Applied Acoustics 79 (2014) 47–57

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Optimising the absorption and transmission properties of aircraft microperforated panels

Teresa Bravo [a,*], Cédric Maury [b], Cédric Pinhède [b]

[a] Centro de Acústica Aplicada y Evaluación No Destructiva (CAEND), Consejo Superior de Investigaciones Científicas (CSIC), Serrano 144, 28006 Madrid, Spain
[b] Laboratoire de Mécanique et d'Acoustique (LMA), UPR-CNRS 7051, 31 chemin Joseph Aiguier, 13402 Marseille Cedex 20, France

ARTICLE INFO

Article history:
Received 27 August 2013
Received in revised form 4 December 2013
Accepted 5 December 2013

Keywords:
Aircraft noise
Micro-perforated partitions
Absorption and transmission properties

ABSTRACT

A method for evaluating the absorption and transmission performances of multi-layer micro-perforated structures whose facings are excited by different noise sources is described here. It is applied to determine if the acoustical performances of a number of Micro-Perforated Panels (MPPs), optimised both in absorption and transmission, exceed those of typical aircraft panels undergoing internal and external acoustic excitations. A fully-coupled modal formulation is presented that accounts for the effects of the sub-structure volumetric resonances on the acoustical properties of the partitions. It is validated against full-scale measurements performed with a pressure–velocity probe and a laser vibrometer to estimate the absorption and transmission coefficients of single- and double-layer micro-perforated partitions. The model is used to optimise the sound power dissipated by three layouts obtained from a typical aircraft partition by micro-perforating the trim panel (MPP–Porous–Panel), removing the fibreglass material (MPP–Cavity–Panel) and adding a second MPP inside the separating cavity (MPP–MPP–Panel). It is concluded that the MPP–Porous–Panel and MPP–MPP–Panel layouts provide excess interior noise reduction above 1.8 kHz and 1.2 kHz respectively, whereas the MPP–Cavity–Panel is not acoustically more efficient than a typical aircraft panel.

1. Introduction

Noise control has become a subject of major concern that has to be considered from the design stage by aircraft, automotive and industrial manufacturers. The mechanical systems are becoming lighter and stiffer and so tend to have poorer acoustical performances with reduced soundproof properties and enhanced radiation efficiency over a broad bandwidth due to lower critical frequencies. In particular, the introduction of mass-saving composite elements in the design of fuselage sidewalls adds higher levels of interior noise inside the cabin of commercial aircraft during cruise conditions, affecting the comfort of the passengers and threatening the integrity of the embarked avionic systems. Most studies have been concerned with the transmission of the flow-induced noise due to the Turbulent Boundary Layer (TBL) through aircraft fuselage panels [1,2], but the noise radiated within the cabin by the operation of air-conditioning systems and auxiliary equipments also affects the interior noise levels, especially for small-sized aircrafts with tight design.

A typical aircraft fuselage shell is composed of a network of circumferential frames and longitudinal stringers covered by a thin aluminium skin. The interior part of the skin is in contact with insulation bags that are inwardly covered with plastic trim panels. Control techniques for the flow-induced noise have considered for instance tuneable vibration absorbers to reduce vibration levels and interior noise at discrete frequencies in the low frequency range [3]. A successful passive insulation of the flow-induced noise such as the TBL or the jet noise requires dissipative materials whose weight and volume would be a major limitation to achieve good performances at low frequencies in this application. Active techniques have then been investigated using acoustic sources acting in the cabin enclosure and located in the gap within the double-partition sidewall in order to block the airborne transmission paths [4]. The vibrations of the radiating panel have been modified by means of Active Structural Acoustic Control (ASAC) techniques using vibrational control sources [5]. Combination of both active and passive materials, such as piezoelectric transducers to actively control the low frequency noise components and acoustic foams to damp higher frequencies, have also been considered [6]. However, such multi-input–multi-output control schemes seem difficult to implement in practice for a typical aircraft fuselage which consist of several hundreds of such panels, unless a limited number of localised transmission paths are well identified, and also because of the difficulty to obtain suitable time-advanced reference signals related to broadband TBL excitation.

* Corresponding author. Tel.: +34 91 5618806; fax: +34 91 4117856.
E-mail address: teresa.bravo@caend.upm-csic.es (T. Bravo).

0003-682X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apacoust.2013.12.009

Insulating partitions composed of Micro-Perforated Panels (MPPs) are promising solutions in order to achieve noise reduction in difficult environments [7,8], that also meet mass-saving, compactness [9] and ecological constraints. These devices are resonance absorbers composed of a panel with sub-millimetric holes backed by a cavity. Optimal performances can be achieved by a proper selection of the panel thickness, of the size and shape of the perforations, of the perforation ratio (or porosity) and of the cavity depth. The goals are to increase the viscous losses through the apertures that dissipate the acoustic energy around the Helmholtz resonance, and to obtain high absorption values over a broad bandwidth. Since the initial works by Maa [10,11], it has been stated that MPPs aim at replacing or completing the passive noise control techniques that mainly use porous or fibrous materials, although they are still only used in a limited number of cases.

Studies carried out in laboratory conditions have usually considered MPPs as rigid structures of infinite extent, neglecting the influence of vibrating effects, less noticeable for small thick samples, but more important when considering large partitions as in architectural applications [12]. Also, the absorption coefficient of the MPP control device has often been considered as the only indicator of its acoustic performance since the thick panel backing the partition is supposed to be rigid and not to transmit sound. Some recent works have started to consider both absorption and insulation effects and have found experimental evidence of the influence of thin MPP vibrations on their acoustical performances [13–15]. In particular, the authors have analysed under which conditions the vibrating response of thin micro-perforated facings can affect the absorbing and transmitting properties of finite-sized MPP partitions [16]. A fully-coupled modal approach has been developed and analytical approximations have been derived from coupled-mode analysis for the Helmholtz-type and structural resonances of a single layer MPP structure together with typical in-phase or out-of-phase relationships on the air-frame relative velocity at these resonances.

The present work provides a theoretical and experimental study of sound absorption and transmission properties through multiple-layer MPPs of relevance to aircraft interior noise problems. Although MPP-based control devices should be suitable for this application due to their small-size and mass-saving characteristics, no direct comparison has been found between the basic performance of a typical aircraft fuselage panel and those obtained from a multi-layer structure composed of MPPs. We will carry out this comparison in several steps. We will first focus on the classical absorption properties of thin MPP resonance absorbers by substituting the interior trim panel by a micro-perforated structure optimised to reduce the external transmitted noise as well as the noise generated inside the cabin, both without and with the insulating layer of porous material in order to analyse each effect separately. In particular, we will evaluate the differences in absorption and transmission in relation with a nominal configuration. We will then substitute the insulating material in the inner cavity by another MPP so that, in combination with the trim MPP, it will form a double-layer micro-perforated partition that will be optimised. Although overframe blankets are required to ensure thermal insulation, the optimised double-layer MPP layout already provides a fair estimate of the absorption and TL performances that can be achieved in the low frequency range and a lower bound on the acoustical performances at higher frequencies.

The paper is organised as follows. Section 2 presents a modal formulation for predicting the structural-acoustic response of multi-layer MPP partitions, eventually filled with a porous material of low frame stiffness, and under general conservative boundary conditions. Experimental verification of the model is carried out in Section 3 for two physical configurations proposed as alternative noise control devices: a single-layer MPP–Porous–Panel partition and a double-layer MPP–MPP–Panel partition. Once the analytical formulation has been validated, a comparison between the absorption and transmission performances of typical aircraft fuselage panels and those modified using MPPs is presented in Section 4. The modified layouts are obtained from an optimisation procedure carried out to determine the physical parameters that best suit a given objective, whether the frequency-averaged cost function is set to be the absorption coefficient, the Transmission Loss (TL) or a combination of both. Conclusions and recommendations could be extracted from the results obtained with the analytical model for the design of MPP-based aircraft panels.

2. Analytical modal formulation for MPP partitions

The vibro-acoustic response of baffled multiple-layer MPP partitions, as the one shown in Fig. 1, is predicted using a modal formulation for the dynamics of the sub-systems involved. This approach leads to an analytical solution that enables parametric studies to be performed at a relatively low computational cost over the frequency range of interest. The general background for the modal formulation is the work developed by Dowell et al. [17] for the study of a coupled panel–cavity system. In this method, the panel deflections are expressed as a finite series of orthogonal functions corresponding to the structural modes, and the cavity pressure fields are expressed as a series of orthogonal acoustic modes of the rigid-walled cavities. The modal formulation is obtained by inserting these expansions into the variational form for the coupled dynamical equations of the sub-systems. This analytical model will not be described in full detail as it has been already developed for simpler MPP configurations [16]. However, the main equations governing the physics of the problem will be summarised and adapted to the typical aircraft partitions that have been tested in laboratory conditions.

2.1. Modal formulation

The MPP–Porous–Panel configuration is outlined first. We now need to include the airborne transmission and dissipation properties of the porous material situated between the panels. The main equations governing the dynamic of the systems are summarised next. The velocities for the MPP front panel, the solid back panel and the acoustic pressure inside the cavity are expressed as finite series of structural and acoustic modes. Assuming a time-dependence $e^{j\omega t}$, they read

$$v_{\mathrm{MPP,P}}(\mathbf{x};\omega) = j\omega \sum_{p=1}^{P_{\mathrm{MPP,P}}} q_{(\mathrm{MPP,P}),p}(\omega)\psi_{(\mathrm{MPP,P}),p}(\mathbf{x}) = j\omega \boldsymbol{\psi}^{\mathrm{T}}_{\mathrm{MPP,P}}\,\mathbf{q}_{\mathrm{MPP,P}}, \quad (1)$$

$$p(\mathbf{r};\omega) = -j\omega\rho_0 \sum_{q=0}^{Q_C-1} a_q(\omega)\varphi_q(\mathbf{r}) = -j\omega\rho_0 \boldsymbol{\Phi}^{\mathrm{T}}\mathbf{a}, \quad (2)$$

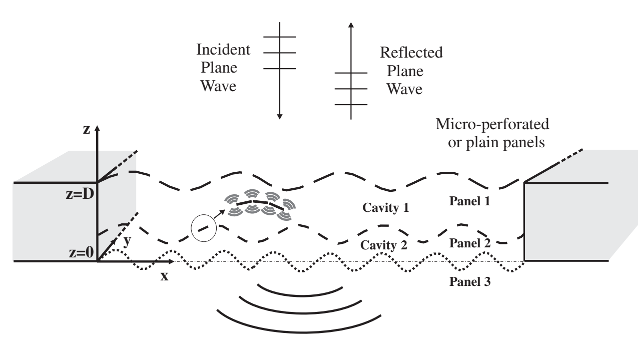

Fig. 1. Finite double-layer partition composed of flexible panels, eventually micro-perforated.