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A Research Project to Propose and Validate a Method to Measure the Sound Power Levels Generated by Fans in Field Conditions

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A RESEARCH PROJECT TO PROPOSE AND VALIDATE A METHOD TO MEASURE THE SOUND POWER LEVELS GENERATED BY FANS IN FIELD CONDITIONS

By Michel Morin
MJM Acoustical Consultants Inc.

December 1991

CMHC Project Officer: Jacques Rousseau

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ACKNOWLEDGEMENTS

The author wishes to thank M. Savio Ricciardi of RACAN Industries for supplying the fan and the silencers which were used during the present study.

ABSTRACT

This research project, funded by the CANADA MORTGAGE AND HOUSING CORPORATION is a first attempt to validate a method using intensimetry to measure the sound power levels generated by fans when they are connected to the ductwork of a ventilating system, and operating in real conditions. The goal of the study was to determine the accuracy and limitations of the proposed method. To achieve this, the results of the measurements made according to the proposed procedure were compared with those obtained in a reverberant room using the method described in the AMCA 300 standard.

All the measurements were conducted in the acoustical laboratories of the NATIONAL RESEARCH COUNCIL OF CANADA under the direction of Dr. Alfred Warnock and the author.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This research project, funded by the CANADA MORTGAGE AND HOUSING CORPORATION is a first attempt to validate a method using intensimetry to measure the sound power levels generated by fans when they are connected to the ductwork of a ventilating system, and operating in real conditions. The goal of the study was to determine the accuracy and limitations of the proposed method. To achieve this, the results of the measurements made according to the proposed procedure were compared with those obtained in a reverberant room using the method described in the AMCA 300 standard.

All the measurements were conducted in the acoustical laboratories of the NATIONAL RESEARCH COUNCIL OF CANADA under the direction of Dr. Alfred Warnock and the author.

In resumé the proposed procedure consists:

a) in measuring the sound intensity inside and outside a section of duct located immediately after the fan discharge with a loudspeaker emitting pink noise at the position of the fan discharge. This is to perform a calibration of the field conditions and to take into account the sound transmission loss through the duct wall;

b) in repeating the measurement outside the duct with the fan operating;

c) in calculating the sound power levels using the data collected in a) and b).

The conclusions reached during this study are:

A) When the sound intensity measurements were made in the low background noise conditions of the large reverberant chamber, the results of 31 third-octave band sound intensity measurements over a total of 42 performed, were reliable.

The SWL determined by the proposed procedure correlate fairly well with the SWL obtained using the reverberant chamber method described in the AMCA 300 procedure for the frequency range going from 50 Hz to 800 Hz with discrepancies inferior to 4 dB except for the 50 Hz band for which a discrepancy of 7 dB was noted.

For the vast majority of ventilating systems, the 50 Hz to 500 Hz frequency range governs the noise control design. The very limited tests results suggest that given a low background noise, the proposed method could be reliable in this range. This would have to be confirmed by further testing involving a large number of tests on different duct sizes.

B) It was hoped that the method proposed would be relatively simple to implement and that it could provide an economical way to measure the sound power levels of fans operating in a multitude of field conditions. It was also thought that the intensimetry technology would permit measurements in noisy environment as publicized in the literature of some manufacturers of these equipments.

In reality however the limitations imposed by intensimetry made the procedure difficult to use in an acoustical environment similar to that of a mechanical room, and unreliable due to the high number of non valid measurements.

This suggests that in field conditions, reliable measurements could not be made in mechanical rooms where the ambient noise level is generally high. The measurements would therefore have to be made outside the mechanical room. Since in many instances the silencers and other noise control devices are installed inside the mechanical room or immediately before or after the mechanical room wall or floor, it would not be possible to evaluate accurately the sound power levels of the fan without major modifications to the ventilating system. This defeats the purpose of the proposed method: to permit reasonably accurate field measurements of sound power levels generated at the discharge of ventilating equipments when they are installed and operational.

Progress must be made to allow for accurate intensity measurements in noisy environment before the proposed method be further developed for reliability.

«Méthode de mesure des niveaux de puissance sonore des ventilateurs»

RÉSUMÉ

Ce projet de recherche, subventionné par la SOCIÉTÉ CANADIENNE D'HYPOTHÈQUES ET DE LOGEMENT, constitue un premier essai de validation d'une méthode de mesure, par intensimétrie, des niveaux de puissance acoustique produits par des ventilateurs en service lorsqu'ils sont raccordés à des conduits de ventilation. Cette étude a pour but de déterminer la précision et les limites de la méthode proposée. Pour y arriver, les auteurs ont comparé les résultats de mesures prises selon cette méthode avec celles réalisées dans une enceinte de réverbération avec la méthode décrite dans la norme AMCA n° 300.

Toutes les mesures ont été prises dans les laboratoires d'acoustique du CONSEIL NATIONAL DE RECHERCHES DU CANADA sous la direction de M. Alfred Warnock et de l'auteur.

La méthode proposée se résume comme suit :

a) Mesurer l'intensité sonore à l'intérieur et à l'extérieur d'une section de conduit située immédiatement en aval de la gaine d'extraction du ventilateur où un haut-parleur émet un bruit rose. Il s'agit, par là, de calibrer les conditions réelles de fonctionnement et de tenir compte de la perte de transmission acoustique dans le mur où passe le conduit.

b) Reprendre la mesure à l'extérieur du conduit pendant le fonctionnement du ventilateur.

c) Calculer les niveaux de puissance acoustique à l'aide des données recueillies aux étapes a et b.

Cette étude permet de tirer les conclusions suivantes :

A) Lorsque les mesures de l'intensité sonore sont prises en présence d'un faible bruit de fond dans la grande enceinte de réverbération, les résultats de 31 mesures de l'intensité sonore par bandes de tiers d'octave, sur un total de 42 analyses, sont fiables.

   Le niveau de puissance acoustique déterminé par la méthode proposée correspond assez bien à celui obtenu en enceinte de réverbération par la méthode décrite dans la norme 300 de l'AMCA pour ce qui est de la bande de fréquence se situant entre 50 et 800 Hz. Les écarts observés sont inférieurs à 4 dB, sauf pour la bande de 50 Hz pour laquelle on a noté un écart de 7 dB.

   Pour la grande majorité des ventilateurs, l'atténuation du bruit est fonction des bandes de fréquence comprises entre 50 et 500 Hz. Des essais très limités laissent supposer qu'en présence d'un faible bruit de fond, la méthode proposée pourrait être

fiable dans cette plage de fréquence. Il faudra toutefois le confirmer au moyen de plus amples analyses qui mettront à contribution un grand nombre d'essais sur des conduits de différentes dimensions.

B) On espérait que la méthode proposée serait relativement simple à mettre en application et qu'elle constituerait une façon économique de mesurer les niveaux de puissance acoustique des ventilateurs en service dans de multiples conditions. On croyait également que la technologie de l'intensimétrie permettrait d'obtenir des mesures dans des milieux bruyants, ainsi que la documentation de certains fabricants le faisait miroiter.

La réalité est tout autre, cependant, car les contraintes imposées par l'intensimétrie rendent la méthode difficile à utiliser dans un milieu acoustique semblable à celui d'un local technique et peu fiable à cause du grand nombre de mesures non valables.

Il serait donc impossible de réaliser des essais en service fiables dans les locaux techniques où le niveau de bruit ambiant est généralement élevé. Il faudrait alors prendre les mesures à l'extérieur du local technique. Or, comme les silencieux et autres dispositifs de lutte contre le bruit sont souvent placés à l'intérieur du local technique ou bien immédiatement devant ou derrière le mur ou le plancher du local technique, il ne serait pas possible d'évaluer avec précision le niveau de puissance acoustique du ventilateur sans modifier considérablement l'installation de ventilation. Cela va donc à l'encontre du but visé par la méthode proposée, c'est-à-dire réaliser des analyses en service relativement précises des niveaux de puissance acoustique produits à l'extraction par les ventilateurs.

Il faudra accomplir des progrès permettant de mesurer l'intensité de façon précise dans des milieux bruyants avant de pouvoir évaluer la fiabilité de la méthode proposée.

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National Office
700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

Bureau national
700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

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INTRODUCTION

This research project is a first attempt to validate a method to measure the sound power levels generated by fans when they are connected to the ductwork of a ventilating system, and operating in real conditions. The project was funded by the CANADA MORTGAGE AND HOUSING CORPORATION; the measurement procedure which was originally presented to the CMHC appears in ANNEX I. The goal of the study was to determine the accuracy and limitations of the proposed method. To achieve this, the results of the measurements made according to the proposed procedure were compared with those obtained in a reverberant room using the method described in the AMCA 300 standard.

All the measurements were conducted in the acoustical laboratories of the NATIONAL RESEARCH COUNCIL OF CANADA under the direction of Dr. Alfred Warnock and the author. The results of all the measurements performed are presented in ANNEX II which has been prepared by Dr. Alfred Warnock. The observations, comments, and conclusions reached during this research project are summarized in the paragraphs below.

RESUMÉ OF THE PROPOSED MEASUREMENT PROCEDURE

The proposed procedure consists:

a) in measuring the sound intensity inside and outside a section of duct located immediately after the fan discharge with a loudspeaker emitting pink noise at the position of the fan discharge. This is to perform a calibration of the field conditions and to take into account the sound transmission loss through the duct wall;

b) in repeating the measurements outside the duct with the fan operating (refer to figure no. 1 in the report for a sketch showing the experimental installation);

c) by comparing the levels measured with the fan and the reference loudspeaker it was assumed that one could deduce the sound power levels emitted by the fan with the equations appearing below:

$$SWL_{fan} = SWL_{ref.\ in.} + (SIL_{fan.\ out.} - SIL_{ref.\ out.})$$

Where :

SWL_{fan} = field Sound Power Level generated by the fan at its discharge outlet (dB re: 10^{-12} Watt)

$SWL_{ref.\ in.}$ = average Sound Power Level calculated inside the duct with the reference source in operation. (dB re: 10^{-12} Watt)

$= SIL_{ref.\ in.} + 10 \log S$

Where :

$SIL_{ref.\ in.}$ = average Sound Intensity Level measured inside the duct using pink noise through a speaker as a reference source. (dB re: 10^{-12} Watt/m^2)

S = the cross-sectional area of the duct (m^2)

$SIL_{fan.\ out.}$ = average Sound Intensity Level measured outside the duct with the fan in operation (dB re: 10^{-12} Watt/m^2)

$SIL_{ref.\ out.}$ = average Sound Intensity Level measured outside the duct using a loud speaker with pink noise as a reference source in operation (dB re: 10^{-12} Watt/m^2)

NOISE SOURCES

The procedure tested requires that sound intensity measurements be made using first a loudspeaker emitting pink noise as a reference source. Many loudspeakers were tested until one was found that had a large enough output for a frequency range of 50 to 5000 Hz; the selected speaker was a JBL E110 250 mm mounted in an enclosure.

The fan used to test the procedure is a centrifugal fan with forward curve blades supplied by Mc QUAY; it is designed to deliver 942 l/s at a static pressure of 185 Pa. (2000 cfm @ 0.75 in. H_2O).

The small reverberation chamber was the room in which both noise sources were placed.

ANALYSIS OF THE MEASUREMENTS PERFORMED

Sound pressure levels measurements in the large reverberation chamber:

The sound power levels generated by the fan were first measured for static pressures of 50, 100, 150 and 200 Pa using the reverberant room method described in the AMCA 300 standard; **figure no. 1 of ANNEX II** shows the corresponding curves. One can note on this figure that the sound power levels measured are considerably lower than the levels submitted to us by the manufacturer which appear to be calculated using the method suggested by ASHRAE.

Sound intensity measurement in the small reverberation chamber:

After the completion of the measurements as per the AMCA 300 procedure, tests were undertaken with the proposed method using intensimetry. For all the tests made with intensimetry, the fan was operating at a static pressure of 50 Pa.

It appeared logical that, in field conditions, the measurements be performed as close to the fan as possible (the procedure called for a distance of 600 mm between the sampling area and the fan discharge). In order to determine the effect of background noise on the sound intensity measurements, the first measurements were performed in the small reverberation chamber where the fan was installed and where the background noise was high.

Measurements were made inside and outside the discharge duct using the reference source: a loudspeaker emitting pink noise. Measurements were also conducted outside the duct with the fan running. In both cases the background noise in the small reverberation chamber was important enough to interfere with the measurements. Attempts have been made to improve the reliability of the data collected in the small reverberation chamber. The NRC staff tried to increase the absorption in the small reverberation chamber and to shield the sampling area on the duct using acoustic barriers: these attempts were not successful.

The complete results of the measurements made in the small reverberation chamber appear in ANNEX II. These results highlighted the limitations of intensimetry when used in high background noise conditions.

Sound intensity measurements in the large reverberant chamber:

Intensity measurements were then performed in the large reverberation chamber where the background noise was relatively low (it is this configuration which was originally submitted in the proposal to the CMHC).

Even in these conditions, the results of the sound intensity measurements performed inside and outside the duct were not reliable at all frequencies. The non reliable results were those for which the intensity level measured was negative, or for which the phase error indicator (PEI) was less than 7 dB. The complete results of the measurements performed in the large reverberation chamber are presented and discussed in ANNEX II of this report.

Determination of the sound power levels using the sound intensity measurements

The sound power levels of the fan were determined using the valid third-octave band intensity measurements made from 50 Hz to 5000 Hz: 31 on a total of 42. These levels are plotted on attached graph no.1 along with the sound power levels obtained by the AMCA 300 procedure. As can be seen on graph no. 1, with the exception of the sound power levels based on the sound intensity measurements made on the vertical surface of the discharge duct for third-octave band no. 29, 30, 31 and 33, the results obtained with the proposed procedure agree within 7 dB with the levels obtained with the AMCA procedure.

CONCLUSIONS

A) When the sound intensity measurements were made in the low background noise conditions of the large reverberant chamber, the results of 31 third-octave band sound intensity measurements over a total of 42 performed, were reliable. The non reliable results were those for which the intensity level measured was negative, or for which the phase error indicator (PEI) was less than 7 dB.

The SWL determined by the proposed procedure correlate fairly well with the SWL obtained using the reverberant chamber method described in the AMCA 300 procedure for the frequency range going from 50 Hz to 800 Hz with discrepancies inferior to 4 dB except for the 50 Hz band for which a discrepancy of 7 dB was noted.

For frequencies higher than 800 Hz however, the discrepancies are larger, especially when using the SIL measured on the vertical surface of the discharge duct for third-octave band frequencies ranging from 800 Hz to 2000 Hz.

For the vast majority of ventilating systems, the 50 Hz to 500 Hz frequency range governs the noise control design. The very limited tests results suggest that given a low background noise the proposed method could be reliable in this range. This would have to be confirmed by further testing involving a large number of tests on different duct sizes.

B) It was hoped that the method proposed would be relatively simple to implement and that it could provide an economical way to measure the sound power levels of fans operating in a multitude of field conditions. It was also thought that the intensimetry technology would permit measurements in noisy environment as publicized in the literature of some manufacturers of these equipments.

In reality however the limitations imposed by intensimetry made the procedure difficult to use in an acoustical environment similar to that of a mechanical room, and unreliable due to the high number of non valid measurements.

This suggests that in field conditions, reliable measurements could not be made in mechanical rooms where the ambient noise level is generally high. The measurements would therefore have to be made outside the mechanical room. Since in many instances the silencers and other noise control devices are installed inside the mechanical room or immediately before or after the mechanical room wall or floor, it would not be possible to evaluate accurately the sound power levels of the fan without major modifications to the ventilating system. This defeats the purpose of the proposed method: to permit reasonably accurate field measurements of sound power levels generated at the discharge of ventilating equipments when they are installed and operational.

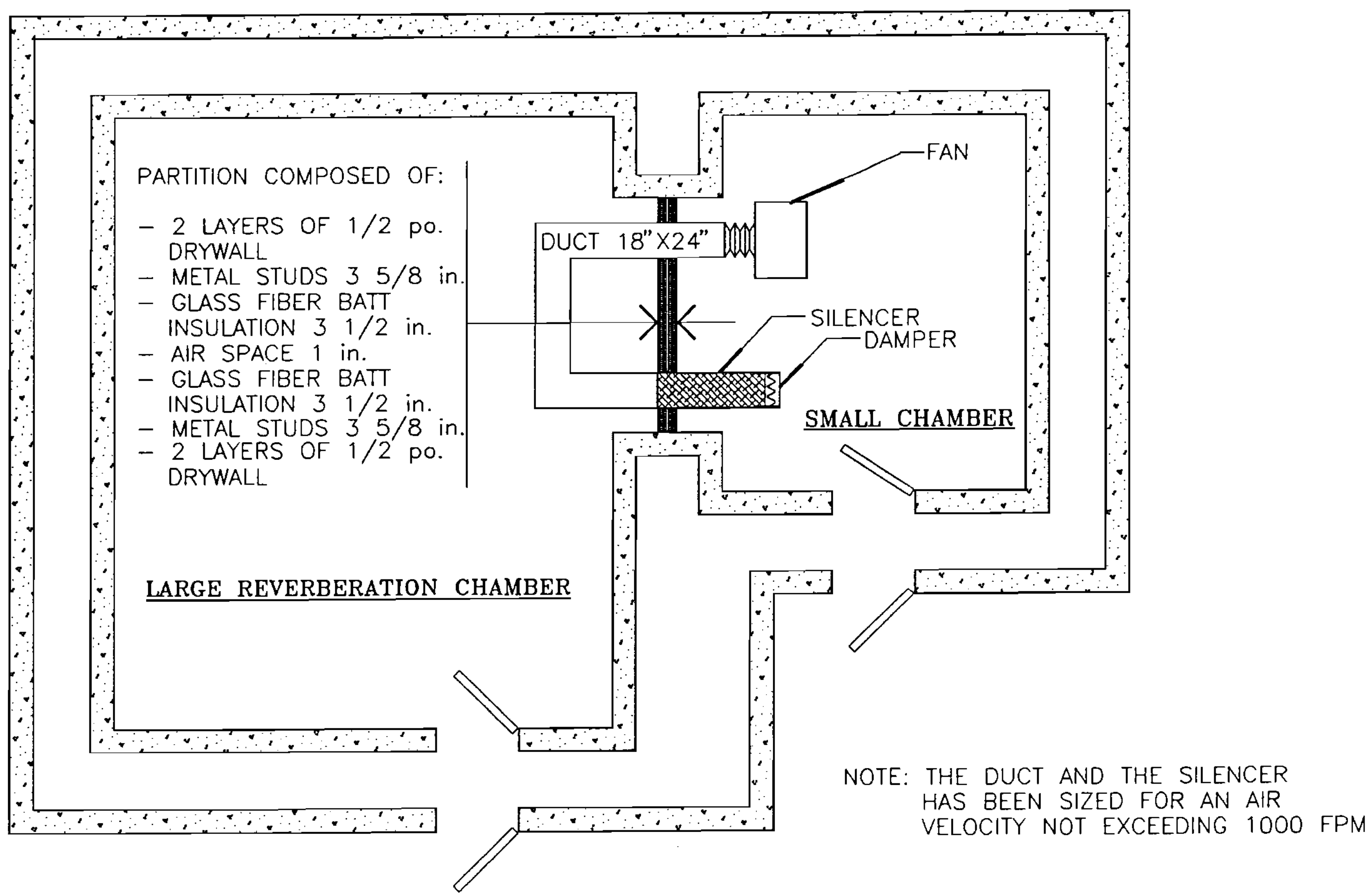
In conclusion progress must be made to allow for accurate intensity measurements in noisy environment before the proposed method be further developed for reliability.

Respectfully submitted on September, 24 1991

Yours very truly,
MJM ACOUSTICAL CONSULTANTS INC.

Michel Morin, architect
President

MM/dp
encl. Figure 1
Graph 1



EXPERIMENTAL LAYOUT – PLAN

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FIGURE 1

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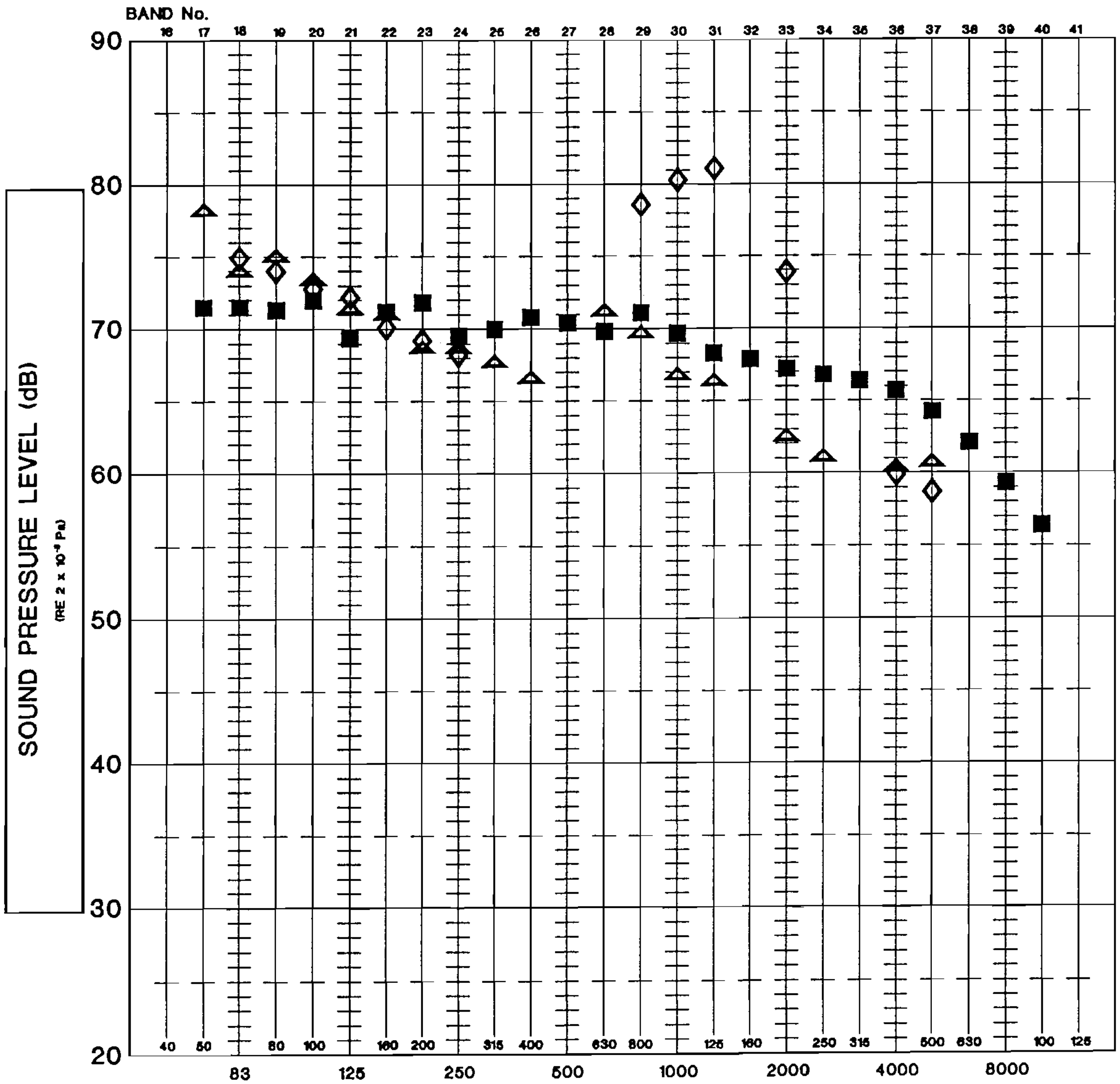
NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

■ SOUND POWER LEVELS OF THE FAN OBTAINED IN REVERBERANT ROOM USING THE AMCA 300 PROCEDURE

Sound power levels calculated using the method described in the present procedure and the sound intensity measurements made over the

△ HORIZONTAL surface of the discharge duct

◇ VERTICAL surface of the discharge duct

PROJECT DESCRIPTION

SOUND POWER MEASUREMENT FOR FANS IN FIELD CONDITIONS

GRAPH TITLE

COMPARISON BETWEEN SOUND PRESSURE AND SOUND INTENSITY VALUES

GRAPH NUMBER 1

PROJECT NUMBER 177.901

DATE 91 08

ANNEX 1

A RESEARCH PROJECT TO PROPOSE AND VALIDATE A METHOD TO MEASURE THE SOUND POWER LEVELS GENERATED BY FANS IN FIELD CONDITIONS

Michel Morin

Architecte

MJM CONSEILLERS EN ACOUSTIQUE INC.

MJM ACOUSTICAL CONSULTANTS INC.

6555, Côte des Neiges, bureau 440

Montréal, Québec H3S 2A6

INTRODUCTION

The purpose of this research project is to propose and validate a method to permit reasonably accurate field measurements of sound power levels generated at the discharge of ventilating equipements when they are installed and operational. The method is based on the measurement of the sound intensity radiated through a portion of the duct wich is located immediately after the fan discharge. The advantage of this method, as opposed to in-duct measurements, is that it rules out the potential for noise generation by the flow of air around the microphones. In order to make accurate measurements, the field conditions are first calibated to take into account the transmission loss through the discharge duct wall. Once this calibration is performed, the fan is turned on, and the generated noise levels are compared to those obtained during the calibration. The octave band sound power levels produced by the fan in the field can then be obtained.

PROCEDURE

Refer to figure no 1 for the laboratory sep up required to perform the validation of the procedure described below.

1.0 CALIBRATION OF THE FIELD CONDITIONS

1.1 Turn the fan off.

1.2 In the air inlet plenum, install a stable reference pink noise source, such as that used to measure the transmission loss through partitions. If there is no inlet plenum, a speaker could be inserted in the fan inlet. In both cases, the structural transmission of vibrations to the casing of the fan must be avoided.

1.3 Select a measurement location along the discharge duct at approximately 600 mm from the fan discharge.

1.4 Make a slot opening in the duct wall to allow for easy insertion of the sound intensity probe inside the duct.

1.5 With the reference source power on, measure the in-duct sound intensity by moving the probe to scan the entire duct cross sectional area. These measurements will provide the Sound Intensity Level inside the duct with the reference source in operation ($SIL_{ref.\ in.}$); they should be performed for octave bands no.1 to 8.

1.6 Using the cross-sectional area of the duct, calculate the Sound Power Level inside the duct with the reference source in operation (SWL ref. in.) for each octave band, using the formula :

$SWL_{ref.\ in.} = SIL_{ref.\ in.} + 10 \log S$

Where :

$SIL_{ref.\ in.}$ = average sound intensity level measured inside the duct as described in item 1.5 above.

S = the cross-sectional area of the duct

1.7 Cover the slot opening made for the in-duct measurements, using sheet metal and duct seal tape.

1.8 With the reference source on, perform outside duct measurements by moving the probe to scan the shaded area shown in figure 1. This area should start at approximately 600 mm from the fan discharge, continues for a length of 500 mm, and is at distance of 50 mm from the exterior of the duct wall. The obtained measurements will provide the Sound Intensity Level outside the duct with the reference source in operation ($SIL_{ref.\ out.}$), and they will be used to establish a relation between the sound intensities measured outside and inside the duct. This relation (cf. item 2.4) will be used to determine the sound power generated in the discharge duct with the fan in operation.

2.0 MEASUREMENT OF THE FAN SOUND POWER LEVELS

2.1 Remove the reference sound source from the air inlet of the fan.

2.2 Turn the fan on and allow the system to operate at normal conditions.

2.3 Measure the sound intensity radiated from the duct wall as described in item 1.8 above, in order to obtain the Sound Intensity Level outside the duct with the fan in operation ($SIL_{fan\ out.}$).

2.4 Calculate the Sound Power Levels (SWL fan) produced by the fan, using the following equation :

$$SWL_{fan} = SWL_{ref.\ in.} + (SIL_{fan.\ out.} - SIL_{ref.\ out.})$$

Where :

SWL_{fan} = field sound power levels generated by the fan at its discharge outlet

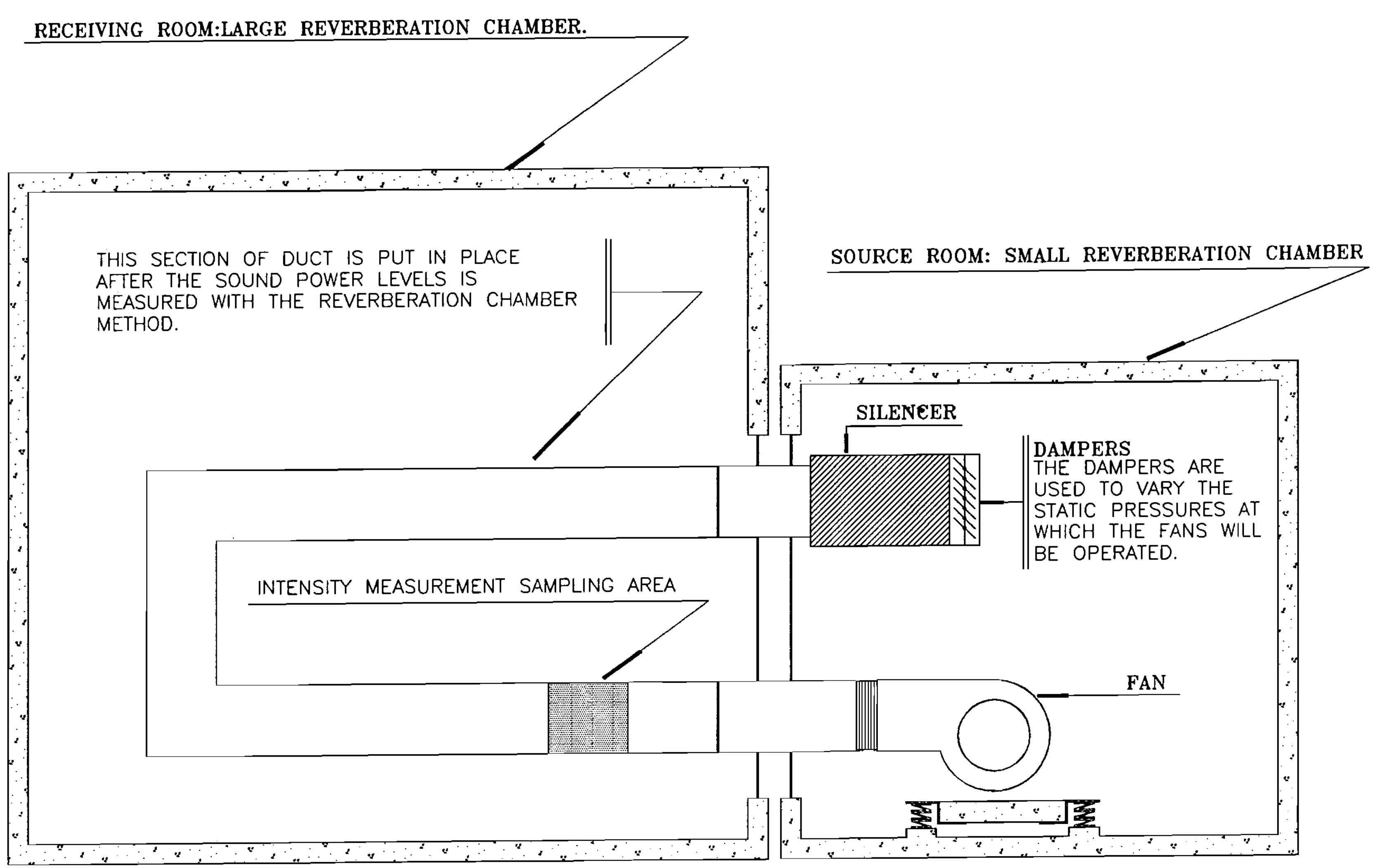
$SWL_{ref.\ in.}$ = average sound power level calculated inside the duct with the reference source in operation (see item 1.6)

$SIL_{fan.\ out.}$ = average intensity level measured outside the duct with the fan in operation

$SIL_{ref.\ out.}$ = average sound intensity level measured outside the duct with the reference souce in operation

PRECISION OF THE MEASUREMENTS

It is the goal of this study to establish the precision of the measurements obtained using this procedure and to compare it with the AMCA 300 procedure for determination of the sound power level generated by ventilating fans in laboratory conditions.



TEST LAYOUT – FAN SOUND POWER LEVELS MEASUREMENT

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FIGURE 1

90 02

ANNEX 2

SUMMARY OF INVESTIGATION OF EXPERIMENTAL TECHNIQUE TO MEASURE FAN SOUND POWER IN SITU.

The purpose of these measurements has been described in the research proposal submitted to CMHC. This report intends only to present the data together with some interpretation where necessary.

CONSTRUCTION.

A filler wall was constructed in the sound transmission loss test opening. A section of duct was installed at one side of the wall and a silencer at the other. (See Fig. 1) The fan supplied by MJM was attached to the section of duct using a short transition section and a vibration isolator.

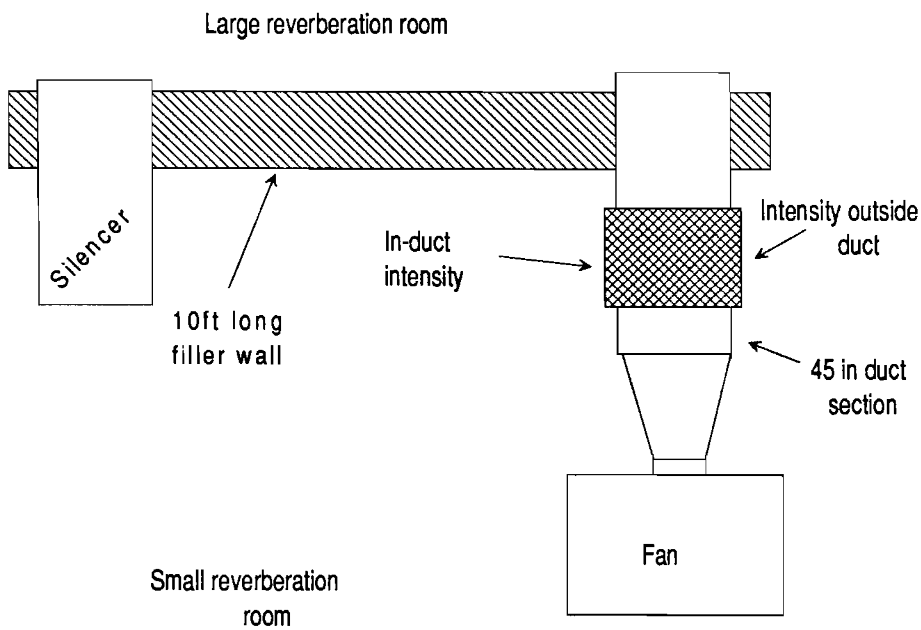

Figure 1: Arrangement of fan and duct sections for measurement of sound power in large reverberation room

STANDARD SOUND POWER MEASUREMENTS IN REVERBERATION ROOM

The output sound power of the fan was measured according to ANSI S12.31 at four static pressures: 50, 100, 150, and 200 Pa. This test procedure is essentially the same as the AMCA 300 procedure. Static pressure was changed by reducing the size of the opening into the small reverberation room of the silencer shown in Figure 1. Figure 2 shows the measured sound power values and the octave band values provided by the manufacturer. The latter clearly come from calculations made in accordance with ASHRAE algorithms. The data are tabulated in Table 1.

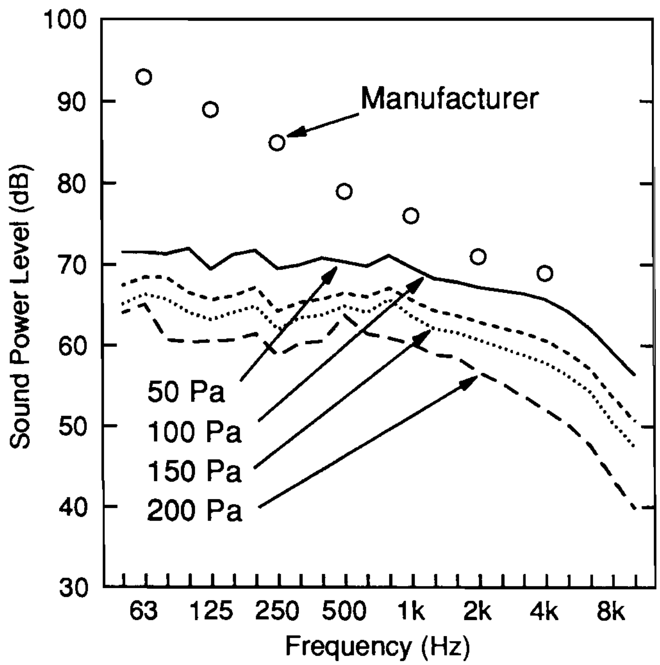

Figure 2: Sound power measured in reverberation room for four values of static pressure.

SOUND INTENSITY MEASUREMENTS.

TRIAL MEASUREMENTS

Trial measurements were made to see if it was possible to make sound intensity measurements in the small reverberation room where the fan was located. The sound source used was the fan itself. There was no restriction of the flow through the system. These measurements were made by sweeping the probe over two exterior surfaces of the duct - one horizontal and one vertical. Two kinds of probes were used: the NE216 pressure-velocity probe and the B&K pressure-pressure or two-microphone probe. With the NE216 probe, it is good practice to measure twice, with the probe axis normal to the duct surface and pointing at it and with it pointing away from it -- forward and reversed orientation. If the measurement is valid, the two results will differ only in sign. Unfortunately, if there is a change in sign only, it does not necessarily mean that the measurement is useful. The intensity vector may have many unwanted components.

Figure 3 shows the NE216 results for the horizontal duct surface. Figure 4 shows the results for the vertical duct surface. In each case the probe was held 75 mm away from the duct surface. The data for the case where the probe axis was reversed were multiplied by -1 to keep the plots together. Raw and processed data are given in Tables 2 and 3.

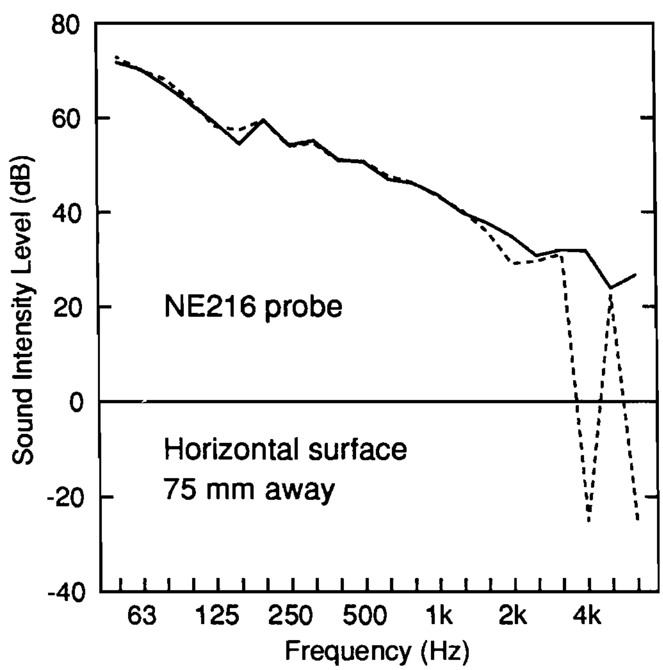

Figure 3: NE216 p-v probe data for the horizontal duct surface. Measurements in the small reverberation room with the probe axis pointing forward and reversed (solid and dashed lines).

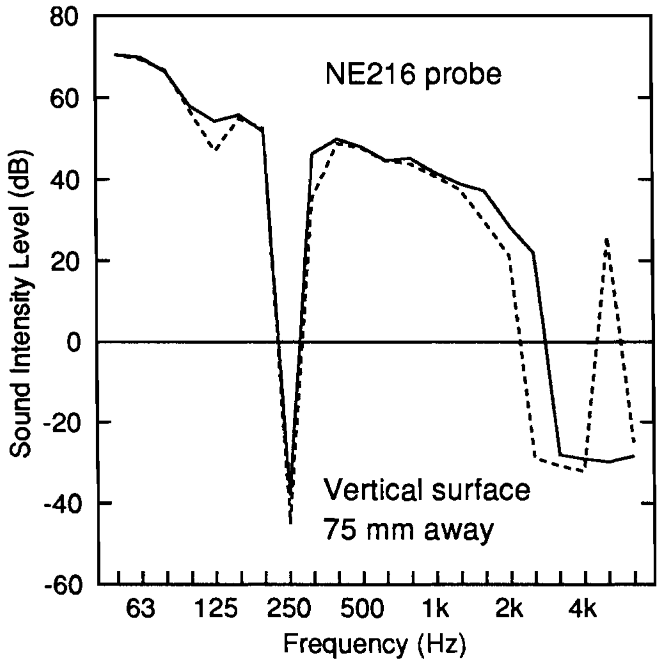

Figure 4: NE216 p-v probe data for the vertical duct surface. Measurements in the small reverberation room with the probe axis pointing forward and reversed (solid and dashed lines).

As the figures show, the top surface measurement appears to work except at high frequencies. The vertical surface measurement has a suspicious negative value at 250 Hz and the high frequency results are clearly not valid. Other measurements were made with the probes held about 15 cm away from the duct surfaces. These gave poorer results and are not plotted although they are given in tables at the end of this report. In these measurements and all those that follow, when suspicious negative intensities were measured or when the measurement appeared invalid, repeat measurements were made to ensure that no error had been made. In all cases, the repeatability was good.

The difficulty with the pressure-velocity probe is that there is no simple way of determining whether measurements are valid. This is very problematic when the sound fields are highly reactive or there is extraneous noise. Despite the fact that sound absorbing material and shielding were used to protect the measurement area from noise in the room, the measurements could not be shown to be reliable. Accordingly, the B&K two-microphone system was used in subsequent measurements.

A major advantage of the B&K probe system in situations where sound fields are reactive and there is external noise is that the assembly can be calibrated and the noise floor determined. This was done in this case using a B&K intensity calibrator type 3541.

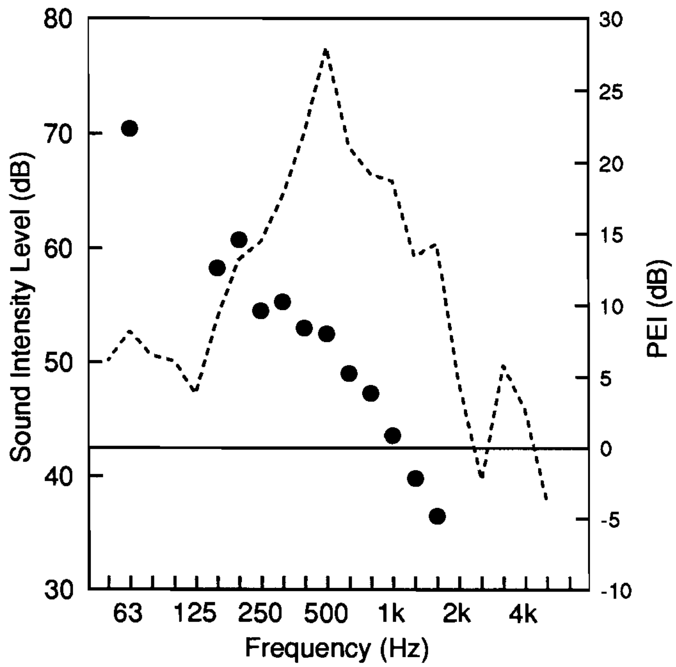

Figure 5: B&K p-p probe data for the horizontal duct surface. Measurements in the small reverberation room with the fan as the noise source.

Figure 5 shows the data for the horizontal surface. This plot and all subsequent similar plots, combine data from a sweep with a probe separation of 50 mm and one of 12 mm. Below 500 Hz, the data from the 50 mm probe were used. Above 500 Hz, the data from the 12 mm probe were used. From the calibration procedure and from the measurements, a phase error indicator (PEI) curve is obtained. This is shown as the dotted line in the figure. The right hand axis should be used for this curve. When PEI is less than 7 dB, errors in the measurement of intensity are considered too large. In such cases, the one-third-octave band levels are not plotted.

Note that it might be possible to use a more complicated procedure for combining the data from the 50 mm and 12 mm measurements. The raw data are available in the tables at the end of the report if such processing is deemed necessary.

Figure 5 shows that, for the horizontal surface, measurements are only valid at 63 Hz and between 160 and 1600 Hz. Figure 6 for the vertical surface shows two large gaps where the data is not reliable. Note that there is no large negative value of intensity at 250 Hz as there was with the NE216 probe. Raw and processed data for these two figures are given in Tables 2 and 3.

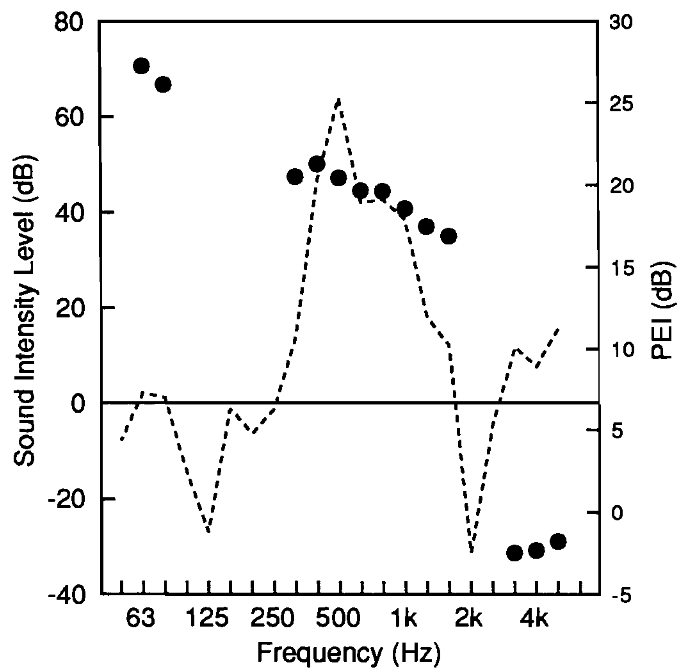

Figure 6: B&K p-p probe data for the vertical duct surface. Measurements in the small reverberation room with the fan as the noise source.

MEASUREMENTS WITH SPEAKER SOURCE IN SMALL REVERBERATION ROOM

The proposed measurement procedure requires that a loudspeaker be put in place of the fan. The sound power in the duct and that passing through the duct walls is then measured. Several speakers were tried before one was found that had a large enough output at all frequencies. The speaker that was finally chosen was a JBL E110 250 mm musical instrument loudspeaker. It was mounted in an enclosure measuring 33 x 48 x 61 cm. Figures 7 and 8 show the intensity values measured on the outside of the duct. It is clear that, while the measured values are valid, they do not represent the energy flow through the duct wall from inside to outside only. They are instead a combination of sound flow into the duct from the room and sound flow out of the duct. In this case the sound flow into the duct predominates at high frequencies but is not necessarily negligible at other frequencies. Thus the resultant vector points into the duct at high frequencies.

The measurements are also complicated by the fact that the sweep surface does not completely enclose the duct (the noise source). Ideally, this should be done to eliminate the effects of external noise. Even if this is done, errors can still be large in noisy environments.

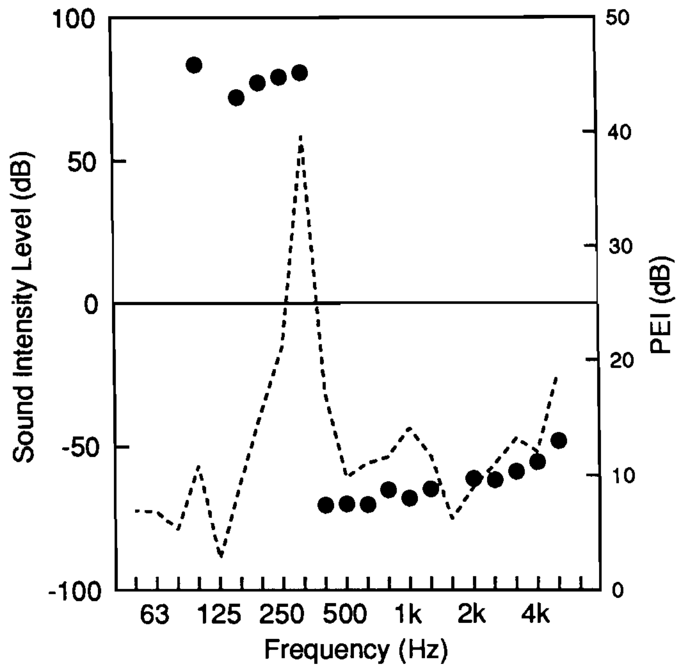

Figure 7: Intensity measurements in the small reverberation room on the horizontal surface of the duct. The loudspeaker was the source.

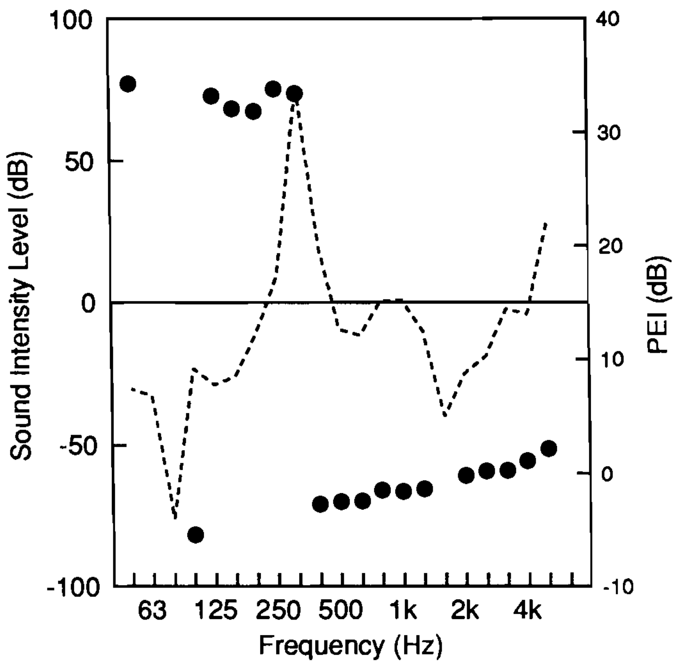

Figure 8: Intensity measurements in the small reverberation room on the vertical surface of the duct. The loudspeaker was the source.

MEASUREMENTS IN THE LARGE REVERBERATION ROOM

On the basis of the results presented above, it was decided that there was no point in continuing with measurements of sound intensity in the small reverberation room where the noise sources were. Instead, additional duct sections were added in the large reverberation room as shown in Figure 9. This is the configuration originally suggested by MJM. As in the small room, the measurement region was shielded and sound absorbing material was added to the room to reduce the reverberant sound field. In the large reverberation room, the only source of sound is the duct surface. This makes measurement easier in principle but this is offset by the fact that the room is more reverberant even with sound absorbing material added in the room.

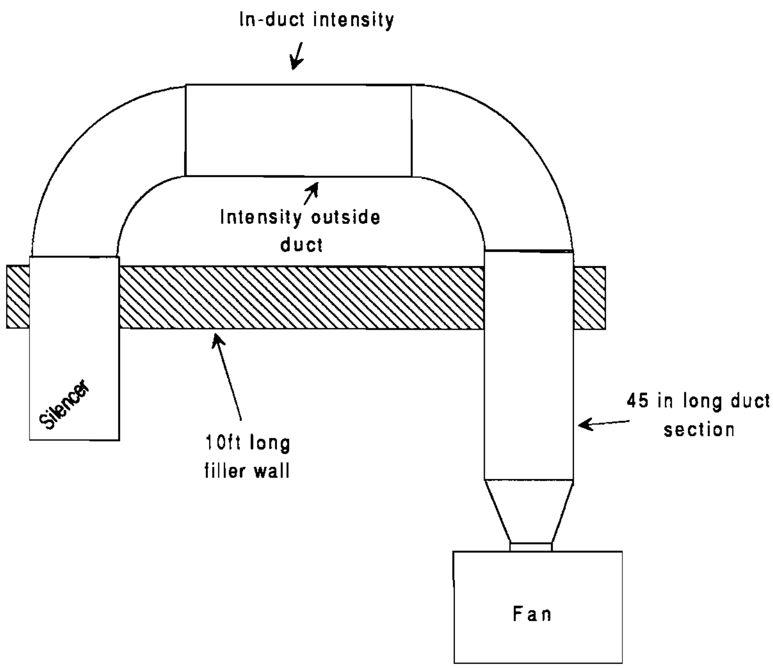

Figure 9: Arrangement of ductwork when sound intensity measurements were made in the large reverberation room.

INTENSITY MEASUREMENTS INSIDE THE DUCT - SPEAKER SOURCE.

Because of space restrictions, it was not possible to use the sweeping technique inside the duct. Instead, measurements were made at 9 fixed positions of the probe. To make these measurements, a slot was cut in the side of the duct. Even in this environment, some of the measured values were not reliable. The probes were probably close to a node in such cases. The mean intensity and the range in the data are shown in Figure 10. There are fairly large differences among the data measured at different points. Tabulated values are given at the end of the report.

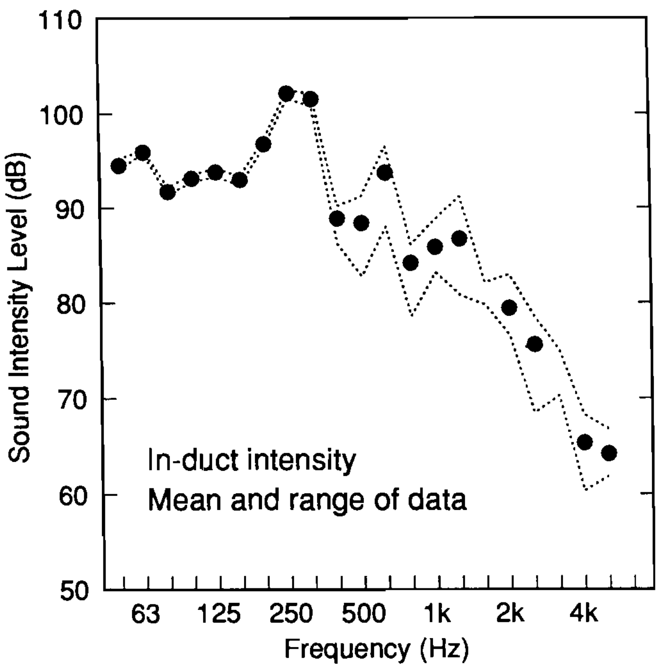

Figure 10: Mean value and range of sound intensity inside the duct for measurements at nine positions. The noise source is the loudspeaker.

INTENSITY MEASUREMENTS OUTSIDE THE DUCT - SPEAKER SOURCE

Measurements of sound intensity outside the duct due to the speaker source were made in the large reverberation room. The results are shown in Figures 11 and 12. The negative value of intensity at 350 Hz was repeatable and is attributed to some duct panel resonance influencing the sound field. To investigate this further would have required a great deal of detailed intensity measurements. This was not possible with the project budget and in any case it was not part of the aim of the project. It is important to know that such negative values can occur. Why they occur is not so important for this project.

INTENSITY MEASUREMENTS OUTSIDE THE DUCT - FAN SOURCE

Figure 13 shows the data for the horizontal duct surface and Fig. 14 shows the data for the vertical duct surface. There are only a few missing data points in Fig. 13. The data in Figure 14 can be relied on over almost the whole frequency range; only one point at 1600 Hz is doubtful.

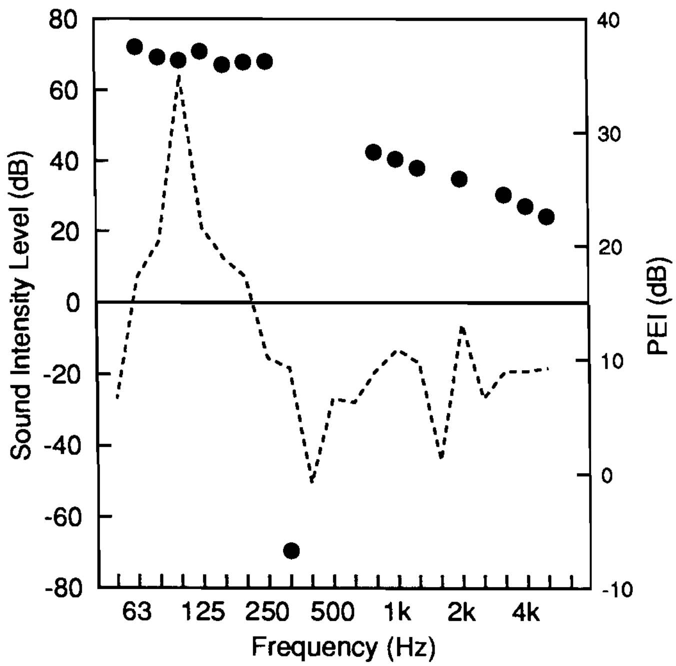

Figure 11: Sound intensity measured in the large reverberation room over the horizontal duct surface. The noise source is the loudspeaker.

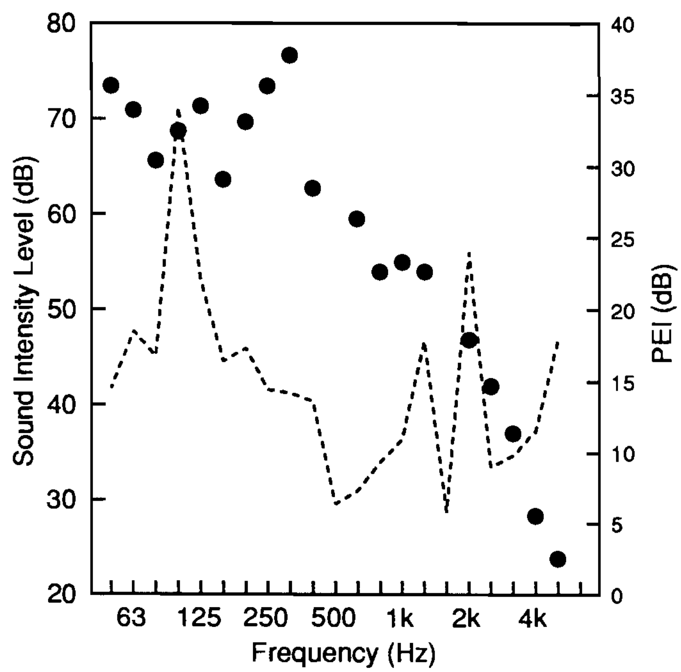

Figure 12: Sound intensity measured in the large reverberation room over the vertical duct surface. The noise source is the loudspeaker.

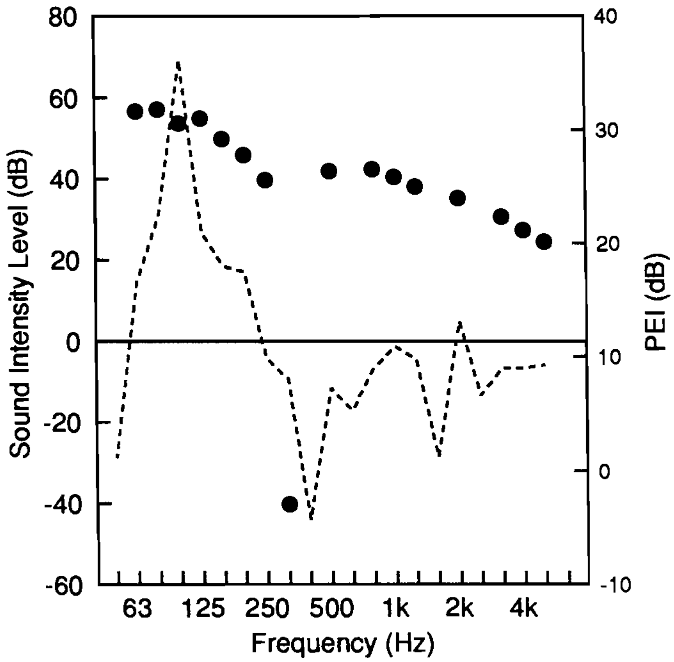

Figure 13: Intensity measurements in the large reverberation room over the horizontal duct surface. The noise source is the fan running unobstructed.

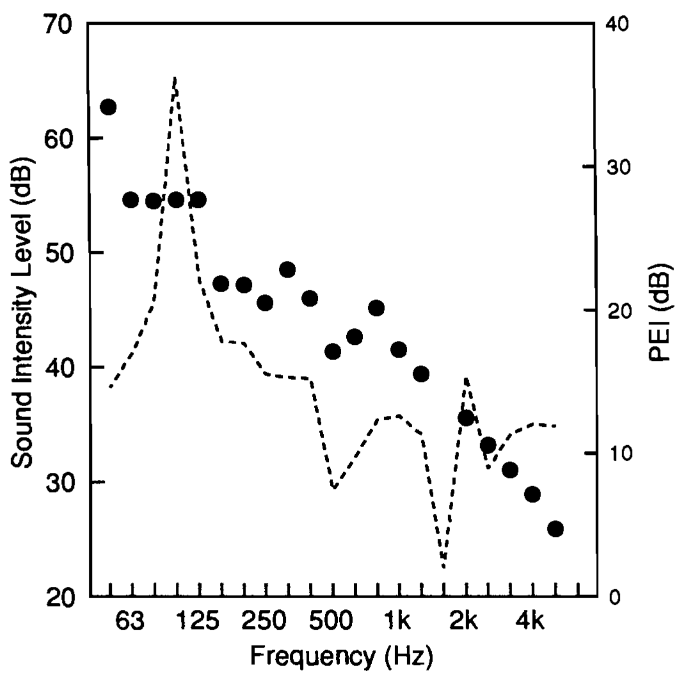

Figure 14: Intensity measurements in the large reverberation room over the vertical duct surface. The noise source is the fan running unobstructed.

Table 1: Fan sound power measured in reverberation room according to ANSI S12.31.

Test Number and Static Pressure	Frequency (Hz) 50	63	80	100	125	160	200	250	315	400	500	630	800
PO-91-043, 50 Pa	71.5	71.5	71.3	72.0	69.4	71.2	71.8	69.5	70.0	70.8	70.4	69.8	71.1
PO-91-044, 100 Pa	67.4	68.4	68.4	66.6	65.6	66.1	67.2	64.2	65.3	65.7	66.5	66.0	67.1
PO-91-045, 150 Pa	65.1	66.3	65.7	64.1	63.1	64.1	64.9	62.0	63.4	63.8	64.9	64.1	65.7
PO-91-046, 200 Pa	64.0	65.1	60.7	60.4	60.5	60.7	61.4	58.7	60.3	60.5	63.7	61.4	60.9

	Frequency (Hz) 1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10k	Awt
PO-91-043, 50 Pa	69.7	68.3	67.9	67.2	66.8	66.4	65.7	64.2	62.1	59.3	56.4	79.3
PO-91-044, 100 Pa	65.6	64.3	63.7	62.9	62.2	61.5	60.6	59.1	57.1	53.8	50.7	75.0
PO-91-045, 150 Pa	63.6	62.1	61.6	60.7	59.7	58.8	57.9	56.3	54.3	50.6	47.5	72.9
PO-91-046, 200 Pa	60.2	58.9	58.6	56.7	55.4	53.7	52.1	50.3	47.6	43.6	39.8	69.4

Octave band data

	63	125	250	500	1000	2000	4000	8000	Awt
PO-91-043, 50 Pa	76.2	75.7	75.3	75.1	74.6	72.1	70.3	64.7	79.3
PO-91-044, 100 Pa	70.6	67.7	65.3	59.4	75.0	72.8	70.9	70.5	70.8
PO-91-045, 150 Pa	68.8	65.5	62.5	56.4	72.9	70.5	68.6	68.4	69.1
PO-91-046, 200 Pa	64.9	61.9	57.0	49.6	69.4	68.4	65.3	65.0	66.9
Manufacturer's data for 2000cfm 3/4" water	93	89	85	79	76	71	69		82

Table 2: Sound intensity measurements in small reverberation room. Fan source - Full Flow.

NE pressure-velocity probe — Frequency (Hz)

	50	63	80	100	125	160	200	250	315	400	500	630	800
#1 Horizontal Surface 3" Away - Forward													
Ieq	71.8	70.3	66.8	63.1	59.0	54.5	59.5	54.2	55.1	51.0	50.6	46.9	46.1
Leq	76.6	73.7	74.1	72.6	69.5	68.9	69.5	64.1	64.3	61.3	59.3	55.1	54.6
Lk	4.9	3.4	7.3	9.5	10.4	14.3	10.0	9.8	9.1	10.3	8.7	8.1	8.4
#2 Horizontal Surface 3" Away - Reversed													
Ieq	-73.0	-70.2	-68.2	-63.9	-58.2	-57.4	-59.6	-53.9	-54.6	-50.9	-50.8	-47.5	-46.2
Leq	76.3	73.6	74.1	72.1	69.1	68.2	69.2	63.7	63.8	61.0	59.1	55.0	55.2
Lk	3.3	3.3	5.9	8.2	10.9	10.9	9.6	9.8	9.2	10.1	8.3	7.5	9.1
#3 Horizontal Surface 6" Away - Forward													
Ieq	71.4	69.1	65.3	63.0	54.6	52.9	59.2	52.5	54.6	50.6	50.0	46.7	45.2
Leq	75.5	73.2	73.8	72.0	68.6	67.4	68.8	63.1	62.4	59.4	57.3	53.9	54.4
Lk	4.1	4.1	8.5	9.0	14.1	14.5	9.6	10.5	7.8	8.8	7.3	7.2	9.2
#4 Horizontal Surface 6" Away - Reversed													
Ieq	-71.3	-68.8	-66.3	-62.7	-56.0	-55.2	-58.1	-53.3	-54.4	-50.0	-50.2	-46.6	-44.8
Leq	75.1	73.0	73.5	71.5	68.4	67.0	68.2	63.0	62.4	59.3	57.4	53.7	54.5
Lk	3.8	4.1	7.2	8.8	12.4	11.8	10.2	9.7	8.0	9.3	7.2	7.1	9.8
#5 Vertical Surface 3" Away - Forward													
Ieq	70.6	69.9	66.4	58.0	54.2	55.9	51.7	-37.8	46.3	49.9	48.1	44.6	45.3
Leq	75.5	74.1	72.5	70.2	65.8	68.2	64.9	63.3	62.5	58.8	56.5	53.3	55.1
Lk	4.9	4.2	6.1	12.2	11.5	12.3	13.2	25.5	16.2	8.9	8.4	8.8	9.9
#6 Vertical Surface 3" Away - Reversed													
Ieq	-70.5	-69.5	-66.7	-56.8	-46.9	-54.9	-52.5	45.0	-35.5	-48.8	-47.7	-44.4	-43.8
Leq	75.5	74.4	72.5	70.1	65.6	68.3	64.9	63.5	62.9	58.6	56.5	53.1	55.4
Lk	5.0	4.9	5.8	13.3	18.8	13.3	12.4	18.4	27.4	9.8	8.8	8.7	11.6
#7 Vertical Surface 6" Away - Forward													
Ieq	69.0	68.0	65.2	54.6	53.9	55.0	50.4	-47.4	42.0	49.0	46.5	43.6	44.0
Leq	74.4	73.6	71.8	69.5	65.6	67.8	63.9	62.7	61.9	58.0	55.4	51.9	55.0
Lk	5.4	5.6	6.6	14.8	11.7	12.8	13.6	15.3	19.8	9.0	8.9	8.3	11.0
#8 Vertical Surface 6" Away - Reversed													
Ieq	-70.2	-69.2	-66.2	-51.7	-51.1	-53.3	-49.3	49.2	38.1	-48.3	-46.9	-42.8	-43.4
Leq	75.1	73.9	72.2	69.9	65.9	68.0	64.4	62.8	61.9	57.6	55.3	51.8	55.2
Lk	4.9	4.7	6.0	18.2	14.7	14.7	15.0	13.5	23.8	9.3	8.4	8.9	11.9

Frequency (Hz)

	1000	1250	1600	2000	2500	3150	4000	5000	6300	Awt	Lin
#1 Horizontal Surface 3" Away - Forward											
Ieq	43.7	39.9	37.7	34.8	30.8	32.0	31.7	23.8	26.7	56.9	75.3
Leq	55.3	52.3	52.4	54.5	53.9	54.8	55.5	55.9	56.7	68.4	81.6
Lk	11.6	12.4	14.7	19.6	23.1	22.7	23.7	32.1	30.0	11.4	6.3
#2 Horizontal Surface 3" Away - Reversed											
Ieq	-43.5	-40.3	-35.8	-29.0	-29.6	-31.1	25.1	-22.4	25.6	-57.1	-76.1
Leq	54.5	52.4	53.3	54.3	54.3	54.2	55.1	55.4	56.4	68.1	81.3
Lk	11.0	12.1	17.5	25.3	24.7	23.1	29.9	33.0	30.8	11.0	5.2
#3 Horizontal Surface 6" Away - Forward											
Ieq	42.4	39.0	37.4	34.7	31.9	30.2	29.0	-27.5	25.1	56.2	74.5
Leq	53.6	52.9	54.2	54.4	55.0	54.7	55.6	55.7	56.8	67.8	80.8
Lk	11.2	13.9	16.8	19.7	23.0	24.5	26.5	28.2	31.7	11.7	6.3
#4 Horizontal Surface 6" Away - Reversed											
Ieq	-41.4	-38.7	-35.7	-33.3	30.2	18.6	28.1	-27.2	27.8	-55.9	-74.5
Leq	52.9	52.8	55.3	54.7	56.3	56.0	56.7	56.9	57.8	68.2	80.5
Lk	11.5	14.1	19.6	21.4	26.1	37.4	28.6	29.7	29.9	12.3	6.0
#5 Vertical Surface 3" Away - Forward											
Ieq	41.6	38.9	37.2	28.4	21.8	-28.0	-29.0	-29.8	-28.3	53.8	74.2
Leq	51.8	51.6	54.6	53.5	55.0	56.2	56.4	56.9	57.6	67.7	80.3
Lk	10.2	12.7	17.4	25.1	33.3	28.2	27.5	27.1	29.3	13.9	6.1
#6 Vertical Surface 3" Away - Reversed											
Ieq	-40.7	-37.5	-29.8	-21.0	28.8	30.9	32.0	-26.0	24.9	-52.7	-73.9
Leq	51.7	51.5	54.8	53.1	54.7	55.7	56.5	56.5	57.3	67.6	80.3
Lk	11.0	14.0	25.0	32.1	26.0	24.7	24.5	30.5	32.4	14.9	6.4
#7 Vertical Surface 6" Away - Forward											
Ieq	39.9	36.7	36.7	31.1	-27.8	-32.6	-29.5	-31.8	-31.3	52.1	72.5
Leq	51.5	51.8	55.0	52.8	54.4	55.0	56.4	56.3	57.0	67.1	79.6
Lk	11.6	15.2	18.2	21.6	26.5	22.4	26.8	24.5	25.7	15.0	7.0

#8 Vertical Surface 6" Away - Reversed

Ieq	-39.6	-34.0	-25.1	31.5	35.0	34.9	32.0	-29.4	17.5	-51.3	-73.6
Leq	51.3	51.7	54.8	52.7	54.2	54.7	56.1	56.2	56.8	67.1	80.0
Lk	11.7	17.6	29.7	21.2	19.2	19.8	24.1	26.8	39.3	15.8	6.4

B & K probe — Frequency (Hz)

	50	63	80	100	125	160	200	250	315	400	500	630	800
#9 Residual Pressure-Intensity Index													
Ieq	-65.3	-63.3	-61.3	-59.3	-57.4	-55.3	-53.1	-50.6	-47.8	-44.4	-33.1	41.1	42.9
Leq	74.2	74.1	74.1	74.1	74.2	74.3	74.4	74.3	74.1	74.0	73.7	73.7	74.1
Lk	8.8	10.8	12.8	14.7	16.8	19.0	21.3	23.6	26.3	29.6	40.6	32.6	31.2
#10 Horizontal Surface 6" Away - 50mm													
Ieq	-71.3	-69.9	-67.2	-63.8	-56.0	-55.9	-60.5	-54.9	-55.8	-52.7	-52.1	-48.7	-46.4
Leq	74.1	72.3	73.5	72.1	68.9	67.2	68.4	63.6	63.0	58.8	56.9	53.0	51.6
Lk	2.8	2.4	6.3	8.3	13.0	11.3	7.9	8.7	7.2	6.2	4.8	4.3	5.2
#11 Vertical Surface 6" Away - 50mm													
Ieq	-69.9	-70.3	-67.0	-57.8	-54.4	-56.6	-43.0	46.9	-39.7	-48.4	-46.5	-43.2	-43.0
Leq	75.1	74.0	72.5	71.1	66.5	68.8	65.5	61.6	62.1	58.1	55.0	50.1	49.3
Lk	5.2	3.8	5.5	13.3	12.1	12.2	22.5	14.8	22.4	9.7	8.5	6.8	6.4
#12 Horizontal Surface 3" Away - 12mm													
Ieq	-74.6	-71.6	-69.5	-65.6	-59.5	-59.6	-61.8	-55.1	-55.9	-53.2	-52.5	-49.0	-47.3
Leq	74.7	72.7	73.3	71.7	68.7	68.4	69.0	63.6	64.1	60.6	58.9	54.3	53.1
Lk	0.1	1.1	3.7	6.1	9.2	8.7	7.2	8.5	8.2	7.5	6.4	5.3	5.8
#13 Horizontal Surface 6" Away - 12mm													
Ieq	-73.7	-71.1	-69.1	-65.7	-58.1	-58.4	-60.9	-54.3	-55.2	-52.3	-51.8	-48.3	-46.3
Leq	74.4	72.4	73.2	71.7	68.5	67.5	68.2	63.1	62.9	59.3	57.7	52.9	51.9
Lk	0.7	1.3	4.1	6.0	10.5	9.1	7.3	8.8	7.7	7.0	5.8	4.7	5.6
#14 Vertical Surface 3" Away - 12mm													
Ieq	-73.9	-72.0	-68.5	-63.3	-55.9	-58.7	-53.8	-48.0	-49.2	-50.0	-47.1	-44.5	-44.4
Leq	75.0	73.8	72.0	70.4	65.8	68.6	65.2	62.2	62.8	59.1	56.2	52.0	50.4
Lk	1.1	1.8	3.5	7.1	9.9	9.9	11.5	14.2	13.5	9.1	9.1	7.5	5.9
#15 Vertical Surface 6" Away - 12mm													
Ieq	-71.8	-71.4	-67.4	-60.7	-55.4	-58.1	-50.1	42.6	-41.0	-47.0	-45.5	-43.1	-42.9
Leq	73.2	73.2	71.3	69.8	65.6	68.2	64.3	61.5	62.2	58.1	54.8	50.2	49.9
Lk	1.4	1.8	3.9	9.1	10.2	10.1	14.2	18.8	21.2	11.1	9.3	7.1	7.0
#16 Horizontal Surface 3" Away - 50mm													
Ieq	-72.6	-70.4	-67.1	-63.4	-55.9	-58.2	-60.7	-54.5	-55.3	-53.0	-52.4	-48.9	-47.0
Leq	75.4	73.0	73.4	72.0	69.0	68.1	68.8	63.6	63.9	60.5	58.8	54.2	52.7
Lk	2.7	2.6	6.3	8.6	13.0	9.9	8.1	9.1	8.6	7.5	6.4	5.3	5.7
#17 Vertical Surface 3" Away - 50mm													
Ieq	-70.7	-70.6	-66.6	-58.2	-47.9	-55.8	-49.0	-45.1	-47.4	-50.1	-47.6	-44.9	-44.3
Leq	75.0	74.1	72.4	70.5	65.9	68.4	65.5	62.4	62.9	59.4	56.5	52.1	50.3
Lk	4.4	3.5	5.8	12.2	18.0	12.7	16.5	17.3	15.5	9.3	8.9	7.2	6.0

	1000	1250	1600	2000	2500	3150	4000	5000	6300	Awt
#9 Residual Pressure-Intensity Index										
Ieq	43.9	-49.4	46.1	49.4	46.4	44.0	48.3	44.1	29.8	53.0	-69.2
Leq	75.4	77.6	76.7	73.3	75.0	74.1	75.9	73.5	59.9	85.9	87.7
Lk	31.4	28.2	30.6	23.9	28.6	30.1	27.6	29.4	30.1	32.9	18.4
#10 Horizontal Surface 6" Away - 50mm										
Ieq	-42.5	-38.7	-35.9	-29.5	21.0	-18.1	23.0	19.5	16.6	-57.5	-75.1
Leq	49.3	48.2	46.2	44.7	43.4	41.6	39.7	37.0	36.3	64.9	80.1
Lk	6.8	9.5	10.2	15.2	22.4	23.5	16.7	17.5	19.7	7.3	5.0
#11 Vertical Surface 6" Away - 50mm										
Ieq	-39.2	-32.9	18.7	32.2	33.8	30.4	10.8	-24.7	-22.4	-52.2	-74.1
Leq	47.8	48.1	46.4	44.8	43.2	40.4	37.9	36.5	36.8	63.7	80.2
Lk	8.6	15.2	27.7	12.6	9.5	10.0	27.1	11.7	14.4	11.5	6.1
#12 Horizontal Surface 3" Away - 12mm										
Ieq	-43.6	-39.8	-36.5	-32.8	-21.1	-26.2	24.3	13.5	-14.2	-58.6	-77.6
Leq	50.1	48.4	46.6	45.9	45.7	44.3	43.0	40.7	38.8	65.7	80.4
Lk	6.5	8.6	10.1	13.1	24.7	18.1	18.7	27.2	24.6	7.1	2.8
#13 Horizontal Surface 6" Away - 12mm										
Ieq	-42.7	-38.3	-35.3	-31.5	23.3	-23.3	25.9	21.8	20.7	-57.9	-76.9
Leq	49.7	48.6	47.4	45.6	45.3	44.1	43.1	40.5	38.5	65.0	80.1
Lk	7.0	10.3	12.1	14.1	22.0	20.9	17.2	18.7	17.9	7.1	3.1
#14 Vertical Surface 3" Away - 12mm										
Ieq	-40.8	-37.1	-35.1	-26.4	29.3	31.2	30.9	29.0	25.4	-55.0	-76.9
Leq	48.1	47.3	49.3	46.6	46.3	44.9	43.4	41.0	38.7	64.2	79.9
Lk	7.3	10.1	14.2	20.2	17.1	13.8	12.5	12.0	13.3	9.2	3.0

#15 Vertical Surface 6" Away - 12mm

Ieq	-38.8	25.9	29.6	35.2	36.6	36.1	35.8	32.1	29.1	-52.5	-75.5
Leq	48.7	48.7	49.0	46.3	46.0	45.1	44.0	41.3	39.0	63.6	79.0
Lk	9.9	22.7	19.4	11.0	9.4	9.0	8.2	9.2	9.9	11.1	3.5

#16 Horizontal Surface 3" Away - 50mm

Ieq	-43.3	-39.4	-35.8	-30.7	-25.9	-27.0	10.4	15.2	14.6	-57.8	-75.8
Leq	49.6	47.9	45.9	44.8	44.2	42.4	40.3	38.2	37.2	65.6	80.6
Lk	6.3	8.5	10.1	14.1	18.3	15.4	29.9	22.9	22.5	7.8	4.8

#17 Vertical Surface 3" Away - 50mm

Ieq	-40.6	-37.2	-34.5	-27.1	24.9	20.3	-24.2	-25.1	-22.6	-53.6	-74.5
Leq	47.7	46.7	46.0	45.1	43.9	41.4	38.6	36.9	37.1	64.1	80.1
Lk	7.1	9.5	11.5	18.0	18.9	21.1	14.4	11.8	14.6	10.5	5.6

Table 3: Processed intensity data from Table 2. B&K probe: 50mm probe data used up to 400Hz, 12mm probe data above that. PEI=Phase error index

Surface and distance	Frequency(Hz) 50	63	80	100	125	160	200	250	315	400	500	630	800
Horizontal,15 cm													
Ieq	NA	69.9	NA	NA	NA	55.9	60.5	54.9	55.8	52.7	51.8	48.3	46.3
PEI	6.0	8.4	6.5	6.4	3.8	7.7	13.4	14.9	19.1	23.4	28.6	21.7	19.4
Horizontal, 7.5 cm													
Ieq	NA	70.4	NA	NA	NA	58.2	60.7	54.5	55.3	53.0	52.5	49.0	47.3
PEI	6.1	8.2	6.5	6.1	3.8	9.1	13.2	14.5	17.7	22.1	28.0	21.1	19.2
Vertical, 15 cm													
Ieq	NA	70.3	67.0	NA	NA	NA	NA	-46.9	NA	48.4	45.5	43.1	42.9
PEI	3.6	7.0	7.3	1.4	4.7	6.8	-1.2	8.8	3.9	19.9	25.1	19.3	18.0
Vertical,7.5 cm													
Ieq	NA	70.6	66.6	NA	NA	NA	NA	NA	47.4	50.1	47.1	44.5	44.4
PEI	4.4	7.3	7.0	2.5	-1.2	6.3	4.8	6.3	10.8	20.3	25.3	18.9	19.1
NE216 probe -Ieq only													
Horizontal, 15 cm													
Ieq	71.4	69.0	65.8	62.9	55.4	54.2	58.7	52.9	54.5	50.3	50.1	46.7	45.0
Horizontal, 7.5 cm													
Ieq	72.4	70.3	67.6	63.5	58.6	56.2	59.6	54.1	54.9	51.0	50.7	47.2	46.2
Vertical, 15 cm													
Ieq	69.6	68.6	65.7	53.4	52.7	54.2	49.9	-48.4	NA	48.7	46.7	43.2	43.7
Vertical, 7.5 cm													
Ieq	70.6	69.7	66.6	57.4	51.9	55.4	52.1	-42.7	43.6	49.4	47.9	44.5	44.6

B&K probe

Distance Surface(cm)	Frequency(Hz) 1000	1250	1600	2000	2500	3150	4000	5000
Horizontal, 15 cm								
Ieq	42.7	38.3	35.3	NA	NA	NA	NA	NA
PEI	18.2	11.7	12.3	3.6	0.4	3.0	4.2	4.5
Horizontal7.5								
Ieq	43.6	39.8	36.5	NA	NA	NA	NA	NA
PEI	18.7	13.4	14.3	4.6	-2.3	5.8	2.7	-4.0
Vertical 15 cm								
Ieq	38.8	NA	NA	NA	-36.6	-36.1	-35.8	-32.1
PEI	15.3	-0.7	5.0	6.7	13.0	14.9	13.2	14.0
Vertical, 7.5 cm								
Ieq	40.8	37.1	35.1	NA	NA	-31.2	-30.9	-29.0
PEI	17.9	11.9	10.2	-2.5	5.3	10.1	8.9	11.2
NE216 probe -Ieq only								
Horizontal, 15 cm								
Ieq	41.9	38.9	36.6	34.1	NA	NA	NA	NA
Horizontal, 7.5 cm								
Ieq	43.6	40.1	36.9	32.8	30.2	31.6	NA	23.2
Vertical, 15 cm								
Ieq	39.8	35.6	34.0	NA	-32.7	-33.9	-30.9	NA
Vertical, 7.5 cm								
Ieq	41.2	38.3	34.9	26.1	NA	-29.7	-30.8	NA

Table 4: Intensity measurements outside the duct in the small reverberation room. The loudspeaker was the source.

	50	63	80	100	125	160	200	250	315	400	500	630	800
#1 Residual Pressure-Intensity index													
Ieq	-63.9	-61.8	-59.6	-57.4	-55.1	-52.7	-49.8	-46	25.5	42.7	44	46.2	46.3
Leq	74.3	74.2	74.2	74.3	74.2	74.2	74.4	74.2	74.1	74.1	73.9	73.7	74.1
Lk	10.4	12.5	14.6	16.8	19.1	21.5	24.6	28.2	48.6	31.4	29.9	27.5	27.9
#2 Horizontal Surface - 3" Away - 50mm													
Ieq	-76.7	-84.7	-81	-83.5	71.3	-71.9	-76.9	-79.1	-80.6	70.3	69.1	69.8	63.7
Leq	80.3	90.5	90.4	89.6	87.6	84.1	85.8	86.1	89.6	84.5	84	80.8	75.2
Lk	3.5	5.7	9.3	6	16.3	12.1	9	7	9	14.2	14.9	11	11.5
#3 Horizontal Surface - 6" Away - 50mm													
Ieq	-76.4	-84.1	-81.1	-83.9	76.3	-70.1	-76.1	-78.5	-79.6	72.4	66.5	71.3	65.3
Leq	80.4	90.2	90.4	90.5	88.2	82.9	85.5	85.5	88.3	83.5	82.2	78.8	74.2
Lk	4	6.2	9.3	6.6	11.9	12.9	9.4	7	8.8	11.1	15.7	7.5	8.9
#4 Vertical Surface - 3" Away - 50mm													
Ieq	-76.9	-83.1	-72.5	81.6	-72.8	-68.3	-67.3	-75.2	-73.6	71	69.6	69.4	65.8
Leq	79.9	88.9	91.1	89.2	84.2	81.4	79.7	86.1	88.2	82.3	81.2	79.1	72.9
Lk	3	5.7	18.6	7.6	11.3	13	12.4	10.9	14.6	11.3	11.6	9.7	7.1
#5 Vertical Surface - 6" Away - 50mm													
Ieq	-76.6	-82.7	-70.2	80.8	-75	-68	-57.2	-73.7	-68.2	72.1	70.2	71.7	66.4
Leq	79.6	88.7	90.5	89.1	84.6	80.9	79.4	85.6	87.1	80.7	79.3	76.9	73.6
Lk	3	6	20.3	8.3	9.6	12.9	22.2	11.8	18.9	8.7	9.1	5.2	7.1
#6 Horizontal Surface - 3" Away - 12mm													
Ieq	-78.4	-86.5	-83.8	-84.6	-72.8	-72.7	-77.9	-79.1	-80.7	72	69.8	70.1	65.1
Leq	80.2	90.2	90.2	89.8	87.8	84	86.1	86.3	89.8	84.6	83.7	80.4	75.2
Lk	1.8	3.7	6.4	5.1	15	11.3	8.2	7.2	9.1	12.6	13.9	10.2	10.1
#7 Horizontal Surface - 6" Away - 12mm													
Ieq	-78.5	-86.8	-84.4	-85.1	64.6	-71.8	-77.1	-79.4	-81.2	72.4	65.5	70.6	65.3
Leq	80.2	90.7	90.9	90.6	88.3	83.1	85.9	86	88.5	83.6	82.3	78.8	74
Lk	1.8	3.9	6.5	5.4	23.7	11.3	8.8	6.6	7.4	11.3	16.8	8.2	8.7
#8 Vertical Surface - 3" Away - 12mm													
Ieq	-78.7	-85.7	-81.4	78.2	-74.7	-70.1	-67.2	-74.5	-73.6	71.4	70.1	69.5	66.1
Leq	79.8	89.1	90.7	89	84.3	81.7	80	86.4	88.4	82.4	81.2	78.7	72.7
Lk	1.1	3.4	9.3	10.8	9.6	11.6	12.7	11.8	14.8	11	11.1	9.2	6.6
#9 Vertical Surface - 6" Away - 12mm													
Ieq	-78.6	-84.9	-81.4	75.7	-77.4	-69.7	-51.4	-74.1	-67.8	72.8	71.1	72.1	67.1
Leq	79.8	88.9	90.7	89.1	85	81	79.4	85.7	87.1	80.3	79.3	77.3	74.3
Lk	1.2	4	9.4	13.4	7.6	11.3	28	11.6	19.3	7.4	8.2	5.2	7.2

	1000	1250	1600	2000	2500	3150	4000	5000	6300	Awt	Lin
#1 Residual Pressure-Intensity index											
Ieq	46.4	-51	54.8	47.7	47.2	44.1	46.2	36	-23.4	57.2	-67.2
Leq	75.4	77.6	76.8	73.3	75	74.1	75.9	73.7	60	86	87.7
Lk	29.1	26.7	22	25.6	27.8	30.1	29.7	37.7	36.6	28.7	20.5
#2 Horizontal Surface - 3" Away - 50mm											
Ieq	67.4	64.6	61	60	59.7	54.9	49.1	40	35.5	-71.9	-89.4
Leq	76.8	73.4	70.3	69.8	69.7	66.1	61.8	56.1	53.6	88.7	98
Lk	9.4	8.8	9.3	9.8	10	11.2	12.7	16.1	18.2	16.8	8.6
#3 Horizontal Surface - 6" Away - 50mm											
Ieq	67.4	65.2	62.2	61.4	61.4	55.7	50.6	42.1	36.9	-61.6	-88.8
Leq	76.6	74.1	71.9	70	69.4	66	61.8	56.4	53.6	87.8	97.7
Lk	9.3	8.9	9.7	8.5	8	10.4	11.2	14.3	16.7	26.2	9
#4 Vertical Surface - 3" Away - 50mm											
Ieq	66.7	63.7	59.1	58.2	56.9	53.6	46.7	-41.2	-39.5	72.3	-82.2
Leq	73.7	71.8	70.9	69.9	68.6	64.9	60	55.3	53.3	86.9	96.8
Lk	7	8.2	11.7	11.7	11.7	11.3	13.3	14.1	13.8	14.6	14.6
#5 Vertical Surface - 6" Away - 50mm											
Ieq	67.6	66.8	61.7	60.9	59.5	57.4	51.3	-35.2	-39.1	75.3	-81
Leq	76.9	75.6	70.9	69.5	68.2	65.3	60.3	55.1	53.2	86.5	96.4
Lk	9.4	8.8	9.2	8.6	8.7	7.8	9	19.9	14	11.2	15.4
#6 Horizontal Surface - 3" Away - 12mm											
Ieq	68	64.7	61.9	61.3	61.7	58.7	55.3	48.1	43.5	-71.1	-90.9
Leq	76.8	73.6	71.5	71.7	72.3	69.5	66.8	60.6	56.8	88.9	98
Lk	8.8	8.9	9.6	10.4	10.6	10.7	11.5	12.6	13.3	17.8	7.1
#7 Horizontal Surface - 6" Away - 12mm											
Ieq	67.3	64.9	63.5	62.6	63.9	59.7	55.9	50	45.6	-71.7	-91.2

Leq	76.6	74.4	73	71.4	72	69.7	66.7	60.6	56.6	88.1	98.1
Lk	9.4	9.5	9.5	8.8	8.1	10	10.8	10.6	11	16.5	6.9
#8 Vertical Surface - 3" Away - 12mm											
Ieq	66.6	65.3	61.7	60.7	59.1	58.9	55.7	51.1	47.2	73.2	-87.3
Leq	74.3	73.3	72.5	71.3	70.4	68.4	65.2	60.4	56.4	87.2	96.8
Lk	7.7	8	10.8	10.6	11.3	9.5	9.5	9.3	9.2	14.1	9.5
#9 Vertical Surface - 6" Away - 12mm											
Ieq	68.8	67.9	63.4	63.2	62.6	61.7	58.2	53.3	49.1	76.3	-86.8
Leq	77.3	75.7	72	70.9	70.4	68.9	65.5	60.6	56.5	86.8	96.5
Lk	8.5	7.8	8.6	7.8	7.8	7.2	7.3	7.3	7.3	10.4	9.7

Table 5: Processed intensity data from Table 4.
50mm probe data used up to 400Hz, 12mm probe data above that.

Surface and Distance	50	63	80	100	125	160	200	250	315	400	500
Horizontal, 15cm											
Ieq	NA	NA	NA	83.9	-76.3	70.1	76.1	78.5	79.6	-72.4	NA
PEI	6.4	6.3	5.3	10.2	7.2	8.6	15.2	21.2	39.8	20.3	6.9
Horizontal, 7.5cm											
Ieq	NA	NA	NA	83.5	NA	71.9	76.9	79.1	80.6	-70.3	-69.8
PEI	6.9	6.8	5.3	10.8	2.8	9.4	15.6	21.2	39.6	17.2	9.8
Vertical, 15cm											
Ieq	76.6	NA	NA	-80.8	75.0	68.0	NA	73.7	68.2	-72.1	-71.1
PEI	7.4	6.5	-5.7	8.5	9.5	8.6	2.4	16.4	29.7	22.7	15.5
Vertical, 7.5cm											
Ieq	76.9	NA	NA	-81.6	72.8	68.3	67.3	75.2	73.6	-71.0	-70.1
PEI	7.4	6.8	-4.0	9.2	7.8	8.5	12.2	17.3	34.0	20.1	12.6

Surface and Distance	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Horizontal, 15cm										
Ieq	-70.6	-65.3	-67.3	-64.9	NA	-62.6	-63.9	-59.7	-55.9	-50.0
PEI	13.1	13.0	13.5	11.0	6.3	10.6	13.5	13.9	12.7	20.9
Horizontal, 7.5cm										
Ieq	-70.1	-65.1	-68.0	-64.7	NA	-61.3	-61.7	-58.7	-55.3	-48.1
PEI	11.1	11.6	14.1	11.6	6.2	9.0	11.0	13.2	12.0	18.9
Vertical, 15cm										
Ieq	-72.1	-67.1	-68.8	-67.9	-63.4	-63.2	-62.6	-61.7	-58.2	-53.3
PEI	16.1	14.5	14.4	12.7	7.2	11.6	13.8	16.7	16.2	24.2
Vertical, 7.5cm										
Ieq	-69.5	-66.1	-66.6	-65.3	NA	-60.7	-59.1	-58.9	-55.7	-51.1
PEI	12.1	15.1	15.2	12.5	5.0	8.8	10.3	14.4	14.0	22.2

Table 6: Sound intensity measurements in large reverberation room. Loudspeaker source, B&K probes

	Frequency (Hz)												
	50	63	80	100	125	160	200	250	315	400	500	630	800
#1 Residual Pressure_Intensity Index													
Ieq	-57.9	-54.1	-51.1	-36.4	48.8	50.2	50.9	51.2	51.3	50.8	50.9	51.0	51.3
Leq	73.9	73.9	73.9	73.9	73.9	74.0	74.1	74.0	73.8	73.7	73.5	73.4	73.9
Lk	16.1	19.8	22.7	37.5	25.1	23.8	23.1	22.7	22.6	22.9	22.6	22.4	22.5
#2 Inside the Duct - 50 mm - Position #1													
Ieq	-94.2	-95.7	-91.9	-93.1	-93.3	-92.9	-96.9	-102.2	-101.4	-89.1	-90.3	-95.0	-79.7
Leq	93.6	93.3	94.3	97.0	97.9	92.5	101.1	103.2	105.1	92.1	95.3	99.7	90.0
Lk	-0.6	-2.4	2.4	3.9	4.6	-0.4	4.1	1.0	3.7	2.9	5.0	4.7	10.3
#3 Inside the Duct - 50 mm - Position #2													
Ieq	-94.7	-95.7	-91.4	-92.7	-93.8	-93.0	-96.7	-101.9	-101.3	-88.2	-88.2	-92.7	-80.8
Leq	93.7	93.2	93.6	96.4	98.1	92.7	100.8	102.6	105.0	89.8	91.4	96.8	89.2
Lk	-1.0	-2.4	2.3	3.7	4.3	-0.3	4.2	0.7	3.7	1.5	3.2	4.0	8.3
#4 Inside the Duct - 50 mm - Position #3													
Ieq	-94.1	-96.1	-91.4	-92.9	-93.6	-92.7	-96.7	-101.9	-100.7	-86.2	-83.4	-88.1	-79.6
Leq	92.7	93.4	93.6	96.6	97.6	92.2	100.5	102.5	104.2	87.9	86.0	92.7	88.0
Lk	-1.5	-2.6	2.2	3.6	4.0	-0.5	3.8	0.6	3.5	1.7	2.7	4.6	8.3
#5 Inside the Duct - 12 mm - Position #1													
Ieq	-94.4	-96.0	-91.8	-93.2	-93.8	-93.0	-96.8	-102.2	-101.4	-89.1	-90.1	-94.8	-78.6
Leq	94.0	93.0	93.5	96.7	98.2	92.9	101.3	102.9	105.6	92.0	95.8	99.7	89.6
Lk	-0.4	-2.9	1.7	3.4	4.4	-0.1	4.5	0.7	4.1	2.9	5.8	4.9	11.0
#6 Inside the Duct - 12 mm - Position #2													
Ieq	-94.7	-95.9	-92.2	-93.3	-94.0	-93.1	-96.7	-102.1	-101.4	-88.2	-88.2	-92.8	-82.3
Leq	93.6	93.0	94.0	96.7	98.3	92.8	101.0	102.6	105.4	89.9	92.0	96.7	89.2
Lk	-1.1	-2.9	1.9	3.4	4.3	-0.3	4.3	0.5	4.0	1.8	3.8	3.9	6.9
#7 Inside the Duct - 12 mm - Position #3													
Ieq	-95.0	-96.2	-91.5	-93.2	-93.8	-93.0	-96.6	-101.8	-100.8	-86.4	-82.8	-88.0	-79.2
Leq	93.1	93.1	93.4	96.5	97.6	92.3	100.4	102.2	104.4	88.1	85.5	92.8	88.1
Lk	-1.9	-3.1	1.9	3.3	3.8	-0.7	3.9	0.4	3.6	1.7	2.7	4.9	8.8
#8 Inside the Duct - 12 mm - Position #4													
Ieq	-94.8	-96.5	-91.7	-93.2	-93.9	-93.4	-97.0	-102.6	-101.5	-89.8	-90.7	-96.5	-85.8
Leq	93.8	94.0	93.8	96.9	98.0	93.0	101.2	103.2	105.6	93.0	96.5	99.0	89.3
Lk	-1.0	-2.5	2.0	3.6	4.1	-0.4	4.2	0.7	4.1	3.2	5.8	2.4	3.6
#9 Inside the Duct - 12 mm - Position #5													
Ieq	-95.2	-96.3	-92.1	-93.6	-94.2	-93.2	-97.2	-102.6	-101.7	-89.2	-88.1	-94.1	-84.6
Leq	93.3	93.5	94.0	96.8	98.1	92.8	101.3	103.1	105.3	90.7	92.5	95.7	88.9
Lk	-2.0	-2.8	1.9	3.3	3.9	-0.4	4.1	0.5	3.7	1.5	4.4	1.7	4.3
#10 Inside the Duct - 12 mm - Position #6													
Ieq	-95.3	-96.3	-92.0	-93.9	-94.2	-93.4	-97.0	-102.3	-101.3	-87.9	-83.5	-90.5	-81.9
Leq	92.8	93.4	93.9	96.9	98.0	92.6	101.0	102.6	104.7	89.0	87.2	94.8	91.0
Lk	-2.6	-2.9	1.9	3.0	3.8	-0.7	4.0	0.3	3.4	1.2	3.8	4.3	9.1
#11 Inside the Duct - 50 mm - Position #4													
Ieq	-94.4	-96.0	-91.5	-93.1	-93.8	-93.4	-97.2	-102.4	-101.8	-89.9	-90.6	-95.9	-85.0
Leq	93.5	93.5	93.8	96.9	98.1	93.0	101.4	103.1	105.7	92.8	96.1	98.4	88.3
Lk	-0.9	-2.4	2.3	3.8	4.2	-0.4	4.2	0.6	3.9	2.9	5.5	2.6	3.3
#12 Inside the Duct - 50 mm - Position #5													
Ieq	-94.8	-95.9	-91.6	-93.5	-94.2	-93.3	-97.2	-102.5	-101.7	-89.3	-88.0	-93.9	-84.1
Leq	93.2	93.7	94.0	97.2	98.3	92.8	101.2	103.2	105.3	90.8	92.2	95.6	88.6
Lk	-1.6	-2.3	2.5	3.6	4.1	-0.5	4.1	0.7	3.6	1.5	4.1	1.6	4.5
#13 Inside the Duct - 50 mm - Position #6													
Ieq	-94.6	-95.9	-91.6	-93.1	-93.9	-92.9	-96.7	-102.0	-101.3	-87.7	-83.4	-90.2	-82.2
Leq	92.6	93.4	94.0	96.6	98.0	92.5	100.7	102.6	104.7	88.9	87.2	94.6	90.3
Lk	-2.0	-2.4	2.4	3.5	4.1	-0.4	4.0	0.6	3.4	1.2	3.8	4.4	8.1
#14 Inside the Duct - 50 mm - Position #7													
Ieq	-94.5	-95.8	-92.2	-93.1	-93.8	-93.1	-96.7	-102.3	-102.0	-90.2	-91.9	-96.1	-86.8
Leq	93.4	93.0	94.5	97.0	98.2	92.6	100.6	102.8	105.5	93.3	96.5	100.4	90.6
Lk	-1.2	-2.8	2.3	3.9	4.4	-0.5	3.9	0.5	3.5	3.0	4.6	4.3	3.8
#15 Inside the Duct - 50 mm - Position #8													
Ieq	-94.3	-96.2	-92.0	-92.8	-93.9	-92.9	-96.9	-102.1	-101.7	-89.7	-89.1	-94.1	-86.1
Leq	92.9	93.1	94.1	96.4	97.9	92.7	100.9	102.7	105.2	91.4	93.0	97.9	90.5
Lk	-1.4	-3.1	2.2	3.6	4.0	-0.3	4.0	0.6	3.5	1.7	3.9	3.8	4.4
#16 Inside the Duct - 50 mm - Position #9													
Ieq	-95.2	-96.1	-91.7	-93.5	-93.6	-92.4	-96.4	-101.6	-101.6	-88.5	-84.8	-90.8	-86.0
Leq	92.8	93.1	93.8	96.5	97.7	92.2	100.2	102.2	104.5	89.7	88.4	94.5	89.4
Lk	-2.3	-2.9	2.1	3.0	4.1	-0.2	3.8	0.6	2.9	1.2	3.6	3.7	3.4
#17 Inside the Duct - 12 mm - Position #7													
Ieq	-94.9	-96.4	-91.8	-93.2	-94.2	-93.2	-96.8	-102.0	-101.9	-90.3	-91.2	-95.8	-86.1
Leq	93.2	93.4	94.0	96.6	98.0	92.7	100.9	102.6	105.7	93.3	96.1	99.5	89.3
Lk	-1.6	-3.0	2.2	3.4	3.8	-0.5	4.1	0.6	3.8	2.9	4.9	3.7	3.2

#18 Inside the Duct - 12 mm - Position #8													
Ieq	-94.6	-96.2	-92.4	-93.4	-94.2	-92.9	-96.7	-102.0	-101.5	-89.6	-88.8	-93.8	-86.1
Leq	92.7	93.1	94.4	96.8	98.2	92.5	100.9	102.6	105.3	91.3	92.8	96.9	90.2
Lk	-1.9	-3.1	2.0	3.4	4.0	-0.4	4.2	0.6	3.7	1.7	4.0	3.1	4.1
#19 Inside the Duct - 12 mm - Position #9													
Ieq	-95.5	-96.8	-91.8	-94.1	-94.2	-92.9	-96.6	-101.7	-101.3	-88.5	-84.3	-90.3	-86.0
Leq	92.8	93.4	93.6	96.8	97.9	92.4	100.4	102.1	104.5	89.7	88.0	94.0	89.5
Lk	-2.7	-3.5	1.8	2.7	3.7	-0.4	3.8	0.4	3.3	1.2	3.6	3.7	3.5
#20 Horizontal Surface - 12 mm - 3" Away													
Ieq	58.0	-73.6	-69.6	-69.3	-70.8	-67.0	-67.7	-69.0	68.6	-37.7	-56.2	-60.5	-51.3
Leq	77.3	74.3	71.4	71.0	74.6	71.8	74.2	80.6	82.7	71.2	66.0	70.4	61.6
Lk	19.4	0.7	1.8	1.7	3.8	4.8	6.5	11.6	14.0	33.5	9.8	9.9	10.3
#21 Vertical Surface - 12 mm - 3" Away													
Ieq	74.4	69.0	68.6	61.0	-63.2	52.7	-65.8	-68.6	-73.3	-59.7	-56.1	-59.5	-54.0
Leq	74.8	72.1	71.5	71.9	74.1	70.7	75.0	81.3	84.8	71.6	66.1	68.4	61.1
Lk	0.4	3.1	2.9	10.9	10.9	18.0	9.2	12.7	11.5	11.9	10.0	8.9	7.0
#22 Horizontal Surface - 50 mm - 3" Away													
Ieq	67.7	-72.1	-69.3	-68.4	-70.9	-67.1	-68.0	-68.1	69.5	47.8	-56.1	-60.5	-51.5
Leq	77.2	74.5	71.7	70.8	74.4	71.9	73.8	80.6	82.8	71.4	66.0	70.5	61.4
Lk	9.5	2.5	2.4	2.4	3.5	4.9	5.8	12.5	13.3	23.7	10.0	10.0	9.8
#23 Vertical Surface - 50 mm - 3" Away													
Ieq	-73.4	-70.9	-65.6	-68.7	-71.3	-63.6	-69.7	-73.4	-76.7	-62.7	-57.3	-60.6	-54.9
Leq	75.0	72.2	71.6	72.1	74.4	71.0	75.5	81.7	85.2	72.0	66.5	68.9	61.4
Lk	1.6	1.3	6.0	3.4	3.1	7.4	5.8	8.3	8.4	9.3	9.2	8.3	6.5

	Frequency (Hz)										
	1000	1250	1600	2000	2500	3150	4000	5000	6300	Awt	Lin
#1 Residual Pressure_Intensity Index											
Ieq	51.9	-48.0	59.1	-36.6	53.3	51.4	50.7	41.2	-29.7	63.0	61.5
Leq	75.2	77.5	76.8	73.3	75.2	74.3	76.2	74.1	60.0	86.0	87.6
Lk	23.2	29.5	17.6	36.6	21.8	22.9	25.5	32.9	30.4	23.0	26.1
#2 Inside the Duct - 50 mm - Position #1											
Ieq	-87.1	-93.1	-78.6	-76.8	-70.7	-68.9	-48.5	54.4	52.9	-100.5	-107.4
Leq	93.5	95.1	83.6	84.4	81.2	77.8	68.4	65.5	65.0	104.1	110.1
Lk	6.4	2.0	5.0	7.6	10.6	8.8	19.9	11.1	12.1	3.6	2.7
#3 Inside the Duct - 50 mm - Position #2											
Ieq	-83.4	-85.4	70.5	-76.0	-73.0	-71.5	-59.8	53.7	53.9	-98.9	-107.0
Leq	90.0	91.0	84.0	83.8	80.3	77.6	68.3	65.6	64.5	102.5	109.5
Lk	6.6	5.5	13.5	7.8	7.3	6.1	8.5	11.9	10.6	3.6	2.5
#4 Inside the Duct - 50 mm - Position #3											
Ieq	-86.4	-80.8	-78.1	-80.2	-71.5	-66.9	51.4	52.0	49.9	-98.1	-106.6
Leq	89.5	89.2	84.2	86.4	81.6	77.5	67.7	64.8	64.8	101.4	108.8
Lk	3.1	8.3	6.0	6.2	10.0	10.6	16.2	12.8	15.0	3.3	2.2
#5 Inside the Duct - 12 mm - Position #1											
Ieq	-84.3	-91.2	-79.8	-78.3	-68.5	-70.3	-60.3	-61.9	-61.7	-100.1	-107.3
Leq	91.6	94.2	85.5	86.0	82.0	79.7	74.1	70.0	67.5	104.1	110.2
Lk	7.2	3.0	5.7	7.7	13.5	9.4	13.8	8.1	5.8	4.0	2.9
#6 Inside the Duct - 12 mm - Position #2											
Ieq	-84.3	-86.1	73.7	-77.4	-74.9	-75.1	-61.2	-62.8	-59.2	-99.2	-107.1
Leq	90.5	91.6	85.5	85.4	82.5	80.7	74.0	70.0	66.9	102.9	109.7
Lk	6.2	5.5	11.7	8.0	7.6	5.7	12.8	7.2	7.7	3.8	2.6
#7 Inside the Duct - 12 mm - Position #3											
Ieq	-87.1	-82.8	-78.8	-83.0	-75.6	-68.3	-65.9	-62.5	-56.5	-98.3	-106.7
Leq	90.3	90.8	86.0	87.8	83.4	81.1	73.3	69.9	66.7	101.8	108.9
Lk	3.2	7.9	7.2	4.8	7.8	12.8	7.4	7.3	10.1	3.5	2.1
#8 Inside the Duct - 12 mm - Position #4											
Ieq	-83.2	-83.9	-82.1	-76.9	-75.0	-71.5	-62.5	-65.5	-61.5	-100.3	-107.6
Leq	92.2	89.2	86.2	86.1	82.5	81.0	73.8	70.8	67.3	103.8	110.2
Lk	8.9	5.3	4.1	9.1	7.5	9.4	11.3	5.3	5.8	3.5	2.6
#9 Inside the Duct - 12 mm - Position #5											
Ieq	-83.8	75.2	-71.0	-81.7	-78.6	-74.4	-66.0	-62.6	-63.3	-99.5	-107.5
Leq	90.9	87.4	84.7	88.2	84.1	81.0	75.2	70.0	68.6	102.7	109.7
Lk	7.1	12.2	13.7	6.5	5.5	6.7	9.1	7.3	5.3	3.2	2.2
#10 Inside the Duct - 12 mm - Position #6											
Ieq	-88.8	-81.9	-82.2	-76.6	-76.6	-72.9	-60.5	-64.8	-62.7	-99.0	-107.2
Leq	93.0	90.4	86.7	86.2	83.5	81.4	73.5	70.4	67.8	102.5	109.4
Lk	4.2	8.6	4.5	9.6	6.8	8.5	12.9	5.5	5.1	3.5	2.1
#11 Inside the Duct - 50 mm - Position #4											
Ieq	-81.6	-82.1	-79.5	-75.8	-71.1	-64.1	-54.0	60.6	58.4	-100.0	-107.6
Leq	90.4	87.2	84.2	85.1	80.9	77.6	67.3	66.7	67.1	103.4	110.1
Lk	8.8	5.1	4.7	9.3	9.8	13.6	13.3	6.1	8.7	3.3	2.6

#12 Inside the Duct - 50 mm - Position #5											
Ieq	-83.5	70.3	-71.9	-78.9	-76.0	-70.4	44.1	52.2	55.9	-99.4	-107.4
Leq	90.3	86.7	84.2	85.9	81.8	77.1	67.7	65.2	66.0	102.5	109.7
Lk	6.9	16.3	12.3	7.0	5.8	6.6	23.5	13.1	10.2	3.1	2.3
#13 Inside the Duct - 50 mm - Position #6											
Ieq	-88.2	-81.3	-80.7	-71.8	-73.9	-69.9	-51.3	57.1	56.4	-98.8	-106.9
Leq	92.2	89.2	85.1	84.3	80.7	77.3	68.0	65.8	65.8	102.1	109.2
Lk	4.0	7.9	4.4	12.6	6.8	7.4	16.7	8.8	9.4	3.4	2.3
#14 Inside the Duct - 50 mm - Position #7											
Ieq	69.8	-90.0	-83.4	-79.0	-75.9	-66.5	-58.6	60.0	56.6	-100.6	-107.7
Leq	91.4	94.7	86.3	84.7	82.7	80.2	70.5	67.6	67.2	104.4	110.2
Lk	21.6	4.7	2.9	5.7	6.8	13.7	11.9	7.6	10.6	3.7	2.6
#15 Inside the Duct - 50 mm - Position #8											
Ieq	-84.4	-83.0	-79.0	-80.1	-74.4	-72.9	-62.1	55.6	50.3	-99.6	-107.3
Leq	90.5	91.4	88.0	86.3	81.5	79.2	69.2	65.2	66.1	103.2	109.7
Lk	6.1	8.3	9.0	6.2	7.1	6.3	7.1	9.6	15.8	3.6	2.4
#16 Inside the Duct - 50 mm - Position #9											
Ieq	-87.6	-88.7	-81.0	-78.3	-71.9	65.1	-57.6	57.7	54.2	-99.3	-107.0
Leq	91.5	91.7	87.6	87.2	83.0	78.7	69.4	66.5	66.9	102.3	109.0
Lk	3.9	3.0	6.5	8.8	11.2	13.6	11.9	8.8	12.7	3.0	2.0
#17 Inside the Duct - 12 mm - Position #7											
Ieq	76.2	-87.9	-80.2	-80.2	-74.4	-70.3	-67.4	-66.8	-62.1	-100.2	-107.6
Leq	88.4	92.6	85.8	85.9	82.3	80.3	74.3	71.1	67.3	103.8	110.1
Lk	12.2	4.7	5.5	5.7	7.9	10.0	6.8	4.3	5.2	3.6	2.5
#18 Inside the Duct - 12 mm - Position #8											
Ieq	-83.6	-80.8	-73.9	-77.4	-75.8	-69.9	-68.3	-65.3	-58.6	-99.3	-107.2
Leq	90.3	89.4	86.2	85.7	83.0	80.3	73.7	70.5	66.9	102.8	109.6
Lk	6.7	8.6	12.4	8.3	7.2	10.4	5.4	5.2	8.4	3.5	2.4
#19 Inside the Duct - 12 mm - Position #9											
Ieq	-87.8	-88.2	-80.8	-78.2	-65.5	-70.5	-65.6	-62.9	-61.8	-99.1	-107.1
Leq	92.1	92.9	87.7	87.5	84.0	80.2	73.0	69.9	68.0	102.5	109.1
Lk	4.3	4.8	6.9	9.3	18.5	9.7	7.4	7.1	6.3	3.3	2.0
#20 Horizontal Surface - 12 mm - 3" Away											
Ieq	-53.0	-53.9	-47.2	-47.1	-42.2	-38.2	-30.0	-24.3	-19.4	-63.6	-78.0
Leq	61.4	60.8	55.8	55.4	50.5	46.2	38.0	32.8	28.3	78.8	86.9
Lk	8.4	6.9	8.6	8.3	8.3	8.0	8.0	8.5	8.9	15.2	8.9
#21 Vertical Surface - 12 mm - 3" Away											
Ieq	-55.0	-54.0	-48.5	-46.9	-42.0	-37.0	-28.3	-23.8	-12.4	-68.8	68.1
Leq	61.1	59.5	54.1	53.3	48.6	43.8	36.1	32.6	30.0	80.0	87.7
Lk	6.1	5.5	5.6	6.4	6.6	6.9	7.8	8.8	17.6	11.2	19.6
#22 Horizontal Surface - 50 mm - 3" Away											
Ieq	-52.5	-53.5	-46.2	-46.3	-41.2	-37.0	-27.8	-21.4	-11.9	-62.2	-76.7
Leq	61.0	60.5	55.1	54.8	49.4	44.8	36.5	31.8	28.9	78.8	86.9
Lk	8.6	7.0	9.0	8.5	8.2	7.8	8.7	10.3	16.9	16.6	10.2
#23 Vertical Surface - 50 mm - 3" Away											
Ieq	-55.1	-54.1	-48.3	-46.5	-41.4	-35.7	-26.7	-21.1	-13.7	-72.2	-81.4
Leq	61.4	59.6	54.0	53.0	48.1	42.8	34.9	31.2	28.8	80.3	88.0
Lk	6.3	5.6	5.7	6.5	6.7	7.1	8.1	10.0	15.1	8.1	6.6

Table 7:
Processed intensity data from Table 6.
B&K probe: 50mm probe data used up to 400Hz, 12mm probe data above that.

Surface, and distance

	50	63	80	100	125	160	200	250	315	400	500	630	800
Horizontal, 7.5cm													
Ieq	NA	72.1	69.3	68.4	70.9	67.1	68.0	68.1	-69.5	NA	NA	NA	42.4
PEI	6.6	17.3	20.3	35.1	21.6	18.9	17.3	10.2	9.3	-0.8	6.6	6.3	9.1
Vertical, 7.5cm													
Ieq	73.4	70.9	65.6	68.7	71.3	63.6	69.7	73.4	76.7	62.7	NA	59.5	54.0
PEI	14.5	18.5	16.7	34.1	22.0	16.4	17.3	14.4	14.2	13.6	6.4	7.3	9.3

	1000	1250	1600	2000	2500	3150	4000	5000
Horizontal, 7.5cm								
Ieq	40.5	38.0	NA	35.0	NA	30.5	27.2	24.3
PEI	10.9	9.8	1.2	13.1	6.6	9.0	9.0	9.3
Vertical, 7.5cm								
Ieq	55.0	54.0	NA	46.9	42.0	37.0	28.3	23.8
PEI	10.9	17.8	5.8	24.0	9.0	9.8	11.5	17.9

Intensity Measurements inside duct

	50	63	80	100	125	160	200	250	315	400	500	630	800
Position 1	94.2	95.7	91.9	93.1	93.3	92.9	96.9	102.2	101.4	89.1	90.1	94.8	78.6
Position 2	94.7	95.7	91.4	92.7	93.8	93.0	96.7	101.9	101.3	88.2	88.2	92.8	82.3
Position 3	94.1	96.1	91.4	92.9	93.6	92.7	96.7	101.9	100.7	86.2	82.8	88.0	79.2
Position 4	94.4	96.0	91.5	93.1	93.8	93.4	97.2	102.4	101.8	89.9	90.7	96.5	85.8
Position 5	94.8	95.9	91.6	93.5	94.2	93.3	97.2	102.5	101.7	89.3	88.1	94.1	84.6
Position 6	94.6	95.9	91.6	93.1	93.9	92.9	96.7	102.0	101.3	87.7	83.5	90.5	81.9
Position 7	94.5	95.8	92.2	93.1	93.8	93.1	96.7	102.3	102.0	90.2	91.2	95.8	86.1
Position 8	94.3	96.2	92.0	92.8	93.9	92.9	96.9	102.1	101.7	89.7	88.8	93.8	86.1
Position 9	95.2	96.1	91.7	93.5	93.6	92.4	96.4	101.6	101.6	88.5	84.3	90.3	86.0
Mean Intensity	94.5	95.9	91.7	93.1	93.8	93.0	96.8	102.1	101.5	88.9	88.4	93.7	84.2

	1000	1250	1600	2000	2500	3150	4000	5000
Position 1	84.3	91.2	79.8	78.3	68.5	70.3	60.3	61.9
Position 2	84.3	86.1	NA	77.4	74.9	75.1	61.2	62.8
Position 3	87.1	82.8	NA	83.0	75.6	NA	65.9	62.5
Position 4	83.2	83.9	82.1	76.9	75.0	71.5	62.5	65.5
Position 5	83.8	NA	NA	81.7	78.6	74.4	66.0	62.6
Position 6	88.8	81.9	NA	76.6	76.6	72.9	NA	64.8
Position 7	NA	87.9	NA	80.2	74.4	NA	67.4	66.8
Position 8	83.6	80.8	NA	77.4	75.8	NA	68.3	65.3
Position 9	87.8	88.2	NA	78.2	NA	NA	65.6	62.9
Mean Intensity	85.9	86.7	NA	79.4	75.6	NA	65.4	64.2

Table 8: Sound intensity measurement in large reverberation room.
Fan source: 2170 rpm. Static pressure 50 Pa.

	50	63	80	100	125	160	200	250	315	400	500	630	800
#1 Residual Pressure_Intensity Index													
Ieq	-58.2	-54.9	-50.4	35.6	48.2	49.9	50.8	50.5	49.7	48.8	49.5	49.1	48.6
Leq	74.1	74.1	74.1	74.3	74.1	74.2	74.2	74.0	73.9	73.9	73.7	73.6	74.0
Lk	15.9	19.2	23.8	38.7	25.9	24.2	23.5	23.5	24.2	25.1	24.3	24.5	25.4
#2 Horizontal Surface - 50 mm - 3" Away													
Ieq	-51.8	-56.6	-57.1	-53.6	-54.9	-49.8	-45.9	-39.7	40.2	-26.4	-43.4	-41.1	-43.9
Leq	66.5	59.2	58.6	56.1	59.7	56.0	51.9	53.3	56.4	55.8	53.0	52.2	52.8
Lk	14.7	2.6	1.4	2.5	4.9	6.2	6.0	13.6	16.1	29.4	9.6	11.1	9.0
#3 Vertical Surface - 50 mm - 3" Away													
Ieq	-62.7	-54.6	-54.5	-54.6	-54.6	-47.3	-47.2	-45.6	-48.5	-46.0	-43.1	-43.5	-45.5
Leq	64.0	56.8	57.7	57.0	58.3	53.7	53.0	53.6	57.4	55.9	52.4	51.3	52.0
Lk	1.3	2.2	3.2	2.4	3.7	6.4	5.8	8.0	8.9	9.9	9.3	7.9	6.4
#4 Horizontal Surface - 12 mm - 3" Away													
Ieq	-55.7	-56.8	-56.1	-53.3	-54.1	-49.7	-45.2	-31.6	43.3	38.6	-41.9	-39.0	-42.4
Leq	65.9	58.9	58.0	55.6	59.2	55.7	51.6	52.8	56.0	55.3	52.7	52.0	52.5
Lk	10.2	2.0	1.8	2.3	5.1	6.0	6.4	21.2	12.7	16.7	10.8	13.0	10.1
#5 Vertical Surface - 12 mm - 3" Away													
Ieq	-63.6	-54.0	-55.1	-54.9	-54.6	-47.3	-46.0	-44.7	-47.9	-45.4	-41.4	-42.7	-45.2
Leq	64.2	57.0	57.7	56.8	58.5	53.7	52.8	53.5	57.3	55.9	52.1	51.3	52.1
Lk	0.6	3.1	2.6	2.0	3.9	6.4	6.8	8.8	9.5	10.5	10.7	8.6	6.9

	1000	1250	1600	2000	2500	3150	4000	5000	6300	Awt	Lin
#1 Residual Pressure_Intensity Index											
Ieq	49.7	53.7	56.6	-45.0	52.8	49.3	50.6	48.1	33.2	62.1	59.6
Leq	75.3	77.6	76.8	73.3	75.2	74.4	76.4	74.3	60.2	86.1	87.7
Lk	25.6	23.9	20.2	28.4	22.3	25.0	25.7	26.2	27.0	23.9	28.1
#2 Horizontal Surface - 50 mm - 3" Away											
Ieq	-41.7	-38.6	-35.1	-35.3	-33.2	-30.8	-27.3	-23.5	-16.3	-49.7	-62.6
Leq	49.4	46.0	48.4	43.8	41.4	39.2	36.5	33.7	30.7	59.7	69.7
Lk	7.7	7.4	13.3	8.6	8.2	8.4	9.2	10.1	14.4	10.0	7.1
#3 Vertical Surface - 50 mm - 3" Away											
Ieq	-41.9	-39.3	-37.1	-35.0	-32.5	-29.9	-26.7	-22.7	-16.9	-51.5	-65.1
Leq	48.2	45.6	48.8	42.1	39.5	37.1	34.7	32.2	30.4	59.3	68.3
Lk	6.3	6.3	11.7	7.2	6.9	7.2	8.0	9.6	13.5	7.8	3.2
#4 Horizontal Surface - 12 mm - 3" Away											
Ieq	-40.5	-38.0	-35.1	-35.0	-32.8	-30.5	-27.2	-24.3	-17.1	-48.3	-62.6
Leq	49.0	45.9	47.9	44.1	42.3	40.3	37.7	35.0	31.7	59.4	69.2
Lk	8.5	7.9	12.8	9.1	9.5	9.8	10.5	10.7	14.6	11.1	6.6
#5 Vertical Surface - 12 mm - 3" Away											
Ieq	-41.6	-39.4	-36.9	-35.6	-33.2	-31.0	-28.9	-25.9	-19.6	-51.2	-65.6
Leq	48.4	45.8	48.9	42.4	40.4	38.5	36.3	34.0	31.6	59.4	68.4
Lk	6.8	6.4	12.0	6.8	7.2	7.5	7.5	8.1	12.0	8.2	2.8

Table 9: Sound intensity measurements in large reverberation room. Processed intensity data from Table 8. B&K probe: 50mm probe data used up to 400Hz, 12mm probe data above that.

Surface and Distance	Frequency (Hz)												
	50	63	80	100	125	160	200	250	315	400	500	630	800
Horizontal, 7.5cm													
Ieq	NA	56.6	57.1	53.6	54.9	49.8	45.9	39.7	-40.2	NA	41.9	NA	42.4
PEI	1.2	16.6	22.4	36.2	21.0	18.0	17.5	9.9	8.1	-4.3	7.3	5.3	9.1
Vertical 7.5cm													
Ieq	62.7	54.6	54.5	54.6	54.6	47.3	47.2	45.6	48.5	46.0	41.4	42.7	45.2
PEI	14.6	17.0	20.6	36.3	22.2	17.8	17.7	15.5	15.3	15.2	7.4	9.7	12.3

	1000	1250	1600	2000	2500	3150	4000	5000
Horizontal, 7.5cm								
Ieq	40.5	38.0	NA	35.0	NA	30.5	27.2	24.3
PEI	10.9	9.8	1.2	13.1	6.6	9.0	9.0	9.3
Vertical, 7.5cm								
Ieq	41.6	39.4	NA	35.6	33.2	31.0	28.9	25.9
PEI	12.6	11.3	2.0	15.4	8.9	11.3	12.0	11.9