Journal of Sound and Vibration 333 (2014) 3585–3597

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Suppression of Helmholtz resonance using inside acoustic liner

Zhiliang Hong [a,b], Xiwen Dai [a], Nianfa Zhou [b], Xiaofeng Sun [a], Xiaodong Jing [a,*]

[a] School of Energy and Power Engineering, Beihang University, Beijing 100191, PR China
[b] Shenyang Liming Aero-Engine Group Co. Ltd., Shenyang 110043, PR China

ARTICLE INFO

Article history:
Received 25 July 2013
Received in revised form
8 February 2014
Accepted 23 February 2014
Handling Editor: L. Huang
Available online 29 April 2014

ABSTRACT

When a Helmholtz resonator is exposed to grazing flow, an unstable shear layer at the opening can cause the occurrence of acoustic resonance under appropriate conditions. In this paper, in order to suppress the flow-induced resonance, the effects of inside acoustic liners placed on the side wall or the bottom of a Helmholtz resonator are investigated. Based on the one-dimensional sound propagation theory, the time domain impedance model of a Helmholtz resonator with inside acoustic liner is derived, and then combined with a discrete vortex model the resonant behavior of the resonator under grazing flow is simulated. Besides, an experiment is conducted to validate the present model, showing significant reduction of the peak sound pressure level achieved by the use of the side-wall liners. And the simulation results match reasonably well with the experimental data. The present results reveal that the inside acoustic liner can not only absorb the resonant sound pressure, but also suppress the fluctuation motion of the shear layer over the opening of the resonator. In all, the impact of the acoustic liners is to dampen the instability of the flow-acoustic coupled system. This demonstrates that it is a convenient and effective method for suppressing Helmholtz resonance by using inside acoustic liner.

1. Introduction

In recent years, the noise pollution issue of civil aircrafts has attracted more and more attention. Aircraft noise is generated from many mechanisms related to various mechanical devices, among which noise radiated from the wheel well has been recognized as an important source during landing and takeoff. Under certain conditions, the shear layer that covers the opening of the wheel well gives rise to self-sustained oscillations, which immediately cause intense tone noise radiation and discomfort in the cabin [1,2]. Similarly, the tone noise from a car's sunroof could annoy the passengers when the car speed is within a certain range [3]. Besides, the flow-excited resonance can cause considerable vibrations in the surrounding mechanical structures [4]. All the practical situations mentioned above can be recognized as the Helmholtz resonance problem. Therefore plenty of work on acoustic resonance excited by grazing flow has been thoroughly motivated by the desire for noise suppression in Helmholtz resonator. For a detailed description of the suppression of Helmholtz resonance over the past few decades we can refer to the reviews of Lawson and Barakos [5], Williams [6], Colonius [7] and so on. In general, the current strategies to eliminate Helmholtz resonance can be classified into two kinds. One is the passive control method, which is usually achieved by an adjustment of the inherent characteristics of the shear layer through alteration of

* Corresponding author. Tel.: +86 10 82338085; fax: +86 10 82317408.
E-mail address: jingxd@buaa.edu.cn (X. Jing).

http://dx.doi.org/10.1016/j.jsv.2014.02.028
0022-460X

the configuration of the opening such as leading edge step, rounded corner and trailing edge ramp [8], or introducing devices like rods [9], spoilers, fences [10] and so on. The other strategy is the active control method, which mainly aims at disturbance of the shear layer through vortex generators, actuators, loudspeakers, mass injection slots and so forth [11,12].

Acoustic liners represent another kind of passive method that is most commonly used in flow ducts to control noise propagation. When applying to the Helmholtz resonator, the acoustic liners have the advantage of easy implementation and zero flow drag [13]. In the early 1990s, Parker [14] successfully used an acoustic liner for the first time to eliminate the acoustic resonance in three types of rigs, including a rectangular passage spanned by a single plate, an annular cascade and a single-stage axial-flow compressor rig. However, the optimal parameters of the acoustic liner were obtained through experiments and no comparison with the theoretical predictions was attempted. In the studies of Wilcox [15], Kim and Chokani [16] and Lai and Luo [13], a venting chamber beneath a porous screen was introduced to control the shallow cavity's tone noise at the resonant state. Acoustic oscillation was noticeably suppressed; the porosity at the bulkhead is found to be more effective than that at the cavity floor. The pressure distribution within the cavity was obtained by directly solving the Navier–Stokes equation, and the porous structure was evaluated using the linear form of Darcy Law. However, there is still a lack of basic understanding of the physical mechanisms underlying the behavior of an acoustic liner inside the Helmholtz resonator, especially for the problem regarding how the inside liner impedance affects the high-intensity sound field within the cavity and the flow-acoustic coupling at the resonator neck.

In this paper, we investigate the potential of an inside acoustic liner in the suppression of Helmholtz resonance. As shown in Fig. 1, two kinds of configurations of the Helmholtz resonator with an inside acoustic liner are considered; one is the liner on the side wall and the other is the liner at the bottom of the cavity, when the flow grazingly passes the up plane of the resonator. Although the mechanism of the flow-induced Helmholtz resonance has been widely explored, the accurate theoretical prediction of the sound pressure oscillation in the resonator is still a challenging issue. Recently, a numerical model based on the vortex–sound interaction has been developed by Dai et al. [17–19]. The basic idea of this model is to depict the unstable shear layer over the opening of the Helmholtz resonator by means of vortex dynamic simulation. A discrete vortex model (DVM) has been set up, which simulates the vortex shedding and the evolution of the vortex sheet when a rectangular orifice in a plate is subjected to one-side grazing flow. Then combining the DVM of the flow at the opening with a lumped element or one-dimensional sound propagation model for the Helmholtz resonator chamber through a dynamical equilibrium relation across the opening, a time-domain numerical model has been established to investigate the flow-induced sound with special attention paid to acoustic resonance.

However, the model mentioned above considers the Helmholtz resonance with a hard wall. In this paper, a time-domain impedance model of the Helmholtz resonator with an inside liner is developed to investigate the effect of acoustic liners. For simplification, we assume that the sound wave frequency is low and the cross sectional area of the resonator is sufficiently small to ensure that only plane waves can propagate along the depth direction. Based on the above hypothesis, a one-dimensional sound wave propagation model is used to obtain the frequency-domain impedance of resonators with the liner placed on the side wall or at the bottom, and then the time-domain impedance boundary condition (TDIBC) is constructed using the inverse Fourier transformation. When the TDIBC is combined into the sound–vortex interaction model based on the DVM, the status of the system can be numerically visualized, which includes both the time history of the sound pressure in the resonator chamber and the shear layer evolution process at the neck region.

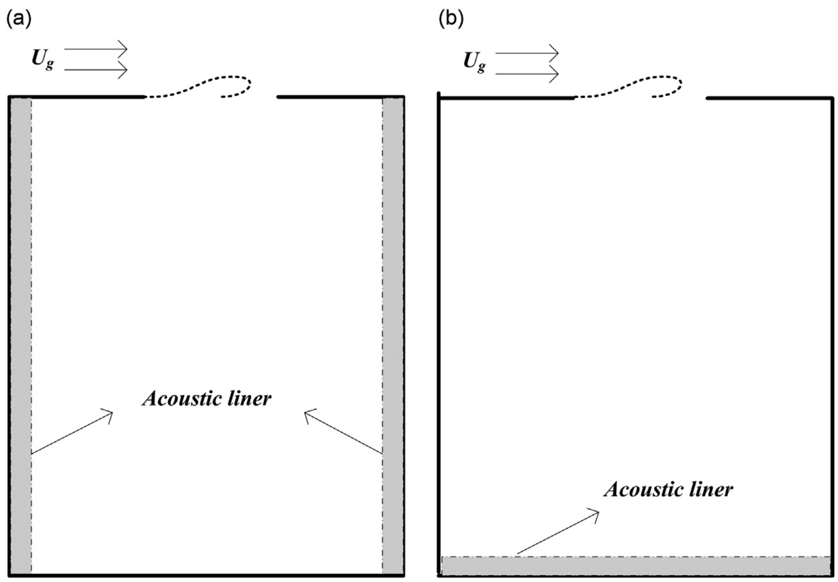

Fig. 1. Helmholtz resonators exposed to grazing flow with inside acoustic liner on the side wall and at the bottom, respectively. (a) Liner on the side wall and (b) liner at the bottom.