

# Prediction of Sound-Absorbing Performance of Micro-Perforated Panels using the Transfer Matrix Method

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## ABSTRACT

Micro-perforated panels have tiny pores which attenuate sound based on the Helmholtz resonance principle. That being the case, an appropriate cavity depth should be chosen to fully capitalize on the attenuation potential of the panel. Generally, the panel's sound absorbing performance can be predicted by Maa's theory given information about the panel and the cavity depth. However, in some cases, one cannot use the theory to predict the panel's performance precisely, especially when the micro-perforate has varying diameters and/or irregular hole shapes. In these cases, the sound-absorbing performance of the micro-perforate is different from that of a uniform pore diameter perforate. This paper presents an alternative method to predict the micro-perforated panel's performance precisely. As a first step, the transfer impedance of the micro-perforate should be measured. Then, the transfer matrix method is employed to predict the sound-absorbing performance of a single panel or system of panels. It is demonstrated that the suggested approach can predict the performance very accurately.

## INTRODUCTION

Micro-perforated panels are normally made from sheet metal or plastic, and have widely been used in building acoustics since a connecting air cavity is practicable. Additionally, the attenuation can be tailored by adjusting the pore size and the cavity depth. When pore diameters are about 0.3 mm or less, the attenuation frequency band of the panel will be very wide. Additionally, the absorption can be tuned by carefully selecting the panel, and the adjoining cavity depth. Usually, the diameters of pores in the panel are approximately the same. Hence, most recent research has assumed a uniform pore diameter.

Certainly, the most notable work on predicting micro-perforate performance is that by Maa [1]. In fact, Maa's

theory can predict the sound absorption of micro-perforated panels very accurately in many cases.

One limitation of Maa's work is that non-uniform pore size and shape is not taken into account. However, advanced manufacturing technologies such as using a laser, etching, and jetting have recently been employed to make smaller pore diameters in order to achieve higher absorption over a wider bandwidth. The diameter of the holes made by these technologies can be uniform or varying. Furthermore, the shape of the pore can be circular or irregular. However, the designer must resort to guesswork to predict the sound absorption performance of the aforementioned panels. Furthermore, it is also troublesome to predict the sound absorption for using one panel in tandem with another.

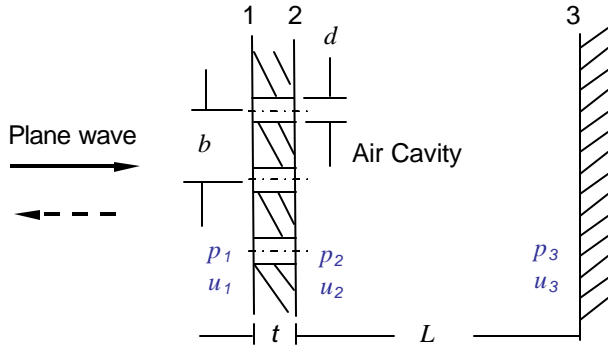
An alternative method for predicting the sound absorption performance of micro-perforated panels is presented in this paper. The transfer impedance of panels with arbitrary holes can be measured first. Then, the four-pole parameters of the panel with an adjoining air cavity can be calculated using the transfer matrix approach. From the four-pole parameters, the surface impedance and sound absorption coefficient can be predicted. This approach can be used for a single panel, or for systems of panels. The predicted results agree well with experimental results.

## TRANSFER MATRIX METHOD APPLIED TO MICRO-PERFORATED PANELS

A micro-perforated panel with thickness  $t$ , hole diameter  $d$ , hole spacing  $b$  and air cavity depth  $L$  is shown in Figure 1. Plane wave propagation is assumed in the study. The proposed method in this paper is based on the transfer matrix approach. An acoustical element can be modeled by its four-pole parameters which relate the sound pressure and particle velocity on each side of the acoustical element (illustrated in Figure 1). The transfer matrix can be expressed as

$$\begin{bmatrix} p_1 \\ u_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} p_2 \\ u_2 \end{bmatrix}, \quad (1)$$

where  $p_1$  and  $p_2$  are the sound pressure;  $u_1$  and  $u_2$  are the particle velocity, and  $A$ ,  $B$ ,  $C$  and  $D$  are the four-pole parameters of an acoustical element. The variables are defined in Figure 1 below.



**Figure 1.** schematic for a micro-perforated panel.

Hence, one can write the following equation for the micro-perforated panel shown in Figure 1 as

$$\begin{bmatrix} p_1 \\ u_1 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} p_3 \\ u_3 \end{bmatrix} = \begin{bmatrix} A_{13} & B_{13} \\ C_{13} & D_{13} \end{bmatrix} \begin{bmatrix} p_3 \\ u_3 \end{bmatrix}, \quad (2)$$

where  $A_1, B_1, C_1$  and  $D_1$  are the four-pole parameters for the panel (the first element), and  $A_2, B_2, C_2$  and  $D_2$  are the four-pole parameters for the air cavity (the second element).  $A_{13}, B_{13}, C_{13}$  and  $D_{13}$ , are the overall four-pole parameters of the panel plus air cavity.

Since the surface 3 is rigid, the particle velocity  $u_3$  at the surface is zero. Also because the thickness  $t$  is small, the particle velocities on the both sides of the micro-perforated panel are the same, i.e.,  $u_1 = u_2$ . In addition, the transfer impedance of the panel  $Z_T$  can be defined as

$$Z_T = \frac{p_1 - p_2}{u_1} \quad (3)$$

i.e.

$$p_1 = p_2 + u_1 Z_T. \quad (4)$$

Assuming  $u_2 = u_1$  in Equation (1), the four-pole parameters of the micro-perforated panel can be represented by

$$\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} = \begin{bmatrix} 1 & Z_T \\ 0 & 1 \end{bmatrix}. \quad (5)$$

After determining the transfer impedance, the absorption can be determined for a cavity depth of any arbitrary length in the following manner. For a connecting air gap, the four-pole parameters are provided in the literature as:

$$\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} = \begin{bmatrix} \cos kL & j r_0 c \sin kL \\ j \frac{\sin kL}{r_0 c} & \cos kL \end{bmatrix}. \quad (6)$$

where  $k$  is the wavenumber,  $r_0$  is the density of the media, and  $c$  is the speed of sound [2].

The overall four-pole parameters ( $A_{13}, B_{13}, C_{13}$  and  $D_{13}$ ) for a perforated plate plus air gap can be obtained simply by multiplying the matrices in (5) and (6) together. The surface impedance can then be calculated for any cavity length ( $L$ ) by

$$Z = \frac{p_1}{u_1} = \frac{A_{13}}{C_{13}}. \quad (7)$$

Once the transfer impedance is obtained, the sound absorption coefficient can be predicted by

$$a = 1 - \left| \frac{Z - r_0 c}{Z + r_0 c} \right|^2. \quad (8)$$

## MEASUREMENT OF TRANSFER IMPEDANCE

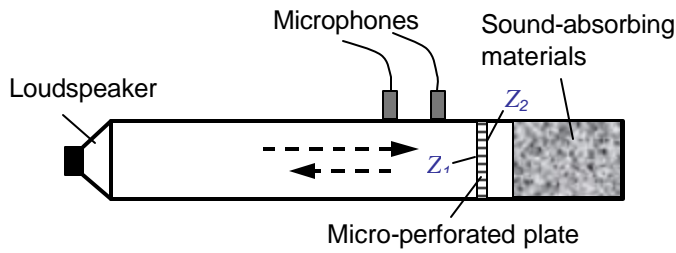
In order to predict the sound absorption performance of the micro-perforated panels, one can see from Equation (8) that the transfer impedance of the panel should be determined first [3]. The transfer impedance can be obtained by theory (i.e. Maa's Theory [1]). However, when the micro-perforate has varying diameters and irregular pore shapes, Maa's theory has not currently been extended to consider this situation. In the absence of suitable theory, an alternative approach is to measure the transfer impedance directly.

The experimental setup for the transfer impedance measurement is shown in Figure 2. In terms of Equation (3), the transfer impedance for this situation can be expressed as

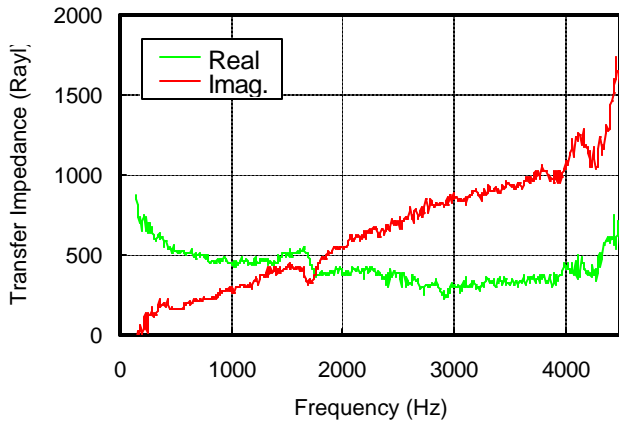
$$Z_T = \frac{p_1 - p_2}{u} = Z_1 - Z_2. \quad (9)$$

The transfer impedance is actually the difference between the surface impedances  $Z_1$  and  $Z_2$ . The surface impedance can be measured with ( $Z_1$ ) and without the panel ( $Z_2$ ). Both surface impedance measurements are conducted in accordance with ASTM E1050-98 [4] which is commonly referred to as the two-microphone method. It is suggested that some sound-absorbing materials be added to the end of the tube so as to reduce sound reflection from the termination.

The measured transfer impedance for a 0.3 mm thickness panel with a porosity of 0.3 % and pore diameter varying between 0.15-0.35 mm is shown in Figure 3.



**Figure 2** Transfer impedance measurement

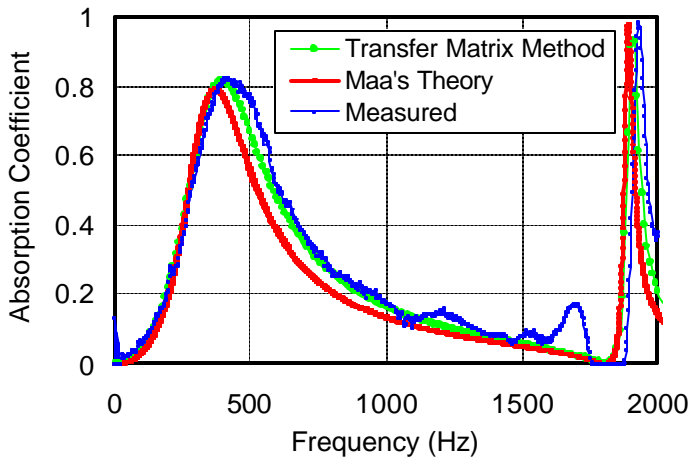


**Figure 3** Measured transfer impedance for  $t = 0.3$  mm, porosity = 0.3 %,  $d = 0.15-0.35$  mm.

## MICRO-PERFORATED PANEL APPLICATIONS

### UNIFORM CIRCULAR HOLES

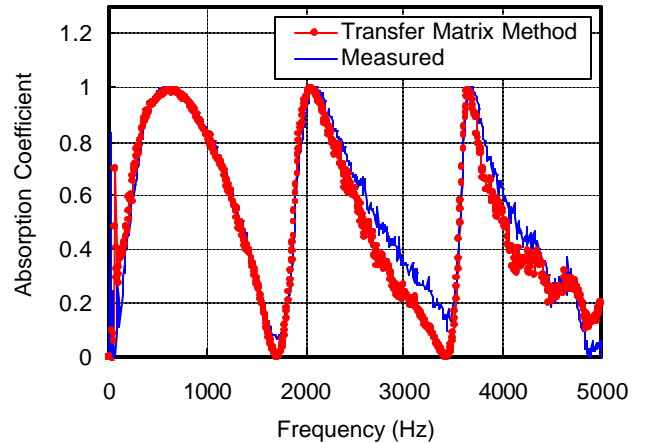
Figure 4 shows the sound absorption coefficient comparison between the predicted and measured results. Here the panel thickness is 1 mm, the diameter of the holes is 1 mm, and the porosity is about 1 %. The air cavity depth is 95 mm. The impedance measurements  $Z_1$  and  $Z_2$  were conducted in accordance with ASTM1050-98 [4]. One can see from the figure that the results using the transfer impedance approach compare well with both Maa's Theory and with the experimental results.



**Figure 4** Sound absorption of single-layer micro-perforated panel:  $d = 1$  mm,  $t = 1$  mm, porosity = 1%,  $L = 95$  mm.

### VARYING PORE DIAMETER

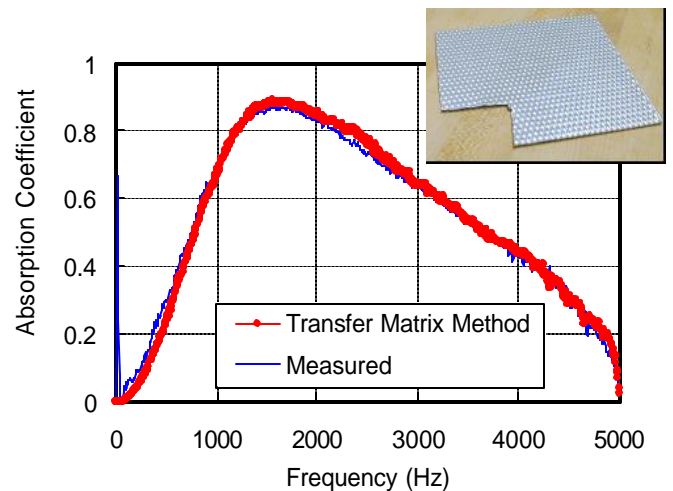
As mentioned previously, it is difficult to apply Maa's theory to a micro-perforated panel with pores having different diameters. Figure 5 compares the sound absorption predicted using the transfer matrix method with measured results for just this case. Here the panel thickness is 0.1 mm, and the pore diameter varies between 0.12-0.35 mm. The porosity is about 0.3 %, and the air cavity depth is 100 mm.



**Figure 5** Sound Absorption single-layer micro-perforated panel:  $d = 0.12-0.35$ mm,  $t = 0.1$ mm,  $L = 100$ mm

### IRREGULAR HOLE SHAPES

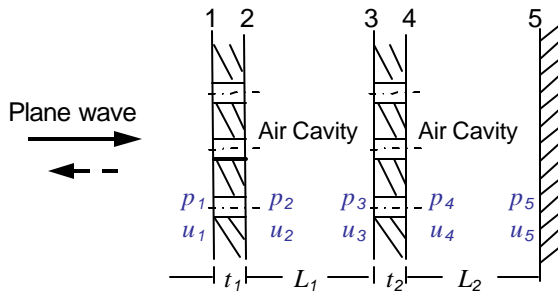
For the case when a micro-perforated panel has irregular holes like that shown in Figure 6, Maa's theory is difficult to apply. However, the transfer matrix method approach works particularly well in this case. Figure 6 shows the sound absorption coefficient comparison between the predicted and measured results. Here the panel thickness is 1.5 mm, the porosity is approximately 1%, and the air cavity depth is 20 mm.



**Figure 6** Sound Absorption single-layer micro-perforated panel with irregular holes.

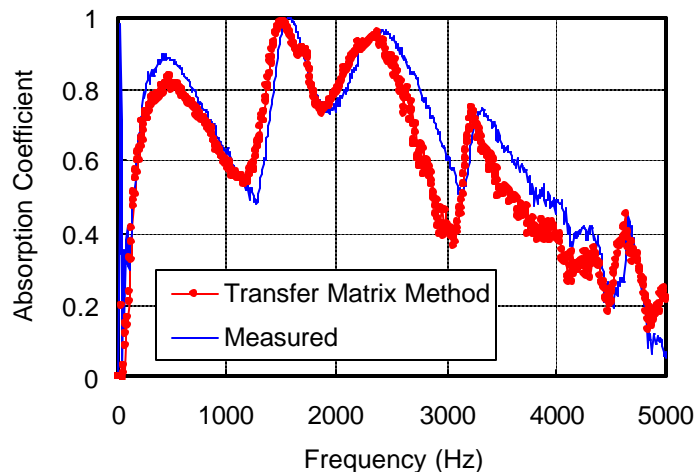
## SYSTEMS OF MICRO-PERFORATED PANELS

The power of the approach can be demonstrated most readily with systems of micro-perforated panels like that shown in Figure 7. Again the transfer matrix approach can be used and each panel and air cavity can be treated as a separate element. The approach is applied in the same manner as previously outlined. In this case, transfer matrices for both perforated panels and both air cavities should be multiplied together in order to develop the total four-pole parameters for the system.



**Figure 7** System with two panels.

Figure 8 shows the sound absorption coefficient comparison between the predicted and measured results for a system of micro-perforated panels akin to that shown in Figure 7. Here the panel thickness is 0.3 mm, the pore diameter varies between 0.15-0.35 mm, and the porosity is about 0.3 %. The air cavity lengths are 25 mm ( $L_1$ ) and 115 mm ( $L_2$ ). One can see that the predicted results compare well with the measured results for this case.



**Figure 8** Sound Absorption of a system of micro-perforated panels.

## CONCLUSIONS

The sound absorption prediction of micro-perforated panels has been discussed in this paper. In the method reported, the transfer impedance of micro-perforated panels should be measured first. Then, the absorption

performance of micro-perforated panels can be predicted by the transfer matrix method. The results indicate that the method can be utilized to predict absorption performance for panels with uniform circular holes, or for panels having varying diameter holes and even for irregular hole shapes. Also the method works well for systems of micro-perforated panels. Additionally, the experimental results indicate that high absorption can be achieved using a system of micro-perforated panels.

It should be noted that the approach can also be utilized to predict the sound absorption performance of thin sound-absorbing materials.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Dah-You Maa, "Potential of Microperforated Panel Absorber," *J. Acoust. Soc. Am.* 104, 2861-2866, (1998).
2. Beranek, L.L. and Vér, I.L., *Noise and Vibration Control Engineering*, John Wiley & Sons, Inc., 377, New York (1992).
3. T. W. Wu, C. Y. R. Cheng, Z. Tao, "Boundary Element Analysis of Packed Silencers with Protective Cloth and Embedded Thin Surfaces," *Journal of Sound and Vibration*, 261, pp. 1-15 (2003).
4. ASTM standard, E1050-98, "Standard Test Method for Impedance and Absorption of Acoustical Material Using a Tube, Two Microphones and a Digital Frequency Analysis System," (1998).

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