Proceedings of The Institute of Acoustics

THE USE OF SOUND INTENSITY TECHNIQUES TO MEASURE DIRECTIVITY IN THE NEAR FIELD OF RADIATING PANELS

M A Rowell and D J Oldham

Department of Building Science, University of Sheffield, SHEFFIELD S10 2TN

INTRODUCTION

When it is desired to obtain the directivity pattern of a radiating object, measurements of the pressure generated by that object have to be made in its 'far field'. This requires measurements to be made at distances from the object that are many times its major dimension. If the object is large, this requirement can present some problems. With measurements requiring to be made in free field conditions, there is a need for either a sufficiently large anechoic chamber or measurements have to be made in the open air. Anechoic test facilities of sufficient size are generally not available. Outdoor measurements are very much affected by the prevailing weather and ground cover. It is, therefore, desirable to be able to obtain the directivity pattern of an object from near field measurements.

A number of methods of obtaining far field pressures resulting from planar radiators, such as plates and panels, have been proposed based on measurements made over a plane close to and in front of the panel. These include holography and integral equation techniques. Both of these methods involve considerable post-processing of digitally acquired measurement data and have critical requirements relating to the size of the measurement grid as a function of frequency. They are essentially single frequency techniques. There is a need for a method that gives far field levels from measurements made in the near field, that does not require a great amount of post processing of experimental data and would be suitable for 3rd octave noise excitation.

A pilot study carried out by Hillarby and Oldham [1] suggested that the measurement of the acoustic intensity, in the near field of a radiating panel at points on an arc centred on the panel centre (i.e. a radius of 1 or 2 panel widths) could be used to determine far field patterns. This paper presents the results of an assessment of this method, using a computer model and experimental measurements.

PREVIOUS WORK

Shen and Oldham have demonstrated that pronounced directivity effects are observed for homogeneous panels acoustically excited above their critical frequency [2]. The results of Shen and Oldham were obtained using scale models. In an early attempt to obtain measurements on full sized sample Hillarby and Oldham investigated the possibility of using an acoustic intensity measuring system to measure in the near field [1]. Following Petterson [3], they first modelled a panel vibrating in the 1:3 mode by three simple sources, the two outer ones vibrating in phase and the central one in antiphase. They calculated the intensity vectors on a series of semi-circles centred at the middle of the simulated panel and observed a "lining up" of the vectors at a short distance from the panel i.e. the phenomenon of hydro-dynamic short circuiting no longer appeared significant. They suggested that measurements of intensity vectors at this distance could be used to calculate far field sound pressure levels.

Although the work of Hillarby and Oldham does lend some support to the idea that near field measurement of intensity can be used to obtain far field sound pressure levels there are a number of limitations in their study.

The simulation of the panel by a small number of simple sources would not give rise to the pronounced directivity affect as reported by Shen and Oldham. In particular, the work of Shen and Oldham suggests that the pronounced directivity of panels radiating in third octaves above the critical frequency is caused by a strongly resonating m:1 mode (where m is a large integer) in that frequency band. Not only does the Hillarby and Oldham simulation relate to a panel vibrating with a low mode number but the simulated panel was operating well below its critical frequency. There is a need, therefore, to examine the radiation from a more realistic panel at higher frequencies.

An initial study was proposed to look at the far field radiation patterns and the near field radial intensity at different distances from a series of test panels composed of different materials with different widths, heights, thicknesses, etc. From this study it was intended that some empirical guide could be formulated which would give information relating to the accuracy in determining far field pressure levels from near field intensity measurements in terms of panel characteristics, frequency and distance from the panel.

The study was in two parts:

(a) A computer model
(b) Measurements on simple panels

THE COMPUTER MODEL

Computer programs were written to calculate the pressure at a point in space due to a simply supported panel, vibrating in a single mode shape (m,n) and at a single frequency using Rayleigh's far field equation:

$$p(x,y,z) = \frac{1}{2\pi} \iint_{-\infty}^{\infty} V(x',y') \frac{e^{jkR}}{R} \, dx' \, dy'$$

where $V(x',y')$ is the velocity profile of the panel

and $R = ((x - x')^2 + (y - y')^2 + z^2)^{\frac{1}{2}}$

with the panel situated in the $z = 0$ plane

NEAR FIELD DIRECTIVITY MEASUREMENTS

Radial intensity values were calculated from the pressure value points using the finite difference formula. Far field pressure levels were calculated using Wallace's formula (4). In all calculations, the intensity and pressure values were calculated for points on an arc at radius r, centred on the panel, in the xz - plane (see Figure 1).

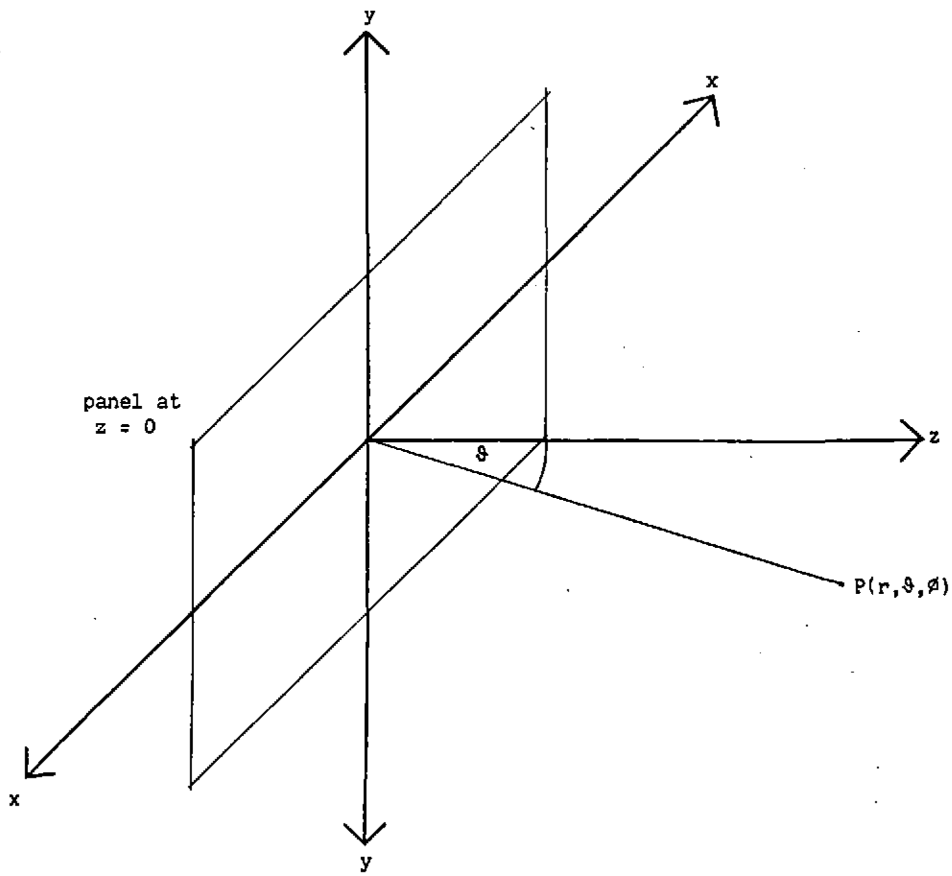

Figure 1 Geometry of simulation and measurements.

NEAR FIELD DIRECTIVITY MEASUREMENTS

MEASUREMENTS

The test panel was fixed to the front of a small enclosure containing two piezoelectric horn tweeters. The far field sound pressure level was measured in third octaves from 1 kHz to 16 kHz as a function of angle at a distance of approximately ten times the panel width away in an anechoic room.

The near field intensity level was also measured on the circumference of a semi-circle using a ½" B&K intensity probe, for radii of 0.5, 1 and 2 times the panel width. To obtain accurate, high frequency intensity values, a 3mm microphone separator was used.

RESULTS

Computer Simulation

On examination of Figure 2 in which the difference in far field sound pressure level and near field intensity level is plotted for a panel of dimensions 0.54m x 0.54m, with a mode number of (3,1) for distances of 0.5, 1, 2 and 100 times the panel width, and a frequency of 100 Hz, it can be seen that, as expected, the difference is zero for the largest distance but as the radius is decreased the difference becomes progressively larger but is still quite small. This simulated mode shape is similar to that of Hillarby and Oldham and the results suggest that the method is valid for low frequencies and low order mode shapes at a radial distance of 2 panel widths.

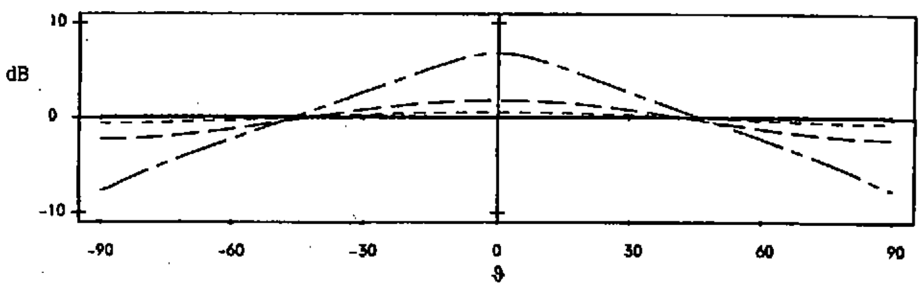

Figure 2 (SPL - IL(r)) for Hillarby and Oldham panel, 0.54 x 0.54m, (3,1) mode, frequency = 100 Hz
—— – —— r = 0.5 x panel with
—— —— —— r = 1.0 x panel width
----------- r = 2.0 x panel width
———————— r = 100 x panel width

NEAR FIELD DIRECTIVITY MEASUREMENTS

With frequency constant at 2 kHz, as the mode number is increased the deviation varies in a non-systematic manner, but increases as the distance from the panel is decreased as is shown in Figures 3a to 3d.

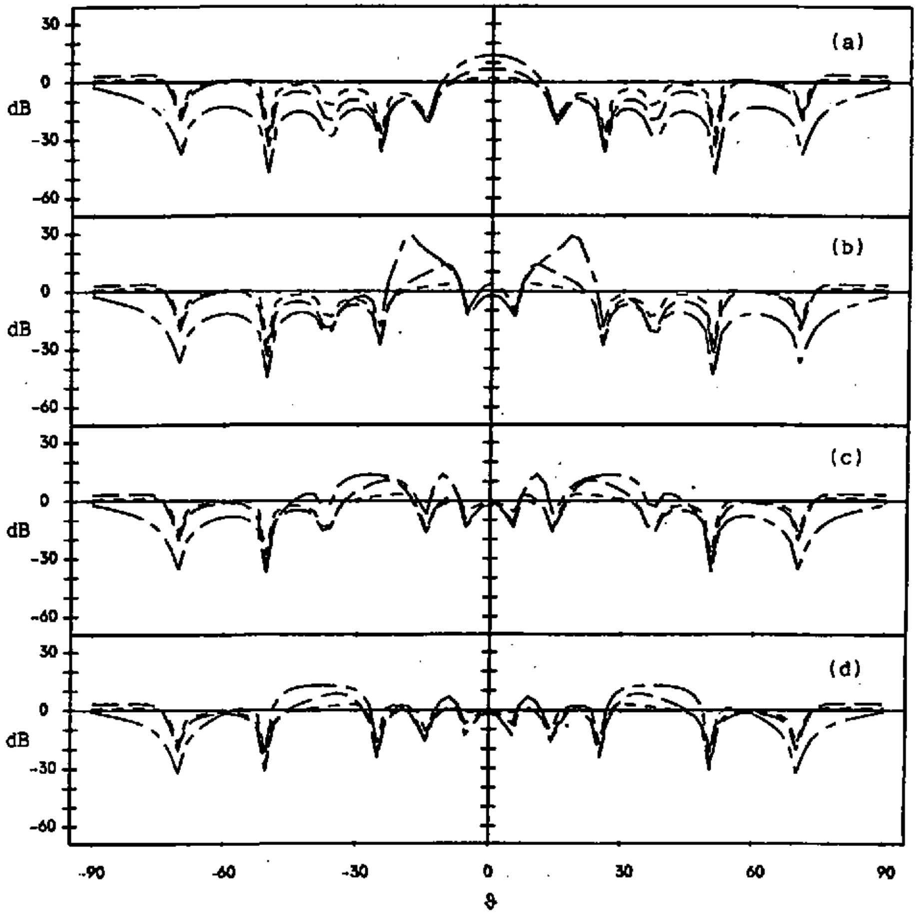

Figure 3 (SPL - IL(r)) for 1m x 1m panel, frequency = 2 kHz
——— – ——— r = 0.5 x panel with
——— ——— ——— r = 1.0 x panel width
----------- r = 2.0 x panel width
————————— r = 100 x panel width
(a) 1,1 mode (b) 3,1 mode (c) 5,1 mode (d) 7,1 mode

NEAR FIELD DIRECTIVITY MEASUREMENTS

These results cast doubts on the feasibility of employing near field intensity measurements to predict far field radiation patterns. Large differences occur between far field SPL directivities and near field IL directivities for a radius of twice the panel width even for low frequencies and lower order modes. This radius would be the maximum practical if apparatus intended for measurements on large panels in the field were not to become unwieldy.

EXPERIMENTAL WORK

Although the results from the computer simulation showed little promise, a programme of experimental work was undertaken to further assess the viability of the technique. The computer model calculations were performed for single mode, single frequency cases whereas actual measurements would be made for 3rd octave excitation. It was thought that 3rd octave excitation of the panels would excite more than one mode in the relevant band, and also, because of the 'spread' of frequencies in a band, some 'smoothing' process might occur in the radiation patterns, reducing some of the minima and maxima and possibly reducing the magnitude of the difference between the far field SPL and near field IL directivity plots.

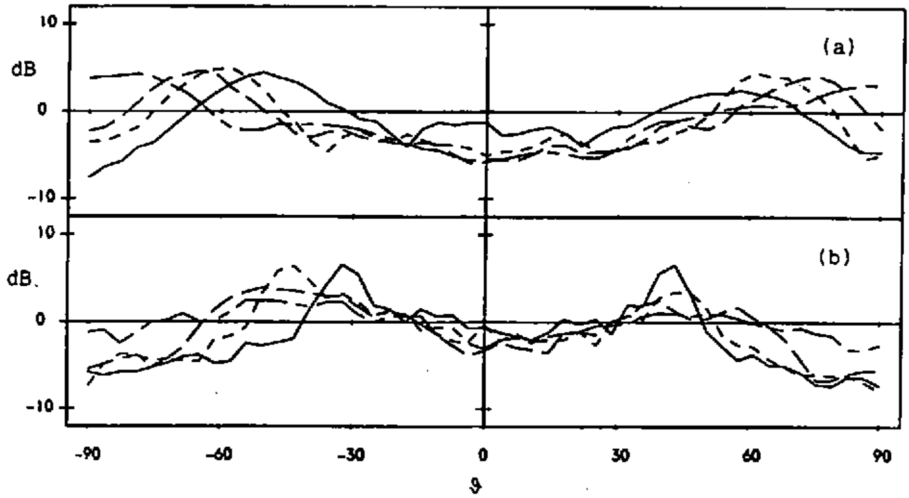

Figure 4 IL(r)) for far field SPL for perspex panel 300 x 200 x 8mm;
——————— far field SPL
—— – —— IL(r) r = 0.5 x panel with
—— —— —— IL(r) r = 1.0 x panel width
----------- IL(r) r = 2.0 x panel width
(a) frequency = 5 kHz (b) frequency = 10 kHz

NEAR FIELD DIRECTIVITY MEASUREMENTS

In this work, two small panels were tested, (a) aluminium, dimensions 0.3 x 0.3m x 3mm and (b) perspex, dimensions 0.3 x 0.2m x 8mm. The small size of the anechoic chamber precluded measurements on larger panels. The far field SPL was measured for both of these panels along with the radial intensity in 3rd octaves for distances of 0.5, 1 and 2 times the panel width.

Figure 4 shows the far field SPL directivity plots and near field directivity plots for the perspex panel, plotted referenced to the log-mean level. The lobes predicted by Shen and Oldham can be seen in the sound pressure plots. The difference between the shapes of the far field SPL and near field IL curves increases as the distance from the panel is decreased. This trend is similar to that observed with the computer model.

It can also be seen from Figures 4(a, b and d) that for the same distance, the difference in shape of the SPL and IL curves increases with increasing frequency. This is equivalent to an increase in the difference between the two quantities, which again is the same result as observed in the computer simulation. However, the magnitude of the difference is less than was observed with the computer model, which indicates that some smoothing of the response occurs for broad band excitation.

CONCLUSIONS

It has been shown that radial intensity measurements in the near field of a panel cannot be used to predict the far field sound-pressure level (and hence the directivity pattern) of the panel apart from the case of low order mode shapes at low frequencies. Further work is now being carried out with a view to using Kirchoff's equation to calculate the far field sound pressure level from sound pressure measurements made over an enclosing surface in the near field.

REFERENCES

[1] Hillarby, S.N. and Oldham, D.J., "Near field directivity measurements using the two microphone intensity measuring technique", Acoustics Letters 6, pp. 36-39 (1982).

[2] Shen, Y. and Oldham, D.J., "A scale model investigation of sound radiation from buildings", J. Sound Vib. p. 331-350 (1983).

[3] Petterson, O.K.O., "Sound intensity measurements for describing acoustic power flow", Applied Acoustics, 14 pp. 387-397 (1981).

[4] Wallace, C.E., "Radiation resistance of a rectangular panel", J. Acoust. Soc. Am., 51, pp. 946-952 (1972).