PA05
Perforated Tube as a Muffler in Jet Noise Reduction

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***Abstract*— Aero-acoustic performance of different perforated tubes with various porosity have been investigated and a forward slanted tube with porosity of 0.063 is found to perform the best in noise reduction. Flow visualization with the Schlieren system along with high-speed video camera has showed the disappearance of shock structure in the jet issued from a forward slanted perforated tube, although, it is present in the jet of a solid tube (without perforation). The performance of a perforated tube with forward slanted perforation has been compared with other perforated tubes of backward slanted perforation and normal perforation to the axis as well as to a solid tube. Among the tested tubes, the perforated tube with forward slanted perforation has showed the best performance. The tube is suffered from minimum thrust loss compared to the backward and to the normal perforated tubes. The performance of the forward slanted perforated tube is further investigated with different porosity and with different porous number. Finally, a forward slanted tube with alternate porous pattern has been found which shows the best performance as a muffler.**

INTRODUCTION

There are two kinds of shock-related noise. One has discrete spectral components, which are commonly referred to as jet screech tone [1]. The other contains more broadband spectral components and is known as the broadband shock-associated noise [2]. The presence of two kinds of shock-associated noise modifies the spectral and directional characteristics of the jet noise. The intensity of these noise components is a strong function of the direction of observation. Many devices such as nozzle with tabs, slotted tubes, chuted nozzle, lobed nozzle, multi-tube nozzle etc. are used for suppressing the jet noise. Contoured and porous plug nozzles are also commonly used for reducing the jet noise. However, in most cases the attachment of a noise-reducing device incurs undesirable effects as increasing dead weight and reducing thrust.

It has been demonstrated that the generated supersonic flow at the exit of the perforated tube changes from under-expanded to correctly expanded or over-expanded jet as the length of the perforated tube is increased. Perforated tubes reduce noise most effectively when the optimum porosity, perforated pattern and length have been combined.

EXPERIMENTAL PROCEDURE

Measurements of sound generated from an under expanded supersonic cold jet are carried out in an anechoic chamber. A condenser microphone of 6.35 mm (Bruel & Kjaer, Denmark) is used and traversed along a measuring path of 60D radial distance from the exit-centers of nozzle, perforated and base tubes as shown in Fig. 1. Perforated tubes with backward (B-type), normal (N-type) and forward (F-type) perforations have been used. Forward type again classified as alternate (A-type) and parallel (P-type) perforations. The microphone is placed making angles of 30º and 90º with the jet axis. Acoustic signals are taken with the help of a signal amplifier and a FFT analyzer. Pressure ratio (the ratio of the jet pressure to the ambient pressure) is changed from 1.2 to 4.0 at a step of 0.2. Thrust data of different tubes are taken by a vertical wind tunnel. The schematic of a perforated tube is shown in Figs. 2.

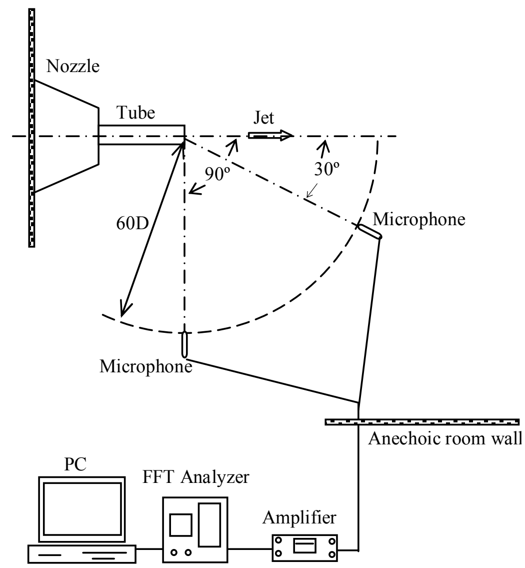


Fig. 1 Schematic view of acoustic measurements

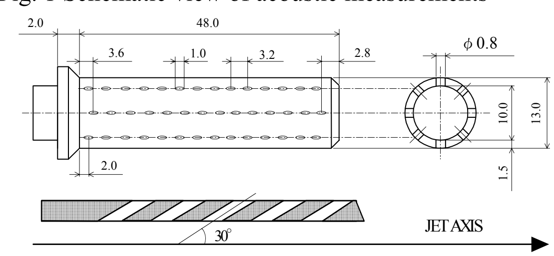


Fig. 2 Schematics of a perforated tube (A14φ0.8)

RESULTS AND DISCUSSION

The overall noise (OASPL) suppression characteristics of perforated tubes are shown in Figs. 3 and 4 respectively for a variety of perforation conditions. Almost all types of perforated tubes have suppressed the noise level compared to the base tube at higher pressure ratios (higher than 4.0), however, the performance of A4-type tube in noise suppression is degraded at lower jet pressure due to generation of tonal components. Noise suppression characteristics of normal perforation and backward perforation are also compared with forward perforations as shown in Figs. 3 to 5. Normal perforation also shows good performance, although, it suffers higher thrust loss with higher porosity. The performance has been investigated both in 90 and 30 degrees observations.

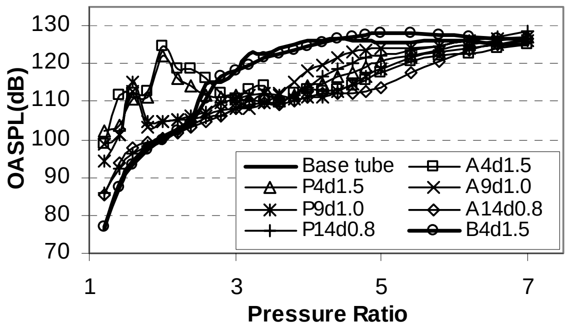


Fig. 3 OASPL observed at 90° of different porous tubes

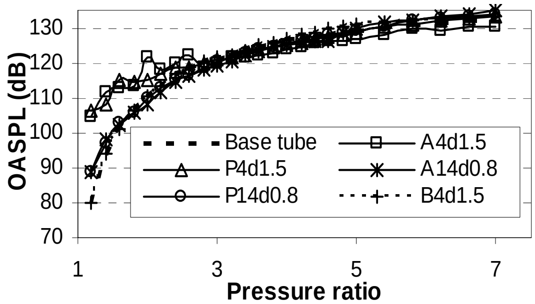


Fig. 4 OASPL observed at 30° of different porous tubes

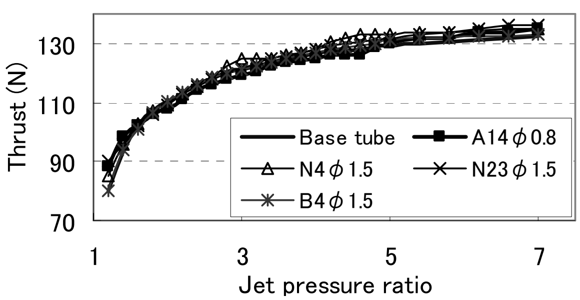


Fig. 5 OASPL compared with different porous patterns.

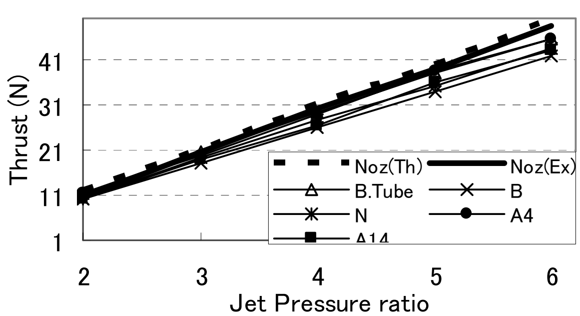


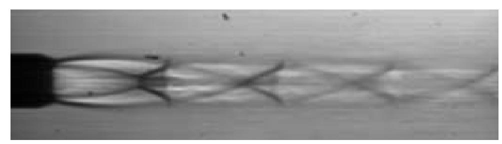
Fig. 6 Comparison of thrust loss.

From the acoustic results it is found that the noise suppression characteristics depends not only the porosity but also the porous number as well as porous pattern and thus it is found that the A14 type forward slanted perforation with a diameter of 0.08D has showed the best performance.

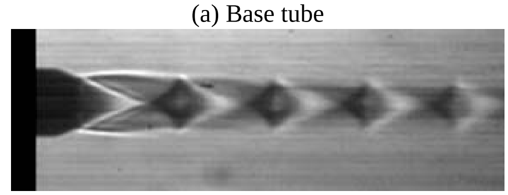
The aerodynamic performance of different perforated tubes was analyzed by evaluating the thrust of the jet from different tubes. The thrust was directly determined in a vertical wind tunnel by measuring the load caused by the issuing jets from the perforated tubes directly to the load cell. The sensible load cell was placed under the nozzle to receive the thrust from the nozzle or tubes when jets were issued from them. The experimental results are compared with a theoretical result and plotted against jet pressure ratios (Fig. 6). The theoretical thrust was given by the jet momentum equation as follows [3]:

$$F = \dot{M} V_j + (P_j - P_0) A \qquad (1)$$

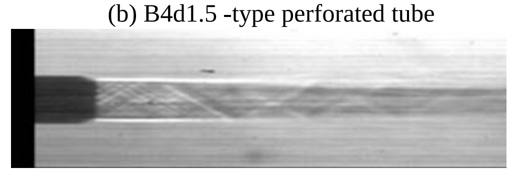
where, $\dot{M}$, V_j, P_j, P_0 and A are mass flux, exit velocity, static pressure at the nozzle exit, atmospheric pressure and the area of nozzle exit respectively.



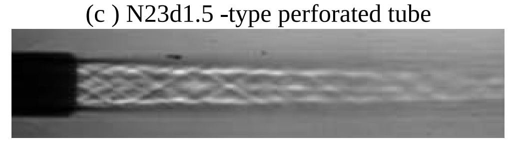
(a) Base tube



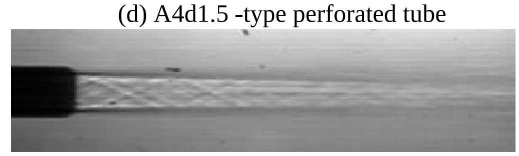
(b) B4d1.5 -type perforated tube



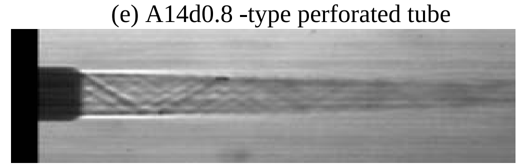
(c) N23d1.5 -type perforated tube



(d) A4d1.5 -type perforated tube



(e) A14d0.8 -type perforated tube



(f) A16d0.8 -type perforated tube

Fig. 7 Schlieren photographs of base-tube (a), B-type, N-type perforations (b), (c), A-type perforation for different diameters of perforation (d) to (f). Pressure ratio is 5.0.

The fluid dynamic behavior of a jet issued from the nozzle (base tube) is shown in Fig. 7. Strong shock structures are present in the jet ejected from the base tube. First to fourth shock cells have been visualized in the nozzle flow. It is observed that the third and the fourth shock cells are oscillated violently which is considered to generate screech component and increase OASPL. The aerodynamic characteristics of different types of perforated tubes are also shown in Fig. 7. The modifications of the jet by all of the mentioned perforated tubes are also clarified by the visualization of each Schlieren picture. The B-type perforated tube, although, has modified the shock waves, however, not weakened the shock structure and thus the reduction of noise level is not sufficiently considered. Aerodynamic modification of the jet by N-type tube is reasonably improved; however, the presence of some over-expanded waves (expansion waves) adversely influences the proposed noise reduction technique. The modification of the jet by using A-type perforated tube with different patterns has been studied in details. Both the lower and the higher porous-diameter cases have been studied. The small-diameter case (A4d1.5) has showed its low performance in noise reduction due to the strong under-expanded waves. Similarly, the large-diameter case (A16d0.8) has degraded the expected result due to the presence of the expansion waves. However, the A14d0.8-type perforated tube has shown the best performance among the tested tubes. The presence of any strong expansion wave in the case of A14φ0.8 perforated tube is not found and thus it shows the favorable performance in noise suppression.

CONCLUSION

Forward slanted perforated tube with appropriate porous diameter, porous number as well as porous pattern improves the performance of a perforated tube in jet noise reduction. Aerodynamic analysis of the tested perforated tubes with thrust measurement as well as Schlieren visualization has confirmed the result as well.

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[3] Md. Tawhidul Islam Khan, Kunisato Seto and Zhixiang Xu, “Improvement of Performance of a Perforated Tube as a Noise Suppressor by Oblique Perforation”, *JSME International Journal* B, 47 (3), 605-611 (2004).