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ACOUSTIC PERFORMANCE OF A SPLITTER DUCT SILENCER WITH ZIGZAG AIRWAYS

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INTRODUCTION

The acoustic performance of a splitter duct silencer of the sound stream type with gourd-shaped absorbers was studied. Silencers of this type are applied to obstruct the transmission waves that pass directly through the straight airways when silencers of the parallel baffle type are used. These splitter duct attenuators are usually installed in a HVAC duct or an air passage of large sectional dimensions, and the lowest order several modes in it come into the important audible range. When the number of the far-field modes possible in all of the connecting straight ducts is M, the number of the transmission factors between every mode incidence and every mode transmission is amount to M squared. To determine these transmission factors, the incoming and outgoing wave pressures of $N+1$ modes at each interface must be decomposed generally from the sound pressures at $2(N+1)$ positions around each interface for M independent sound field conditions. A significant preciseness is required in the sound pressure observation to achieve this. Last year [1], we presented transmission factors obtained from sound pressures by a measurement and a BEM numerical simulation at frequencies below second mode cutoff. The agreement of these was satisfactory. However, as the number of the possible far-field modes increases, difficulty increases in meeting the preciseness in the pressure measurement. In this study, we carried out the numerical simulations rigorously to obtain precise sound pressures in the duct. Consequently, for 2D attenuators of a sound-stream type and a parallel baffle type as shown in Figure 1, we attained the purpose to determine and to compare the transmission factors between the incidence and transmission modes possible at frequencies below eighth mode cutoff.

DECOMPOSITION INTO TRAVELING WAVE PRESSURES

Taking an interface, the coordinates and the origin $(0,0)$ as shown in Figure 2 in the straight duct region of each duct connected to the attenuator where evanescent modes from the discontinuities have died out, the sound pressure $p(x,y)$ is represented as

$$p(x,y)=\sum_{n=0}^{N} a_{(n)} \exp(-jk_x^{(n)}x)\cos(k_y^{(n)}y) \quad +\sum_{n=0}^{N} b_{(n)} \exp(+jk_x^{(n)}x)\cos(k_y^{(n)}y) \qquad (1)$$

where $n(=0,1,2,\cdots,N)$ represents the number of the pressure nodes in the y direction, and N is the highest number of the propagating modes for the frequency of interest in the straight duct. The quantities $k_y^{(n)}=n\pi/W$ and $k_x^{(n)}=\{(\omega/c)^2-(k_y^{(n)})^2\}^{1/2}$ are the wave numbers of the n th mode in the y and x directions, respectively. The quantities $a_{(n)}$ and $b_{(n)}$ denote the outgoing and incoming plane wave pressures, respectively, of the n th mode at the origin. These traveling wave pressures can be determined by solving simultaneously a set of equations (1) corresponding to the sound pressures $p(x,y)$ at $2(N+1)$ positions. These sound pressures were observed by conducting a BE numerical simulation [2] for both types of Figure 1 (a) and (b). Typical results of these are shown in Figure 3.

DETERMINATION OF CHARACTERISTIC FACTORS

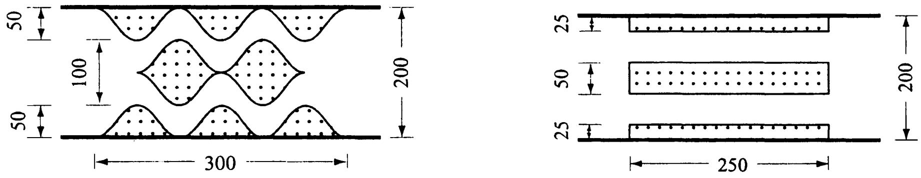
The outgoing wave pressure, $a_{\ell(n)}$, of the n th mode on a interface ℓ is represented by the superposition of the contributions of the incoming waves, $b_{\ell'(n')}$, of all of the modes n' of all of the interfaces ℓ' as

$$a_{\ell(n)} = \sum_{\ell'=\mathrm{I}}^{L} \sum_{n'=0}^{N_{\ell'}} \tau_{\ell(n)\ell'(n')} b_{\ell'(n')}, \quad \text{for } \ell = \mathrm{I},\mathrm{II},\cdots,L\text{, and } n = 0,1,2,\cdots,N_{\ell} \tag{2}$$

where N_{ℓ} and $N_{\ell'}$ are the highest orders of the propagating modes in the ℓ th and ℓ' th straight duct sections, respectively, L denotes the number of the ducts connected to the attenuator, and $\tau_{\ell(n)\ell'(n')}$ represents the characteristic transmission (or reflection when $\ell = \ell'$) factor between an incoming wave $b_{\ell'(n')}$ and its contribution to an outgoing wave $a_{\ell(n)}$. To determine these factors, M deferent cases of the sound fields were generated and measured, where $M = N_{\mathrm{I}} + N_{\mathrm{II}} + \cdots + N_{L} + L$. Having and solving a set of M independent equations (2) for every $\ell(n)$, we can determine the unknowns $\tau_{\ell(n)\ell'(n')}$ of total M without using anechoic terminations.

TRANSMISSION FACTORS

Figure 4 shows the amplitude of the transmission factors $\tau_{\mathrm{II}(0)\,\mathrm{I}(0)}$ of the attenuators installed in a straight duct section as shown in Figure 1. The glass fiber blanket of 32 kg /m^3 and the flow resistance of 8500 kg · s /m^3 was supposed. The empirical formulae by Delany and Bazley [2] were employed to give the acoustic properties of the blanket. Since the attenuators have symmetry in shape and were installed in a straight duct section, the transmission and reflection factors related to the non-zero order modes, though these results are omitted here, were negligibly



(a) Sinusoidal sound-stream type

(b) Parallel baffle type

Fig.1 Splitter duct attenuators studied

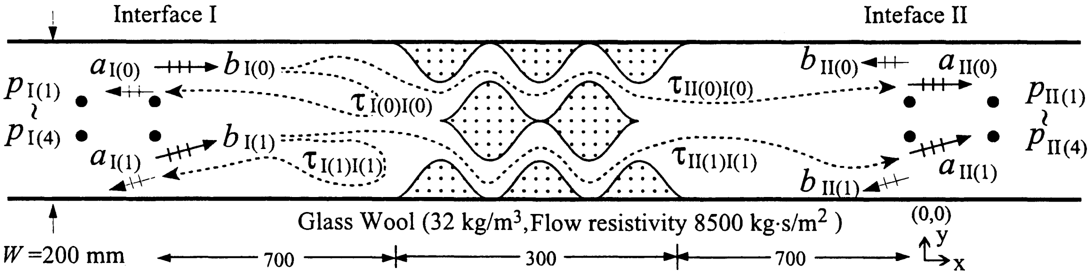
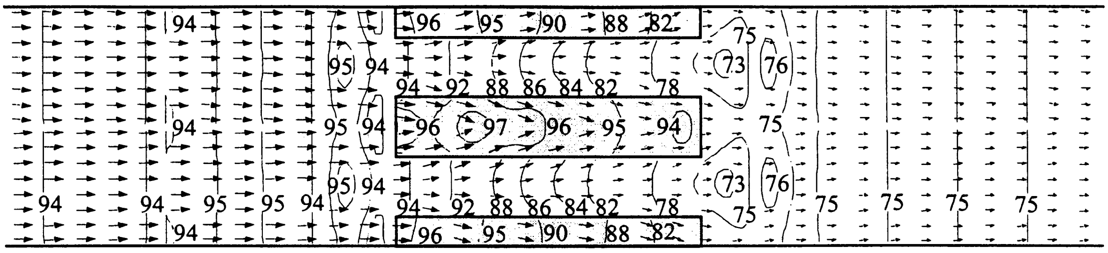
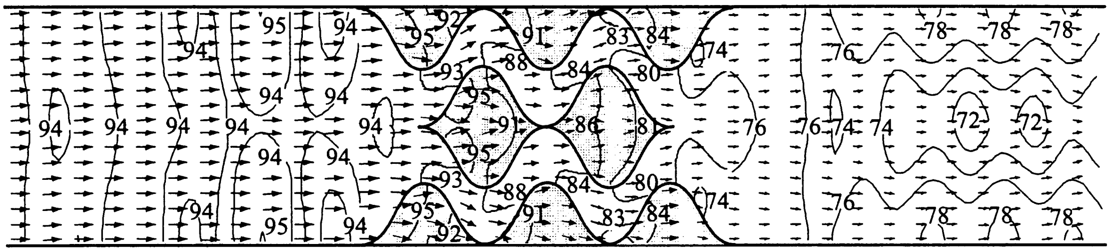


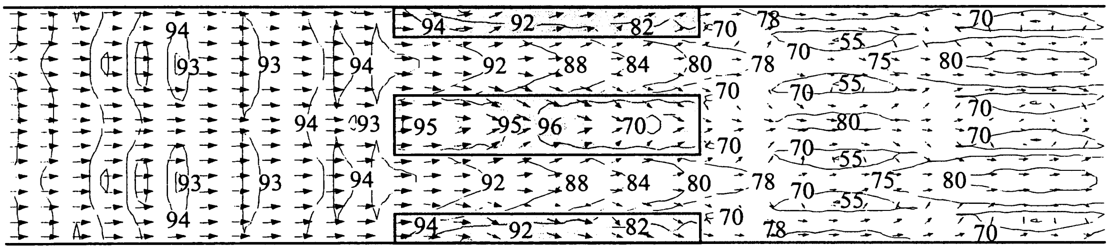
Fig.2 Pressures, traveling wave pressures and transmission factors



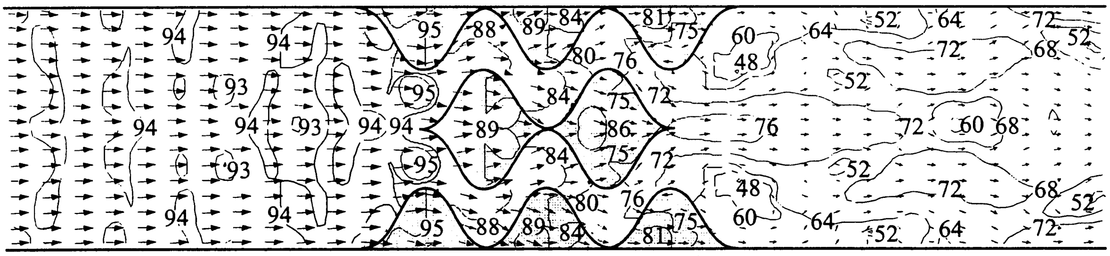
(a) Parallel baffle type 3000Hz ($2W/\lambda=3.53$)



(b) Sound-stream type 3000Hz ($2W/\lambda=3.53$)



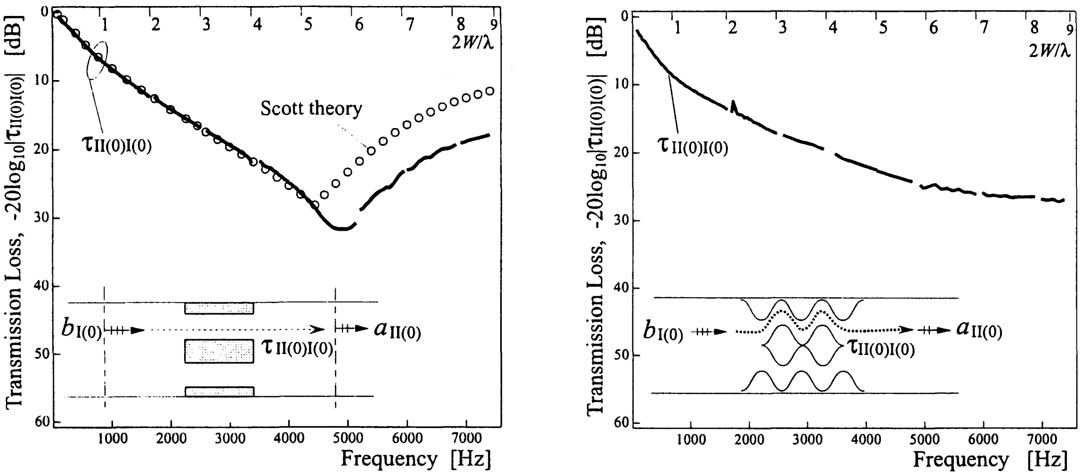
(c) Parallel baffle type 6000Hz ($2W/\lambda=7.06$)



(d) Sound-stream type 6000Hz ($2W/\lambda=7.06$)

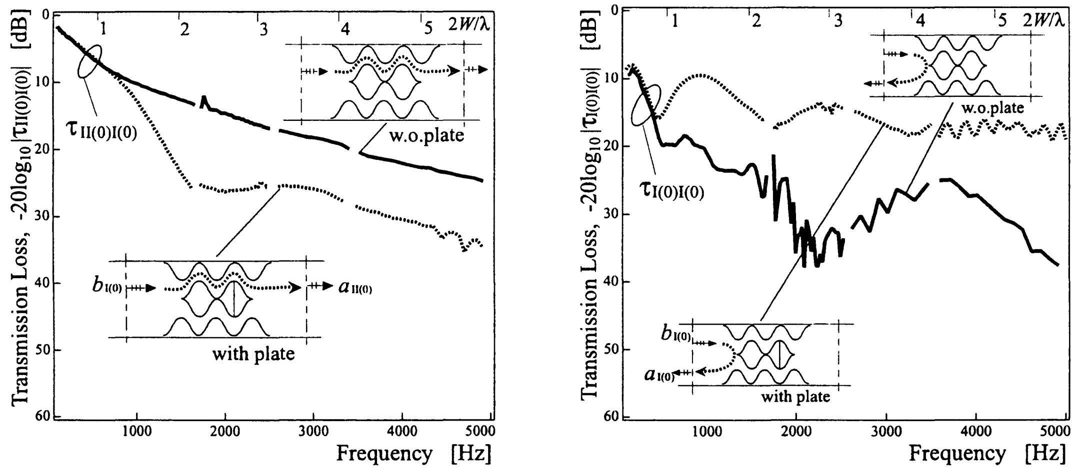
Fig.3 Pressure (in dB) and net-intensity distributions around absorbers

small compared with those for the fundamental mode incidence and the fundamental mode transmission, $\tau_{\mathrm{II}(0)\,\mathrm{I}(0)}$ and $\tau_{\mathrm{I}(0)\,\mathrm{I}(0)}$. The frequency of the maximum transmission loss of the fundamental mode (the least attenuation mode) for the parallel baffle attenuator of finite length is higher than that given by the Scott's theory [3] for infinite length liners. The obstruction effect of the zigzag airway on the passing-through transmission shows a tendency to be cancelled out by the sound waves passing through the absorbers of the sound-stream attenuator. This passing-through transmission in the absorbers is interrupted significantly by a plate inserted in a absorber as shown in the Figure 5.



(a) Parallel baffle type (b) Sinusoidal sound-stream type

Fig.4 Characteristic transmission factors (0th mode incidence and 0th mode transmission)



(a) Transmission factors (b) Reflection factors

Fig.5 Effect of insertion of a plate on charastristic transmission and reflection factors
(0th mode insidence and 0th mode transmission)

CONCLUSIONS

The transmission and reflection coefficients of splitter duct attenuators of a parallel baffle type and a sound-stream type were determined for the incidence and transmission modes possible at frequencies below eighth mode cutoff in each connecting ducts. It was found that the frequency of the maximum transmission loss of the fundamental mode for the parallel baffle attenuator of finite length was higher than that given by the Scott's theory for infinite length liners. The obstruction effect of the zigzag airways on the passing-through transmission shows a tendency to be cancelled out by the sound waves passing through the absorbers of the sound-stream attenuator.

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3. "The propagation of sound between walls of porous material," R.A Scott, *Proceedings of the Physical Society* **58**, 358-368(1946).