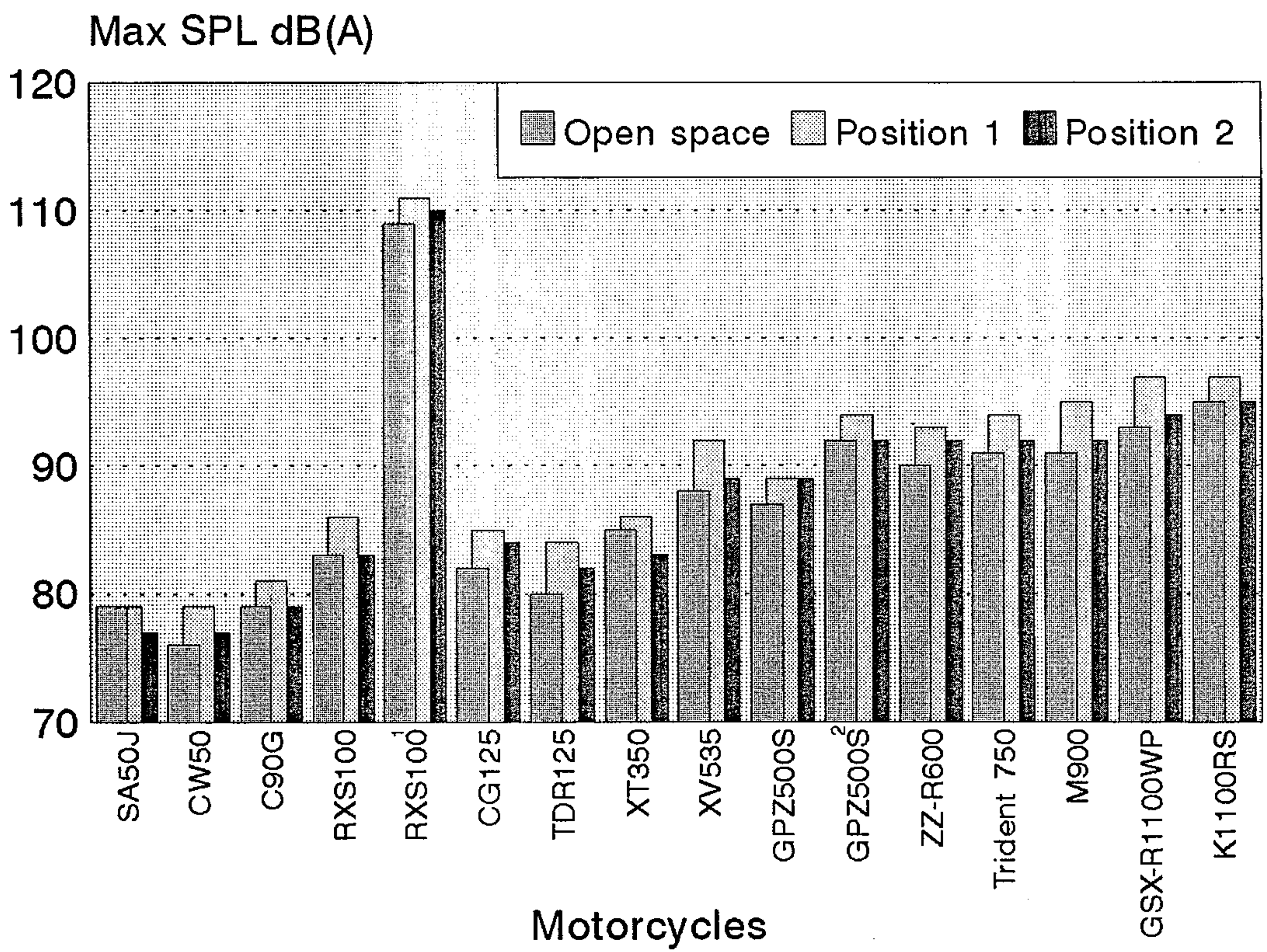
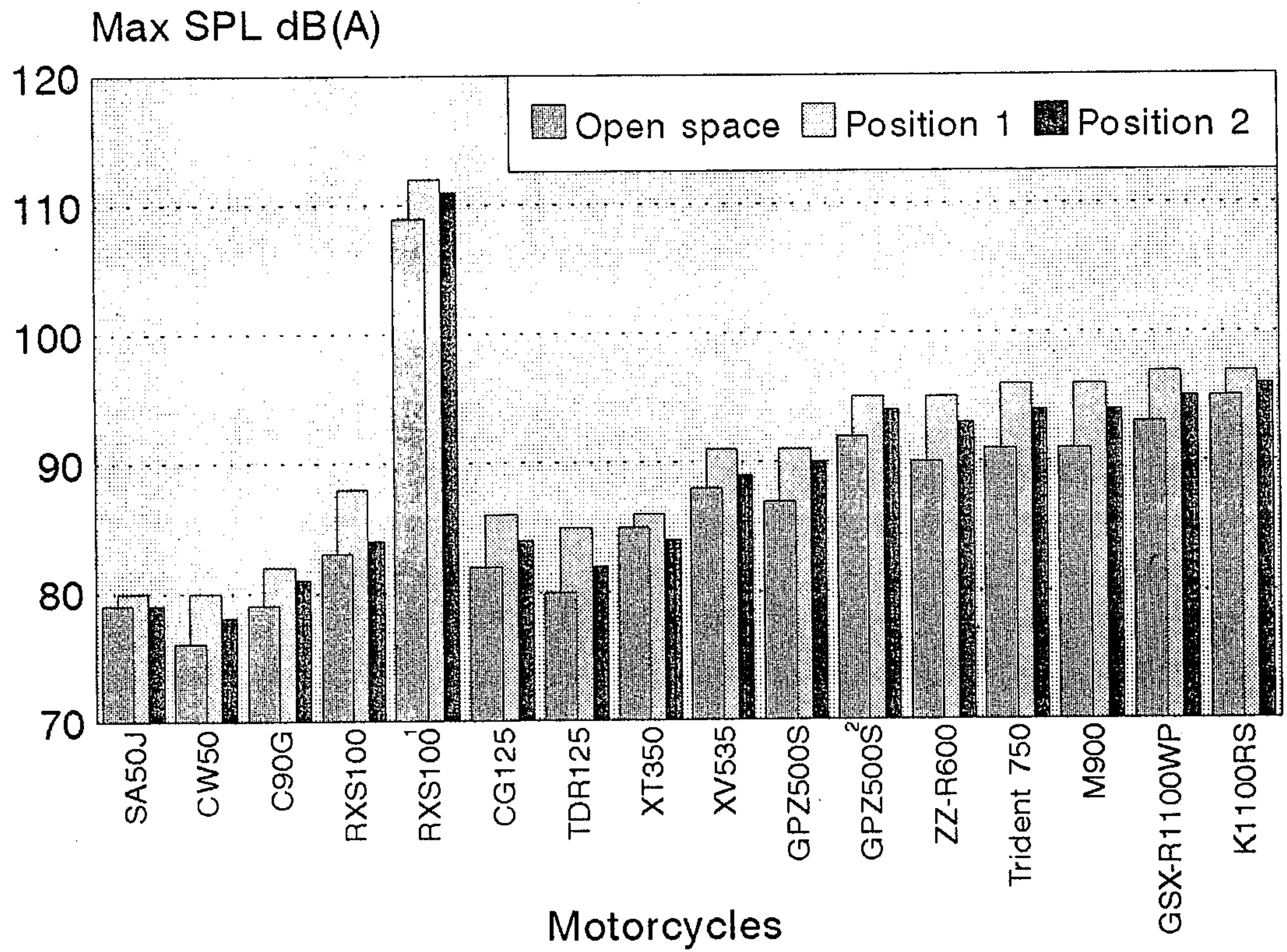


Figure 4.2 Comparison of close proximity noise levels obtained on the test track with corresponding levels obtained in the large workshop



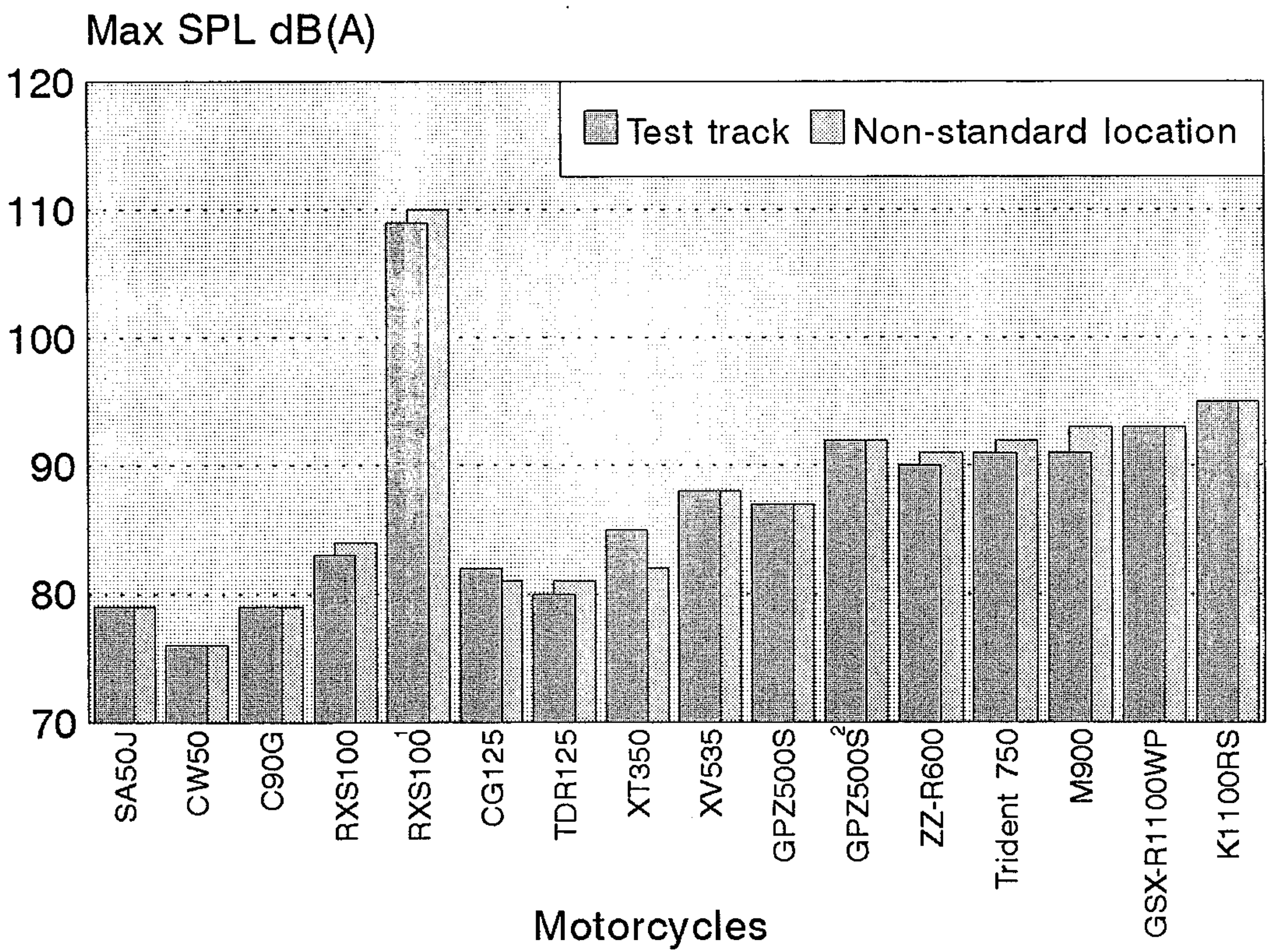
1, Baffle removed from exhaust silencer
2, Fitted with '2 into 1' replacement exhaust silencer

Figure 4.3 Comparison of close proximity noise levels obtained on the test track with corresponding levels obtained in the small workshop



1. Baffle removed from exhaust silencer
2. Fitted with '2 into 1' replacement exhaust silencer

Figure 4.4 Comparison of close proximity noise levels obtained on the test track with corresponding levels obtained at a non-standard outdoor location



1, Baffle removed from exhaust silencer
2, Fitted with '2 into 1' replacement exhaust silencer

Figure 4.5 Comparison of close proximity noise levels obtained at position 1 in the large workshop using type 1 and type 2 instrumentation

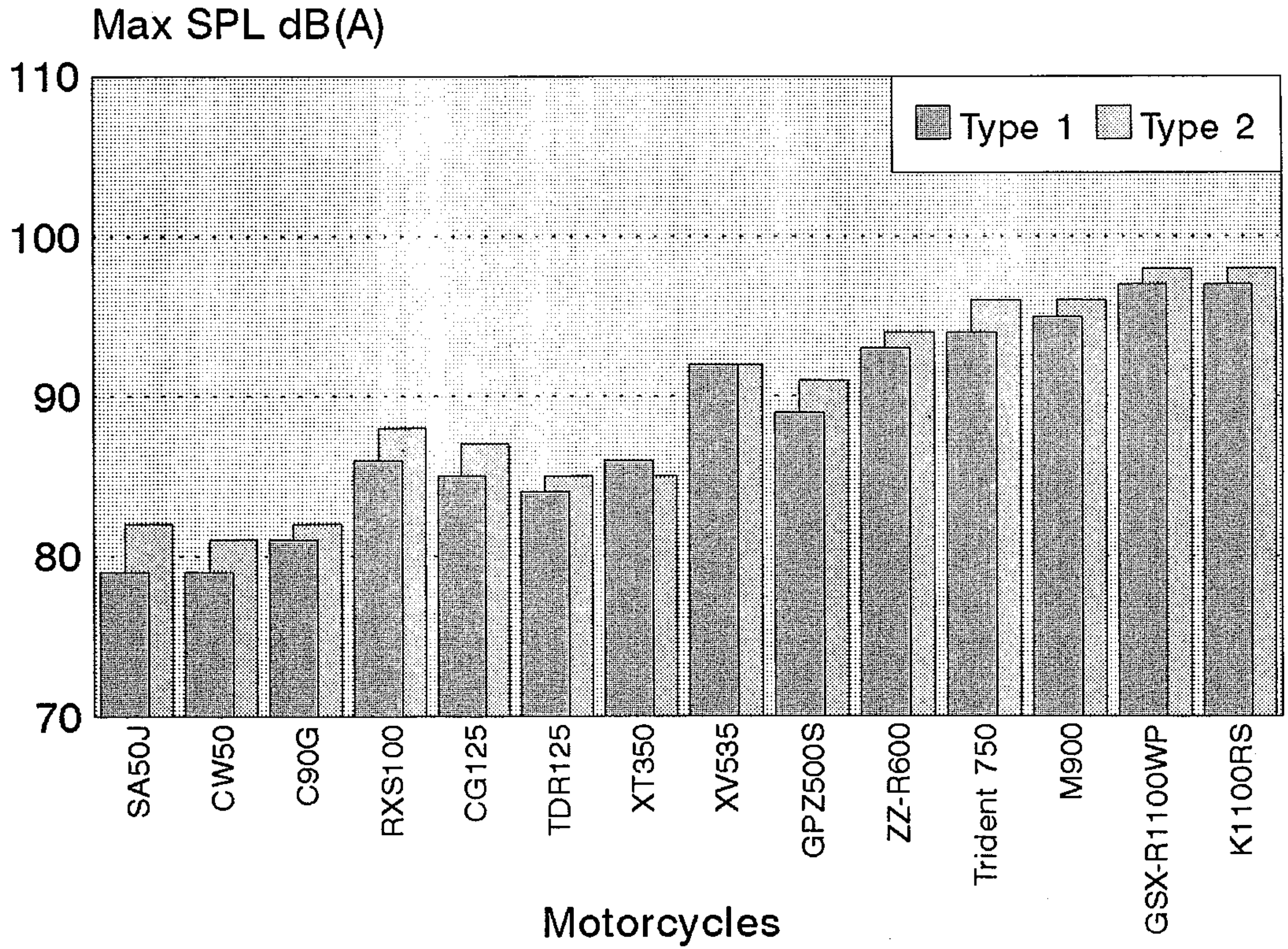


Figure 4.6 1/3 octave band reverberation time spectra for the large and small workshops

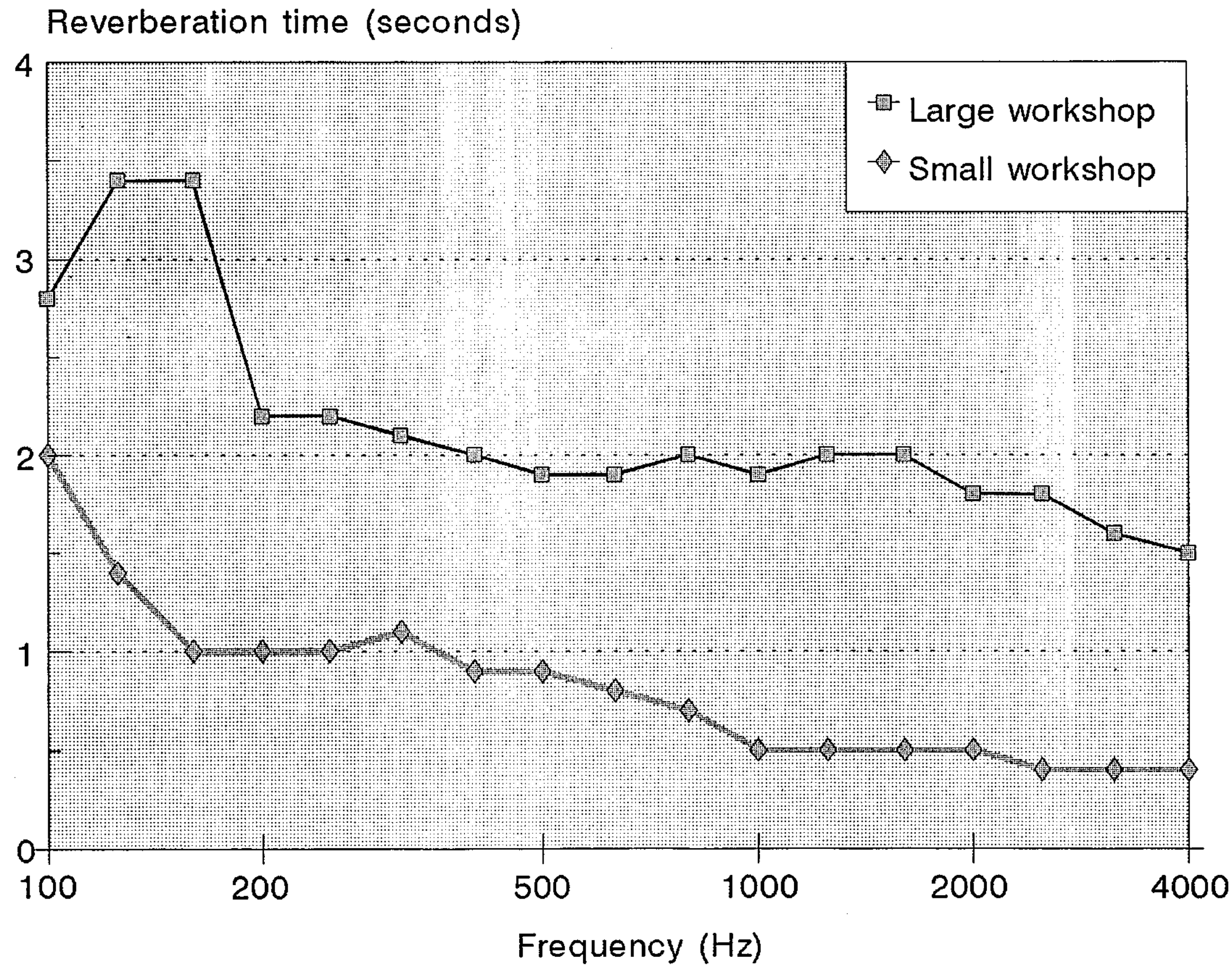
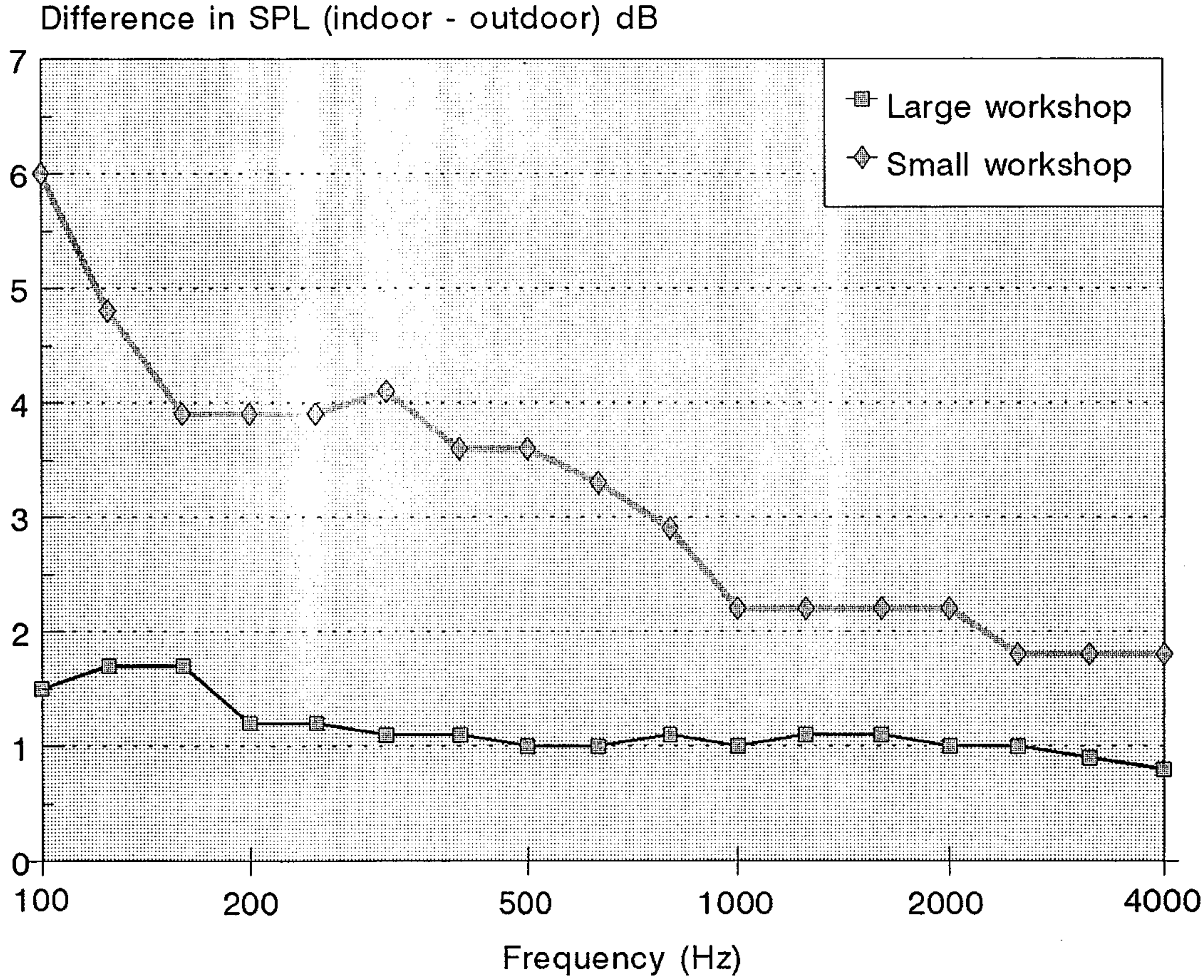


Figure 4.7 Estimated difference in SPL between indoor (position 1) and outdoor locations (calculations based on measured reverberation times at the test position)



5. DISCUSSION

The primary objective of the work described in this Report was to consider the development of an in-service test procedure for the measurement of motorcycle noise emission. It was stated at the outset that the procedure chosen should be simple to perform and one which could be carried out without the need for sophisticated instrumentation. It should also be capable of producing both reproducible and repeatable results under a wide range of test site conditions.

For these reasons the motorcycles selected for this study have been tested under both ideal (i.e. standard conditions) as well as a variety of non-standard conditions using test sites located inside buildings and outdoors. Low cost, industrial grade instrumentation, has also been tried in order to provide information on the additional errors which may be introduced due to the use of lower cost test equipment with lower specification tolerances.

It was evident from the results of the study that the test procedure described in the European Union Directive 78/1015/EEC was, as expected, a relatively simple test to perform which could be carried out without the need for complex instrumentation. The test procedure gave a satisfactory degree of reproducibility of the test results indicating that, at standard test locations at least, the results should also be repeatable.

The measurements in the workshop locations indicated, however, that under these test conditions, the measured noise levels were not consistent with the test levels obtained at the standard outdoor test site. The errors were particularly noticeable when the motorcycles were positioned in the centre position in each workshop where differences between the correct test levels and those measured in the workshops were found to differ in the range 0 - 6 dB(A) depending upon the motorcycle under test and the test site location.

It has been shown that these errors can be attributed to several factors associated with the acoustical characteristics of the room. The main effects are associated with the reverberation characteristics of the space, which is related to the amount of acoustic absorption in the enclosure, and to the presence of standing waves caused by reflections, particularly between the walls.

The measurements of reverberation time taken in each of the workshops has indicated that greater enhancements of the measured close proximity noise levels would be expected in the smaller workshop, particularly at low frequencies. Clearly, the higher noise levels generally recorded for different motorcycles located at the centre of the small workshop is consistent with this observation.

Evidence of the influence of standing wave effects in the two workshops has been provided from the results obtained with the absorbing panels. With the panels in position, noticeable reductions in the measured close proximity test levels were obtained in both workshops. In this case, it was apparent that the panels were acting as barriers which effectively interfered with the establishment of standing waves being set up in the vicinity of motorcycle exhaust and the measurement position in the room. Further tests, not reported earlier, were carried out in the large workshop with the panels positioned some distance away from the motorcycle

under test. In this case the measured levels were the same as those obtained without the panels in the room. This confirms that the panels were acting as barriers to reduce standing waves and that the noise reductions observed were not associated with changes to the reverberant conditions in the workshop as a result of introducing additional absorbing surfaces.

Further evidence of the importance of standing wave effects can be gauged by examining the frequency spectra given in Figure 5.1. The one-third octave spectra given in the Figure refer to measurements taken in close proximity to a BMW K100 motorcycle located at the central position in the small workshop[4]. In this workshop, the distance between the internal faces of the two side walls is 2.4m. With this dimension the 2nd lateral standing wave mode will tend to occur at a frequency of 140Hz. At this frequency the central position of the workshop coincides with a sound pressure maxima and further maxima will occur, of course, at the walls of the workshop. The distance between maxima (also described as antinodes) is 1.2m and therefore the corresponding distance between a node and antinode is 0.6m. A cross section of the workshop showing a schematic of the 140Hz sound pressure wave at this frequency, and the approximate positions of the nodes and antinodes, is given as an inset on the Figure. Clearly, by moving the motorcycle from the central position towards one of the walls, the measurement microphone would also need to move along the waveform, potentially moving from a region in the space of low amplification to a region of high amplification.

This phenomena is clearly shown in the spectra given in the Figure. In the Figure, a one-third octave band close to the 2nd lateral mode frequency of 140Hz has been highlighted. This occurs at a frequency of 160 Hz. It can be seen that the one-third octave levels in the 160 Hz band recorded for the BMW motorcycle located in the centre of workshop differ substantially from the levels recorded when the same motorcycle was tested at different lateral positions in the workshop. By moving the motorcycle by 30 cms. to one side of the centre position, the sound levels in the 160 Hz band increased by approximately 10 dB(A). By moving the motorcycle a further 30 cms in the same direction the sound levels at 160 Hz were lower, as might be expected from the shape of the standing wave in this region, by approximately 6 dB(A). The position of the microphone at each location is shown in the inset on the Figure.

It is interesting to note that, conversely, higher noise levels were recorded at 100 Hz and 125 Hz for the open site conditions than for the corresponding measurements recorded in the small workshop. At these frequencies it would appear that the microphone located in the small workshop was coincident with a region of low SPL due to the presence of the standing waves.

Clearly, the possibility of standing waves being produced inside enclosed spaces provides, probably the most compelling reasons for excluding this type of test location from any in-service noise test procedure. With standing waves, the positioning of the motorcycle exhaust in the test workshop or cell will be critically important since by moving the motorcycle by

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[4] The BMW KD100 motorcycle was not part of the sample of motorcycles used for the main study. This motorcycle was taken from TRL's test fleet and was used in this study purely to demonstrate the importance of standing waves in the small workshop.

just a few centimetres large differences in the measured noise levels at different frequencies can result. It is clear therefore that the results of close proximity measurements will depend greatly upon the frequency characteristics of the motorcycle under test and the frequency response characteristics of the enclosed space. It follows that it is virtually impossible to account for these effects in establishing a repeatable test procedure which will work with acceptable error at all possible test locations.

Although there are considerable reservations associated with using the close proximity test procedure with the motorcycle located at the centre position inside an enclosed space, the errors associated with this test location were reduced when the motorcycle was positioned in the doorway position and were virtually eliminated when the motorcycle was tested just outside the large workshop. This clearly indicates that provided motorcycles can be tested outdoors, virtually any location will be suitable provided the ambient noise levels produced by other sources are not excessively high. It follows that tests carried out on garage forecourts, outside workshops and at the roadside, would, with few exception, all be suitable for in-service testing. It would also be a relatively simple matter to specify the minimum test site conditions for a valid test.

The measurements taken with the low cost instrumentation produced disappointing results. Previous laboratory checks of the instrumentation obtained for this study had shown that the frequency response characteristics of the type 2 instrumentation matched very closely the frequency response characteristics of the precision grade equipment. Additionally measurements, again taken in the laboratory, of steady state broad band noise gave very similar results using both sets of instrumentation. It was expected therefore that the close proximity measurements taken using the two grades of instrumentation would also have produced closely similar results. However, the results showed that the close proximity test noise levels obtained using the low cost equipment were systematically higher than the corresponding levels obtained using the precision equipment. The differences were, on average, 1 to 2 dB(A).

Bearing in mind the results of the laboratory tests on the two instruments, it would appear that the only possible explanation for these systematic differences in the results is that there are significant differences in the performance of the averaging time circuitry in the two instruments. Since the test procedure requires the noise levels to vary during the test, any differences in the way the signal detected by the microphones is averaged by the instrumentation will lead to different results. This will be particularly noticeable for the measurement of rapidly varying sound levels. In general, an instrument with a short averaging time will register higher maximum noise levels when measuring a rapidly fluctuating sound level than an instrument with a longer averaging time constant.

The results obtained with the type 2 instrumentation underlines the difficulty of using low cost instrumentation for legal purposes unless some allowance in the limit values or method of interpreting the data is given to compensate for instrumentation errors. Clearly it is beyond the scope of this present study to determine what degree of compensation would be needed but, clearly, with the instrumentation used for this study an allowance of approximately 2 dB(A) would be needed in order to align the test data obtained with the corresponding test results obtained using the precision grade equipment. Further work in this area is indicated to provide a better understanding of the range of results obtained with different

instrumentation and to determine whether improvements can be made to the equipment tolerances without affecting the overall cost.

Finally, this study has provided useful guidance on the limit values that might be set for close proximity noise levels for motorcycles of different capacity.

A fundamental principle guiding the setting of limits for in-service noise levels must be to ensure that, to a reasonable probability, a motorcycle failing to meet the in-service limit for the appropriate category of motorcycle should not be found to subsequently pass the drive-by type approval test. In order to determine the levels of probability associated with different limit values the data given in Figure 4.1 can be used.

The Figure shows a significant correlation between close proximity noise levels and drive-by type approval noise levels for the sample of motorcycles tested. Assuming that the relationship between close proximity and type approval test values are the same for each class of motorcycle the following generalisation can be made using the results of this sample:-

From the statistical analysis of all measurements it is possible to estimate the probability of a motorcycle failing the close proximity test and then subsequently passing the drive-by type approval test. For example, using the upper 95% confidence boundary (i.e. 2 standard deviations from the mean) as a means of determining pass or fail under the test it would appear that the limits for the small (<80cc) motorcycles should be set at approximately 91 dB(A), and the corresponding limits for the medium and large capacity machines should be set at approximately 94 dB(A) and 99 dB(A) respectively. With these limits, the statistics suggest that only about 2-3 motorcycles in every 100 tested that just meet the type approval limit will fail the close proximity test. For example a large capacity motorcycle with a type approval noise of 82 dB(A), i.e. just meeting the limit value, will have a 2.5% chance of failing the close-proximity test. For motorcycles in this category which have lower type-approval noise levels, the probability of the same bikes failing the close proximity test will, of course, be less than 2.5%.

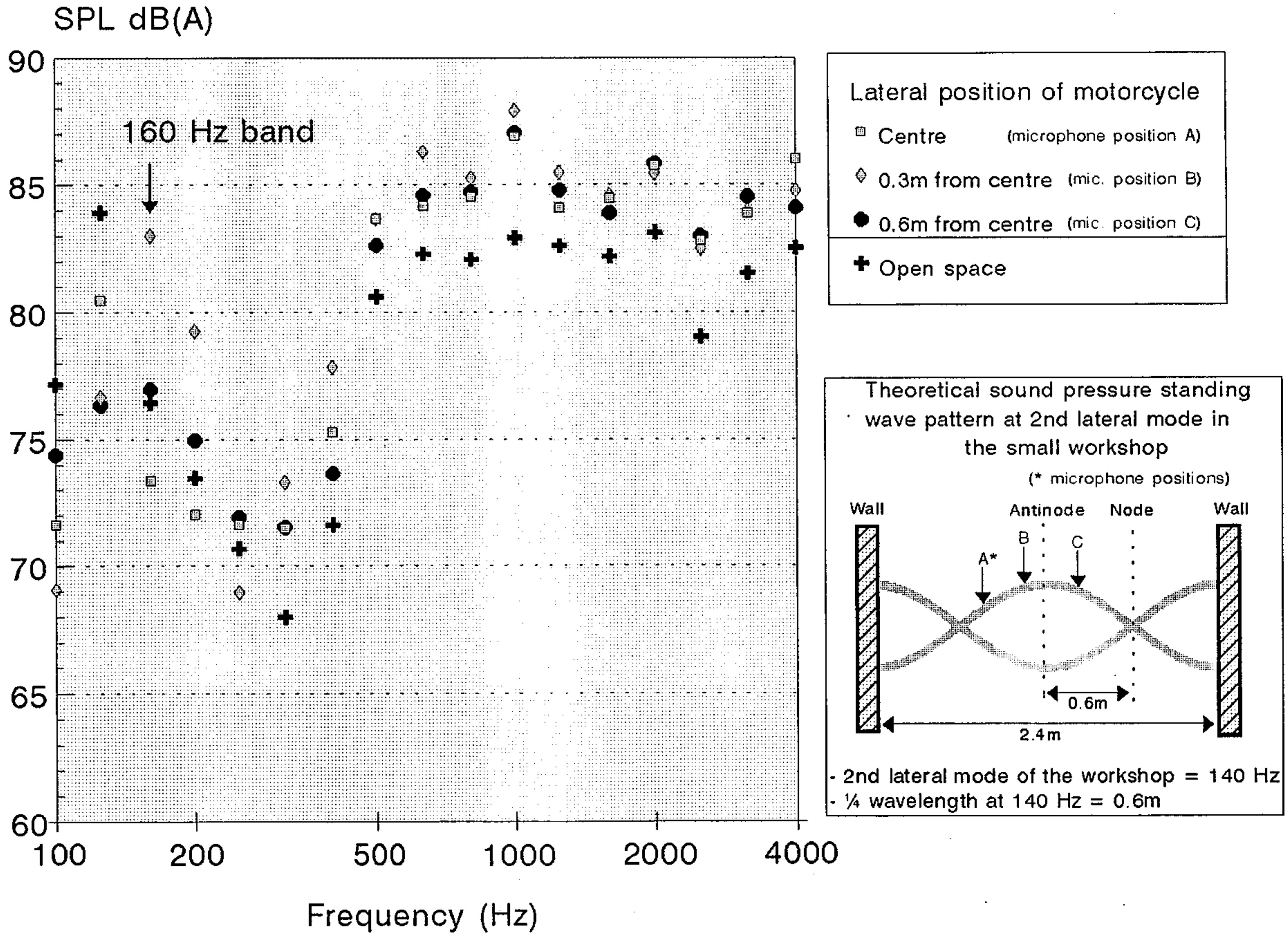
Clearly, the probability of this situation occurring can be reduced by raising the close-proximity limit values further. For example, by setting the limit values at three standard deviations from the mean rather than two as suggested in the previous paragraph, would mean raising the close proximity limit values by approximately 4 dB(A) for each category of motorcycle. However, with this higher setting it would be expected that there would be a 0.1% chance that a motorcycle just meeting the drive-by type approval limit will fail to meet the close proximity noise limit.

By applying these limit values to the data set obtained as part of this study only one motorcycle would fail the close proximity test. However, this motorcycle would also fail the drive by test by a substantial margin. It is, perhaps, reassuring to note that this motorcycle was tested with the baffles removed from the silencer.

To obtain greater confidence in the setting of appropriate limit values it is recommended that a larger sample of motorcycles are tested. It is possible that there is a different relationship between close proximity and type approval test values for the different classes of motorcycles and it would be important to obtain further test data in all categories and particularly for the

small capacity machines where sample data was limited.

Figure 5.1 Close proximity 1/3 octave band spectra obtained for the BMW motorcycle located in the small workshop



6. CONCLUSIONS

The following main conclusions can be drawn from the results of this study:-

1. The in-service motorcycle noise test procedure described in the European Union Directive 78/1015/EEC was found to be a relatively simple test to perform which could be carried out without the need for complex instrumentation. The test procedure gave a satisfactory degree of reproducibility of the test results indicating that, at standard test locations at least, the results should also be repeatable.

2. The measurements in the workshop locations indicated, that the close proximity test procedure did not give measured noise which were consistent with the test levels obtained at the standard outdoor test site. The errors were particularly noticeable when the motorcycles were positioned in the centre position in each workshop where differences between the correct test levels and those measured in the workshops were found to differ in the range 0 - 6 dB(A) depending upon the motorcycle under test and the test site location.

3. It was found that the results obtained for motorcycles located in the centre position of the two workshops were significantly influenced by the acoustical response of the workshops in a manner that cannot be simply accounted for by calibration or an adjustment factor to correct for the acoustical response of the test space.

4. Since different indoor test locations will have different acoustical characteristics over the frequency range of interest, and the range of motorcycles that will need to be tested will also provide a broad range of noise sources with widely differing frequency characteristics, it is not possible to conceive of a practical test procedure based on measurements taken inside an enclosed space such as a garage test bay or workshop.

5. Although there are considerable reservations associated with using the close proximity test procedure with the motorcycle located at the centre position inside an enclosed space, the errors associated with this test location were reduced when the motorcycle was positioned in an open doorway with the exhaust pointing outwards and were virtually eliminated when the motorcycle was tested outdoors but under non-standard site conditions.

6. This indicates that provided motorcycles can be tested outdoors, virtually any location will be suitable provided the ambient noise levels produced by other sources are not excessively high. It follows that tests carried out on garage forecourts, outside workshops and at the roadside, would, with few exceptions, all be suitable for in-service testing.

7. The measurements taken with the low cost instrumentation produced close proximity noise levels which were systematically approximately 2.0 dB(A) higher than the corresponding noise levels obtained using the precision grade equipment. These differences were attributed to differences in the tolerances associated with the averaging time circuitry in the two instruments. Further work in this area is indicated to provide a better understanding of the range of results obtained with low cost instrumentation and to determine whether improvements can be made to the equipment tolerances without affecting the overall cost.

8. Using the results of this study possible limit values for close proximity noise levels have been suggested. It was found that with the close proximity limits for small (i.e. <80cc) motorcycles set at 91 dB(A), and the corresponding limits for the medium and large capacity machines set at approximately 94 dB(A) and 99 dB(A) respectively, there would be a low probability that a motorcycle would fail to meet the close proximity limits and then would subsequently pass the drive-by type approval test.

9. To obtain greater confidence in the setting of appropriate test limit values it is recommended that a larger sample of motorcycles are tested.

7. ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution made to this work by Mr Martin Biddescombe who assisted with the measurements and Mr Eric Pysden who produced some of the graphics used in the report.

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