MEASUREMENT OF SOUND TRANSMISSION LOSS BY SOUND INTENSITY

A Preliminary Report

by

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ABSTRACT

The sound intensity technique is being implemented to measure sound transmission loss at the Centre for Building Studies acoustics test facility.

The use of the intensity technique for this purpose is being investigated in three main areas; validation with respect to standard techniques; determination of appropriate measuring procedure; exploiting the analytical capabilities of the technique. This paper presents some preliminary findings with respect to these areas.

SOMMAIRE

Dans le laboratoire d'acoustique du Centre des études sur le bâtiment, la technique de mesure de l'intensité acoustique est introduite afin de déterminer la transmission du son.

A cet effet, l'utilisation de cette technique est examinée dans les trois domaines suivants: validation par rapport aux normes, détermination d'une procédure de mesure appropriée et exploitation des capacités analitiques de cette méthode. Cet article présente quelques conclusions préliminaires à cet égard.

1. INTRODUCTION

Traditionally the sound transmission loss of a panel or wall has been measured using the standard, classic approach as described by the ANSI/ASTM E90-81. However, the numerous contradictions between reported results based on this method [1] suggests the need for further investigation and this is being achieved through the application of the Sound Intensity Technique at the Centre for Building Studies at Concordia University, Montreal.

This new method has several advantages, for example: it gives the transmission loss directly without having to make corrections for the panel area and the absorption of the reception room; it eliminates the effect of flanking transmission; no restrictions are placed on the characteristics of the reception room, that is it neither has to be reverberant or anechoic; this fact eliminates the need of an actual transmission loss suite, although currently the existance of at least one reverberant chamber is exploited.

As opposed to pressure, intensity is a vector quantity and therefore provides directional information. In order to measure the transmitted intensity through a surface, only the component perpendicular to the surface is needed. However, to describe the power flow distribution, direction or transmission, three directional powerflow may be determined. The relative contributions to the total sound transmission of different sections of the test panel can be determined.

This paper presents the evaluation procedure employed to implement the Sound Intensity Technique. The technique was applied to the measurement of Sound Transmission loss through a panel with and without absorbent lined reveal; the results thus obtained were then compared with those obtained using the standard approach. In addition the effect of the lining was studied and the distribution of the intensity radiated through the panel determined.

2. METHODS TO MEASURE THE SOUND TRANSMISSION LOSS

The transmision loss is given by:

$$TL = 10 \log_{10} (\vec{I}_i / \vec{I}_t) \qquad (1)$$

where $\vec{I}_i$ is the incident intensity and $\vec{I}_t$ the transmitted intensity.

2.1 Standard Approach

The standard method of measuring the Sound Transmission loss of a panel or wall involves the use of two vibration-isolated reverberation chambers that are separated partially or completely by the partition to be studied. The transmission loss is then:

$$TL = L_{ps} - L_{pr} + 10 \log_{10} (S/A) \qquad (2)$$

where L_{ps} and L_{pr} are respectively the average sound pressure levels (dB) in the source and receiving rooms, S (m^2) the partition's surface area and A (m^2) the absorption of the receiving room.

It is assumed that the sound fields in both rooms are diffuse and that there is no flanking transmssion.

2.2 Sound Intensity Approach

The determination of the transmission loss of a panel or wall is now done through the direct determination of both the intensity incident on and transmitted through the test partition.

The incident intensity I_i can be calculated from the measured space-averaged sound pressure P_{rms} in the source room assuming the sound field is diffuse [3].

$$|\vec{I}_i| = (P_{rms})^2/4\rho c \qquad (3)$$

where ρ is the density of air and c the speed of sound in air. The accuracy of this equation has been verified by Crocker et al [3] by the direct measurement of the intensity through the aperture formed after removal of the test partition.

From equation (3) the following relationship between the incident intensity level L_{Ii} and the space averaged sound pressure level L_{pm} can be derived [4].

$$L_{Ii} = L_{Pm} - 6 \quad \text{(dB)} \qquad (4)$$

The transmitted intensity $|\vec{I}_t|$ is measured on the receiving side of the panel as the intensity vector's component perpendicular to the panel's surface.

The sound transmission loss is then calculated from:

$$TL = L_{Pm} - 6 - L_{It} \quad \text{(dB)} \qquad (5)$$

where L_{It} is the transmitted intensity level.

3. TEST FACILITIES

3.1 Transmission Loss Suite

The transmission loss suite of the Centre for Building Studies (C.B.S)at Concordia University consists of 2 rectangular rooms of differing dimensions. The larger room, the source room for all the reported experiments has a volume of approximately 94m^3. The smaller room, the receiving room in this case has a volume of about 32 m^3. The test aperture between the rooms has an area of 7.5m^2 and the facility is shown in Fig. 1.

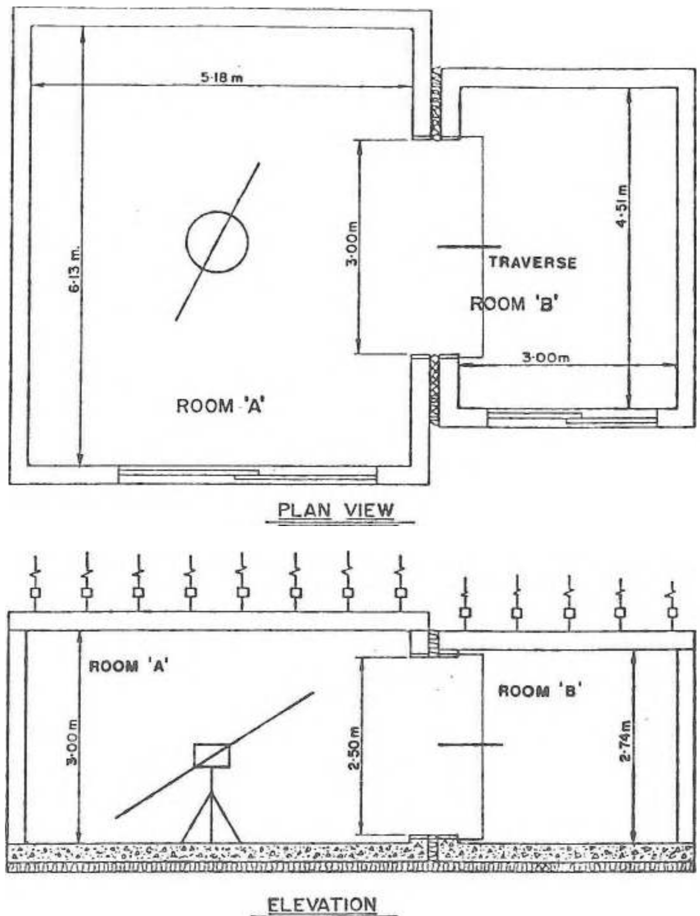

Fig. 1 General Layout of Transmission Loss Suite at the Centre for Building Studies, Concordia University.

The Schroder cut-off frequency is 250 H_Z for the larger room and 400 H_Z for the smaller one.

Diffusing elements consisting of one rotating and two stationary diffusers were located in the source room, and four stationary diffusers were located in the reception room.

The test facility is described in detail by Lang et al [6].

3.2 Test Wall

In order to accomodate the panel size tested, a heavy filler wall was constructed in the test aperture between the two rooms. The composition of the wall is given in Fig. 2.

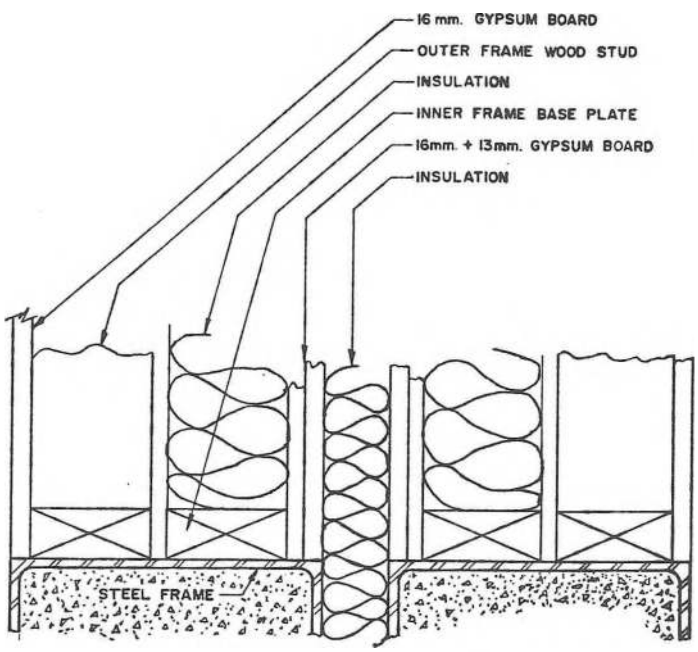

Fig. 2 Cross Section of Filler Wall at Base Plate

As can be seen the filler wall consists of two walls, mounted one in each room on their respective room's aperture and separated from each other by insulation material.

The STC value of the complete filler wall was 60.

The test panel was mounted flush to the source room, leaving a 39.4 cm. (15.5") deep reveal on the receiving side. The aperture was further splayed at 45° towards the reception room to minimize the efect of the remaining wall depth. The method of installation of the test panel is displayed in Fig. 3.

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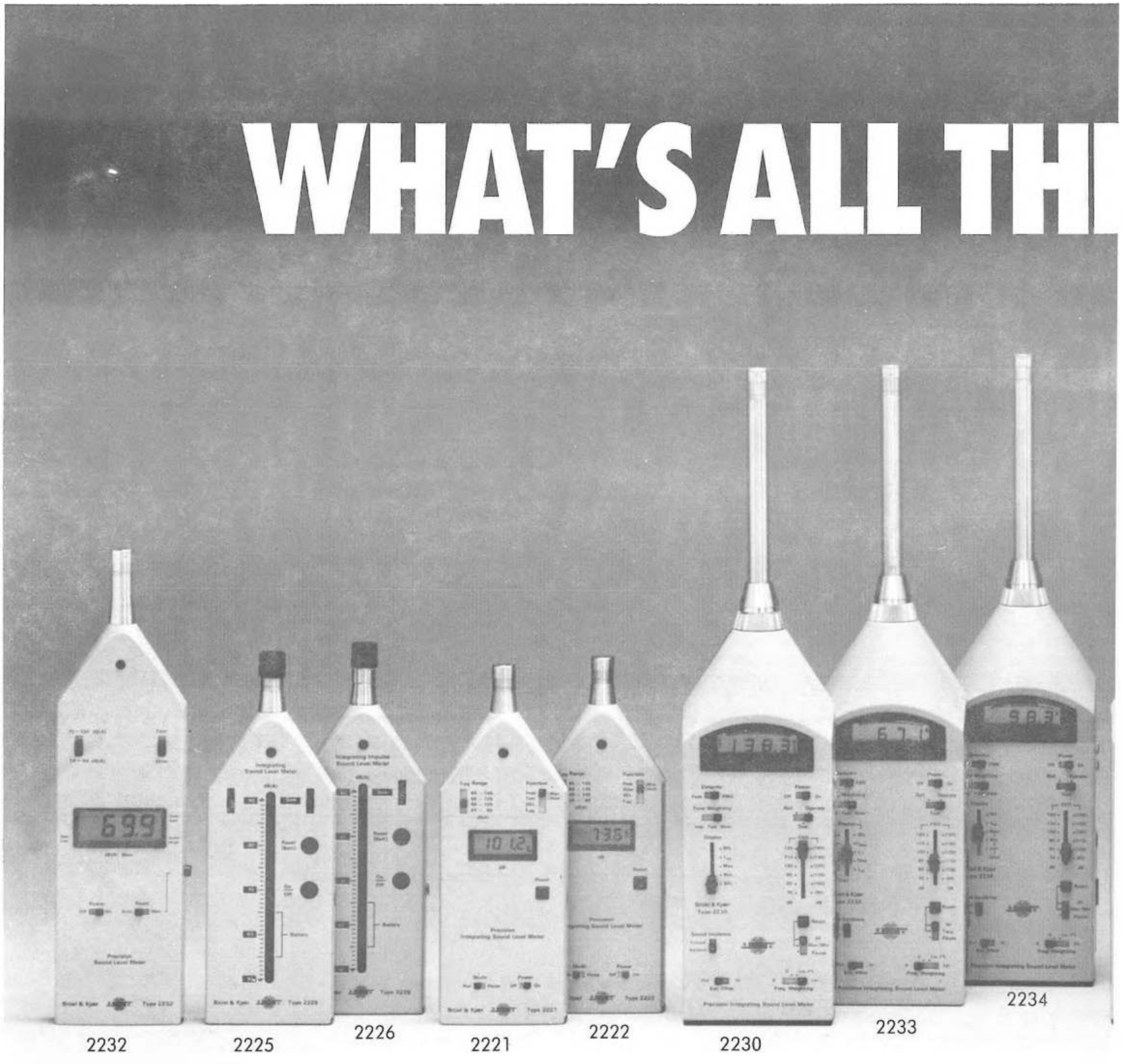

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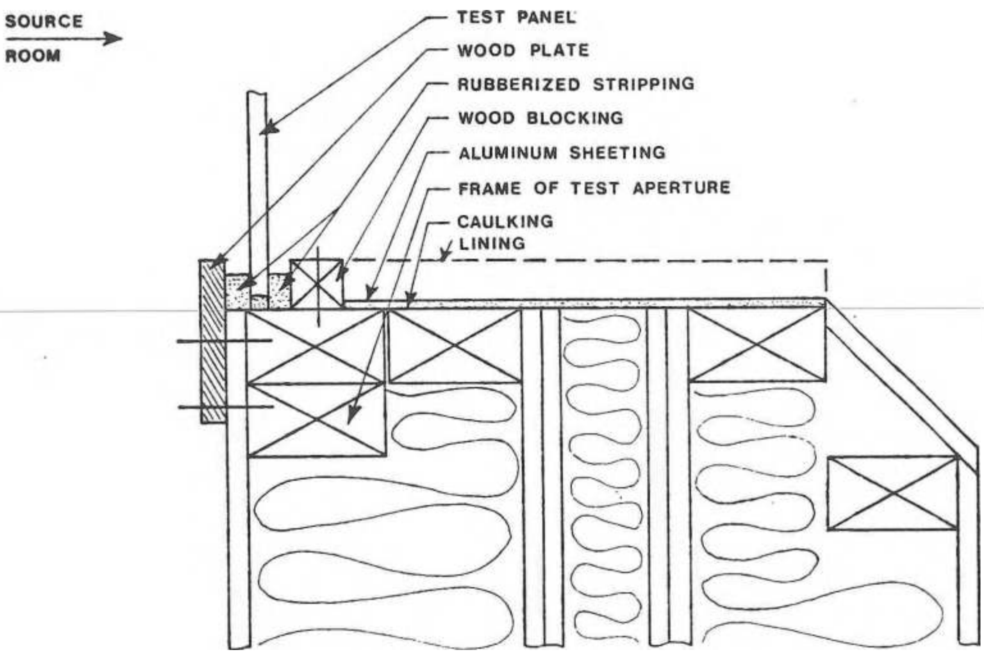

Fig.3 Mounting of Test Panel on Filler Wall

The test panel used was a 1.14 m x 1.14 m. (45" x 45") glass panel, 0.64 cm (¼") thick.

During the experiments reported here, the reveal on the receiving side was left either bare or lined with a 2.54 cm (1"), 5.08 cm (2") and 10.16 cm (4") absorbent material: Conaflex-F (by Blachford). For material properties, see Table 1.

TABLE 1. Absorption Coefficients of Conaflex F as Supplied by the Manufacturer.

Freq. (H_Z)	Absorption Coefficient (%)* F-100 (1")	F-200 (2")
125	8	28
250	19	68
500	57	90
1000	88	98
2000	96	98
4000	87	96

*Test method ASTM C 423-66
Test sample size 72 square feet

*Approximate values derived from chart

*Absorption coefficient for Conaflex F-400 (4") not available

4. TEST PROCEDURE

4.1 Standard TL Measurement

White noise was generated in the source room by two loudspeakers placed in the corners of the room opposite the test aperture.

The mean sound pressure levels in the source room were measured using a rotating microphone boom (B & K 3923). The microphone described a plane circular path at 70° from the horizontal and the length of the arm was 1.6 m, this configuration was chosen so that the microphone cleared the walls and stationary diffusers by at least 0.8 m (1/4 wave length at the 125 H_Z centre frequency is 0.68 m). The minimum distance from the microphone to speakers was 1 m. and the period of a complete revolution of the microphone was 32 seconds.

In the receiving room, the mean sound pressure level measurment was performed in the same manner as in the source room, however because of its smaller size, the length of the arm was changed to .95 m and the turntable was tilted at 60° from the horizontal.

The reverberation time in the receiving room was calculated from the averaged decay points (16 per second and 50 decay samples) with the turntable in the same position as described above and with the microphone rotating. A linear regression analysis was used in the range -5 dB below the upper decay points down to 10 dB above background level.

All measurements were computer controlled and fed to a third octave analyser. In this case, the Sound Intensity Analyser type 2134/3360 from Bruel and Kjaer.

4.2 Sound Intensity Method

The incident intensity was calculated from the mean sound pressure level as measured by the reverberant room method described earlier.

The transmitted sound intensity was measured directly using the B & K Sound Intensity Microphone Probe type 3519, using the face-to-face microphone configuration. The ½" microphones with 12 mm spacer were chosen which gives a useful frequency range, of 125 H_Z to 5 k H_Z with an accuracy of $\pm$ 1dB assuming a monople source

The intensity radiated through the panel was measured at 5.08 cm. (2") behind the surface employing an array of 81 evenly distributed points over the surface; this choice of measuring parameters will be discussed later. It became obvious during the preliminary test phase that in the presence of the reveal, the transmitted sound intensity used in the determination of the transmission loss had to be measured on the receiving room side of the reveal where it merges into the filler wall's surface. The same array of points was used.

During the measurements the microphone probe was mounted on a mechanical traverse system that enabled the microphones to be fixed during each measurement interval. It was then moved by hand from point to point, although later developments will include the automation of this traverse.

All data was stored on disk through the use of the Remote Indicating Unit ZH 0250 (B & K).

In order to avoid reverberant field effects on the intensity method measurement accuracy the three non-parallel walls of the receiving room were covered with a thick aborbent material: Conaflex F-400. Naturally this material was removed for the corresponding sound pressure measurements.

4.2.1 Estimation of the Phase Errors in the Intensity Measurements

Given the experimental conditions described above, the reactivity of the sound field was determined in both measurement planes for the purpose of estimating the errors resulting from the phase mismatch between the two measuring channels. The reactivity is the ratio between the sound pressure and the sound intensity.

The error L_{er}, defined as the difference between the measured intensity level (dB) and the true intensity level (dB) can be calculated from [8]:

$$L_{er} = -10 \log_{10} \left(1 - \frac{I_{re} \cdot P_t^2}{P_{rc}^2 \cdot I_{me}}\right) \quad \text{(dB)} \qquad (6)$$

where P_{re} (Pa) is the sound pressure in a completely reactive field, I_{re} (W/m^2) the apparent, residual intensity associated with it, and P_t(Pa) and I_{me} (W/m^2) respectively, the actual measured sound pressure and intensity.

The measurement errors as given by (6) were relatively high (up to 3 dB) at the extreme lower end of the frequency range. However, for frequencies equal to or higher than 250 Hz, they were found to be less than 1 dB at 5.08 cm (2") from the test panel and less than .5 dB at the receiving room side of the reveal.

If the receiving room had not been lined, the reactivity of the sound would have been higher, thus increasing the measurement errors even further.

5. PRELIMINARY TESTS

Although the use of the sound intensity technique for transmission loss measurement has been established by others, experimental details of the procedure are still vague and left up to the user. For example, typically what relationship exists between measuring point distance and included radiation surface area. The solutions available are quite variable

Cops [5], for example uses a mesh size of 19.5 cm x 20.75 cm with a measurement distance of 4 cm, while Fahy [4] uses the same distance but for a mesh of 4.5 cm x 7.5 cm. Therefore, before the actual transmission loss tests it was necessary to determine these parameters experimentally. During these measurements only the transmitted intenstity level was determined, the incident power being held constant for each of the series.

5.1 Influence of Absorbent Material in the Reception Room

Intensity measurements were made with and without absorbent material in the reception room. In the former case, three non-parallel walls of the reception room were covered with Conaflex F-400.

As expected the values of the measured transmitted intensity levels for the unlined case were lower than those obtained in the presence of the absorbent material although the differences were very small with a maximum discrepancy of 1 db.

However, in order to avoid any effect of the reverberant field on the measurement accuracy involving sound intensity measurements the reception room was always lined as described.

5.2 Averaging Time

The averaging time is an important parameter in a measurement procedure both for accuracy and for total duration of test. The object was to minimize time without loss of accuracy.

For an array of 81 points the transmitted intensity was measured using different linear averaging times: 4,8,16 and 32 sec. The results obtained were compared with the 32 sec. averaging time which was deemed accurate for steady state measurement.

The intensities averaged over the total test panels surface were very similar in all cases ($\pm$ .5 dB). However, after a comparison of the results point for point, a linear averaging time of 8 sec. was chosen since the maximum point deviation from the 32 sec. measurement did not exceed 1dB.

5.3 Mesh Size

Four different mesh sizes were tested 38.1 cm x 38.1 cm (15" x 15"), 22.86 x 22.86 cm (9" x 9"), 16.33 x 16.33 cm (6.5" x 6.5"), 12.7 x 12.7 cm (5" x 5") giving a total number of measuring points of respectively 3 x 3 (9), 5 x 5 (25), 7 x 7 (49), 9 x 9 (81) evenly distributed over the test panel's surface. No attempt to increase the total number of points has been made because of the time penalty incurred. Each time the power flow was measured at the centre of the subarea so created at a distance, (test panel to centre of microphone pair) of half the mesh size.

The results with respect to the average transmittd intensity show the following (Fig. 4):

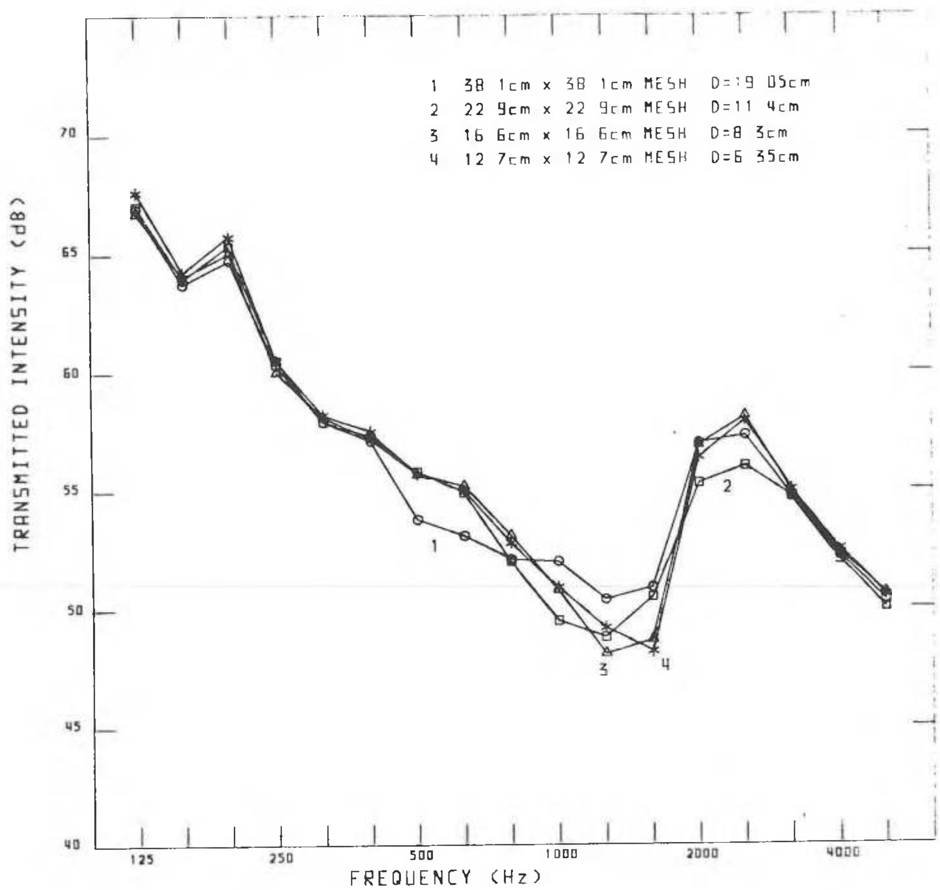

Fig 4 The Influence of the Mesh Size on the Measured Transmitted Intensity (t_{av} = 8 sec)

Little difference is seen between the results of the 7 x 7 and 9 x 9 meshes, also with one exception differences were less than .5 dB.

For the 5 x 5 mesh, the only large deviation observed was around the coincidence frequence in the 2500 H_7 third octave band. The peak in the transmited intensity, which gives rise to the coincidence dip in a transmission loss plot, is seen to be much lower and wider.

The results of the 3 x 3 mesh were more irregular together with large differences from the smaller mesh sizes.

For the present purpose, the smallest mesh size was chosen to avoid inaccuracies and because of the more detailed information possible with respect to establishing the contours of radiated intensity distribution.

5.4 Measurement Distance

In order to optimize the measurement distance the transmitted intensity was measured at several distances from the test panel.

With regard to the 9 x 9 mesh the distances chosen were 3.81 cm (1.5"), 5.08 cm (2"), 7.62 cm (3"), 10.16 cm (4") and 12.7 (5").

Certain trends in the results can be observed (Fig. 5).

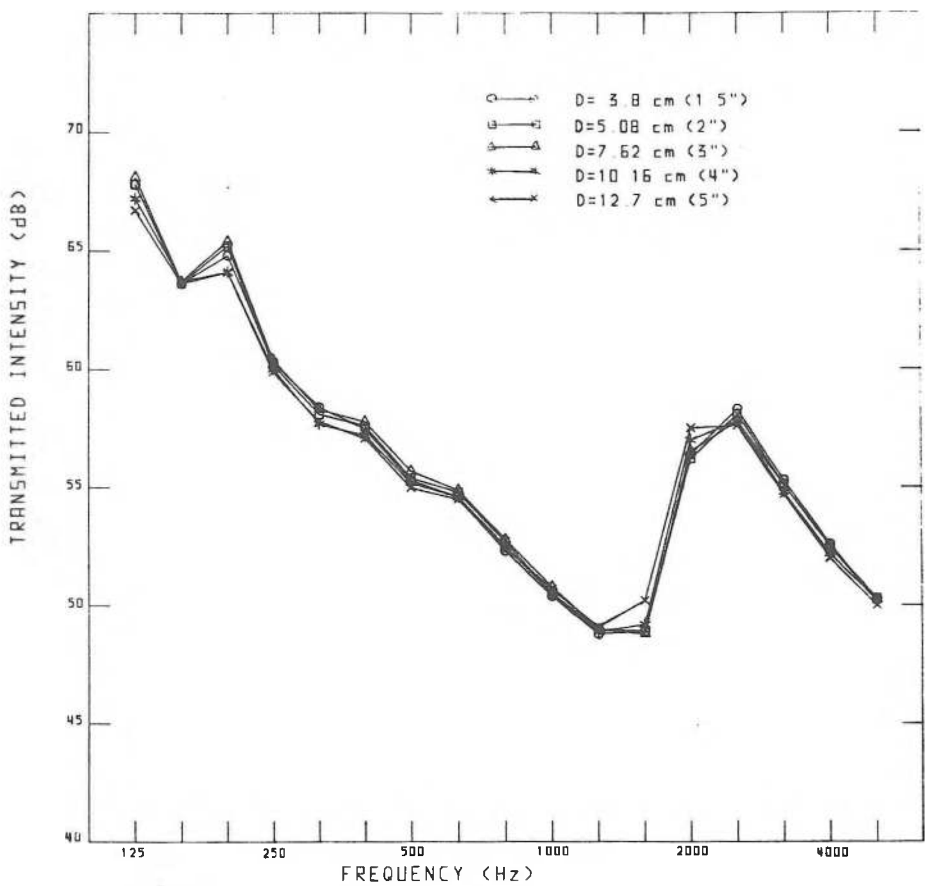

Fig. 5 Influence of Measurement Distance

12.7 cm x 12.7 cm Mesh t_{av} = 8 sec

When the distance is smaller than 10 cm (4"), there is very little difference (+ .6 dB) between results. However, L_{It} increases with increasing distance below coincidence. This trend reverses above coincidence.

The larger the measurement distance the less prominent the coincidence peak, with the measured coincidence frequency finally falling to the next lower third octave frequency band.

As a consequence the measurement distance chosen was 5.08 cm (2").

6. TRANSMISSION LOSS TESTS

6.1 Comparison of Standard and Intensity-Based Transmission Loss Measurement

For the sake of comparison between the two measurement methods and in order to take account of the reveal effect, the transmitted intensity reported in this section was measured on the reception room side of the reveal.

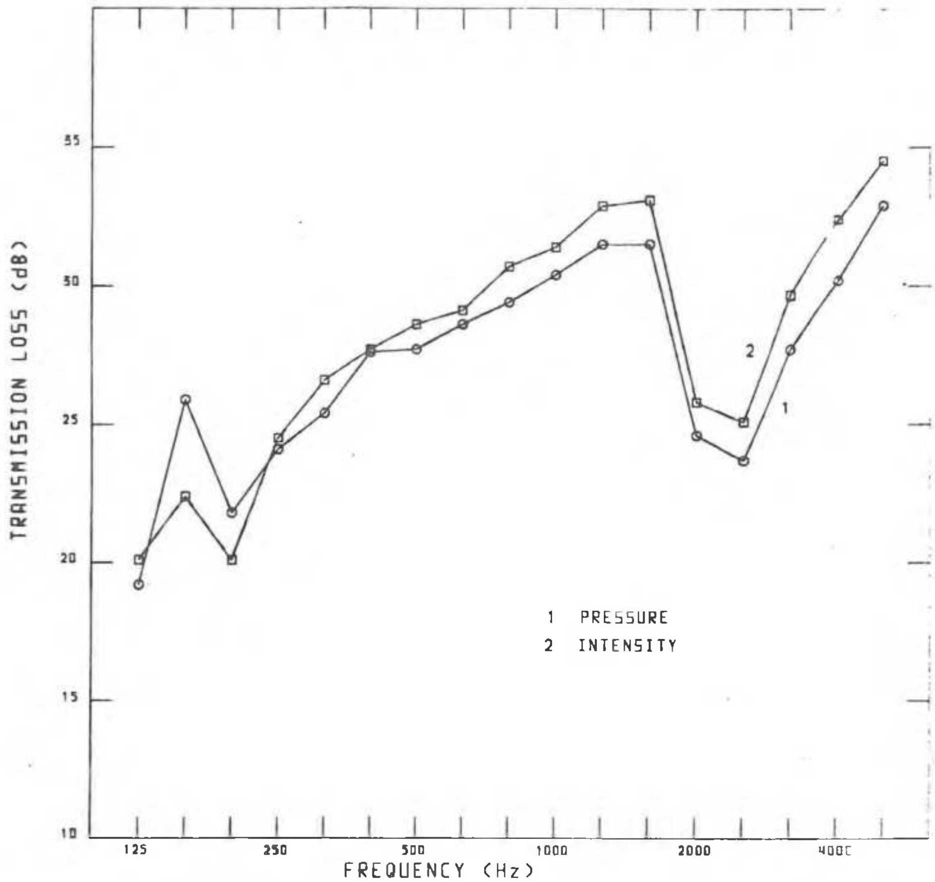

Fig. 6 Comparison between Standard and Intensity-Based Transmission Loss Measurement
12.7cm x 12.7cm Mesh t_{av} = 8 sec

As shown in Fig. 6 for the reveal left bare the results obtained are generally very similar with a maximum difference of 2 dB. Greater differences can be seen at lower frequencies and this is probably due to the small reception room size. The same trends were observed with the reveal lined.

Overall, one may conclude that the earlier reported technique validity, Crocker et al [3], Fahy [4], and Cops [5], has been demonstrated.

6.2 Lining of the Reveal

The transmitted intensity was again measured on the reception room side of the reveal.

Fig. 7 shows that the effect of lining thickness increases graduallyover most of the frequency range, peaking in effect between, 1KH and $2KH_Z$.

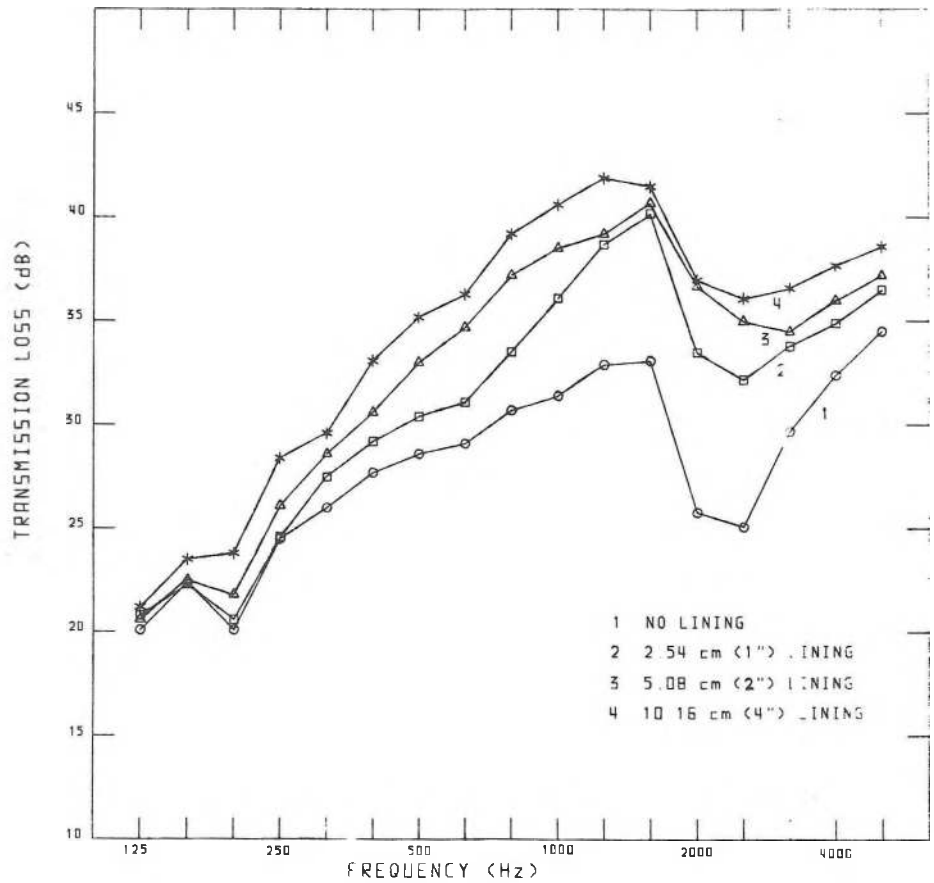

Fig. 7 Influence of Lining the Reveal on the Total Transmission Loss

12.7cm x 12.7cm Mesh t_{av} = 8 sec

Generally the thicker the lining, the higher the measured transmission loss, but only as a function of lining material absorption coefficient as one might expect (see Table 1).

Little effect is observed at the lower frequencies and this is probably due to the low frequency absorption characteristics of the lining material, although the prominence of grazing mode transmission with respect to the lining at low frequencies might also influence this result.

When the transmitted intensity is measured directly behind the test panel at a 5 cm (2") distance, the measured transmission loss in the cases when the reveal was lined with 0, 2.54 cm (1") or 5.08 cm (2") were the same, as can be seen in Fig. 8.

Thererefore, the transmission loss of the test panel alone is not influenced by the lining, and this suggests that the panel vibration is only loosely coupled to the airborn modes of energy transfer.

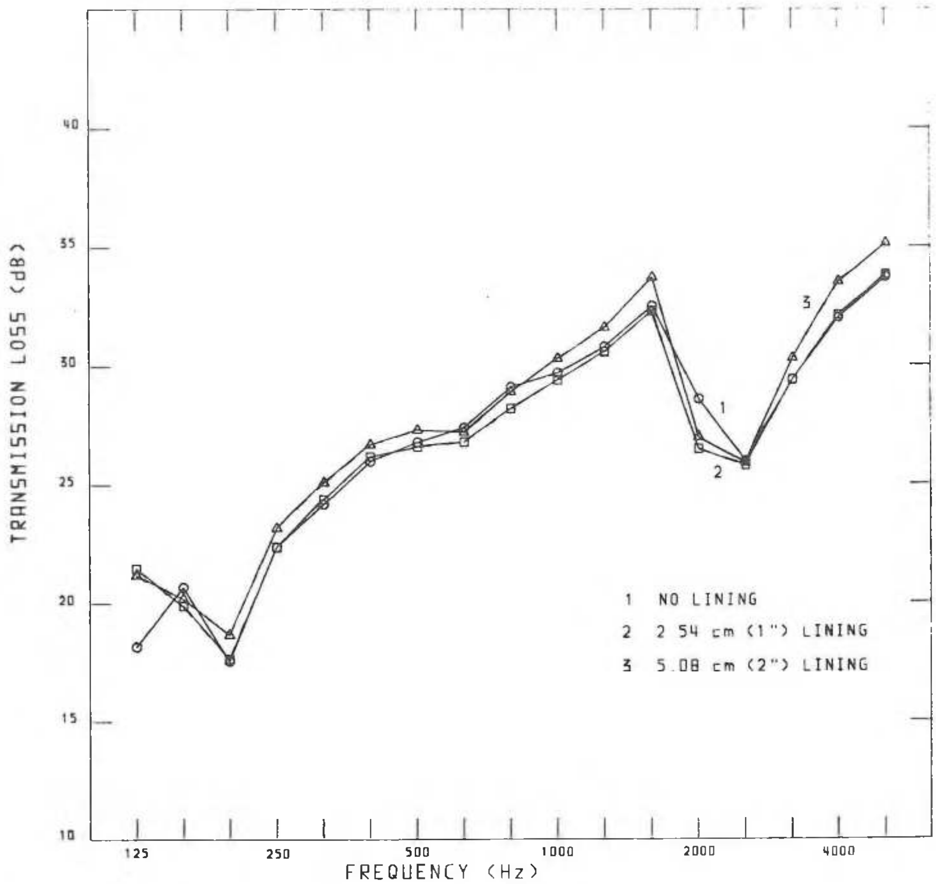

Fig. 8 Influence of Lining the Reveal on the Transmission Loss Measured at the Panel
12.7cm x 12.7cm Mesh D= 5.08cm (2") t_{av} = 8 sec

6.3 Distribution of the Intensity Radiated Through the Test Panel

This topic has been studied theoretically by for example Maidanek [7] and recently also experimentally by Fahy [4] using the sound intensity technique. For frequencies below coincidence the theoretical model demonstrates that the wave pattern at the edges of a finite plate cause most radiation, in contrast with an infinite plate. It is further suggested that for these frequencies only a strip of plate around the edges radiate sound power. Above the coincidence frequency, panels radiate from their whole surface, although the experimental results of Fahy did not completely agree with this.

The basic experiment has been repeated; the radiated intensity was for this purpose measured directly behind the test panel at a distance of 5.08 cm (2") and contours of equal normal intensity were then plotted; results are shown at 250 H_Z (Fig. 9), and 5000 H_Z (Fig. 10).

At very low frequencies (Fig. 9) the panel is radiating predominantly through the corners. The intensity transmitted through a small center portion of the panel is much lower and therefore negligable.

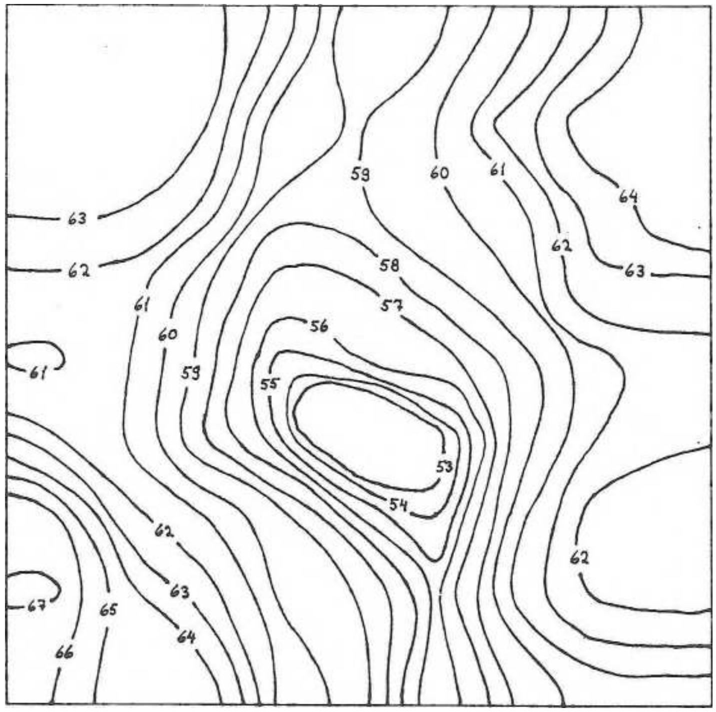

Fig. 9 Intensity Contours Normal to the Panel Surface at 250 Hz

At mid frequencies closer to the coincidence frequency it was found that the center portion contribution becomes larger, however greater intensity is found around the panel border and the gradients are found to be much steeper at the edges than at lower frequency. Closer to and at the coincidence frequency the strong intensity around the border of the plate remains, but the center portion of the panel tends to radiate much more than at lower frequencies.

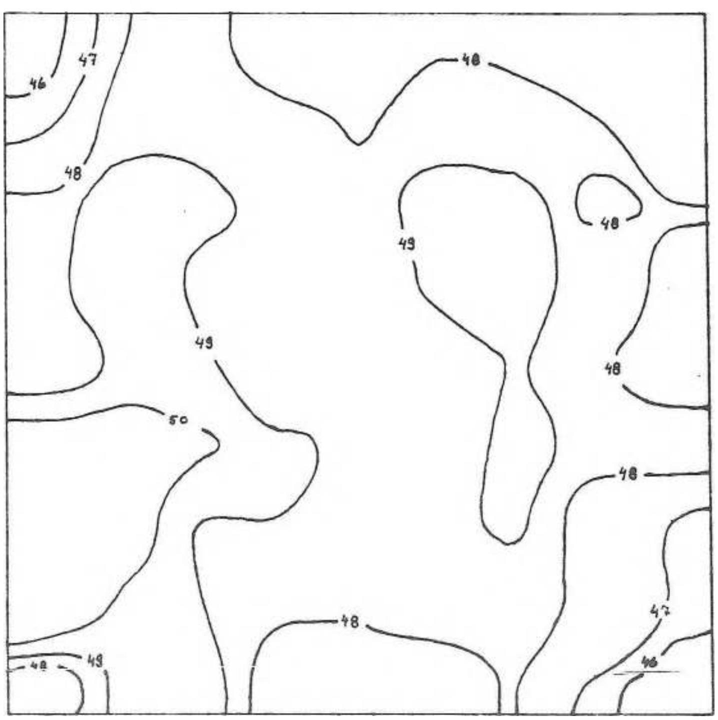

Fig. 10 Intensity Contours Normal to the Panel Surface at 5000 Hz

Above the coincidence frequency (Figure 10) a quite uniform radiation over the whole surface of the panel can be observed.

6.4 Fault Finding

The capabilities of the sound intensity technique with regard to the detection of construction or material deficiencies was also examined.

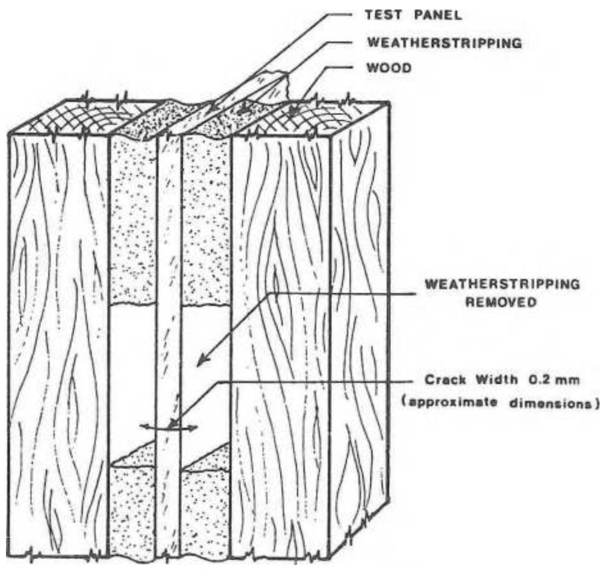

Fig. 11 Scheme of Fault Introduced by Removing Weatherstripping.
Strip Length 9.5 cm ; Crack Width 0.2 mm (approximate dimensions)

For this purpose a fault was introduced by removal of the weatherstripping on both sides of the panel as shown in Fig. 11. The exposed portion revealed a crack approximately 9.5 cm long and 0.2 mm wide between the panel edge and its mounting frame.

Intensity measurements were made directly behind the test panel at a distance of 5.08 cm (2"). The intensity pattern obtained was investigated for observable irregularities. It was found that close to the fault, the values of transmitted intensities were generally higher than at the same points before the fault was introduced. The differences in local intensity were slight at lower frequencies, up to 3dB at 250 H_Z, increasing to 10 dB at 2000 H_Z and falling lower again beyond this frequency.

As can be seen in Fig. 12 the effect is indicated by the intensity contours. However, when comparing the overall sound transmission loss before and after the introduction of the fault (see Figure 13) the influence of the fault is only noticeable above 800 H_Z and leads to a maximum difference in overall transmission loss of 2.5 dB at $1KH_Z$ with smaller, to negligable differences over the rest of the frequency range.

Such a fault could easily be overlooked by consideration of the overall spectrum alone.

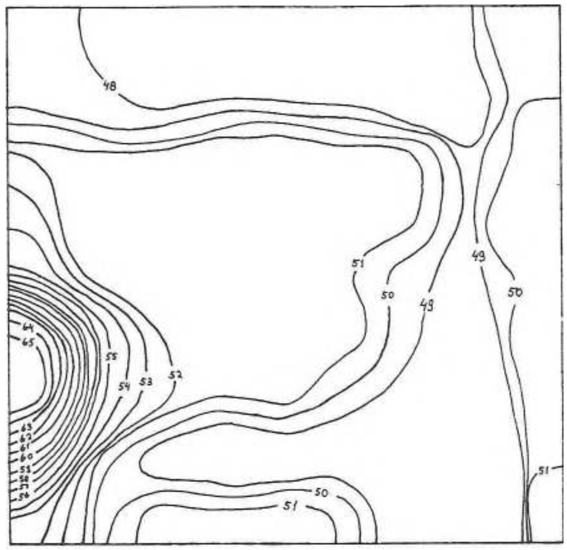

Fig.12 Fault Finding. Influence of Removing Weatherstripping at 1600 Hz

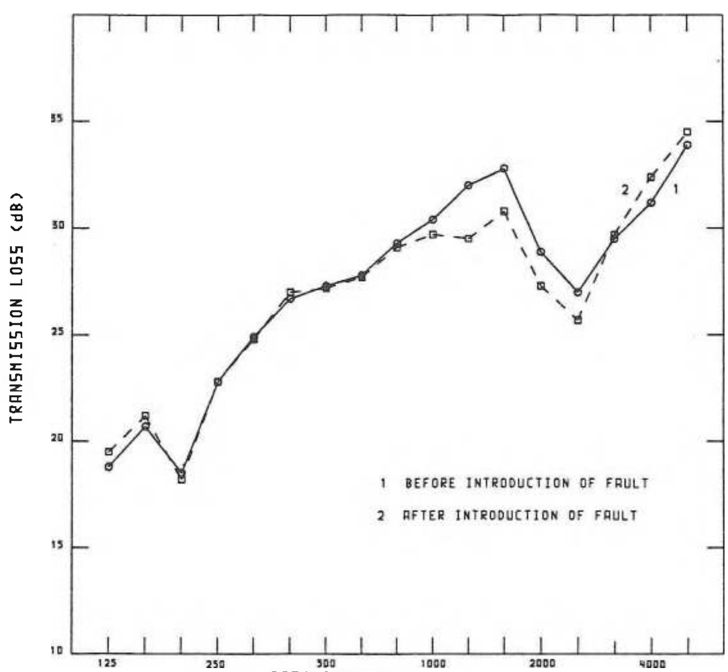

Fig. 13 Comparison between the Transmission Loss of the Test Panel before and after the Introduction of the Fault
12.7cm x 12.7cm Mesh $t_{av} = 8$ sec D = 5.08cm (2")

CONCLUSION

The validation of the intensity-based transmission loss measurement has been confirmed. A detailed measurement procedure has been established, and the analytical capabilities of the new method exploited to determine the influence of lining the reveal of the test panel with absorbent material. The overall transmission loss has been shown to increase with increasing thickness of absorbent lining. However the intensity measurement technique indicates that the panel radiation is not influenced by the presence of the lining, such a conclusion would not have been possible employing the standard reverberation room technique.

It was also demonstrated that the intensity technique can be used to identify the existance of untoward sound transmission paths as part of a normal measurement procedure.

ACKNOWLEDGEMENT

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