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Diagnostics of Aero-acoustic Performance of Forward Slanted Perforated Tube

Kunisato Seto [1], Md. Tawhidul Islam Khan [1] , Kenbu Teramoto[1] and Hiromiostu Ohta [2]

[1] Department of Mechanical Engineering, Saga University, 1 Honjo-machi, Saga, 840-8502, Japan.
[2] *Dept. of Mechanical Engineering, National Fishery University, Shimonoseki, 759-6595, Japan*
kunisato@cc.saga-u.ac.jp

Abstract

The aero-acoustic performance of a forward-slanted perforated tube with different perforation patterns and different porosities has been theoretically evaluated and diagnosed. We have already reported that a forward slanted perforated tube has a better performance of noise reduction of supersonic jets than the tubes of backward-slanted perforations and normal perforations to the tube axis. The only drawback of the tube with forward-slanted perforation was found to generate a tonal component at low pressure. However, that problem also has been overcome partly by removing the sharpness of the inner surface of the perforations. Again to improve the efficiency of the forward slanted perforated tube in noise suppression, the perforation patterns (alternate and parallel) have been changed. Moreover, the numbers of perforation as well as the porosities of the forward slanted tubes were modified again to improve the performance of the tube and found the reasonable results. In the present report, we analyzed the thrust loss of different types of forward slanted perforated tubes for various porosities and different perforation patters and identified a suitable type of forward slanted perforated tube which prevented the generation of peculiar tone at a wider range of pressure. The aero-acoustic performance has been diagnosed from the view points of sound pressure level and thrust. All experiments were conducted inside an anechoic chamber. Acoustic data were taken by 8-channel data acquisition devises along with other apparatus and the jet structures were observed by Schlieren apparatus along with high-speed video camera. Thrust loss was measured through a vertical wind tunnel to receive the data directly.

1. INTRODUCTION

Most supersonic jets are imperfectly expanded. In those jets, a quasi-periodic shock cell structure is formed in the jet plume. The passage of flow fluctuations through such repetitive shock structure results in the generation of shock associated broadband noise [1] and feedback induced screech noise [2]. At high supercritical pressure ratios, the noise generating mechanisms of the major sources of the radiated noise from supersonic jet flows (e.g., the mixing and the shock associated noise components) are often coupled [3]. Normally, the intensity of the shock generated acoustic radiation is directly dependent upon the shock strength and the level and coherence of the flow fluctuations convected through the shock front. Therefore, to suppress aerodynamic noise components radiated by imperfectly expanded single stream supersonic jet flows, the extent, the spacing, and the strength of the repetitive shock structure and the level and coherence of the jet fluctuations convected through the shock fronts need to be modified, so that the overall strength of the noise contributing sources and the effectiveness of their noise generating mechanisms are reduced. It has been known that the supersonic flow is produced by the addition of a perforated tube, and the 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. In the present experimental study a comparison of different types of forward-slanted perforated tube with various numbers of perforation as well as the different porosities has been carried out for a complete series of specifics sand has been diagnosed from the view points of noise reduction and thrust loss.

2. EXPERIMENTAL APPARATUS

A preliminary experiment using a convergent nozzle was carried out to obtain reference data for the nozzle of interest. The convergence angle, exit diameter (D), lip thickness, total length and the length of the converging parts of the nozzle were 30°, 10, 10, 110 and 26 mm respectively. Different types of forwarded-slanted perforated tube and a base tube (solid tube) were attached to the nozzle exit as shown in Fig. 1. The diameter of perforation (ϕ) and the number of perforation and the alignment of perforation of the tube were varied for different experiments. The thickness of the tube and the perforation angle were kept constant as 0.15D and 30º respectively. The parameters of perforated tubes are shown in Table. 1. The effective length of each tube was selected as 5D for the best performance [4, 5]. The diameters of all tubes were same as that of the nozzle exit. The porosity of the perforated tube was calculated as the ratio of the total porous area to the total surface area of the tube. The projected cross-sectional area on the tube surface was used to calculate the porous area of the perforated tube. Air compressor, air cooling separator, air dryer, oil mist filter were used to maintain the dry unheated jet of air.

Measurements of sound generated from an under expanded supersonic cold jet were

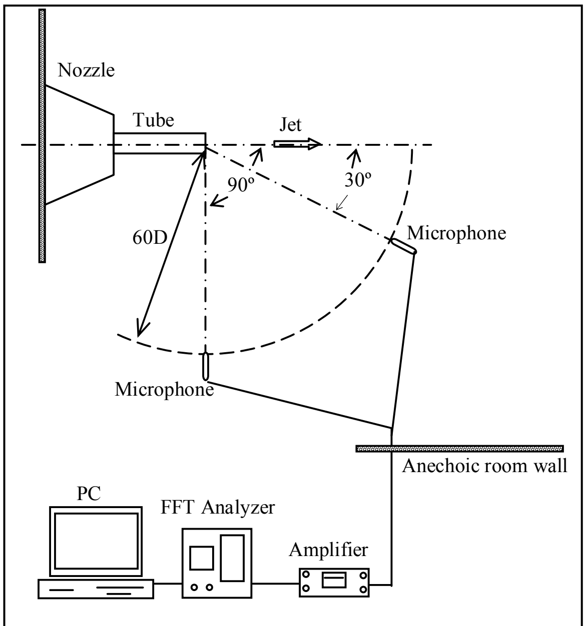


Figure 1- Schematic view of apparatus

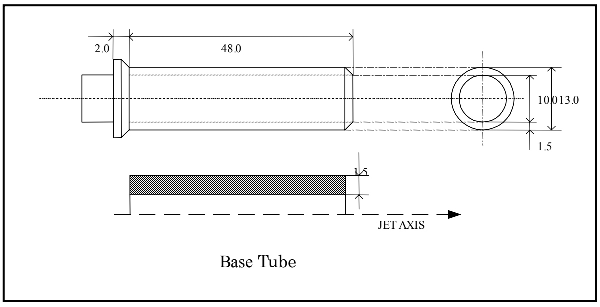


Fig.2 Cross section of Base Tube

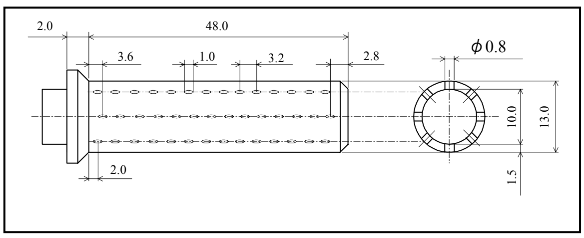


Fig.3 Cross section of a Perforated Tube (A14)

Table 1: Dimensions of Perforated Tubes

Tube	Diameter(a)	arrangement	Row×Line	Porosity
A4ϕ0.8	0.8mm	Alternation	8×4	0.018
A4ϕ1.0	1.0mm	Alternation	8×4	0.028
A4ϕ1.2	1.2mm	Alternation	8×4	0.040
A4ϕ1.5	1.5mm	Alternation	8×4	0.063
A6ϕ0.8	0.8mm	Alternation	8×6	0.027
A6ϕ1.0	1.0mm	Alternation	8×6	0.042
A8ϕ0.8	0.8mm	Alternation	8×8	0.036
A8ϕ1.0	1.0mm	Alternation	8×8	0.056
A9ϕ1.0	1.0mm	Alternation	8×9	0.063
A10ϕ0.8	0.8mm	Alternation	8×10	0.045
A10ϕ1.0	1.0mm	Alternation	8×10	0.070
A10ϕ1.2	1.2mm	Alternation	8×10	0.100
A12ϕ0.8	0.8mm	Alternation	8×12	0.053
A12ϕ1.0	1.0mm	Alternation	8×12	0.083
A12ϕ1.2	1.2mm	Alternation	8×12	0.120
A12ϕ1.5	1.5mm	Alternation	8×12	0.188
A14ϕ0.8	0.8mm	Alternation	8×14	0.062
A14ϕ1.0	1.0mm	Alternation	8×14	0.097
A14ϕ1.2	1.2mm	Alternation	8×14	0.140
A16ϕ0.8	0.8mm	Alternation	8×16	0.071
B4ϕ1.5	1.5mm	Back	8×4	0.063
N4ϕ1.5	1.5mm	Normal	8×4	0.031
N23ϕ1.5	1.5mm	Normal	4×(22+23)	0.176
P4ϕ1.5	1.5mm	Parallel	8×4	0.063
P9ϕ1.0	1.0mm	Parallel	8×9	0.063
P14ϕ0.8	0.8mm	Parallel	8×14	0.062

carried out in an anechoic chamber of 6 x 4.35 x 2.18 m in internal dimension. A condenser microphone of 6.35 mm (1/4 inch) (Bruel & Kjaer, Denmark) was used and traversed along a measuring path of 60D radial distance from the center of the nozzle (as well as perforated and base tubes) exit as shown in the figure. The microphone was plae making angles of 30º and 90º with the jet axis. Acoustic signals were taken with the help of a signal amplifier and a FFT analyzer. Pressure ratio (the ratio of the jet pressure to the ambient pressure) was changed from 1.2 to 4.0 at a step of 0.2. Moreover, the acoustical data were taken also for the pressure ratios of 4.5, 5.0, 5.5 and 6.0. Thrust data of different tubes were taken by a vertical wind tunnel as shown in Fig. 4. Furthermore acoustic power level was measured in a reverberation room of about .60m^3 in volume.

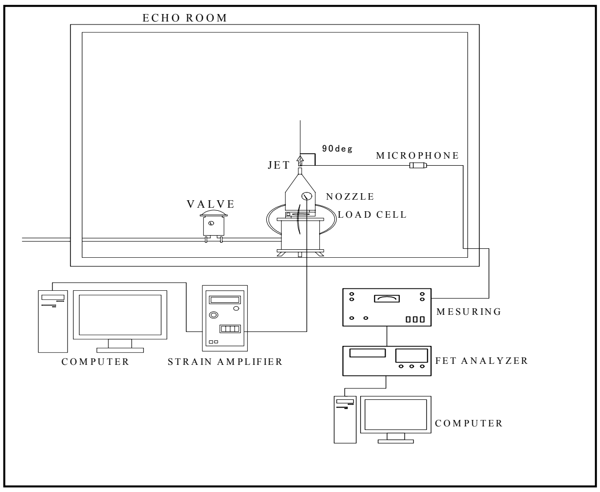


Fig.4 Thrust measuring system by using a vertical wind tunnel

3. EXPERIMENTAL RESUTLS AND DISCUSSION

The performance of noise suppression of a forward-slanted perforated tube was compared with various types of forward-slanted perforations. The differences among perforated tubes were done mainly by changing the numbers and the diameters of the perforations. The perforated tubes named A-type were selected according to the alignments or distribution patterns of the perforations

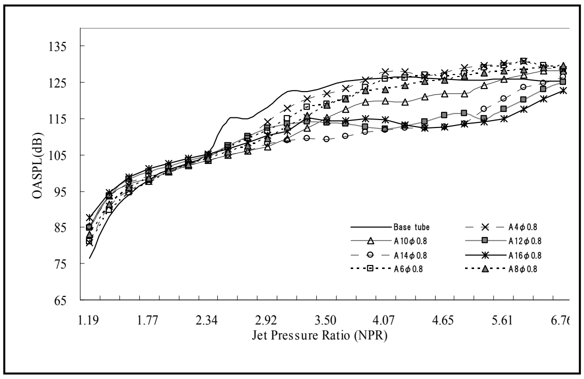


Fig. 5 OASPL of A-type perforation for different perforation numbers (90º)

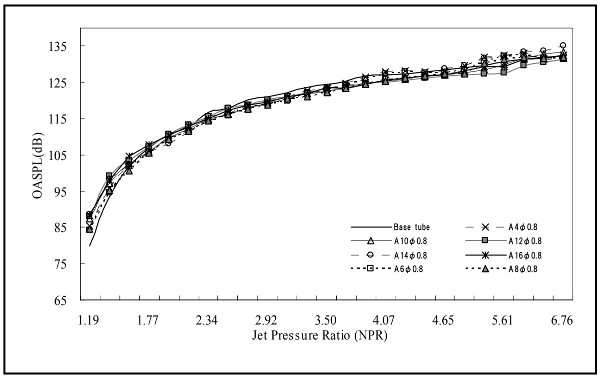


Fig. 6 OASPL of A-type perforation for different perforation numbers (30º)

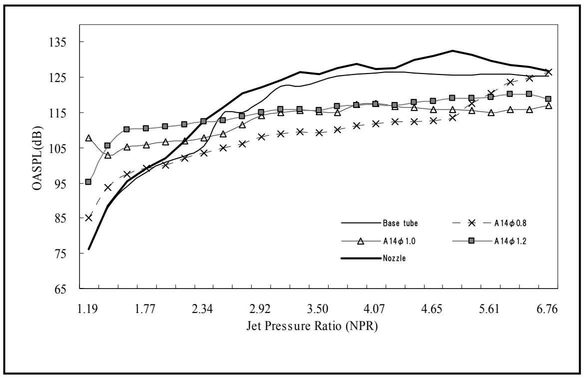


Fig. 7 OASPL of A-type perforation for different perforation diameters (90º)

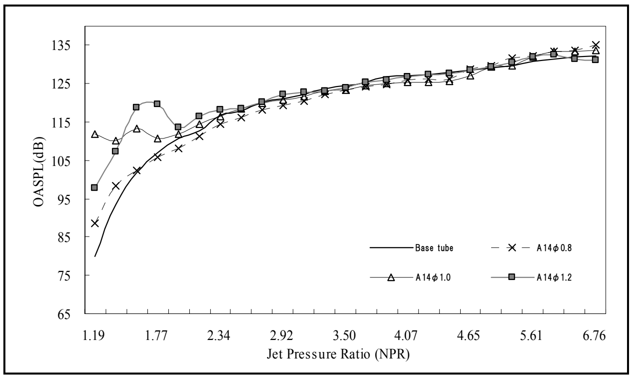
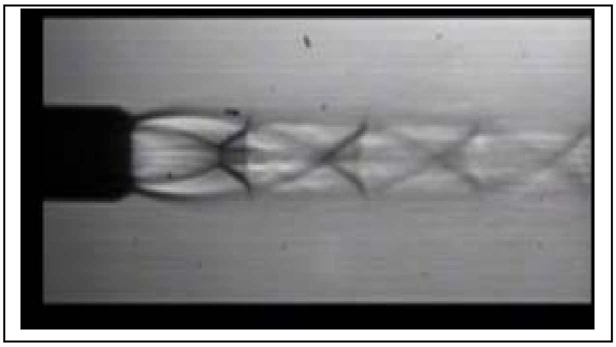
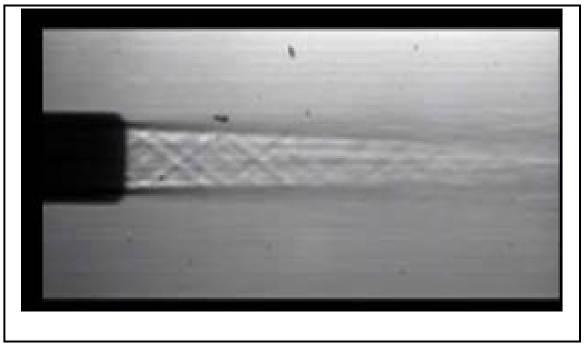


Fig. 8 OASPL of A-type perforation for different perforation diameters (30º)

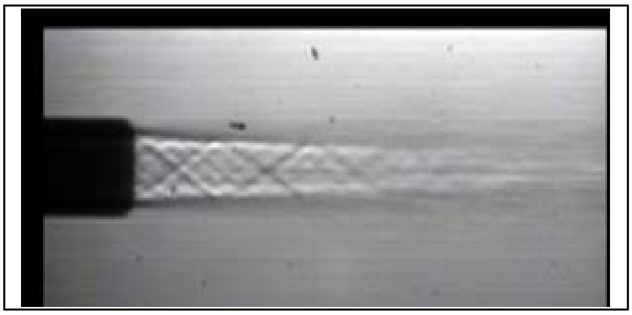
on tubes since A-type tubes contained the alternate (staggered) distributions of perforation. That type of tube was classified again based on the numbers of perforation as well as the diameters of perforation on the tube surface. The numbers of perforation were selected as 8x4, 8x6, 8x8,8x10, 8x12, 8x14 and 8x16with keeping the diameter of each perforation hole constant to 0.08D. Furthermore, three A14-type tubes were constructed with three different diameters of perforation hole as φ (mm) = 0.8, 1.0 and 1.2. and four A12-type tubes were constructed with four different diameters of perforation hole as φ (mm) = 0.8, 1.0 ,1.2 and 1.5. According to the changes in perforation number and in perforation diameter change in porosity is caused. Therefore, the numbers as well as the diameters of perforations of the tube were changed to check the performance of the tubes as the noise suppressor. The specifications of all tested tubes are shown in Table 1 and base tube is shown Fig. 1. Furthermore a typical example of a tube with forward slanted perforation is shown in Fig.3.The suppressions of overall noise (OASPL) observed at 90° and 30° points are shown in Figs. 5 and 6 respectively for a variety of perforation numbers with a diameter fixed at 0.8mm. Almost all types of perforated tubes suppressed the noise level compared to base tube. At higher pressure ratios (higher than 4.0), however, the performance of A4-type tube was degraded in noise suppression in 90º. A14-type perforated tube showed excellent performance at almost all pressure ratios. The advantages were found in both cases of observations. The better performance in noise suppression was found however in 90° observations for the case of A14-type perforated tube (Fig. 5). The performance of noise suppression for A-type perforated tube with various perforation diameters are shown in Figs. 7 and 8. Among all perforated tubes the A14φ0.8-type perforation showed the best performance. The tube with perforation of A12φ0.8 specification also showed the



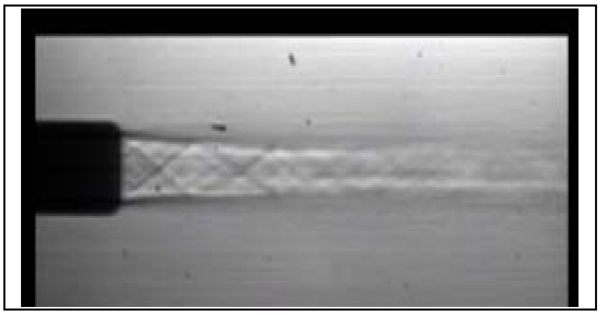
(a) Base tube



(b) A14φ0.8



(c) A14φ1.0



(d) A14φ1.2

Figure 9. Schlieren photographs of A-type perforations for different diameters of perforation. Pressure ratio 4.0

better noise suppression compared to the A4φ0.8 or A10φ0.8 type perforated tubes. At lower pressure ratios, the performances of those two tubes (A4φ0.8 or A10φ0.8) were also degraded.

The fluid dynamic behavior of the jet issued from the nozzle is shown in Fig. 9. Strong shock structures were present in the jet ejected from the base tube. First to fourth shock cells were visualized in the nozzle flow. It was observed that the third and the fourth shock cells were oscillated violently which was considered to generate screech component and increased the OASPL. The modification of the jet by using each A14-type perforated tube is shown in the figures. The presence of the strong expansion waves showed that the jet was over-expanded in the case of A14φ1.0 or A14φ1.2 tubes and increased the noise level; however, in the case of A14φ0.8 tube that effect is relatively smaller and thus the tube showed the favorable performance in noise suppression.

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 were compared with a theoretical result and plotted against jet pressure ratios. The theoretical thrust was given by the following jet momentum equation as follows [5]:

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

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. The thrust of an underexpanded nozzle is considered as

$$F_n = \dot{M}V_j + (P_j - P_0)A = \rho V_j^2 A + \frac{1}{2}\rho \overline{V}^2 - \frac{1}{2}\rho V_j^2 = \frac{1}{2}\rho V_j^2 A + \frac{1}{2}\rho \overline{V}^2 \cdots (2)$$

where $\overline{V}$ means the average velocity after expansion.
On the other hand, the thrust of a perforated tube is

$$F_v = \dot{M}\overline{V} = \rho \overline{V}^2 A \cdots (3)$$

Since $\overline{V}$ is greater than V_j, the latter is greater than the former thrust if the mass flow is same. Comparisons of the theoretical thrust and the measured thrust of a nozzle as well as of a base tube and of different A14-type perforated tubes are shown in Fig. 10. The comparison concerning a nozzle shows the close relation between the theoretical and the experimental result of the nozzle. Thrusts of base tube and different perforated tubes were also measured and plotted against jet pressure ratio, which are shown also in the same figure. As the porosity of the A14φ0.8 perforated tube was smaller, it showed the lower thrust loss than that of A14φ1.0 or A14φ1.2 tubes. Another comparison of thrust loss of two perforated tubes (A8x14φ0.8 and A8x12φ0.8) and one slotted tube (S8 30 10; indicates 8 slot, each slot 30mm long and 1mm thick) is shown in Fig. 9. The vertical axis of the figure shows the reduction of thrust in percentage compared to a base tube. It is found that as the porosity of the A8x14φ0.8 perforated tube is higher, it suffered also the higher thrust loss compared to other two tubes. It has been confirmed however, compared to the overall aero-acoustic performance, A8x14φ0.8 perforated tube showed the best performance as a noise suppressor if the pressure ration is not very high. Figure 11 shows the reduction of acoustic power (that is represented in positive value) and thrust loss (that is represented in negative value) by using A14 φ1.0 perforated tube.

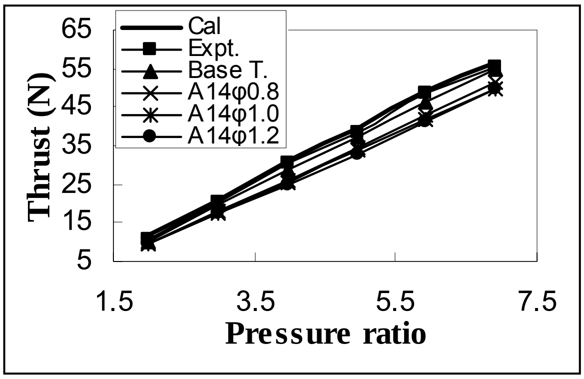


Figure 10 – Thrust loss compared to nozzle, basetube and different A14-type perforated tubes.

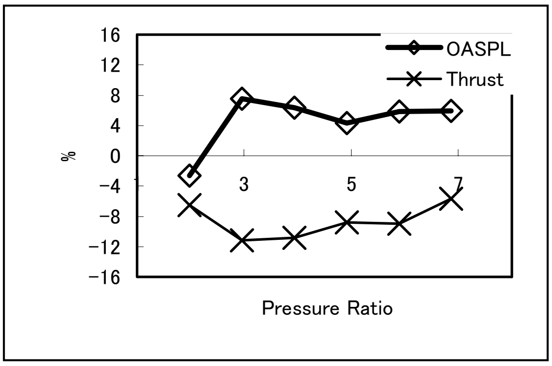


Fig.11 Reduction of Power spectrum and thrust loss of A14 φ1.0 . Measured in a reverberation room.

CONCLUSIONS

A forward-slanted perforated tube with 8x14 numbers of perforations which were alternately distributed on the tube surface (A8x14-type tube) showed the best performance in reducing the noise generated from a supersonic jet among all other forward slanted perforated tubes that were tested in the present research.

The A8x14φ0.8 (also expressed as A14φ0.8) type perforated tube performed the best performance as a noise suppressor. It also negotiated well with the low thrust loss.

Thus, it may be stated as a concluding remark that the forward slanted perforated tube with specification of A8x14φ0.8 shows the preferable performance as a noise suppressor concerning overall aero-acoustic characteristics.

However, at very high pressure ratio, A14φ1.0 is preferable to A14φ0.8, the former generating a peculiar discrete tone at very low pressure ratio.

REFERENCES

[1] C. K. W. Tam, "Supersonic Jet Noise", *Annu. Rev. Fluid Mechanics*, **27**, 17-43 (1995).

[2] A. Powell, "On the Mechanism of Choke Jet Noise", *Proc. Phys. Soc.*, **66**, 1039-1056 (1953).

[3] J. M. Seiner, "Advances in High Speed Jet Aeroacoustics", AIAA Paper 84-2275 (1984).

[4] K. Seto, M. Matsuoka, and T. Maeda, "Study of Porous Tubes as a Noise Suppressor: 1st Report, Experiments on Fundamental Characteristics and Optimal Length", *Trans. Jpn. Soc. Mech. Eng., (in Japanese)*, **53**, 268-273 (1987).

[5] 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).