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# Sound absorption of a porous material with a perforated facing at high sound pressure levels

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ABSTRACT

A semi-empirical model is proposed to predict the sound absorption of an acoustical unit consisting of a rigid-porous material layer with a perforated facing under the normal incidence at high sound pressure levels (SPLs) of pure tones. The nonlinearity of the perforated facing and the porous material, and the interference between them are considered in the model. The sound absorptive performance of the acoustical unit is tested at different incident SPLs and in three typical configurations: 1) when the perforated panel (PP) directly contacts with the porous layer, 2) when the PP is separated from the porous layer by an air gap and 3) when an air cavity is set between the porous material and the hard backing wall. The test results agree well with the corresponding theoretical predictions. Moreover, the results show that the interference effect is correlated to the width of the air gap between the PP and the porous layer, which alters not only the linear acoustic impedance but also the nonlinear acoustic impedance of the unit and hence its sound absorptive properties.



## 1. Introduction

Traditional perforated panel resonator has received a lot of attention in the control of noise with high sound intensity in the early stage of development, mainly because it has simple configuration and is not readily to be polluted. It has been used in a number of environments with high SPL, such as the acoustic liner of aero-engine. In recent years, researchers [1] also considered the application of micro-perforated panel in the interior of launcher fairings to reduce the internal acoustic load with high intensity. Further studies have been published on the acoustic characteristics and sound absorptive mechanism of the PP and the acoustic liner consisting of a PP and honeycombs under high SPL [2–9]. These results indicate that the sound absorptive properties of a PP depend on the incident SPL, i.e. exhibiting nonlinear sound absorption characteristics. Different from viscous dissipation under low SPL, the sound absorption mechanism under high-amplitude acoustic excitation is mainly dissipation in the jet formed at the exit and via the vortex shedding at the sharp edge of orifice [2,4,6,8,9]. It should be pointed out that the effective band of high sound absorption of a perforated plate is normally limited in the lower frequency range and high sound absorption is difficult to realize in the middle-to-high frequency range, while many intense noise sources in practice contain not only pure tones of middle-to-high frequencies, but also broadband components, such as the noise at the inlet of aircraft engine [10]. Accordingly, this study mainly focuses on the sound absorption of an absorber in the middle-to-high frequency range.

Excellent performance such as wide band and high sound absorption in the middle-to-high frequency range can be readily realized by proper design and selection of porous material, which has been widely used in the field of noise control. The linear acoustic model of porous materials is relatively sophisticated, and a few studies have been conducted on the nonlinear

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acoustic characteristics of porous materials [11–22]. Among these studies, Wilson et al. [14] proposed a corrected form of the equivalent complex density of material by using the static flow resistance relation of Forchheimer's law [23], and pointed out that the Forchheimer-type nonlinearity might be the dominant type of nonlinearity for the propagation of high-amplitude acoustic waves in porous media. McIntosh and Lambert [15,16] studied the effects of viscosity and thermal conduction within porous material under high SPL and pointed out that the nonlinear effect of viscosity is significant, while the nonlinear thermal effect is not. Aurégan and Pachebat [17] measured the flow resistivity elaborately and found two types of seepage velocity regions; after comparing an equivalent fluid model with acoustic measurements for high-level sound propagation in rigidly framed porous media, they pointed out that the increase in flow resistivity describes the main nonlinear effect. Umnova and Attenborough et al. proposed models to predict reflection coefficient of single-layer [18] and multi-layer [19] porous material backed by hard wall under high SPL; in their models, the static flow resistivity in equivalent fluid model was directly replaced with the resistivity which is linear with airflow velocity, i.e. Forchheimer's correction. Peng et al. [20,21] used the linearization method and finite difference method to solve the particle velocity inside the porous layer with rigid frame and finite thickness under high SPL and further predicted the nonlinear sound absorptive properties of the layer. Zhang et al. [22] used the 4th-order Runge-Kutta method to solve the Ricatti equation for the acoustic admittance of porous material under high SPL and then predicted the sound absorption.

In many practical applications, a porous layer usually need to be covered by a perforated facing (i.e. a hard perforated panel) to protect the material and improve the surface stiffness of the structure. There have been a number of studies on the characteristics of this type of sound absorptive structure under linear conditions [24–29], but the sound absorption properties under high SPL are less studied because both the PP and the porous material display nonlinear characteristics and it is more complicated to construct a theoretical model. Tayong et al. [30] predicted the sound absorption of a porous layer covered with a micro-perforated panel under high sound excitation using an approach based on the equivalent fluid method. In their studies, the transfer matrix method was adopted for the coupling between the micro-perforated panel and the porous layer, and the flow resistivity of each layer was corrected with the Forchheimer's law. However, it should be pointed out that when the acoustic nonlinearity inside a porous material is considered, its characteristic impedance and propagation constant are no longer irrelevant to the local particle velocity; moreover, the amplitude of the particle velocity in a porous material with finite thickness varies in the direction of propagation. Hence the transmission line method or transfer matrix method used in linear problems cannot be applied under the nonlinear condition [14,19]. Although the results predicted by Tayong agreed with the experimental results, the details of dealing with the nonlinearity of porous material using the transfer matrix method were not described; meanwhile, the perforation ratio of the micro-perforated panel in their experiment is very low (less than 2%), so the nonlinearity of the PP may be dominant, and the nonlinearity of porous layer could not be significantly reflected in the predicted results. In addition, Tayong only put the nonlinear static flow resistivity of the PP and the porous layer into respective equivalent fluid models, without considering the interference effect, i.e. the jet that may be formed at the end of the perforations will interfere with the porous layer, thus affecting the nonlinear absorption characteristics of the whole unit.

This study investigates the sound absorption characteristics of an acoustical unit consisting of a porous material with rigid frame covered by a perforated facing under high sound pressure excitation, with the aim of constructing a simple model that can predict the nonlinear absorptive properties of such an acoustical unit. The nonlinearity of the PP and the porous material, and the nonlinear effect brought by the interference between them are considered in the model. The model is described in Section 2, and the experiments conducted to validate the model are introduced in Section 3, including the related experimental setups and the comparison of experimental results with theoretical predictions. The influences of the air gap between the porous layer and the PP are discussed. Finally, conclusions are drawn in Section 4.

## 2. Model of the nonlinear absorption of the acoustical unit

The sound absorptive unit consisting of a porous layer covered with a PP is illustrated in Fig. 1. At the incidence of sound with high SPL, the characteristic impedance and propagation constant of the porous material may not be independent on the acoustic particle velocity because of the nonlinear effect, so neither the impedance transmission line method nor the transfer matrix method is applicable. Meanwhile, when the SPL is high enough, previous study [2] showed that the impedance of a PP may be altered by the nonlinear effect associated with jet and vortex shedding at the outlet of orifice in the PP. In addition, the porous material located behind the PP could hinder the free development of jet at the outlet of orifice, so the flow pattern at the end of the PP is bound to be significantly different from the case without porous material. It may be further conjectured that the jet formed by the large particle velocity at the end of the PP may interfere with the porous layer under certain conditions, and consequently alter the acoustic impedance of the whole structure.

A method of predicting the nonlinear sound absorptive performance of this acoustical unit is proposed as follows. To avoid the difficulty of directly solving the surface acoustic impedance of the whole acoustical unit under a given incident SPL, a calculation procedure from the inner to the outer is adopted. The main solution steps are as follows:

Step 1 Determine the particle velocity $u_{\mathrm{ps}}$ under a given sound pressure $p_{\mathrm{ps}}$ at the front surface of the porous layer.