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Acoustic quasi-steady response of thin walled perforated liners with bias and grazing flows

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ABSTRACT

This paper considers the acoustic performance of a passive damper in which acoustic energy is absorbed by orifices located within a thin plate (i.e. a perforated liner). The perforated liner, which incorporates orifices of length to diameter ratios of ~0.2, is supplied with flow from a passage. This enables the liner to be subject to a flow that grazes the upstream side of each liner orifice. Flow can also pass through each orifice to create a bias flow. Hence the liner can be subjected to a range of grazing and bias flow combinations. Two types of liners were investigated which incorporated either simple plain or 'skewed' orifices. For the mean flow field, data is presented which shows that the mean discharge coefficient of each liner is determined by the grazing to bias flow velocity ratio. In addition, measurements of the unsteady flow field through each liner were also undertaken and mainly presented in terms of the measured admittance. For a given liner geometry, the admittance values were found to be comparable for a given Strouhal number (with the exception of the lowest bias to grazing flow velocity ratio tested) which has also been noted by other authors. The paper shows that this is consistent with the unsteady orifice flow being associated with variations in *both* the velocity and the area of the vena contracta downstream of each orifice. These same basic characteristics were observed for both of the liner geometries tested. This provides a relatively simple means of predicting the acoustic liner characteristics over the specified operating range.

1. Introduction

Acoustic dampers are used for the suppression of noise in a wide range of applications that include, for example, automotive exhaust mufflers and liners for aircraft engines. In the presence of reacting flows, dampers may also be used to suppress instabilities that can potentially arise due to unsteady heat release. Typically a passive damper consists of a multitude of orifices located within a thin plate (i.e. a perforated liner) with open area ratios that can vary significantly (e.g. up to 20%). To improve acoustic performance and/or ensure liner integrity (e.g. in hostile environments where hot gases dictate the need for liner cooling) flow may also be passed through the orifices to create a so called bias flow. In many practical engineering applications this bias flow is supplied from a passage, parallel to the liner, and a grazing flow is therefore created from which fluid can be drawn to pass through each orifice. Alternatively a grazing flow may also be present on the downstream side of the liner (i.e. into which the bias flow is passing). This paper considers the acoustic performance of a

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Nomenclature

A_{duct}	Area of bias passage
A_h	Area of orifice
A_{liner}	Area of liner
A_{vc}	Area of vena contracta
c	Speed of sound
$C_{d(p)}$	Discharge coefficient for the plenum fed liner
C_d	Discharge coefficient
D	Orifice diameter
H_n	Helmholtz number
k	Wave number
K_R	Orifice Rayleigh conductivity
L	Orifice length
m_{meas}	Measured mass flow
p	Static pressure
p'	Fluctuating pressure
$\widehat{p}_i$	Incident acoustic wave
$\widehat{p}_r$	Reflected acoustic wave
P	Total pressure
$\widehat{Q}$	Orifice volume flux
Q'	Unsteady volume flow
R	Radius
R	Resistance
St	Strouhal number
u'	Fluctuating velocity
U	Mean velocity
U_b	Bias flow velocity
U_g	Grazing flow velocity
U_j	Jet flow velocity
X	Reactance
Z	Impedance
δ	Admittance
δ_{qs}	Quasi-steady conductivity
$\Delta\widehat{p}$	Unsteady pressure drop
Γ	Inertia
ρ	Density
ω	Angular frequency

passive damper in which acoustic energy is absorbed by orifices located within a thin plate (i.e. a perforated liner). The liner is supplied with air from a passage and can therefore be subject to a range of both grazing and bias flows.

Numerous investigations have considered the absorption mechanisms associated with an orifice in which bias flow is supplied from an upstream plenum (i.e. no grazing flow). Examples include Bellucci, Flohr, & Paschereit [1], Dowling & Hughes [2], Forster & Michel [3], Howe [4], Luong, Howe, & McGowan [5]and Rupp [6]. A review of some of this work is also provided by Lawn [7]. In such studies the bias flow is usually modulated by a locally uniform time harmonic pressure differential $\Delta\widehat{p} = \widehat{p}(us) - \widehat{p}(ds)$ that results in an unsteady orifice volume flux $(\widehat{Q})$. The acoustic properties of the orifice with bias flow can be described in a number of ways. For example, the Rayleigh conductivity of the orifice (K_R) (as defined by Rayleigh [8]) relates the unsteady volume flow through the orifice to the unsteady pressure drop and is defined such that:

$$\frac{K_R}{2R} = -\frac{i\omega\rho\widehat{Q}}{\Delta\widehat{p}} \tag{1}$$

The Rayleigh conductivity for an orifice is unknown, but an analytical model was developed by Howe [4] for a circular orifice with a high Reynolds number bias flow that is being subjected to an unsteady pressure drop. The orifice was assumed to be infinitesimally thin, the bias flow large relative to the unsteady velocity amplitude, and the bias (or 'jet' flow) irrotational