



STUDY OF AERO-ACOUSTIC PERFORMANCE OF FORWARD SLANTED PERFORATED TUBE

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Abstract

The aeroacoustic performance of a forward-slanted perforated tube with different perforation patterns and different porosities has been experimentally investigated. 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 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 also compared 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. 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 analyzed by Schlieren apparatus along with high-speed video camera. Thrust loss was measured through a vertical wind tunnel to receive the data directly. The performances of different types of slotted tubes were compared in the present experiment.

INTRODUCTION

Most supersonic jets are imperfectly expanded. In these 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 improperly 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 and has found the reasonable results.

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 forward-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 30° 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 carried out in an anechoic chamber of $6 \times 4.35 \times 2.18$ 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 placed in the same horizontal plane of the tube making angles of 30° and 90° 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 2.2 to 4.0 at a step of 0.2. Moreover, the acoustical data were taken also for the pressure ratios of 4.4, 4.8, 5.0, 5.8, 6.2, 6.6 and 7.0. Thrust data of different tubes were taken by a vertical wind tunnel.

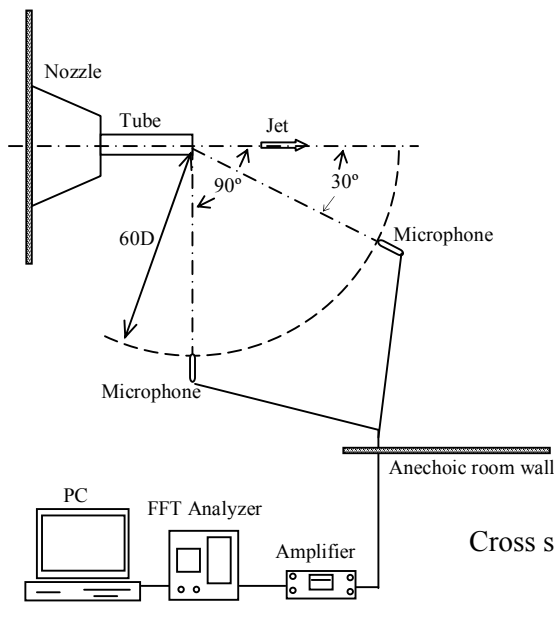


Table 1: Dimensions of Perforated tubes

Tube	Alignment	ϕ , mm	No. of hole	Porosity
A4	Alternate	0.8	8x4	0.018
A10	Alternate	0.8	8x10	0.045
A12	Alternate	0.8	8x12	0.053
A14	Alternate	0.8	8x14	0.062
A14	Alternate	1.0	8x14	0.097
A14	Alternate	1.2	8x14	0.14

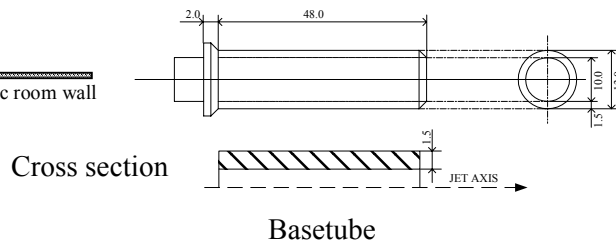


Figure 1- Schematic view of apparatus.

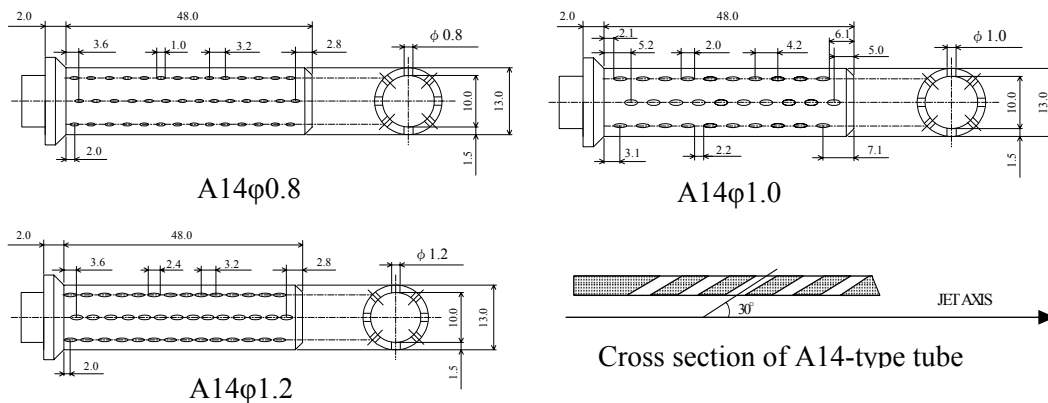


Figure 2 – Schematic view of each forward-slanted perforated tube.

EXPERIMENTAL RESULTS 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 on tubes since A-type tubes contained the alternate 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, 8x10, 8x12 and 8x14 with 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. According to the changes in perforation number and in perforation diameter change in porosity takes place. 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 Fig. 1 and in Table 1. The suppressions of overall noise (OASPL) observed at 90° and 30° points are shown in Figs. 3 and 4 respectively. Almost all types of perforated tubes suppressed the noise level compared to Nozzle and base tube. At higher pressure ratios (higher than 4.4), however, the performance of A4-type tube was degraded in noise suppression. And, at lower pressure ratios (lesser than 1.5) the performances of all perforated tubes deteriorated except the A14-type perforated tube. 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. 3). The performance of noise suppression for A-type perforated tube with various perforation diameters are shown in Figs. 5 and 6. Among all perforated tubes the A14 ϕ 0.8-type perforation showed the best performance. The tube with perforation of A12 ϕ 0.8 specification also showed the better noise suppression compared to the A4 ϕ 0.8 or A10 ϕ 0.8 type perforated tubes. At lower pressure ratios, the performances of those two tubes (A4 ϕ 0.8 or A10 ϕ 0.8) were also degraded.

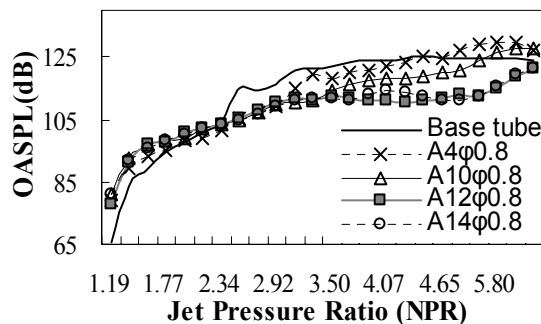


Figure 3 - OASPL of A-type perforation for different perforation diameters (90°)

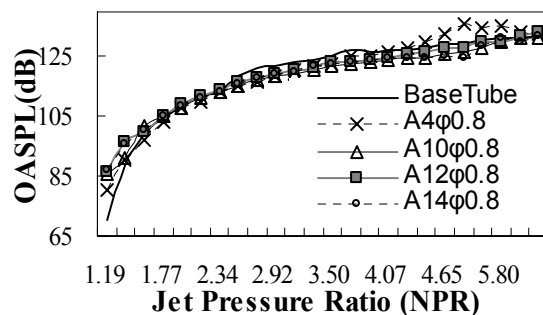


Figure 4 - OASPL of A-type perforation for different numbers of perforation (30°)

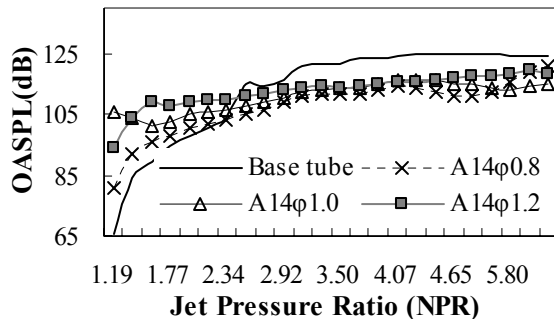


Figure 5 - OASPL of A-type perforation for different perforation diameters (90°)

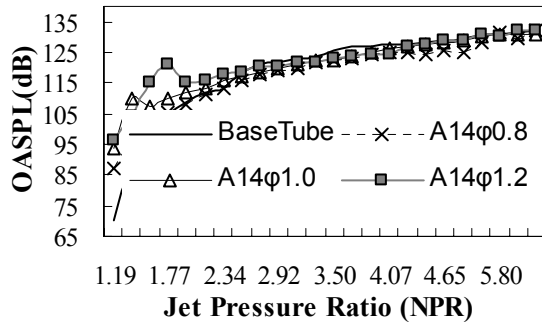
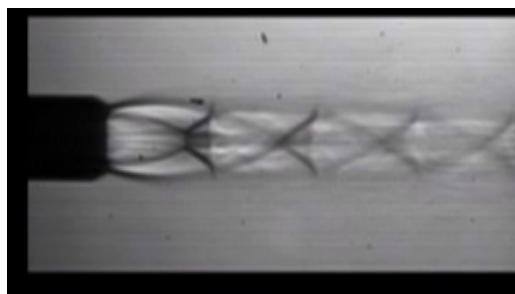
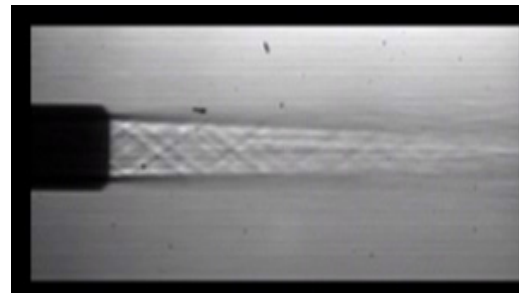


Figure 6 - OASPL of A-type perforation for different numbers of perforation (30°)

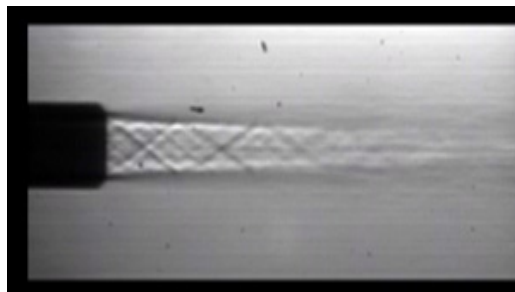
The fluid dynamic behavior of the jet issued from the nozzle is shown in Fig. 7. Strong shock structures were present in the jet ejected from the base tube. First to fourth shock cells were visualized in the nozzle flow. It was observed that the third and the fourth shock cells were oscillated violently 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.



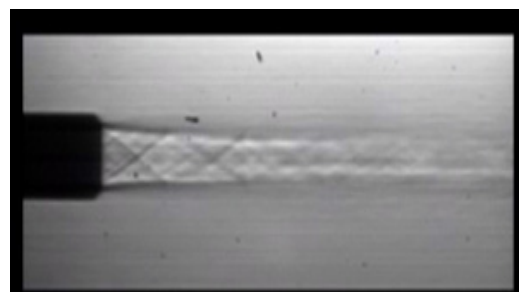
Base tube



A14φ0.8



A14φ1.0



A14φ1.2

Figure 7 – Schlieren pictures of A-type perforations for different diameters of perforation.

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. 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. 8. 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 A14 ϕ 0.8 perforated tube was smaller, it showed the lower thrust loss than that of A14 ϕ 1.0 or A14 ϕ 1.2 tubes. Another comparison of thrust loss of two perforated tubes (A8x14 ϕ 0.8 and A8x12 ϕ 0.8) 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 A8x14 ϕ 0.8 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, A8x14 ϕ 0.8 perforated tube showed the best performance as a noise suppressor.

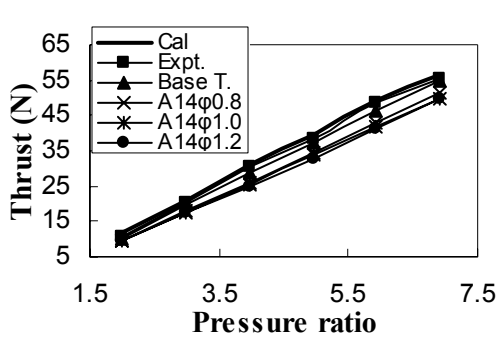


Figure 8 – Thrust loss compared to nozzle, basetube and different A14-type perforated tubes.

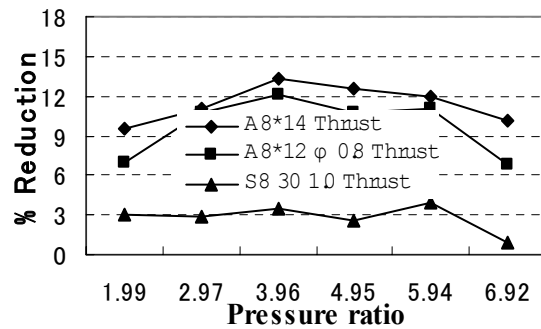


Figure 9 – Thrust loss compared to A-type perforated tubes and the best performed slotted tube.

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 A8x14 ϕ 0.8 (also expressed as A14 ϕ 0.8) 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 A8x14 ϕ 0.8 shows the best performance as a noise suppressor concerning to overall aero-acoustic characteristics.

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