Acoustical Performance of Single Helmholtz Resonator-Type Silencers with Air Flow inside a Duct

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Abstract

Noise is a kind of pollution which has been continuously studied and researched through many methods in order to reduce it. Helmholtz resonator is a device that can be achievable by analysing its transmission loss(TL). This paper presented the effects of flow on single Helmholtz resonator. The calculated and experimental result are compared for main duct of square and round cross-sections, and it can be shown that noise reduction performances of Helmholtz resonator are differed due to the effects of flow and the type of main duct.

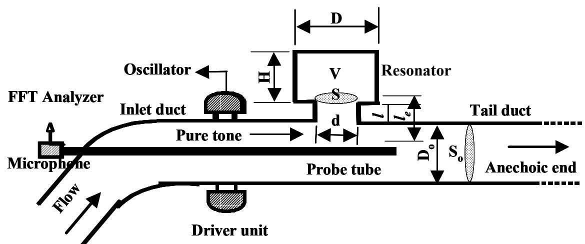
1. Introduction

Helmholtz resonators have been used for several decades for radiation of sound so as to reduce noise from exhaust and ventilation systems. On the basis of the linear wave theory, disregarding flow, Davis et al, presented the equations for a single resonator and for the multiple resonators[1]. These have contributed to the reduction of narrow frequency-band noise traveling in a duct with fairly low-speed flow. The additional investigations have indicated that the performance of a single resonator drops as flow speed is increased [2,3]. The reason appears to be induced by entropy fluctuations at discontinuity [4]. Since such energy dissipation may occur close to the resonator entrance and are almost unable to be controlled, the acoustic performance of this type of resonator needs investigation to determine the noise reduction level that can be expected.

This study is aiming for a more efficient use of the single resonators for a duct with incompressible higher-speed flow. The silencer transmission loss has been calculated and measured, and its characteristics are examined in relation to Mach number, and effective ranges of frequency. The effects of two different noise sources, that is pure tone and jet-generated noise, on silencer performance has also been examined.

2. Experimental apparatus and method

The experimental apparatus used in this investigation is shown schematically in Fig.1. In Fig.1(a) the pure tone was produced by an oscillator feeding through an amplifier and conducted to the system by means of two loud speakers. The sound which passed through the single Helmholtz resonator



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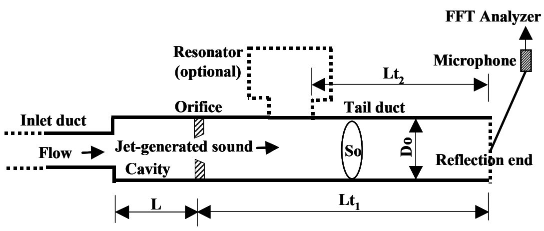


(b)

Fig.1 Schematic of experimental apparatus: (a) pure tone; (b) jet-generated noise.

continued down through the tailpipe to the termination, which consisted of glass wool surrounded by an involute tube. The propagating signal which was detected with the probe tube microphone traversing axially along the test section. The air flow from the blower whose noise was sufficiently reduced by a pre-muffler, progressing together with the sound from the driver unit, was continuing into the anechoic room. The mean flow velocity U was correspondingly measured with a Venturi meter.

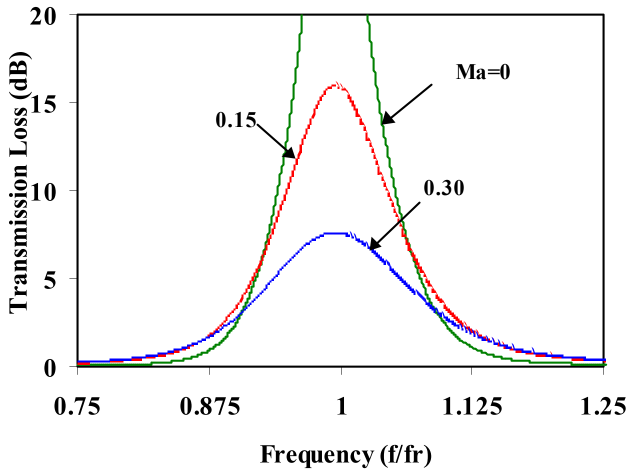


Fig.2 Typical variation of the transmission loss with frequency and Mach number.

Figure1 (b). depicts the air flow from a blower whose noise was sufficiently reduced by a pre-silencer, led through the inlet duct having a circular cross-section, and passed over the test section. Then it was finally emitted into the anechoic room after running in the conical tube and non-reflection involute tube lined with glass wool. In the test section shown in Fig.1 (b), the sharp-edged circular orifice was installed inside the main duct, and its diameter was bigger than the inlet duct from which the jet was emitted.

3. Equation for resonance transmission loss

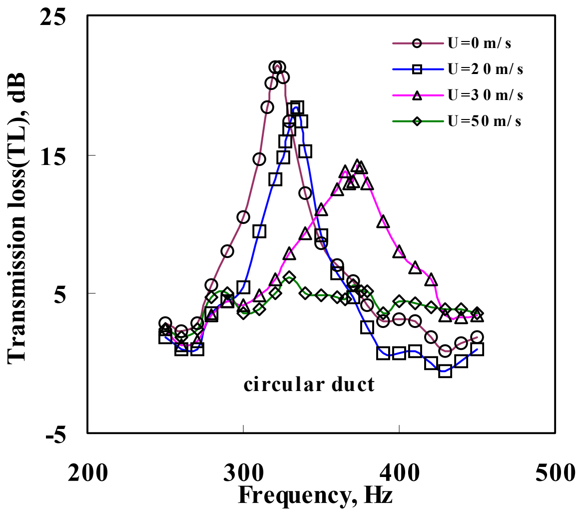
The equation for transmission loss TL has been obtained by means of the transfer matrix[5] which is based on the linear wave theory. Figure 2 shows the effect of flow on the theoretical characteristic of resonator. At resonance frequency, one of the two terms in the specific acoustic reactance, that is $[X/Z_o]_r$ vanishes, this will put the resonance (or maximum) transmission loss(dB) into the form of

$$[TL]_r = 10\log_{10}\left| 1 + \frac{(1-Ma)^2\left\{(1+Ma)^2 + 4\left(Ma + \left[\frac{R}{Z_o}\right]_r\right)\right\}}{8\left\{Ma^2 + \left(Ma + \left[\frac{R}{Z_o}\right]_r\right)^2\right\}} \right| \quad (1)$$

where Ma symbolizes the Mach number, the specific acoustic resistance at resonance $[R/Z_o]_r$ can be written as

$$\left[\frac{R}{Z_o}\right]_r = \frac{K}{c}\left(\frac{l_e}{d}\right)\left(\frac{D_o}{d}\right)^2\sqrt{\frac{\mu f_r}{\rho_o}} \quad (2)$$

where K equals to 4π for circular duct or $16/\sqrt{\pi}$ for square duct; c denotes the sound speed(m/s); l_e, d the effective length (m) obtained from experiment, the diameter(m) of connector respectively; Do the diameter(m) or the width(m) of main duct; μ the viscosity(Pa•s); ρ_o the medium density; and f_r the resonance frequency.



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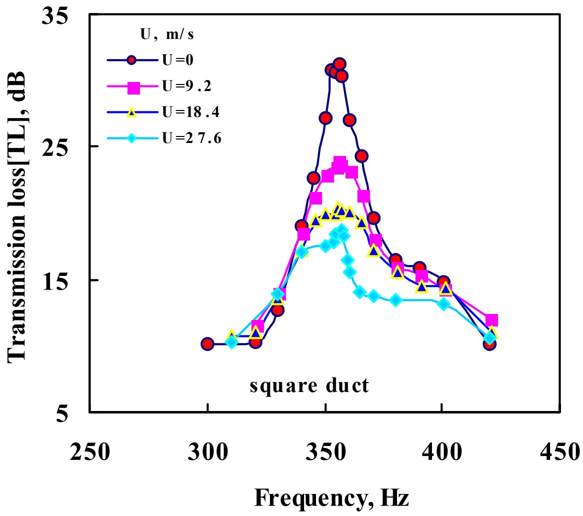


(b)

Fig.3 Transmission loss characteristics of resonators: (a) circular duct; (b) square duct.

4. Results

4.1 Experimental characteristics of resonators

The transmission loss characteristic of resonator obtained from the experiment has been shown in Fig.3 for main duct of circular and square cross-section. An increase in mean flow velocity of about 10 and 9.2 m/s has resulted in a drop of approximately 18 and 6%, in relative to the case of no flow in duct, for the value of resonance transmission loss in circular and square duct respectively. For the same amount of rise in mean flow velocity, a shift-up of approximately 12%, in relative to the case of no flow in duct, and a no shift of resonance frequency has been found in circular and square duct respectively. This could be due to the fact that there is higher sound energy radiation at the entrance of resonator in circular duct. Accordingly, the effective length gets lower as the flow velocity increases.

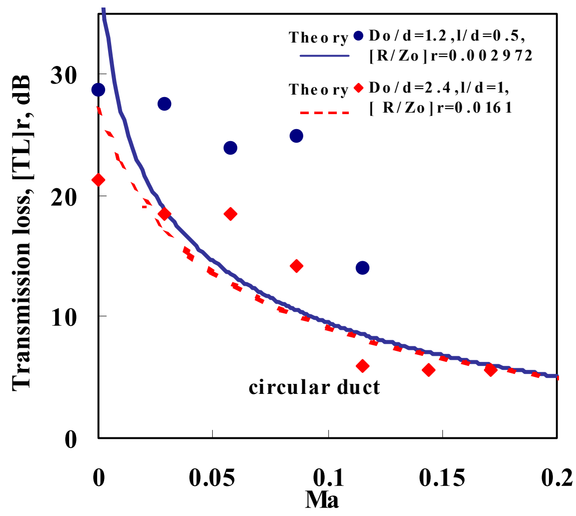
4.2 Effects of flow on resonator performances

Figure 4 describes the relationship between the resonance transmission loss and Mach number obtained from experiment as compared with that from eq.(1). A circular duct with larger specific acoustic resistance seems to be well predicted by the theory. But for square duct, the specific acoustic resistance has a very slight influence on the flow characteristic of the transmission loss.

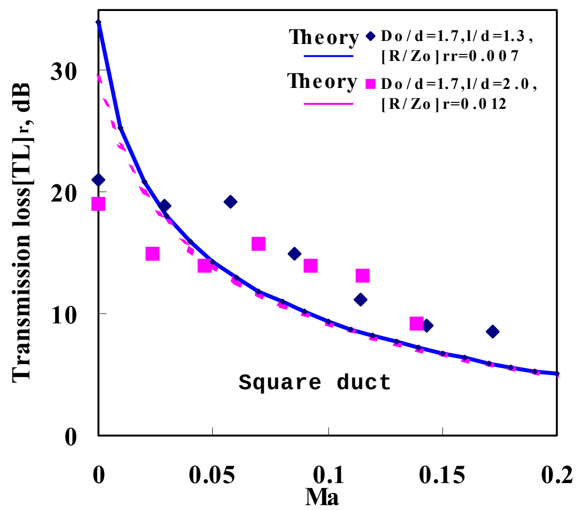
The variation of transmission loss difference between experimental and theoretical values for varied specific acoustic resistance has been plotted as shown in Fig.(5). It confirms what has been observed a priori. Moreover there is a distinct peak value of the transmission loss difference over a certain range of Mach number for the case of circular duct.

4.3 Examples and comments for narrow-band frequency noise control

The spectra of sound pressure level measured in the conical tube, according to Fig.1(b), are shown in Fig.6 . When the ratio of cavity length to orifice diameter L/d is under four, some peak components occur to add to the characteristics of the flow noise, which cover a wide frequency region and show relatively large level at lower frequency. All these dominant pressure components of the generated noise may be due to the jet periodically hitting against the orifice edge since the resonant effect between the duct open-ends is hardly observed. The first and second peaks are higher than the others, and either of them will be excellent. As the jet speed is increased, these peaks further heighten with sound pressure levels. Such appearances of the dominant pressure components in spectra are also remarkable with decreasing of the cavity length. Especially, if the



(a)



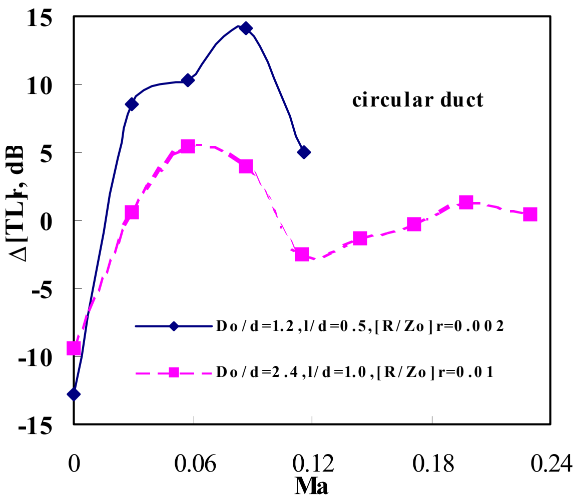
(b)

Fig.4 Effect of flow on the resonance transmission loss for different [R/Zo]r: (a) circular duct; (b) square duct.

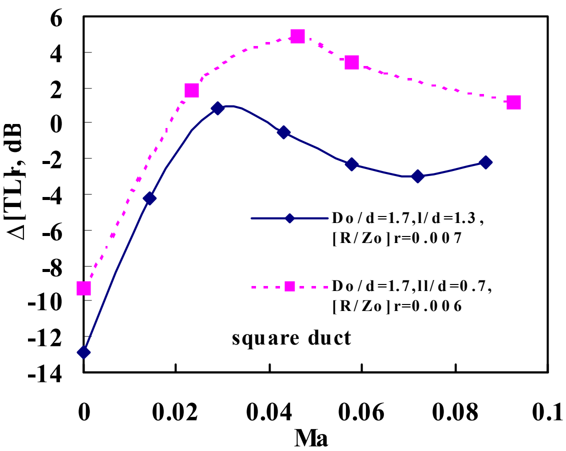
jet is comparatively fast and so short as to progress nearly straight, the peaks will be very sharp. But they are not much in evidence, as fairly low-speed jet becomes so long as to approach to a reattachment flow.

5. Conclusions

The above performance falls with the flow velocity may be caused by the fact that the excess pressure oscillating the medium in the volume chamber is weakened by energy loss of flow passing over the resonators. That is hardly to be controlled by a method of fluid dynamics, however, the silencer attenuation required at narrow frequency band could be raised by the effect of an orifice.



(a)



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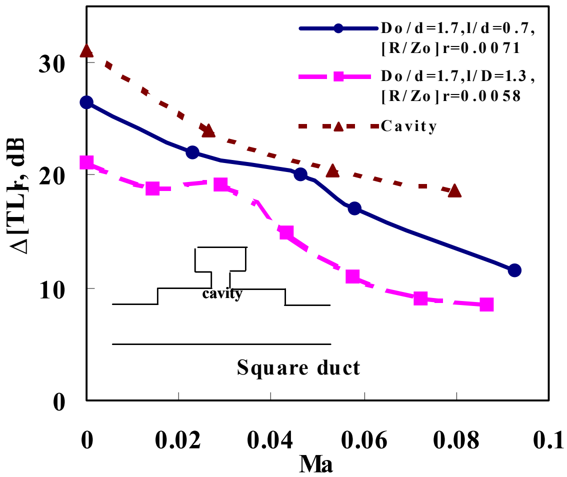
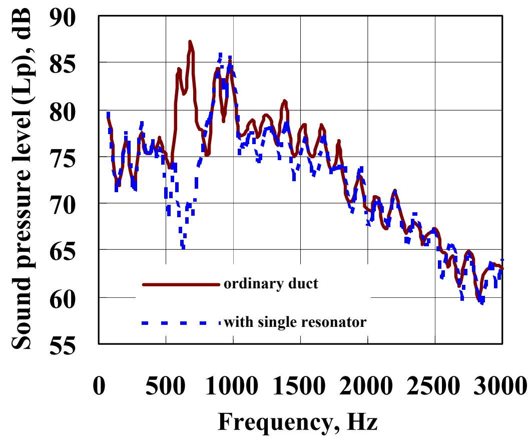


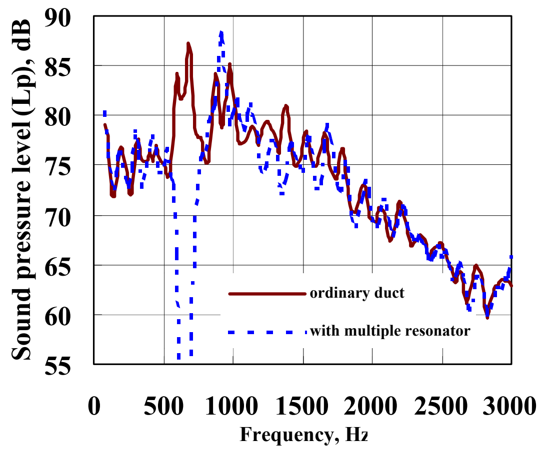
(c)

Fig.4 Variation of resonance transmission loss

Fig. 5 Variation of resonance transmission loss difference for varied [R/Zo]r: (a) circular duct; (b) square duct; (c) square duct with or without cavity.



(a)



(b)

Fig.6 Examples of jet-generated noise control by resonators: (a) single resonator; (b) multiple resonators.

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