FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

Invited Paper

Experimental Estimation of Aerodynamic Noise Radiated from Ventilating Gas Exit of Vehicle Tunnels

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ABSTRACT

There are some aerodynamic noise source around the ventilating gas exit of vehicle tunnels, although many silencers are installed in ventilating duct for fully reducing the fan-noise. Small model experiments have been done by using the Quiet-Flow Acoustic Wind-Tunnel to study a method of aerodynamic noise estimation from ventilating gas exit of vehicle tunnels. It was considered by experimental results that the dominant noise source is aerodynamic noise generated by vortex shedding at the front side edge of exit port. Two-type equations with using side length of the exit for predicting exhaust flow noise have been induced by this experimental study. Basical methods to estimate the exhaust flow noise from ventilating gas exit of vehicle tunnels have been understood .

1. INTRODUCTION

Noises heard around a ventilation tower are usually consist of fan noises, flow-noises of induct objects or exit wire-meshes for protections, and aerodynamic self noises from an exhaust gas flow as indicated in Figure 1. Those of first two can be completely reduced by using strong scilencers. However, the rest can not be controlled only by using silencers. In this study, the key factor was to understand characteristics of aerodynamic self noises from an exhaust gas flow for the basical noise estimation around the ventilation tower. Aerodynamic noise sources were still generated by the exhaust gas around the exit port of ventilation towers in spite of many scilencers being installed in the ventilating duct for complete fan-noise reduction. For studying the method of estimating aerodynamic noises radiated from the exhaust gas flow of vetilating towers at the higher velocity condition than the usual velocity, small model experiments were examined using the Quiet-Flow Acoustic Wind-Tunnel[1]. In this experimental study, noise change by flow velocity, noise reductions by distances, and noise change by exit area were investigated. In addition, we developed a method for estimating far-field noise through consideration on the experimental results.

2. EXPERIMENTAL METHOD

Model nozzles of a ventilation tower exit port were installed on the measuring section of the Quiet-Flow Acoustic Wind-Tunnel which is located in the anechoic chamber. Aerodynamic noises generated from blowing out flows of model nozzles were measured by

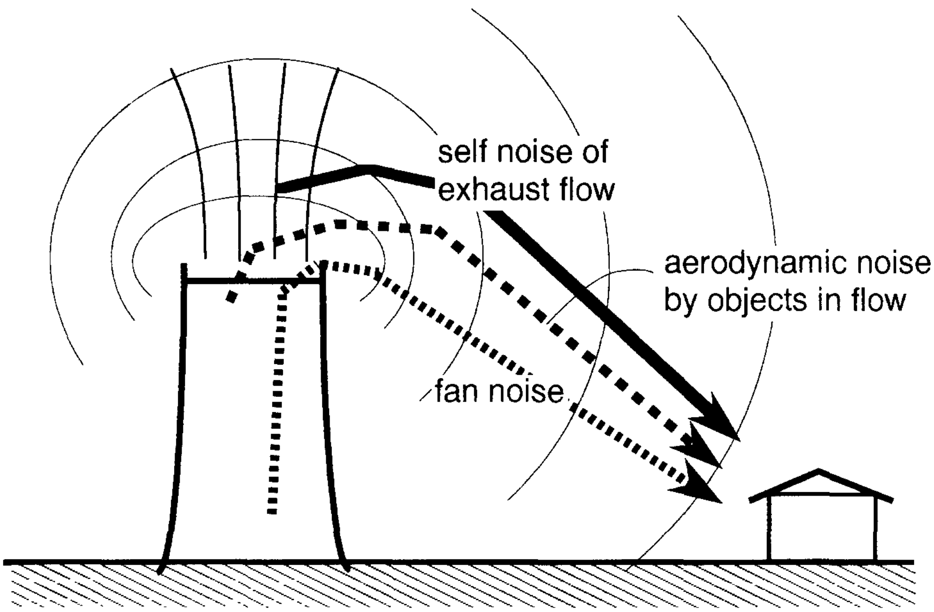


Fig. 1 Noises heard around a ventilation tower usually contain several noises.

precision microphones around nozzle exits. The shape of model nozzle exits was rectangular but scales were varried from 100mm × 100mm to 600mm × 600mm as shown in Table 1 and in Figure 2. These nozzles were exchangeable to connect with the straight duct 600mm × 600mm of the acoustic wind tunnel. The velocity of blowing out flow changed from 10m/s to 30m/s. Distances from the exit center to each micropohnes differed from 0.8m to 4.0m in the anechoic chamber. Noise data measured in this experiment were examined in overall A-weighted sound pressure levels although the measured noises were analyzed to frequency components by a realtime type 1/3octave band frequency analyzer.

Table 1 Exit shapes used in the model experiments.

Exit type	d_a (mm)	d_b (mm)
□ 600 × 600	600	600
□ 500 × 500	500	500
□ 400 × 400	400	400
□ 300 × 300	300	300
□ 200 × 200	200	200
□ 150 × 150	150	150
□ 100 × 100	100	100
□ 300 × 600	300	600
□ 200 × 600	200	600
□ 150 × 600	150	600
□ 100 × 200	100	200
□ 50 × 200	50	200

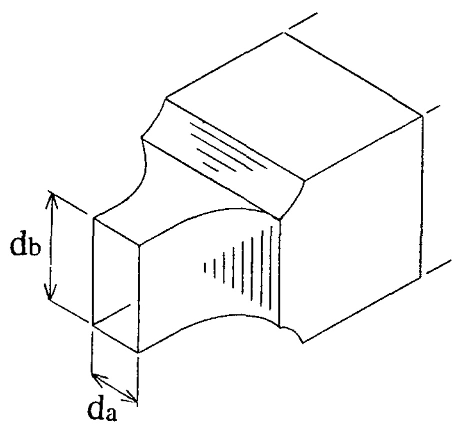


Fig. 2 A rectangular model exit.

3. EXPERIMENTAL RESULT

3.1. Characteristics of the noise by the change of flow velocity and distance.

Our experiments made clear on characteristics of exhaust-flow noise from model nozzles as follows. The aerodynamic noise power was proportional to the 6th power of gas flow velocity as shown in Figure 3. This figure indicates the one of similar results at many measuring positions with respect to the velocity change. This result meant that the dominant aerodynamic noise source of nozzle exhaust flow was not the jet-flow self noise. Changes of these noise spectra with respect to the exhaust velocity were nearly similar to each other on diferent observing positions as shown in Figure 4.

Low frequency components showed relatively decrease in the far direction from downstream exhaust flow. And middle frequency components decreased proportionally to the about square of distance from the exit center. While, A-weighted noise levels were a little larger in the direction of perpendicular to the exhaust flow than in downstream directions.

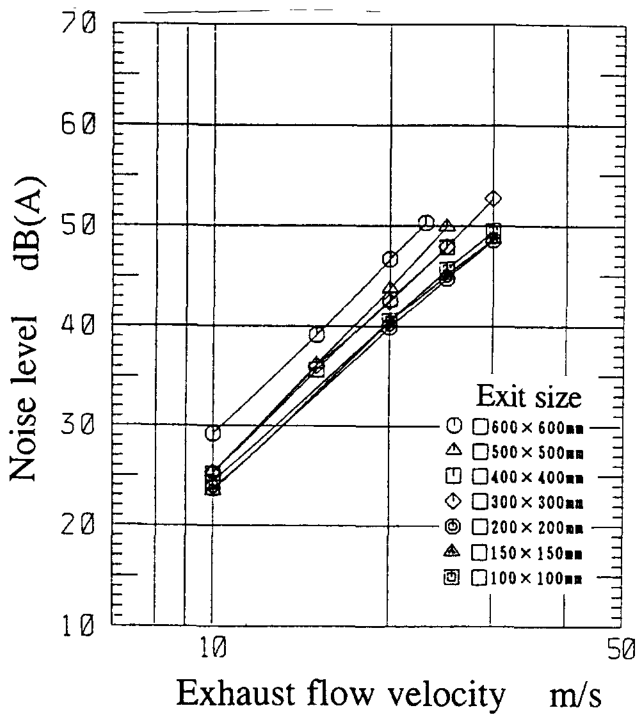
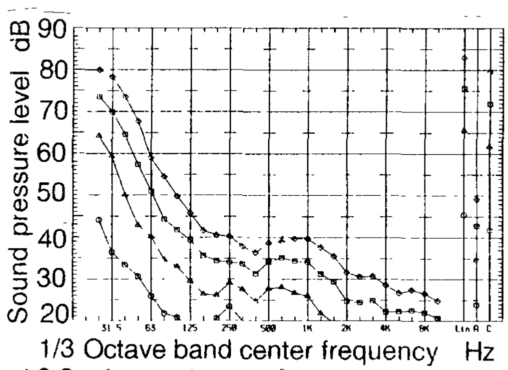
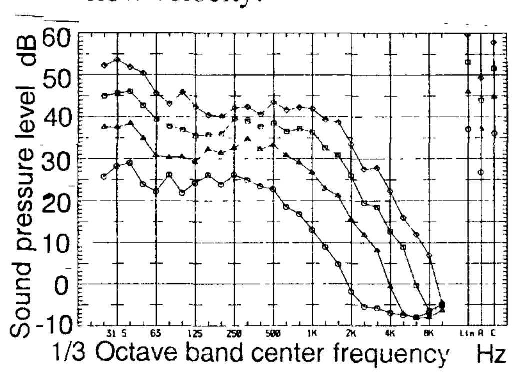


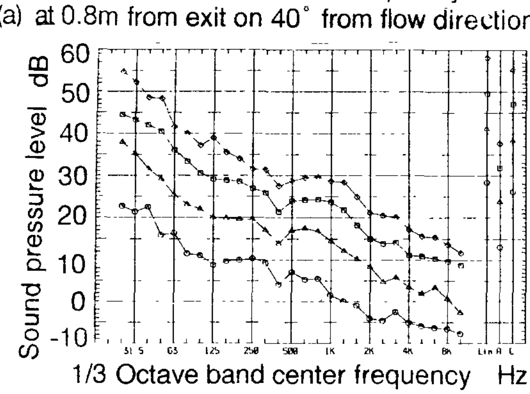
Fig. 3 The measured noise power was proportional to the 6th power of gas flow velocity.



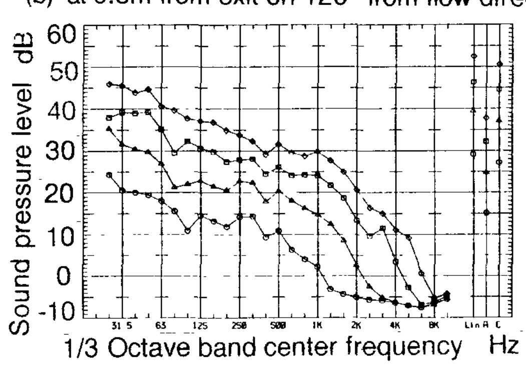
(a) at 0.8m from exit on 40° from flow direction.



(b) at 0.8m from exit on 120° from flow direction.



(c) at 3.2m from exit on 40° from flow direction.



(d) at 3.2m from exit on 120° from flow direction.

Fig. 4 Noise spectra at typical positions change with flow velocity
○ : 10m/s, △ : 15m/s, □ : 20m/s, ◇ : 25m/s (exit size ; 400 × 400)

3.2. Noise changes with exit cross section area

Change of noise levels was rearranged with respect to the exit areas as shown in Figure 5. In this figure, distances from the each exit center are varied as parameters and each curves those indicate level changes on a same distance were similar to others. Noise powers from exhaust flow were independent on the exit cross section area less than $0.04m^2$. Such noise power was proportional to the 1/2nd power of the exit area from $0.04m^2$ to $0.2m^2$ and to the 3/2rd power of the area larger than $0.2m^2$. Thus relations between noise powers and exit cross section areas were not simple.

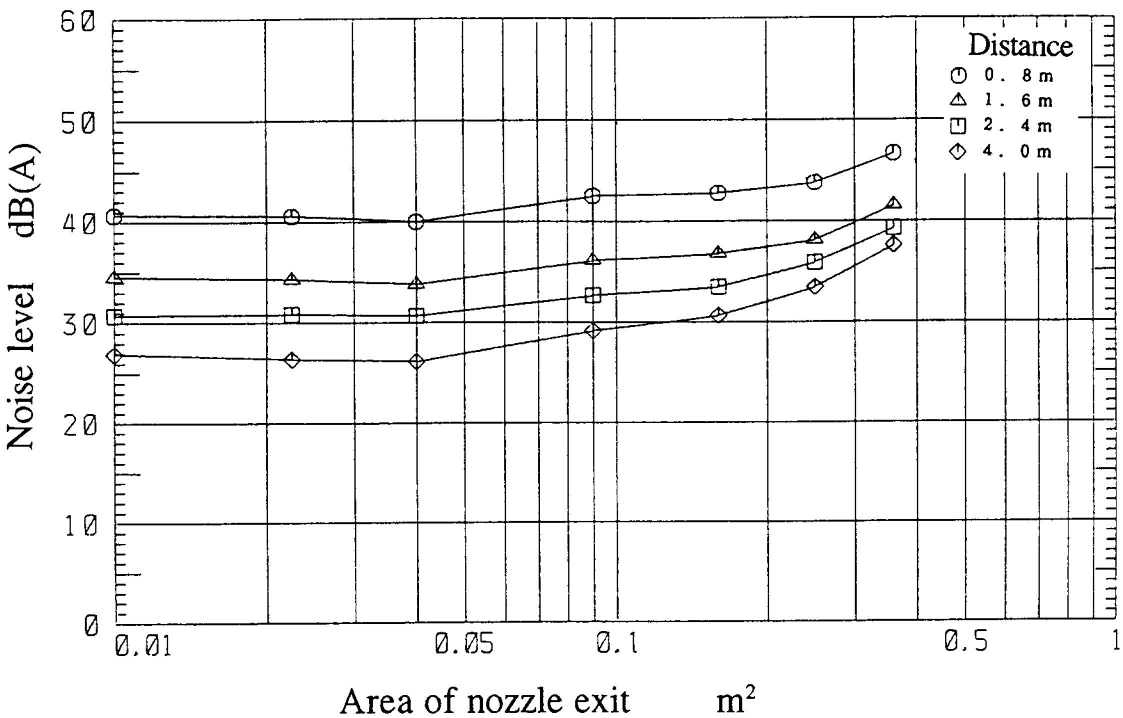


Fig. 5 Noise pressure changed with non-linear function of exit areas.
(at exhaust flow velocity 20m/s, in the direction of perpendicular to the flow)

4. CONSIDERATION

4.1. Identification of noise source

Generally speaking, the blowed out flow from a nozzle like an exit port of a ventilation tower ordinaly generates three aerodynamic noise sources; jet-flow noise, shear flow layer noise, and noise by vortexe sheddings, as shown in Figure 6[2]. Detail characteristics of aerodynamic noise around the exthaust gas flow are depending on the dominant of these noise sources, which may be determined by flow conditions. Considering noise sources based on above experimental results that the noise power was proportinal to the 6th power of the flow velocity and noise levels were a little larger in the direction of perpendicular to the exhaust flow than in downstream directions, the dominant noise source from exhaust flow might be the aerodynamic noise which was generated by vortexe sheddings from edges of the nozzle exit[3].

We assumed that the length of exit side was more inportant factor for predicting aerodynamic noises radiated from exhaust flows of ventilation towers. Using non-dimentional distance normalized by the front side length of each exit, rearrangement of noise data indicated that decrease rates were nearly same each other as shown in Figure 7. Noise intensity was decrease proportionally to about the 1.5th power of the non-dimensional distance. The noise level of small size exit was larger than that of large size exit of the same non-dimensional distance. Such results suggested that the shape of noise source was considered as the finite line on exit side as shown in Figure 8. And the assumption that

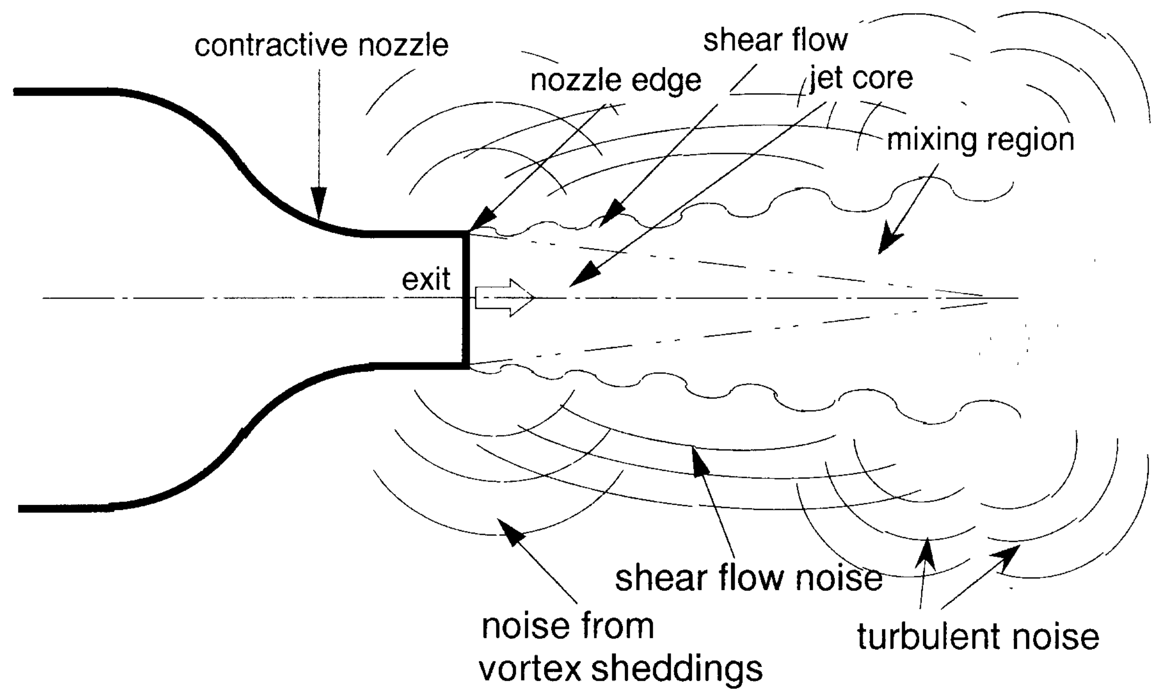


Fig 6 The blowed out flow from a nozzle ordinaly generats three kinds of aerodynamic sound sources.

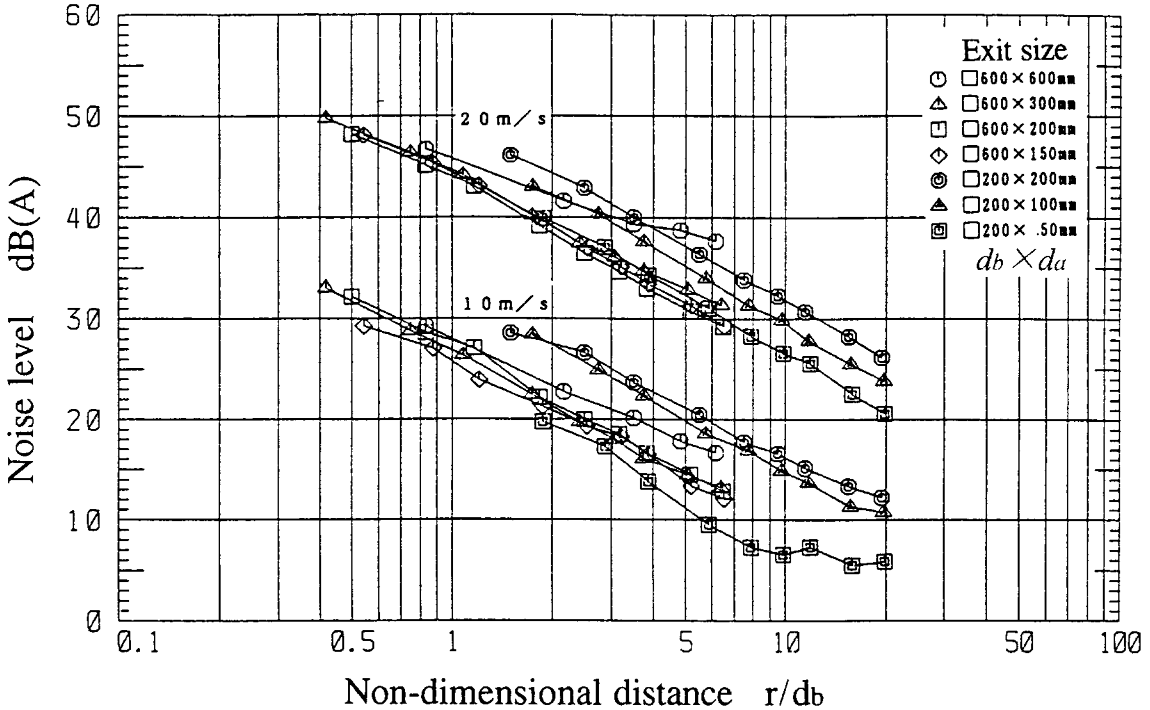


Fig. 7 Exhaust flow noise decreases almost constant by the non-dimensional distance normalized by the front side length of retangular exit.

dominant noise sources were aerodynamically generated by vortexe sheddings on exit side edges was effective. Noise source power per unit length of exit side was calculated from measured data based on the assumption that noise source shape was finite line[4]. They were nearly constant and almost independent on exit sizes as shown in Figure 9.

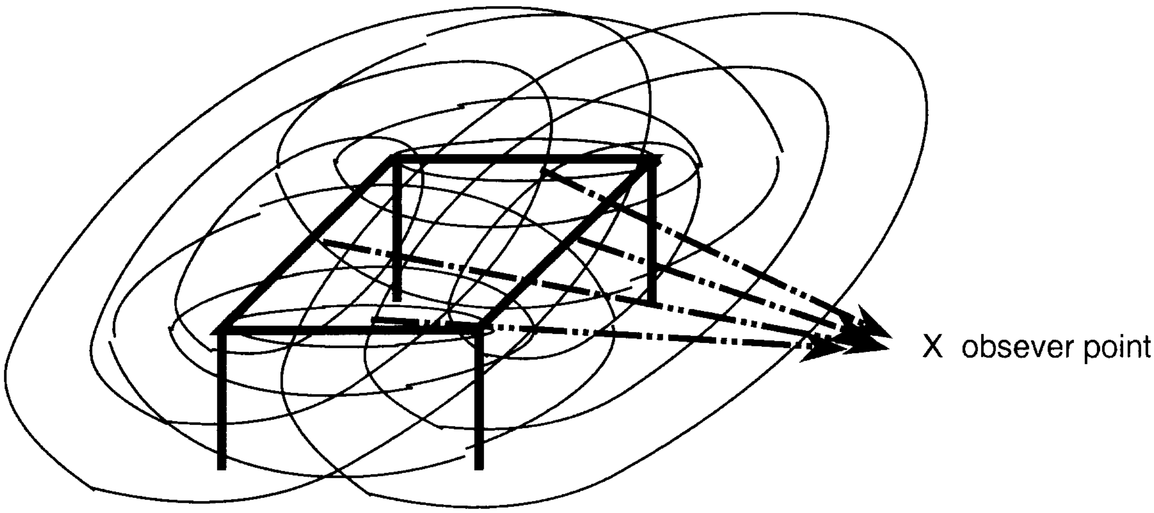


Fig. 8 The assumption that the shape of noise source was regarded as the finite line on exit side of the ventilation tower was suggested by the consideration of experimental resuls.

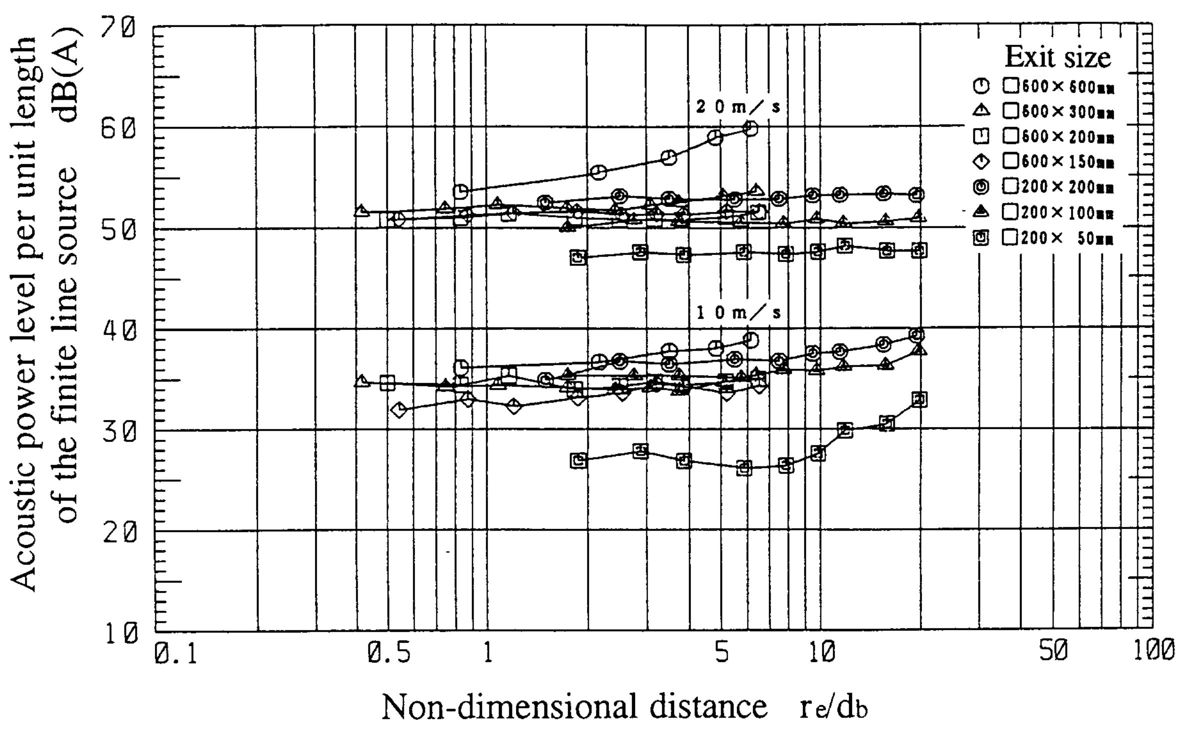


Fig. 9 Noise source powers calculated on the asummption of the finite line source were also nearly constant for the rectangular exit cases.

The characteristics that noise source power per unit length of exit sides were almost constant was the proof that the above assumption was reasonable. And from this conclusion that the source shape was a finite line on exit sides, aerodynamic noises radiated from exhaust flows were almost proportional to the length of exit sides.

4.2. Approximated equations for exhaust flow noise prediction

The uniform distribution of noise source power generated by vortex sheddings with the exhaust flow on four exit sides radiated the exhaust flow noise of the ventilation tower. Noise level L_A (dB) around a ventilation exit could be estimated by using the next equation formed from above considerations.

$$10(L_A/10)/(U^6 w_s/2\pi) = \tan^{-1}(d_b/2r_e)/r_e + \tan^{-1}\{d_b/2(r_e+d_a)\}/(r_e+d_a) + [\tan^{-1}\{2(r_e+d_a)/d_b\} - \tan^{-1}(2r_e/d_b)]/(d_b/2)$$

where, U is the exhaust flow velocity, and w_s is the sound power per unit length of exit side edge measured by experiments in the specific condition. And d_b is the length of front side edge of a exit, d_a is the length of lateral side edge, and r_e is the distance from the front side to the observing point for noises as shown in Figure10. On the above equation, the 3rd term of right hand side indivates noise components radiated from both lateral side edges. This term could be omitted as smaller than other terms. Then next equation was approximated as the decibell transformation.

$$L_A = 10\log[1+\{1/(1+d_a/r_e)\}^2] + 10\log\{\tan^{-1}(d_b/2r_e)/2\pi r_e\} + 60\log U + 10\log w_s \quad (1)$$

This equation expresses radiation noise from front and back side edges of an exit in detail. As the more dominant noise source was the front side edge, sipmlifying this equation in the far-field condition, next equation was approximated as follows.

$$L_A = 10\log(d_b/2\pi r_e^2) + 60\log U + 10\log w_s \quad (2)$$

Through copmaring these two predicting equations and experimental data, they made a good agreement as shown in Figure 11. Therefore, above assumptions and aproximations can be considered reasonable.

Here, noise level on the next condition was estimated by using this simplified Equation (2) with respect to the real ventilation tower, as an example[5]. In the case of the exhaust flow velocity at 20m/s, the exit size, d_a=d_b=5m, and the distance from the front side edge to observing point, r_e=17.5m, the predicted noise level is 34 dB(A). Such noise is usually lower than back ground noise levels around the ventilation tower.

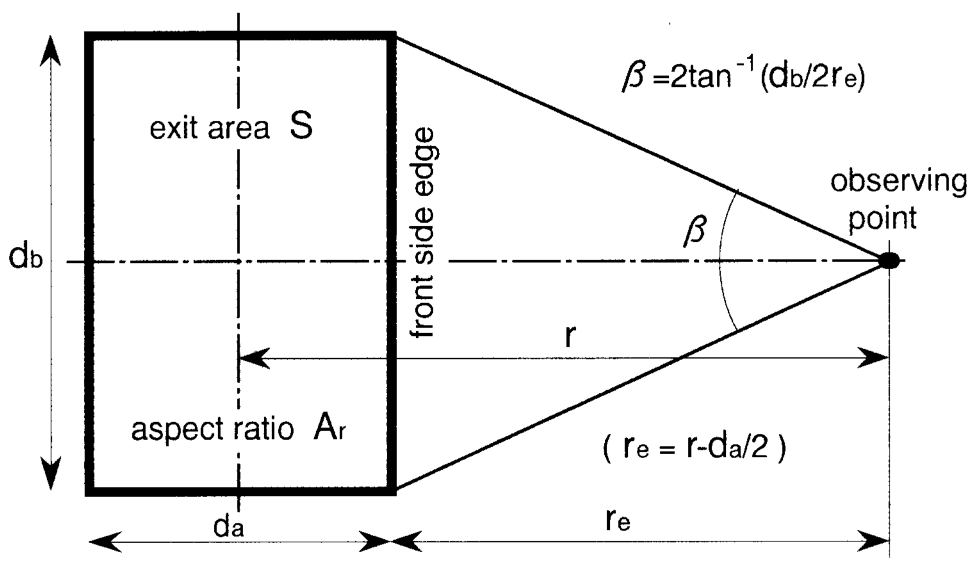


Fig. 10 Configulation of typical sizes around the exit used for estimations.

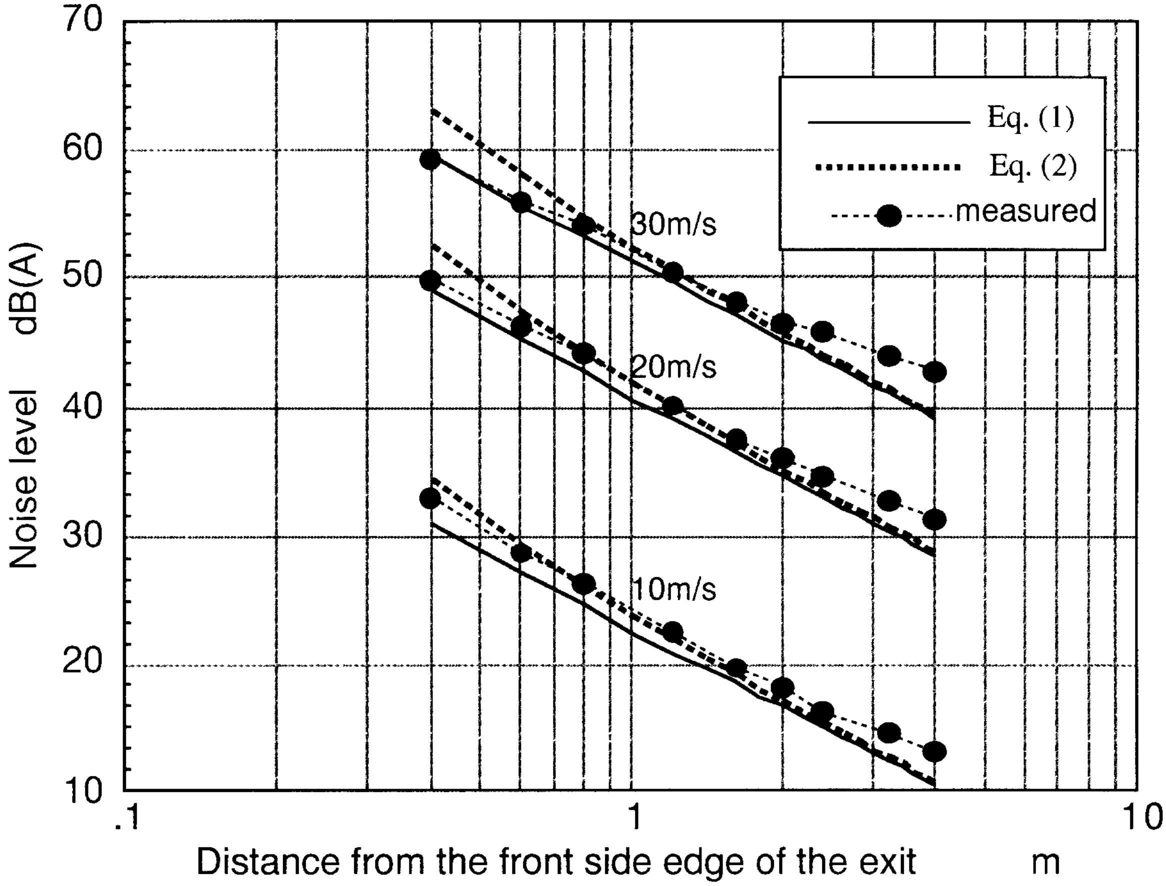


Fig. 11 Examples of estimated noise radiated from exhaust flows (exit type 600 x 300).

5. CONCLUDING REMARKS

Small model experiments have been performed for studying the method of estimating exhaust gas flow noise radiated from vetilation tower, using the Quiet-Flow Acoustic Wind-Tunnel. In this experimental study, shapes of the exits are square or rectangular and the length of exit-side was changed from 0.15m to 0.6m. The velocity of exhaust gas flow was also changed from 10m/s to 30m/s. Characteristics of exhaust-flow noise and methods for noise prediction have been made clear as follows.

(1) The aerodynamic noise power was proportional to the 6th power of gas flow velocity and was proportional to the front side length of exit.

(2) It was considered that the dominant noise source was aerodynamic noise generated by vortex shedding at the front side edge of the exit.

(3) Exhaust flow noise could be estimated by using side lengthes of exit, distance from front side of exit, and the velocity of exhaust flow.

(4) Two types of equations for predicting exhaust flow noise were formed. One was for a precise approximation and another one was for a rough prediction.

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