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SOUND RADIATION INTO DISSIPATIVE MEDIA

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ABSTRACT

Radiation of sound from a baffled rectangular plate into air is relatively well understood. Surface radiation is important above critical frequency and edge radiation is the dominant mechanism below critical frequency. This paper investigates the effect that replacing air with a dissipative medium (such as mineral quilt) has on the sound radiated by the plate. The problem is evaluated using an asymptotic approach similar for that used in studies of a plate radiating into air. This yields an analytic solution for radiation efficiency in the regions above and below critical frequency. The results indicate that above critical frequency, the radiation efficiency tends to that of a plate radiating into air. Below critical frequency, the presence of a dissipative medium is shown to result in increased sound radiation.

1 - INTRODUCTION

Porous materials are frequently used in structures where high levels of sound insulation are required. Common applications include enclosures where porous blankets are used in conjunction with a thin panel to reduce break-in/out of sound, e.g., noise control in ventilation ducts, machine enclosures, sound proofing in vehicles. Cavity wall construction represents a second major area of application. When the leaves of the wall are thin or lightweight, such as in fuselage structures in aircraft or in plasterboard partitions in buildings, it is common to include absorption in the cavity to improve sound insulation. In both cases the porous layer is included primarily to damp resonant modes in the airspace to reduce transmission via this element in the construction.

In order to predict the behaviour of sound transmission through such structures, it is important to understand not only the effect that the porous materials have on cavity modal behaviour but also the interaction between the porous medium and the structural elements. This paper describes a model for predicting the radiation of sound from a simply supported baffled panel into a porous medium. The results provide some insight into the mechanism of radiation and offer a means for predicting the structural damping in construction of this type.

2 - MODEL

The system investigated is shown on Figure 1. It consists of a thin simply supported plate with dimensions, $a \times b$ in a baffle occupying the x-y plane.

The plate is bounded in the region $z > 0$ by a porous medium, represented by an equivalent fluid with complex wavenumber, k_a, and complex density ρ_a. The plate is assumed to carry an imposed velocity

$$U\left(x', y', t\right) = U_o \sin k_x x' \sin k_y y' e^{i\omega t} \tag{1}$$

where U_o is the velocity amplitude, $k_x = m\pi/a = \alpha k$ and $k_y = n\pi/b = \beta k$ are the plate wavenumbers (m and n being integers) and ω is angular frequency.

If the plate is considered as an array of acoustic monopoles positioned at arbitrary points x' and y' whose volume velocity may be found from the plate velocity, it is possible to obtain an expression for the

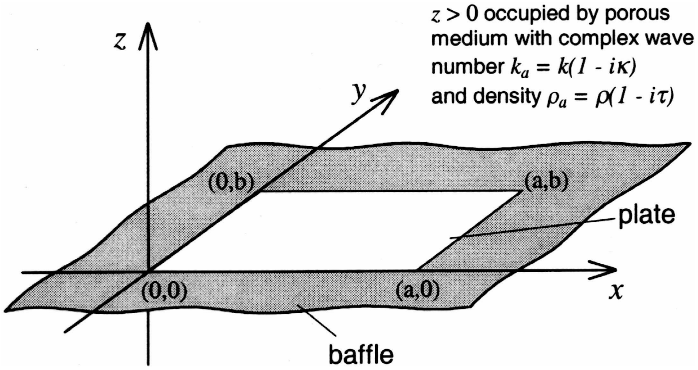

Figure 1: Baffled plate radiating into a porous medium.

pressure field at the plate surface. This may be used in conjunction with the plate velocity to determine the acoustic intensity normal to the plate, which may be expressed as a radiation efficiency, σ, for the plate.

$$\sigma = \frac{2\rho k_0}{ab\pi\rho_0}\left\{\int_0^b\int_0^a\int_0^b\int_0^a \sin k_x x\ \sin k_y y\ \sin k_x x^{'} \sin k_y y^{'}\frac{\sin kr}{r}e^{-\kappa kr}\,dxdydx^{'}dy^{'}\right. \tag{2}$$
$$\left. -\tau\int_0^b\int_0^a\int_0^b\int_0^a \sin k_x x\ \sin k_y y\ \sin k_x x^{'} \sin k_y y^{'}\frac{\cos kr}{r}e^{-\kappa kr}\,dxdydx^{'}dy^{'}\right\}$$

where $r^2 = (x - x')^2 + (y - y')^2$, and k_o and ρ_o are the acoustic wave number and density of air respectively. This is in the same form as the expression obtained by Cummings *et al.* who investigated radiation from low order plate modes using numerical methods [1].

3 - SOLUTION

The approach adopted for the solution of Equation 2 follows that used by Leppington *et al.* for a baffled plate radiating into air [2]. It involves splitting the integral into a sum of four simpler integrals, which relate approximately to the contributions from surface, edge and corner radiation. These may be reduced to integrals of a single variable and solved using asymptotic methods by assuming that $k\overline{a}$ tends to infinity, $\overline{a}$ being the lesser of a and b.

For a plate radiating into air, the surface radiation term is insignificant below the plate critical frequency. This corresponds to a cancellation of the pressure field over most of the plate surface leaving only the edges to radiate sound effectively. At these frequencies the plate is therefore a relatively poor radiator of sound. Above critical frequency, the surface radiation term dominates and the plate radiates efficiently from its entire surface.

For a plate radiating into a porous medium, some additional manipulation is required to deal with the presence of an exponential term in the integrands. These terms occur as a consequence of representing a dissipative medium in the expression for radiation efficiency and result in the area dependent term being dominant at all frequencies. It is therefore possible to predict σ at any frequency using

$$\sigma \approx \frac{\rho k_o}{2\pi\rho_o k}\int_0^{2\pi}\left\{\frac{\ell + \tau\kappa}{\kappa^2 + \ell^2}\right\}d\theta = \frac{\rho k_o}{\rho_o k}\left\{\frac{\cos\frac{1}{2}\phi - \tau\sin\frac{1}{2}\phi}{2}\right\} \tag{3}$$

where

$$\ell(\theta) = 1 - \alpha\cos\theta - \beta\sin\theta,\ \mu^2 = \alpha^2 + \beta^2,\ \phi = \tan^{-1}\left\{\frac{2\kappa}{\mu^2 + \kappa^2 - 1}\right\},\ -\pi < \phi < 0$$

The presence of a dominant area dependent term below critical frequency may be explained if it is assumed that the porous material interferes with the hydrodynamic short circuit mechanism responsible in air for the cancellation of sound over the plate surface. Figure 2 shows the predicted radiation efficiency for a 553 mm × 485 mm × 0.75 mm steel plate radiating into air, and radiating into a fibrous porous material with a flow resistivity of 1900 Rayls/m. It may be seen that the presence of the porous medium has resulted in a significant increase in radiation efficiency at low frequencies. The slower wavespeed in the porous medium also results in a reduction of the critical frequency of the plate.

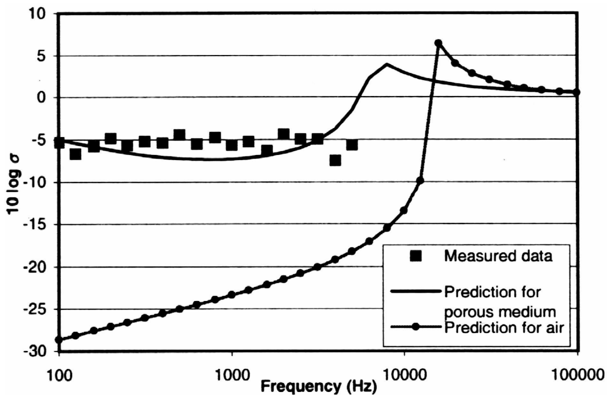

Figure 2: Radiation efficiency for a plate radiating into air and into a porous medium.

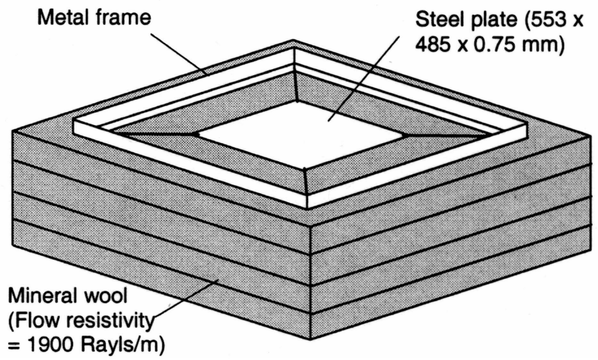

Figure 3: Experimental set up.

4 - EXPERIMENTAL RESULTS

Experimental data were obtained for comparison with the theory from damping measurements performed on a steel plate suspended from a metal frame by its corners as shown in Figure 3. The plate was excited with a light impact and the response was measured using an accelerometer. The damping was obtained from the decay rate. Initially measurements were performed for the plate radiating into air to give the sum of the radiation losses, coupling losses to the frame and internal material losses. The plate was then suspended over a 400mm thick layer of glass fibre thermal insulation and the damping measurements were repeated. Significant increases in damping were observed due to radiation into the quilt. The radiation damping was obtained by subtracting the results from the measurement for the plate radiating into air from the results for the measurement with the porous layer. This procedure will result in a slight underestimate of the radiation damping induced by the porous layer as air radiation from both sides of the plate has been subtracted from the porous data. However, because radiation into air is so weak below critical frequency, the effect will be insignificant. The radiation efficiency obtained from the damping measurements is also plotted on Figure 2 and shows good agreement with the predicted data.

5 - DISCUSSION AND CONCLUSIONS

This paper has presented a relatively simple expression for predicting the radiation efficiency of a plate bounded by a porous medium. The form of solution indicates that unlike air, where edge radiation dominates below critical frequency, surface radiation is important both above and below critical frequency for plates bounded by porous media. This suggests that an alternative method for tackling the problem would be to examine radiation from an infinite plate into a porous medium.

Predictions obtained using the model indicate that thin plates radiating into porous media are subject to relatively high levels of damping below critical frequency. This represents the transmission of acoustic energy from the bending wave field on the plate, to the acoustic field in the porous medium, where it is rapidly dissipated by viscous and thermal mechanisms. The assumption of a semi-infinite layer of porous material will probably be relatively accurate for plates radiating into thick porous layers or layers that have a high flow resistivity. In both cases any wave reflected from the free surface of the porous layer would be heavily attenuated and unlikely to influence the plate response. Under such circumstances, the model provides a means of predicting the correct structural damping for linings and double walls. This would make it possible to accurately predict structural sound transmission in systems where linings or the leaves of double walls are coupled to adjoining structural components.

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