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# Noise control of dipole source by using micro-perforated panel housing

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ABSTRACT

Mitigating low-frequency noise in a small ducted fan system such as hairdryer is still a technical challenge. Traditional duct lining with porous materials work ineffectively due to the limitation of its thickness and length of small domestic product with ducted fans. This study presents a passive approach to directly suppress the sound radiation from the fan housed by a short microperforated panel covered with a shallow cavity backing. The noise suppression is achieved by the sound cancellation between sound fields from a fan of a dipole nature and sound radiation from a vibrating panel via vibro-acoustic coupling and by sound absorption in micro-perforations to widen the stopband. A two-dimensional theoretical model, capable of dealing with strong coupling among the vibrating micro-perforated panel, sound radiation from the dipole source, sound fields inside the cavity and the duct is developed. Through modal analysis, it is found that the even modes of the panel vibration are very important to cancel the sound radiation from the dipole source. Experimental validation is conducted with a loudspeaker to simulate the dipole source, and good agreement between the predicted and measured insertion loss (IL) is achieved.


## 1. Introduction

Fan installed in duct with a low aspect ratio can often be found in domestic and industrial applications, for example, the driving fan in ventilation system or the cooling fan in computers or turbo-fans in aircrafts. When the fan operates at low rotational speed such as in domestic product, the low frequency noise component is normally dominant and it is very annoying. The ducted fan noise can be mitigated in the propagating path or directly on the noise source itself. For the first approach such as in the ductwork of central air conditioning systems, porous materials lining the duct wall [1,2] have been frequently adopted to absorb the noise, but it only works well at high frequencies and the fibrous materials may cause environmental problems such as accumulation of dust due to its low durability. Besides, the concept of expansion chamber [3,4] or multiple chambers with perforated tubes [5] are commonly implemented in exhaust system in vehicles. It can abate the noise at a desirable frequency range but it will be very bulky for controlling the low frequency region. In addition, there is also significant pressure loss in a flow duct due to the sudden expansion and blockage of flow attributed to the internal tubes.

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Aiming to design a broadband passive noise control device that works effectively in the low-to-medium frequency range with negligible pressure drop, Huang introduced the concept of a drum-like silencer [6] which is formed by an expansion chamber with light membranes covering the side-branch cavities under fairly high tension. To ease the installing process without any machine for exerting force, the membrane has been replaced by a plate [7] and non-uniform plate [8]. In order to further improve the silencing performance, the plate with perforations [9] which is the so-called micro-perforated panel (MPP) has been adopted. The MPP was proposed by Maa [10–12] and is widely used in different areas such as room acoustics [13], barrier design [14] and duct mufflers [9,15–18]. A typical MPP absorber takes the form of a MPP in front of backing cavity that can only provide efficient sound absorption within a rather narrow frequency band. The vibro-acoustic behavior of thin and flexible MPPs has been studied by Bravo [19,20]. To broaden the effective frequency band, it is possible to reduce the size of perforations [12] or adopt MPP with an irregular cavity [21] which was investigated theoretically and validated by experiment with normal incidence of sound wave. Subsequently, a wider absorption bandwidth was achieved due to the increased vibro-acoustic coupling between the cavity and air motion in the MPP. In order to obtain broader absorption band, recently some researchers introduce a device which consists of a micro-perforated panel (MPP) backing with cavity array [15,22]. Compared with single MPP absorber, the device can provide significantly better sound absorption performance over a broad frequency band. This is not only attributed to the combination of different resonances of MPP with each cavity, but also the frequency shifts due to inter-resonator interactions [22].

Such parallel-arranged MPP absorber array was recently examined at oblique incidence and in diffuse field. The sound absorption of this MPP absorber array with periodic arrangement can be maintained in a wide frequency range in diffuse field [23]. For the theoretical study of the sound absorption of a finite flexible MPP backed by an air cavity, the team of Lee developed a solution procedure based on the modal analysis approach [24]. The theoretical model established takes into account the full coupling between the sound wave in the cavity and the panel vibration. It assumes a rectangular cavity and the exterior acoustic loading on the MPP surface is simplified as a uniformly distributed sound pressure. However, when vibro-acoustic coupling between the light MPP and cavity with irregular shape is investigated, the exterior acoustic loading is non-uniform due to the radiation pressure from the MPP. In addition, the acoustic mode of the cavity in irregular shape is needed to be found by numerical method instead of directly adopting this modal analysis approach [21]. Besides, many researchers considered the uniform incident pressure when they studied the performance of MPP absorbers [21,24,25] and then their theoretical models are limited to predicting the performance of MPP backed with a cavity that is far away from the sound source.

Practically, due to the limitation of space or duct length, the silencer is frequently installed close to the sound source, such as a fan. As a result, the incident pressure excitation on the silencer surface is non-uniform. In addition, the sound wave from a real-life fan blade can be modeled as a dipole source [3]. In this regard, the team of Liu recently introduced a passive method to suppress the subsonic axial fan noise of dipole nature by membrane housing through the interaction between membrane vibration and the sound fields in the duct and cavities via vibro-acoustic coupling, undergoing sound cancellation [26]. The proposed noise control device with tensioned membrane can achieve 10 dB of IL with a stopband wider than an octave, but the geometry is not compact and there is a need for installing a special machine on the duct to apply tensile force on the membrane. To solve both problems, the membrane is replaced by a micro-perforated plate which can undergo sound cancellation with the sound radiation from the fan of dipole nature and supplemented with sound absorption to widen the stopband in a more compact geometry. Therefore the objectives of the current study are (1) To establish a theoretical model which allows a thorough analysis on the vibro-acoustic coupling among the MPP vibration, the non-uniform incident pressure excitation from a dipole sound source, the sound fields in the duct, and the acoustic waves inside the cavity. (2) To understand the physics behind the achievement of a wide stopband by the combination of sound cancellation and sound absorption due to the coupling between the MPP and dipole source. It is expected that the MPP housing device will outperform the device of tensioned membrane with side-branch cavities which only involves sound cancellation mechanism. (3) To further investigate the performance of the MPP housing device on sound sources of different nature (i.e., monopole and dipole). This is because the real-life fan is not a pure dipole, and the design of the MPP housing device will be different for controlling the combination of monopole and dipole source.

In what follows, Section 2 outlines the analytical model for a cavity-backed MPP with dipole sound waves excitation at the center of the MPP housing device. Section 3 focuses on the numerical validation, optimization process, and understandings of the mechanism of noise suppression by using MPP housing. The experimental validation of the theoretical model is described in Section 4 and the main conclusions is given in Section 6.

## 2. Theoretical modeling

A two-dimensional model of a cavity-backed MPP housing a dipole sound source is shown in Fig. 1. It consists of a rectangular duct of height $h^*$, and two rigid side-branch cavities of length $L_c{}^*$ and depth $h_c{}^*$. The cavities are covered by two pieces of MPP which are equal to the cavity length with fixed boundary support. A dipole source which is applied to simulate fan noise is located at the mid-point of the MPP; $x^*=0.5L^*$, $y^*=0.5h^*$. For convenience, all variables are non-