스치는 유동과 관통 유동의 영향을 고려한 천공 요소의 음향 임피던스 모델

Acoustic impedance model of perforated elements with both grazing and bias flow

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Key Words: Perforated Element (천공 요소), Acoustic Impedance (음향 임피던스), Grazing Flow (스치는 유동), Bias Flow (관통 유동)

ABSTRACT

The simplified impedance model which can consider a combined flow condition was suggested. Although the strength and position of the shear layer cannot be obtained by a linear sum of two separate contributions when both flows occur together, it was simply assumed that the impedance under the combined flow follows from summing the separate flow impedance. To validate the simplified impedance model, acoustic properties of a concentric resonator was predicted and measured. The predicted transmission loss using the simplified model shows reasonable agreements with measurements. One can find that the simplified impedance model obtained by the superposition of the separate flow impedances can be adjusted to predict the acoustic properties of a concentric resonator.

1. Introduction

In practical applications, most of perforated liners in automotive silencers or modern combustion engines are exposed to the mean flow, which consists of both grazing flow and bias flow. The effect of the mean flow on the acoustic performance of perforated elements has been studied. However, most of previous works focused on the respective component of the mean flow[1-11]. The simplified impedance model which can consider effects of both grazing and bias flow is necessary for more accurate analysis for silencing devices. The effects of both grazing and bias flow on the impedance are determined by the strength and position of the shear layer. Figure 1 shows illustrations of generated shed vortices when there is both grazing and bias flows in the vicinity of an orifice. Although the strength and position of the shear layer hardly can be considered as a linear sum of the two separate contributions when both grazing and bias flows occur together, it was assumed that the impedance under the combined flow condition follows from summing the separate flow impedances to obtain the very simplified model that can be easily adjusted to practical applications.

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2. Simplified impedance model

As mentioned in the previous section, the simplified impedance model was suggested for easy applications under the assumption that the conductivity under a combined flow condition is same with the linear sum of that under two separate conditions. Because the Rayleigh conductivity means the easiness of the acoustic energy propagation through an orifice, the total conductivity can follow from summing the conductivity for the separate flow,

$$\frac{1}{K_R^{tot}} = \frac{1}{K_R^{gra}} + \frac{1}{K_R^{bias}}. \qquad (1)$$

Because the flow velocity in the grazing flow case is different from that in the bias flow condition, a summation should be done after the synchronization of the flow velocity. The effects of a thickness was only considered in the conductivity under bias flow condition because the numerical model for grazing flow condition is exact only for an orifice of zero thickness.

The conductivity of the very thin orifice with grazing flow can be expressed by only the Strouhal number defined as $R_{ori}\ \omega / U$ because the effects of thickness and interaction were neglected[12]. However three non-dimensional parameters are needed to express the conductivity of perforated plates under bias flow condition[13]. Those are Strouhal number defined as $T\ \omega\ /\ U$, thickness to radius ratio, and porosity. For suggesting the simplified model, non-dimensional parameters are necessary to consider three parameters at once. After non-dimensional analysis using the predicted conductivity within various ranges of parameters for the bias flow condition, following non-dimensional parameters were obtained,

$$\overline{K_R^{\ bias}} \times \frac{1}{\sigma^{0.125}} \times \left(\frac{T}{R_{ori}} \right)^{0.75}, \quad St \times \left(\frac{T}{R_{ori}} \right)^{-0.25}. \quad (2)$$

The ranges of parameters were as follows: $0.05 \le St\ (=T\ \omega\ /\ U_0) \le 20$, $0.5 \le T\ /\ R_{ori} \le 2$, and $0.0025 \le \sigma \le 1$. Figure 2 shows predicted conductivity obtained with various parameters and the curve fitted model with respect to non-dimensional parameters. The curve fitted conductivity model under bias flow condition was used for the simplified model for the combined flow.

Figures 3 and 4 show the simplified impedance models for the combined flow condition with varying parameters. Figure 3 shows the effects of bias to grazing Mach number ratio on the impedance. Resistance tends to increase at low Strouhal numbers with increasing the ratio of bias to grazing Mach number. Reactance is hardly influenced by the velocity ratio. The effect of the thickness to radius ratio on the impedance is illustrated in Fig. 4. With increasing thickness to radius ratio, the gradient of reactance tends to increase and resistance shows few variations. One can find that the bias flow velocity plays a dominant role in the resistance and the effect of thickness is important in the reactance.

In order to verify the simplified impedance model for considering both flow effects, the transmission loss of a concentric resonator was predicted and compared with measured results. Figure 5 shows the geometric shape of a concentric resonator. Orifices on the perforated pipe are located along 18 columns with respect to the axial direction. The length of a resonator is 0.2 m, the diameter of an inner tube is 0.032 m, the diameter of an outer jacket is 0.11 m, the orifice diameter is 4 mm, the orifice thickness is 2 mm, and the porosity of the perforated pipe equals to 10%. The distribution of the bias flow velocity was obtained using the computational fluid dynamics (CFD). Figure 6 shows the predicted bias flow velocity through the perforated pipe when the grazing flow Mach number is 0.085. The bias flow velocity varies from -6 m/s to 11 m/s and the averaged absolute bias flow velocity are ranged from 1 m/s to 4 m/s. The transmission loss of the concentric resonator was predicted using the unified impedance model using the predicted averaged bias flow velocity. Figure 7 compares predicted transmission loss with measured results. The predicted transmission loss shows reasonable agreements with measured results. Even in case of Mach number equals to 0.17 the predicted transmission loss with the simplified impedance model shows better results than that with the empirical model suggested for the grazing flow condition.

3. Conclusions

Even though the strength and position of the shear layer can hardly be assumed as the linear sum of the two separate contributions, the simplified impedance model for considering both grazing and bias flows was suggested for easy applications in the engineering sense. The theoretical model in the grazing flow condition and the curve fitted non-dimensional theoretical model in the bias flow condition were adopted for suggesting the simplified impedance model. To verify the proposed model, the transmission loss of the concentric resonator was predicted and compared with measured results. The bias flow velocity through the perforation was also predicted using CFD. The averaged absolute bias flow velocity is almost 10% of the grazing flow velocity. The predicted transmission loss by the proposed simplified impedance model agrees well with measurements.

Although the very simplified approach to obtain the impedance model was used, both the impedance and the predicted acoustic property show reasonable agreements with measured results. One can find that the simplified impedance model can be adjustable to the practical application.

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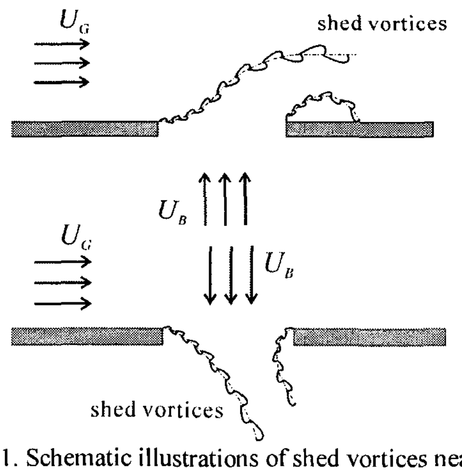


Figure 1. Schematic illustrations of shed vortices near the orifice exposed to both grazing and bias flow. (upper) Combination of grazing flow and bias inflow, (lower) combination of grazing flow and bias outflow.

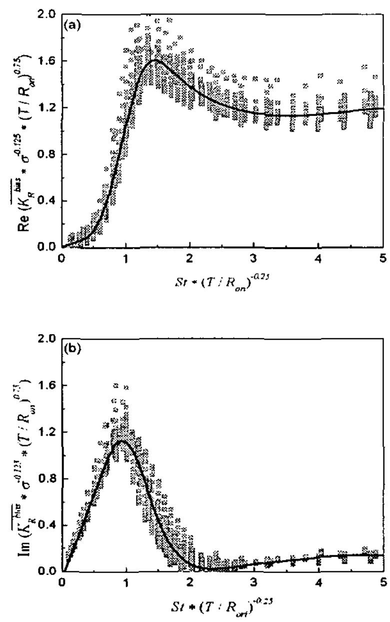


Figure 2. Numerical Rayleigh conductivity model of a perforated plate under bias flow condition with respect to non-dimensional parameters: □ ; numerical model obtained using various parameters, ▬▬ ; curve fitted model. (a) Real part, (b) imaginary part.

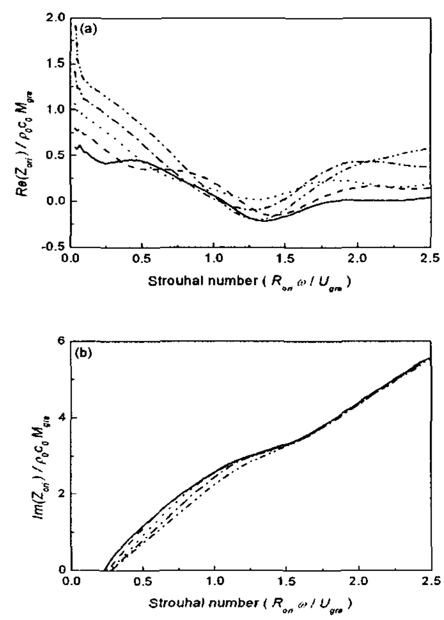


Figure 3. Predicted impedance model of a perforated plate under combined flow condition with varying bias to grazing Mach number ratio (T / R_{ori} = 0.5, σ = 10%): ▬▬, M_{bias} / M_{gra} = 0.1; — —, M_{bias} / M_{gra} = 0.2; - - - - -, M_{bias} / M_{gra} = 0.3; — - —, M_{bias} / M_{gra} = 0.4; ▬ ▪ ▪ ▬, M_{bias} / M_{gra} = 0.5. (a) Real part, (b) imaginary

part.

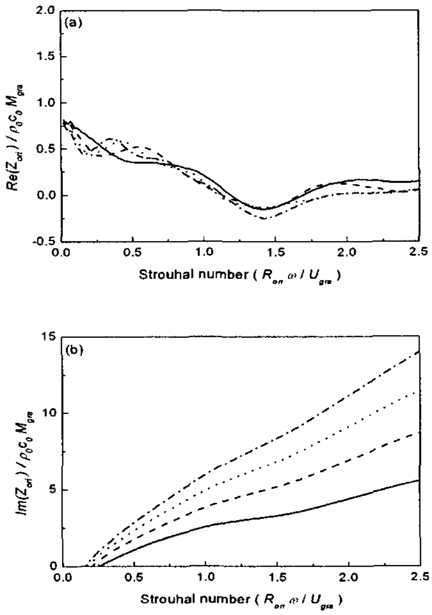


Figure 4. Predicted impedance model of a perforated plate under combined flow condition with varying thickness to radius ratio (M_{bias} / M_{gra} = 0.2, σ = 10%): ▬▬, T / R_{ori} = 0.5; — —, T / R_{ori} = 1; - - - - -, T / R_{ori} = 1.5; — - —, T / R_{ori} = 2. (a) Real part, (b) imaginary part.

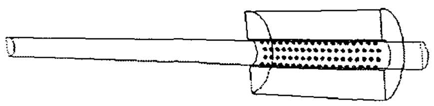
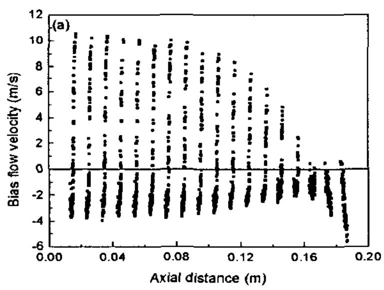


Figure 5. Geometric shape of concentric resonator model for CFD analysis.



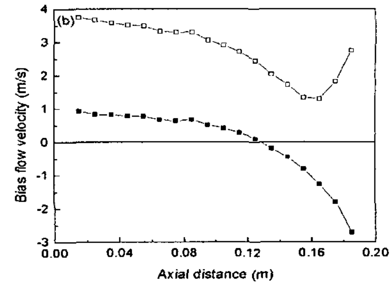


Figure 6. Predicted bias flow velocity on a uniformly distributed concentric resonator (M_{gra} = 0.085). (a) Bias flow velocity distribution, (b) —■—; averaged bias flow velocity, —□—; averaged absolute bias flow velocity.

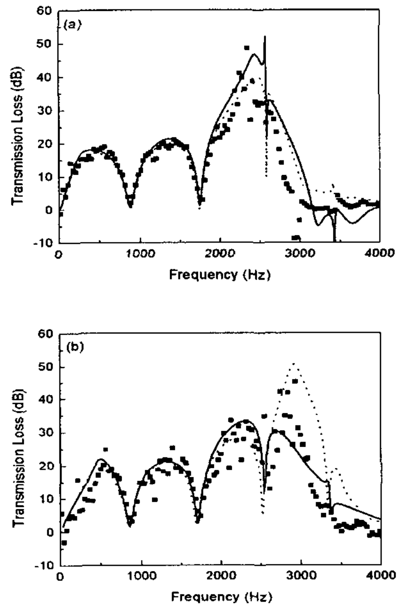


Figure 7. Predicted transmission loss compared to measured results (L = 200 mm, d_1 = 32 mm, d_2 = 100 mm, R_{ori} = 2 mm, T = 2 mm, σ = 10%): ■, measured transmission loss, ▬▬, predicted by the simplified model for combined flow condition; - - - - -, predicted by the empirical model[14]. (a) M_{gra} = 0.085, (b) M_{gra} = 0.17.