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Sound radiation from a perforated panel set in a baffle with a different perforation ratio

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ABSTRACT

A finite flexible perforated panel set in a differently perforated rigid baffle is considered. The radiation efficiency from such a panel is derived using a 2-D wavenumber domain formulation. This generalization is later used to represent a more practical case of a perforated panel fixed in an unperforated baffle. The perforations are in the form of an array of uniformly distributed circular holes. A complex impedance model for the holes available in the literature is used. An averaged fluid particle velocity is derived using the continuity equation and the surface pressure is derived using an appropriate momentum equation. The discontinuity in the perforate impedance (due to different hole dimensions or perforation ratio) at the panel–baffle interface is carefully taken into account. It is found that there exists a 'coupling' of different wavenumbers of the spatially mean fluid particle velocity field. The change in the resonance frequencies and the modeshapes of the panel due to the perforations is taken into account using the Receptance method. Analytical expressions for the radiated power and radiation efficiency are derived in an integral form and numerical results are presented. Several comparisons are made to understand the radiation efficiency curves. Since both the resistive and reactive components of the hole impedance are taken into account, the model is directly applicable to micro-perforated panels also.

1. Introduction

Perforated panels are widely used as sound absorbers or as replacements to noisy panels. In both the applications, the perforated panel is treated as an equivalent impedance model. Usually, the perforated panels are mounted on a baffle which is both unperforated and rigid in construction. The objective of this theoretical study is to understand the radiation efficiency of a perforated panel set in an unperforated rigid baffle.

Maa [1] developed a model for a single hole and used it to represent a perforated absorptive panel. The micro-perforated panel considered was rigid and of infinite extent. The effect of flexibility of the perforated panel was taken into account by Takahashi and Tanaka [2]. They studied the acoustic coupling of perforated plates and plates of porous elastic materials by introducing a spatially mean velocity field over the plate surface which satisfies the flow continuity. They investigated both the transmission and the radiation of sound from perforated plates. Sound radiation from a plate with absorptive backing

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was studied by Toyoda and Takahashi [3]. However, in both the above studies, the plate considered was of infinite extent and no modification in the inertial or the elastic characteristics of the panel due to perforations was accounted for.

Radiation efficiency of a baffled perforated rigid strip piston was studied by Fahy and Thompson [4]. The baffle and the piston were differently perforated. Importantly, this resulted in a coupling between the various wavenumbers. Putra and Thompson [5] developed a prediction model to quantify the sound radiation from an unbaffled perforated plate. The article also explained the model of Fahy and Thompson [4] for a perforated flexible panel embedded in a similarly perforated baffle. As the paper focused on the hole diameter of the order of several millimeters, the viscous effect was ignored and the perforate impedance was purely reactive (inertial). Their flexible panel and the baffle were similarly perforated reducing the computational cost. They also did not account for the inertial and stiffness change in the panel due to the perforations.

O'Donnel [6] derived the effective elastic constants for perforated plates with square and triangular array of holes based on experiments and compared it with the available theoretical results [7]. An analytical expression for the effective bending stiffness of perforated plates with circular holes was proposed by Soler and Hill [8]. It was found that the effective bending stiffness was a function of the hole array parameters and the thickness of the plate. The results were compared with those reported earlier. Forskitt et al. [9] used the Finite Element technique to estimate Young's modulus, Poisson's ratio and the stress concentration factor for the perforated plates with elliptical holes. Bergemeister and Hansen [10] deduced a simple cubic function to determine the effective resonance frequency ratio of perforated panels.

In this paper, sound radiation from a finite 2-D perforated flexible panel fixed in a baffle with simply supported boundary conditions is studied in the wavenumber domain. The perforation ratio and/or the hole size in the panel and the baffle are chosen arbitrarily. An expression for the panel radiation efficiency is analytically derived and computed for various values of perforation ratios. Several comparisons are made to understand the radiation mechanism. This work extends the studies by Fahy and Thompson [4] and Putra and Thompson [5] by considering a flexible 2-D perforated panel in an unperforated baffle. Here, the effect of the perforations on the panel natural frequencies is also accounted for using the Receptance method. Also, as the hole impedance takes into account the resistive and the reactive components, it can be directly applied to micro-perforated panels as well.

Following the introduction section, in Section 2, an expression for the radiated pressure field is derived in terms of a locally averaged fluid particle velocity which satisfies the continuity equation. In Section 3, the perforate impedance of the panel is defined and used to obtain the momentum equation in terms of the radiated pressure field and the locally averaged fluid particle velocity. In Section 4, this averaged fluid velocity is transformed into the wavenumber domain. In Section 5, the sound power radiated from a perforated panel set in a similarly perforated baffle is studied and compared with the results available in the literature. Here, the radiated power is obtained using the unperforated panel modes. However, the perforations alter the inertial and stiffness properties of the panel. In Section 6, the Receptance method is used to obtain the modified resonant frequencies and modeshapes of the perforated panel. An integral expression for the radiation efficiency for a point harmonic excitation is derived and results are discussed in detail. Curves for radiation efficiency averaged over all the forcing locations are also presented. A few conclusions are drawn in Section 7.

2. Radiated pressure on a perforated panel surface set in a baffle

Consider a finite thin elastic rectangular perforated panel ($-a/2 \le x \le a/2$, $-b/2 \le y \le b/2$) lying in the plane $z=0$, set in an infinite rigid baffle with simply supported boundary conditions (see Fig. 1). The partition separates the fluid (air) into two regions of characteristic acoustic impedance $\rho_0 c$. Perforations are of a circular profile and have a diameter much less than the wavelength of the incident acoustic field. The panel is excited by a point harmonic force of magnitude F at an angular frequency ω. The panel vibration creates a pressure difference across its plane. On the side $z<0$, the total pressure p_1 is given by [11]

$$p_1(x,y,z,t) = p^-(x,y,z,t). \tag{1}$$

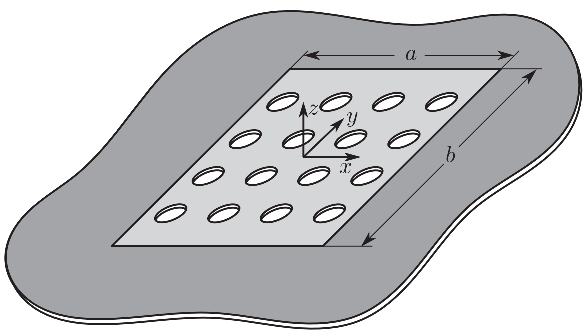

Fig. 1. Schematic of a perforated panel set in an unperforated baffle.