

Computational investigation of microperforated materials: end corrections, thermal effects and fluid-structure interaction

J. Stuart Bolton¹ and Thomas Herdtle²

¹Ray W. Herrick Laboratories, School of Mechanical Engineering, 177 S. Russell Street, Purdue University, West Lafayette IN 47907-2099, USA

²3M Corporate R & D, SEMS, MSPD, Predictive Engineering & Analysis
3M Center, 235-3F-08, St. Paul, MN 55144, USA

1 Introduction

The concept of microperforated noise control treatments was introduced by Maa 1975; in that theory, the transfer impedance of the microperforated layer was calculated based on oscillatory viscous flow within a small cylinder combined with resistive and reactive end corrections (see Ref. [1] for a comprehensive literature review related to microperforated materials). Initially, microperforated materials were the subject of mostly academic study since practical implementations were rare owing to the cost of manufacturing the materials with acceptable accuracy. However, recently, new manufacturing procedures have dramatically lowered the cost of these materials, and perhaps as a result, there has been renewed interest in studying their properties. Since 1975, Maa's original theory has been widely used to predict the performance of microperforated materials. However, in principal, that theory can only be used to describe cylindrical perforation, while in practice, perforations are rarely cylindrical. In addition, there have been questions about the dependence of end corrections on frequency, and on the effect of coupling between the motion of the fluid in the perforations and the solid sheet in which they are formed. Additionally, in his original paper, Maa drew a distinction between the dissipative properties of thermally conducting and adiabatic materials. The latter topic, in particular, has not been considered by any investigators since the idea was introduced. The purpose of our presentation is to introduce the numerical tools that can be used to address the open questions mentioned above, and to highlight important results obtained by using those tools.

2 Approach

Initially, this work involved the use of a CFD code to model arbitrary hole shapes [2]. A single perforation and inlet and outlet regions were modelled, and were assumed to represent a spatially periodic arrangement of perforations. Owing to the small size of the perforation, flow through the hole was assumed to be incompressible, which reduces the computational demand entailed by this approach. A finite-length, broadband velocity input was applied to the system in the time domain, and the subsequent motion of the fluid was calculated, up to the point that the fluid motion stopped. At the same time, the pressure upstream and downstream of the perforation was sensed, and then Fourier transformed. That information, along with the Fourier transform of the input velocity, allowed the transfer impedance of the microperforated treatment to be calculated. This approach has been used to study both cylindrical [2] and tapered perforations [1], and can be easily extended to accommodate arbitrary perforation geometries.

To study thermal effects and the influence of fluid-structure interaction, a different approach has been adopted [3]. In this case, finite element calculations based on the linearized Navier-Stokes equation along with the corresponding energy equation have been performed. Once again, a single perforation and the up- and downstream fluid regions were modelled. When considering fluid-structure interaction, the solid component of the microperforated sheet was modelled using three-dimensional elastic elements.

3 Principal Results

The main outcome of the initial work based on incompressible CFD was that the resistive end correction results from shearing within the fluid exterior to the perforation rather than from shearing at the solid surface surrounding the perforation, as was suggested by Maa. Further, it was shown that the magnitude of the resistive end correction is essentially independent of frequency rather than being proportional to $f^{1/2}$ as was previously thought (i.e., the resistive end correction does not vanish at 0 Hz). Thus, standard theories of microperforated materials need to be revised in this respect.

Secondly, the finite element calculations based on the linearized Navier-Stokes equation along with the energy equation, have demonstrated that the effect of heat conduction is generally very small compared to viscous dissipation, although this effect increases with frequency and so may be significant under some circumstance. Further, it has been shown that the thermal dissipation originates at the planar surfaces of the microperforated material rather than within the perforations themselves, as originally suggested by Maa. For essentially rigid microperforated materials, the thermal dissipation occurs on the incident side of the panel, while for flexible panels, thermal dissipation may occur on both faces of the panel.

Finally, it has also been demonstrated by using the fluid-structure interaction models that the transfer impedance of lightweight, and hence flexible, microperforated panels can be accurately calculated as the simple parallel addition of the impedance of an impervious limp film, and a rigid microperforated material. That is, solution of the fully coupled problem is not, in general necessary. This simplicity results from the large disparity of the fluid velocity within the perforations and the velocity of the surrounding solid; that disparity itself results from the relatively small surface porosity of typical microperforated systems.

References

- [1] T. Herdtle, J.S. Bolton, N.N. Kim, J.H. Alexander and R.W. Gerdes, "Transfer impedance of microperforated materials with tapered holes," *Journal of the Acoustical Society of America*, Vol. 134(6), Pt. 2, 11 pages, 2013. DOI: 10.1121/1.4824968.
- [2] J. S. Bolton and N. Kim, "Use of CFD to calculate the dynamic resistive end correction for microperforated materials," *Acoustics Australia*, Vol. 38, issue 3, 134-139, 2010.
- [3] Thomas Herdtle and J. Stuart Bolton, "Effect of Thermal Losses and Fluid-Structure Interaction on the Transfer Impedance of Microperforated Films," *Proceedings of Noise-Con 2014*, Fort Lauderdale FL, 12 pages, 2014.