Journal of Sound and Vibration 424 (2018) 15–31

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Numerical study on non-locally reacting behavior of nacelle liners incorporating drainage slots

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ARTICLE INFO

Article history:
Received 2 September 2017
Received in revised form 2 February 2018
Accepted 6 March 2018

Keywords:
Acoustic liner
Drainage slot
High sound pressure level
Computational aeroacoustics

ABSTRACT

For acoustic liners used in current commercial nacelles, in order to prevent any liquid accumulating in the resonators, drainage slots are incorporated on the partition walls between closely packed cavities. Recently, an experimental study conducted by Busse-Gerstengarbe et al. shown that the cell interaction introduced by drainage slots causes an additional dissipation peak which increases with the size of the slot. However, the variation of damping process due to drainage slots is still not fully understood. Therefore, a numerical study based on computational aeroacoustic methods is carried out to investigate the mechanism of the changed attenuation characteristics due to drainage slots in presence of grazing incident sound waves with low or high intensities. Different slot configurations are designed based on the generic non-locally reacting liner model adopted in the experimental investigation. Both 2-D and 3-D numerical simulations of only slit resonators are carried out. Numerical results indicate that the extra peak is a result of a resonance excited in the second cavity at specific frequency. Under high sound pressure level incoming waves, the basic characteristics of the acoustic performance remain. However, vortex shedding transpires at the resonances around both the slits and the drainage slot. Vorticity contours show that the connection of two coupled cavities decreases the strength of vortex shedding around the basic Helmholtz resonance due to a higher energy reflection. Meanwhile, the cell interaction significantly increases the vorticity magnitude near the extra resonant frequency. Finally, a semi-empirical model is derived to predict the extra attenuation peak frequency.

1. Introduction

Acoustic liner is one of the foremost ways to prevent fan noise radiation to far field, which is successfully used in commercial aircraft engine nacelles. A commonly used type of acoustic liner in aero-engine application is a perforated plate or resistive meshes backed by a honeycomb cell structure and a solid backing sheet, which represents an array of Helmholtz resonators and generally is assumed to be locally reacting (Fig. 1). However, for an actual nacelle liner, the assumption of liners being locally reactive does not hold due to the presence of drainage slots or misalignment, as shown in Fig. 2, which incontrovertibly provide an undesired path for the sound waves propagating through the cavities parallel to the liner panel

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https://doi.org/10.1016/j.jsv.2018.03.005

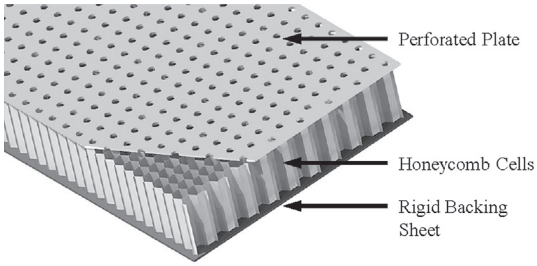

Fig. 1. Sketch of a locally reacting liner.

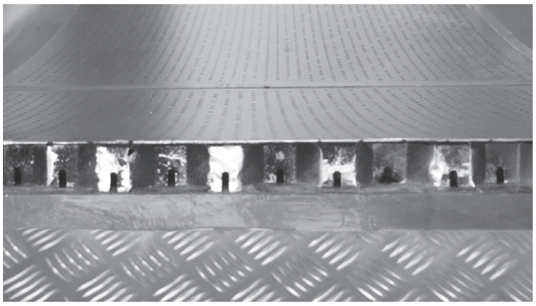

Fig. 2. Acoustic liners for a real aero-engine.

surface. In practice, the drainage slots can not be removed, since they allow the removal of water from the honeycomb cells. If the liquid is possible to build up in a resonator, two potential undesirable effects would be occur. Firstly, the accumulated water will alter the effective depth of the cavity. Therefore, the reactance of the cavity would be changed which ultimately gives a detrimental influence to the absorption performance at designed frequency. Secondly, when the temperature drops to minus, the structure of liners could be damaged by icing.

Zandbergen [1] first pointed out this problem and conducted insertion loss measurements of two test panels of resonators which shown that the liner-cell interaction caused a considerable shift in the frequency of maximum attenuation and the attenuation at some frequencies lower than resonance is halved by the drain holes. Tagg & Faulkner [2] developed an analytical procedure to optimize the acoustic attenuation of parallel coupled resonator. Measured data shown acoustic attenuation increased 5–6 dB compared to a single uncoupled resonator. Eaton [3] adopted a 3D finite element prediction technique combining with a coupled impedance procedure, which gave an empirical local impedance of the slots, to simulate cells with longitudinal and lateral slots. The numerical results compared well with experimental data and confirmed Zandbergen's conclusion. The investigation also indicated that the slots altered the corresponding cell-averaged reactances significantly. Murray et al. [4] performed a parametric study of drainage slots on single layer perforated and linear liners with and without grazing flow in the NLR Flow Duct Facility (FDF). Experimental data shown that the influence of slots is intricate depending on the geometry of slots, the facing sheet resistance, grazing flow, sound pressure level and source modal content. Busse-Gerstengarbe et al. [5] examined the impact of slots, which is caused by a condenser welding procedure during the production process, on the acoustic damping performance. A more broadband damping behavior was obtained by the resonator cell communication.

Recently, Busse-Gerstengarbe et al. [6,7] and Abdel Hay et al. [8] conducted experimental and numerical investigations on liners incorporating drainage slots. Linearized Euler equations are employed to solve the sound field of two linked cavities under normal incoming waves by a CAA solver TUBA3D. The experimental and numerical results indicated that an additional peak of dissipation occurs when two coupled cavities are connected by a slot. The slot size or the corresponding percent open area of the cell wall (POA_w) have a major influence on the dissipation spectrum. The frequency of additional maximum attenuation increases with the POA_w. Further more, an empirical impedance model for two coupled cavities was derived by combining the extended Helmholtz resonator model (EHR) [9] with an analytical model of the non-local impedance.

Based on the previous findings, it could be concluded that the non-locally reacting behavior has complex effects on the absorption characteristics of the equivalent locally reacting liner design. However, the resulting effects of these drainage slots are currently not taken into account during the acoustic liner design process. Therefore, a comprehensive understanding of the flow physics and dissipation mechanism of non-locally reacting liners is still pending, especially with regard to non-linear phenomena occurring for high intensity incident acoustic waves. Unfortunately, the small geometrical dimensions of the cavities lead to high computational expense for studying the fundamental flow physics in the resonator region as well as cause difficulties in experimental arrangement. Since 2000, direct numerical simulation (DNS) method has been successfully adopted to investigate the flow and sound fields of resonant liners [10–14]. By the use of DNS, the physical procedure could be reproduced in the simulation, which is critical for understanding the absorption mechanism of liners.