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Characteristics of flow-induced noise generated by air flow passing through perforated plates and impinging on a flat plate

Kazuya Koyama (1), Akikazu Uchikawa (1), Naoya Kojima (1), Masato Mikami (1), Takashi Esaki (2)

(1) Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi 755-8611, Japan
(2) Sango Co., Ltd., 5-35 Yawatayama, Miyoshi, Miyoshi, Aichi 470-0224, Japan

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ABSTRACT

Mufflers are employed in the exhaust pipe to reduce the exhaust noise from automobiles. Perforated plates are often placed inside the muffler to reduce noise and enhance the strength of the muffler. However, the flow passing through the perforated plate would impinge on another inner plate and generate flow-induced noise. This study experimentally researched characteristics of the flow-induced noise generated by air flow passing through perforated plates and impinging on a flat plate. The perforated plate was installed at the end of the pipe through which steady air flow was supplied from a blower. The air flow passing through the perforated plate impinged on the flat plate. The noise level was measured by a sound level meter in an anechoic room. We examined effects of the hole diameter, dimensionless hole spacing, and distance between the perforated plate and the flat plate with constant total hole area and constant flow velocity at the hole. The results show that the flow-induced noise decreased with the increase in the distance between the perforated plate and the flat plate at frequencies higher than 100 Hz but increased at lower than 100 Hz. The flow-induced noise at higher than 100Hz was less dependent on the hole diameter and dimensionless hole spacing.

1. INTRODUCTION

Mufflers are employed in the exhaust system to reduce the exhaust noise from automobiles. Inner plates are often placed inside the muffler to enhance the strength of the muffler. The reduction of flow-induced noise is expected with a lot of punching holes in inner plates (afterward perforated plates). However, since recent automobiles tend to increase its power, a large amount of the exhaust gas flow passing through perforated plates would impinge on another inner plate and generate flow-induced noise. The flow field and flow-induced noise have been studied when a single jet impinging on a flat plate [2][3][4]. Characteristics of flow-induced noise generated by multi-jets impinging on the flat plate have not been clarified yet. This study experimentally researched characteristics of the flow-induced noise generated by air flow passing through perforated plates and impinging on a flat plate. The steady air flow passing through the perforated plate impinged on the flat plate. We examined effects of the hole diameter d, dimensionless hole interval L/d, and distance between the perforated plate and the flat plate z on flow-induced noise with constant total hole area and constant flow velocity at the hole.

2. EXPERIMENTAL APPARATUS AND METHOD

This study investigated the flow-induced noise generated by air flow passing through a perforated plate and impinging on a flat plate. We used perforated plates with triangle lattice hole arrangement. Table 2.1 summarizes specifications of the perforated plates used. Figure 2.1 shows schematics of perfolated plates based on Table 2.1. Figure 2.1(a) shows hole arrangement for different dimensionless hole interval L/d=2.0, 2.5 and 3.0 with hole diameter d=6.0mm and number of holes n=19. No. 4 and No. 5 plates shown in Fig. 2.1(b) and (c) were also tested to study the effect of hole diameter with dimensionless hole interval L/d=2.0 and total hole area A=537-553 mm^2.

The air flow was supplied to a surge tank from a ring blower (VFZ601AN, Fuji Electric Systems). Acoustic absorption form was set inside of the surge tank to reduce the noise from the blower and pressure fluctuation of the air flow. The pipeline with the air flow was contracted with three stages, and then the air flow was introduced to the pipe with the perforated plate at its one end in an anechoic room, as shown in Fig. 2.2. The air flow passing through the perforated plate impinged on a flat plate. Glass wool with length of 200 mm, outside diameter of 170mm and inside diameter of 40 mm was set leftmost inside in the pipe with the perforated plate to suppress the cavity resonance. This was able to suppress the cavity resonance higher than 450 Hz. Mesh was set rightmost of the glass wool to prevent the glass wool dispersion. Bellmouse forming with radius of 10 mm was set at the end of the inlet pipe with 32 mm in inner diameter to reduce separation noise.

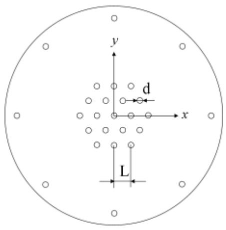
The radiated sound pressure was measured by a precision sound level meter (NA-20, RION) at 500 mm away from the center of the multi-jets impinging on the flat plate in 120 degree direction, as shown in Fig. 2.2. This postion of the sound level meter was determined through a preliminary experiment where precision measurement could be done and the air flow did not impinge on the sound level meter. If the flat plate size were small enough, the flow-induced noise would generate at the plate edges. A preliminary experment showed the radiated sound pressure did not include flow-induced noise generating at the edge of the flat plate with 600 mm in width and 4 mm in thickness.

We varied the distance z between the perforated plate and the flat plate with the flow velocity U=50 m/s at the hole center of the perfolated plate. Here, x- and y-directions were respectively definded as the horizontal and the vertical directions as shown in Fig. 2.1.The origin position was set at the center of the perforated plate. The mean velocity and velocity fluctuation were measured by a hot-wire anemometer at 3 mm away from the flat plate along x axis, at 1 mm interval from x=0 to 50 mm, at 2 mm interval from x=50 to 140 mm, and at 5 mm interval from x=140 to 300 mm.

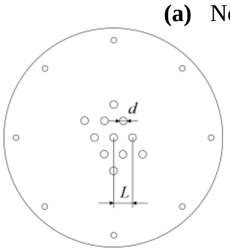
The signals from the sound level meter and hot-wire anemometer were converted into the digital signals by an analog-digital converter. FFT operation and 1/3 octave-band analysis were employed in the signal processing using a personal computer. The sampling frequency was 20.48 kHz. The number of the data of the time step was 65,536 points. The number of data per 1 block was 16,384 points to obtain a frequency resolution to 1.25Hz.

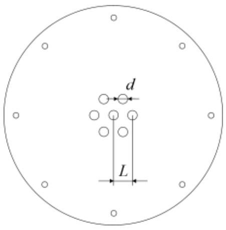
Table 2.1 Specifications of perforated plates.

	No.1	No.2	No.3	No.4	No.5
Thickness of perforated plate t [mm]	1.0	1.0	1.0	1.0	1.0
Hole diameter d [mm]	6.0	6.0	6.0	8.0	10.0
Dimensionless hole interval L/d	2.0	2.5	3.0	2.0	2.0
Number of holes n	19	19	19	11	7
Total hole area A [mm^2]	537	537	537	553	550



(a) No.1～No.3





(b) No.4 **(c)** No.5

Figure 2.1 Hole arrangements in perforated plates.

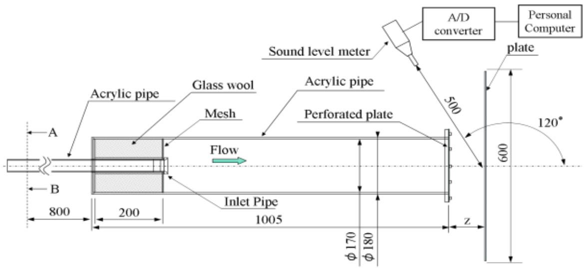
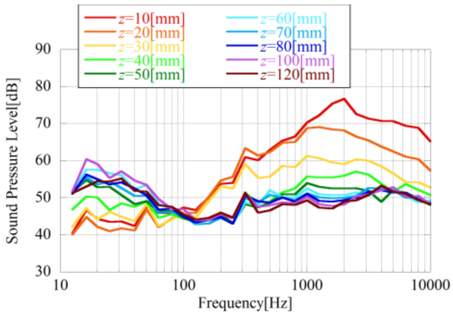


Figure 2.2 A schematic of the structure of the pipe with the perforated plates at its one end and the flow-induced noise measurement

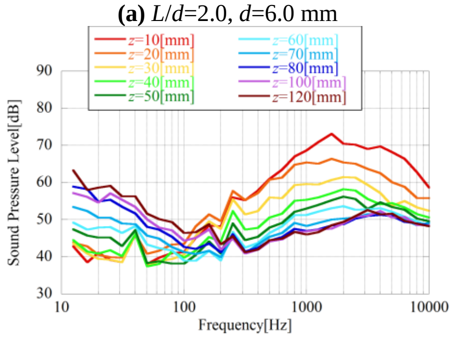
3. RESULT AND DISCUSSION

3.1. Effect of distance between the perforated plate and the flat plate

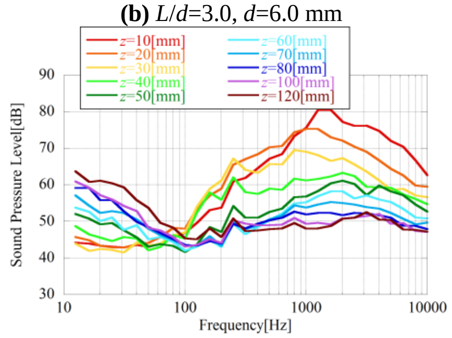
The flow-induced noise was measured at different distances z between the perforated plate and the flat plate from z=10 to 120 mm with flow velocity U=50 m/s at the hole center of the perfolated plate. Figure 3.1 shows the sound pressure levels for different z. The sound pressure level decreased with the increase in z at frequencies higher than 100 Hz. At lower than 100 Hz, the sound pressure level incresed with the increase in z and attained maximam at z=100 mm, as shown in Fig. 3.1(a).



(a) L/d=2.0, d=6.0 mm



(b) L/d=3.0, d=6.0 mm



(c) L/d=2.0, d=10.0 mm

Figure 3.1 Effect of the distance z between the perforated plate and the flat plate on sound pressure level

3.2. Dependence of sound pressure level on dimensionless distance between the perforated plate and the flat plate

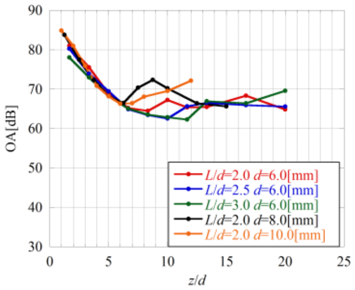
Here we focuse on a tendency that the flow-induced noise decreased with the increase in the distance between the perforated plate and the flat plate at frequencies higher than 100 Hz, but increased at lower than 100 Hz, as can be seen in Fig. 3.1 and investigate dependences of partial overall levels of sound pressure for frequency ranges lower than 100 Hz and higher than 100 Hz on dimensionless distance z/d between the perforated plate and the flat plate. Figure 3.2 shows overall level and partial overall levels for frequency ranges lower than 100 Hz and higher than 100 Hz with U=50 m/s.

As can be seen in Fig. 3.2(c), the partial overall level for frequency range higher than 100 Hz decreased with the increse in *z/d* and shows almost same value for same *z/d* regardless of *L*/*d* and *d*. In general, jet velocity distributions for different hole diameters are similar to each other if the space scale is nondimensionilized with hole diameter. Jet velocity decreased with the increase in *z*/*d*, and thus the sound generating at the flate plate surface decreased. The effect of interaction of jet flows could be disregarded because the noise generation at frequencies higher than 100 Hz did not depend on hole arrangements.

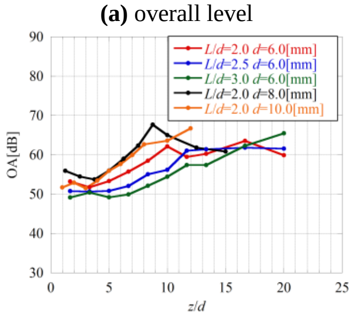
Next, as can be seen in Fig. 3.2(b), contrary to that for frequency range higher than 100 Hz, partial overall lever for frequency range lower than 100 Hz depended on *L*/*d* and *d*. It increased with *z*/*d* in most cases but had maximum at a certain *z/d* for *L/d*=2 and *d*=8 mm.

As can be seen in Fig. 3.2(a), overall level of sound pressure depends on *L*/*d* and *d* because of the effect of the partial overall level for frequency range lower than 100 Hz.

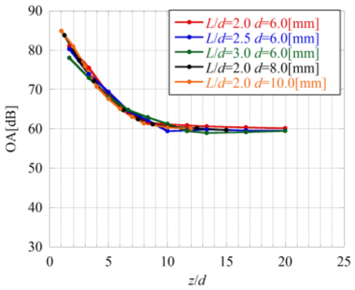
When the jet flow is introduced into stationary fluid, eddies evolve in the shear layer and then the eddies turn into small eddies in the downstream. The noise at frequencies lower than 100 Hz was conceivably generated by impingement of eddies on a flat plate evolving in the periphery of multi-jets. The partial overall level for frequency range lower than 100 Hz with constant *d* was greater with smaller *L*/*d* for *z*/*d*<10. This result suggests that the eddy development in the peripheral shear layer of the multi-jets was faster for smaller *L*/*d*. On the other hand, the partial overall level for frequency range lower than 100 Hz with constant *L*/*d* decreased in order of d=8.0 mm, 10.0 mm, 6.0 mm for 8<*z*/*d*<9. The eddy development might be complexed for *d*=8.0 mm because the hole arrangement of the perforated plates with *d*=8.0 mm deviates from symmetrical shape.



(a) overall level



(b) partial overall level (*f*<100Hz)



(c) partial overall level (*f*>100Hz)

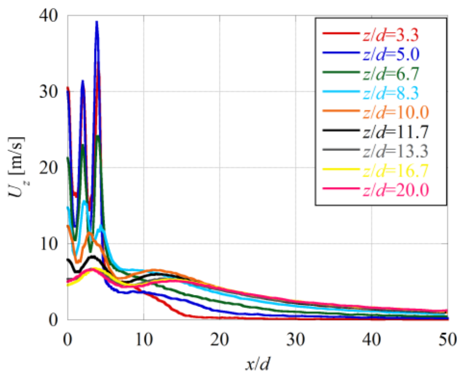
Figure 3.2 The dependence of overall level and partial overall levels of sound pressure on the distance *z/d* between the perforated plate and the flat plate

3.3. Mean velocity and velocity fluctuation near the plate

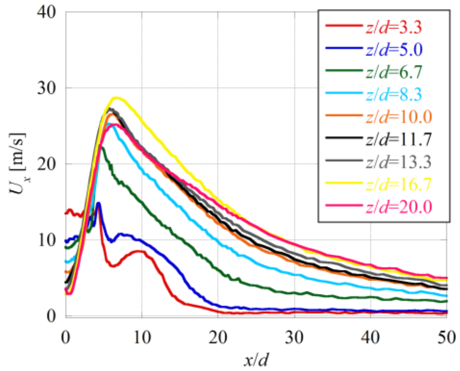
The mean velocity and velocity fluctuation near the plate were measured with the perforated plate No. 1 (*L*/*d*=2.0, *d*=6.0 mm). Figure 3.3 show the distributions of flow velocities normal and parallel to the flat plate. Figure 3.4 show the distributions of velocity fluctuations normal and parallel to the flat plate.

As can be seen in Fig. 3.3(a), the local maximam velocities normal to the plate exist at three positions *x* corresponding to the hole positions. The mean velocity without the flat plate at *z*/*d*=3.3, *x*/*d*=0 was 50 m/s. On the other hand, the mean velocity near the plate decreased to about 30 m/s. As can be seen in Fig. 3.4(a), the peak positions of the velocity fluctuation normal to the plate are the same as the peak positions of the mean velocity near the central part.

Next, we focused on the area of *x*/*d*>8.3. As shown in Fig. 3.3(a), the mean velocity normal to the plate increased first with the increase in *z*/*d*, attained the maximum value at *z*/*d*=10 in 8.3<*x*/*d* <16.7, and decreased. The fluctuation velocity tends to the same as the mean velocity, as shown in Fig. 3.4(a). As can be seen in Fig. 3.3(b), the flow parallel to the plate is more dominant than that normal to the plate in *x*/*d*>8.3. The mean velocity parallel to the plate was maximum around the outer edge of the multi-jets, and increased once with the increase in *z*/*d*, and decreased after attaining the maximum value at *z*/*d*=16.7. As can be seen in Fig. 3.4(b), the velocity fluctuation parallel to the plate incresed around the outer edge of the multi-jets in *z*/*d*>5.0, and indicated maximum value at the outside of the position of the maximum mean velocity in *z*/*d*>6.7. The position of the maximum velocity fluctuation shifted to the outside as *z*/*d* was increased.

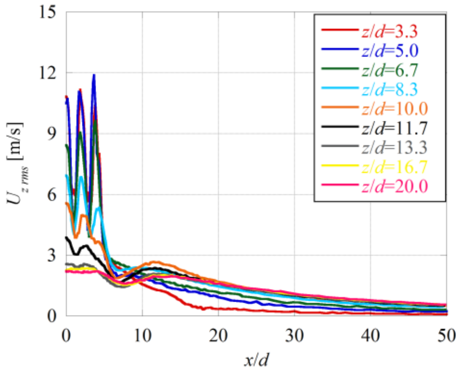


(a) mean flow velocity normal to the flat plate

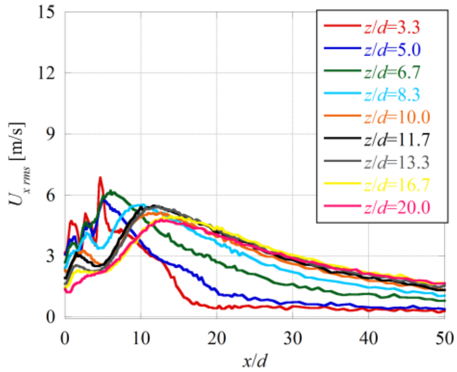


(b) mean flow velocity parallel to the flat plate

Figure 3.3 The mean flow velocity distributions for different distances *z/d* between the perforated plate and the flat plate



(a) velocity fluctuation normal to the plate



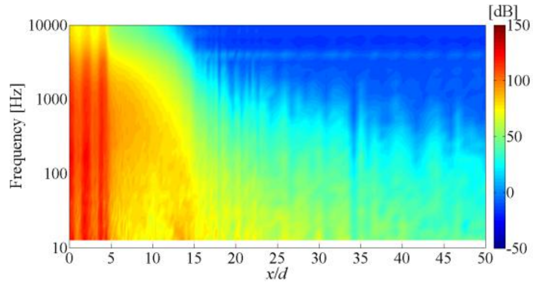
(b) velocity fluctuation parallel to the flat plate

Figure 3.4 The velocity fluctuation distributions for different distances *z/d* between the perforated plate and the flat plate

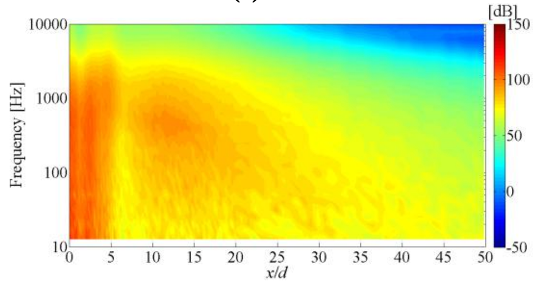
Figure 3.5(a)-(c) show the spectrum contor map of the velocity fluctuation normal to the plate and Fig. 3.6(a)-(c) show that parallel to the plate. As can be seen in Fig. 3.5(a)-(c), the velocity fluctuation normal to the plate indicated high values in entire frequency band at 0<*x*/*d*<5. Afterwards, the velocity fluctuation tended to decrease with the increase in *z*/*d*. This result suggests that the strong turbulence generate by high speed jets impinging on the flate plate.

Next, as can be seen in Fig. 3.6(a)-(c), in the area of x/*d*>8.3, the velocity fluctuation parallel to the plate in relatively low-frequency band and the area tended to increase with the increase in *z*/*d*. This result suggest that the flow impinging on the flat plate in the center part turned parallel to the plate, and the turbulence was generated by developed eddies in the peripheral shear layer of the multi-jets interacting with the paralle direction flow.

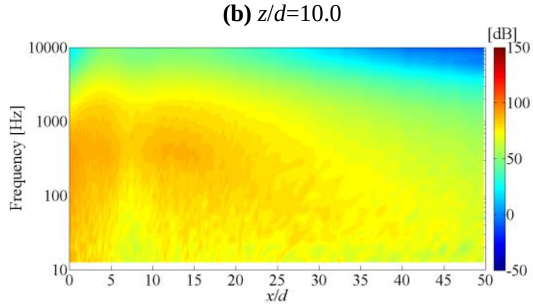
The tendency of the sound pressure level of the impingement noise at frequencies higher than 100 Hz was different from that at lower frequencies than 100 Hz. The sound pressure level increased with the decrease in *z*/*d* at frequencies higher than 100 Hz. This result is the same as the tendency of the velocity fluctuation normal to the plate at 0<*x*/*d*<5.0. This result suggests that the turbulence component at this position caused the impingement noise at frquencies higher than 100 Hz. In contrast, the sound pressure level increased with the increase in *z*/*d* at frequencies lower than 100 Hz. This result is the same as the tendency of the velocity fluctuation parallel to the plate at *x*/*d*>8.3. This result suggests that the turbulence component generated by developed eddies in the peripheral shear layer of the multi-jets interacting with the paralle flow caused the impingement noise at frquencies lower than 100 Hz.



(a) *z*/*d*=3.3

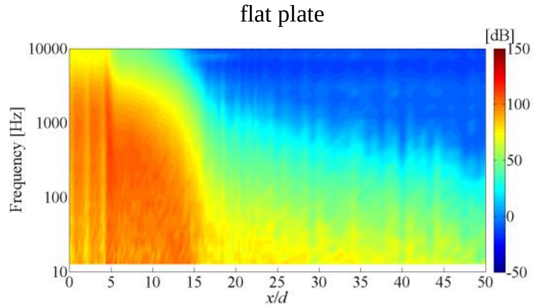


(b) *z*/*d*=10.0

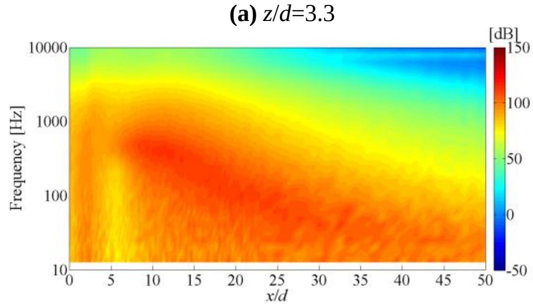


(c) *z*/*d*=20.0

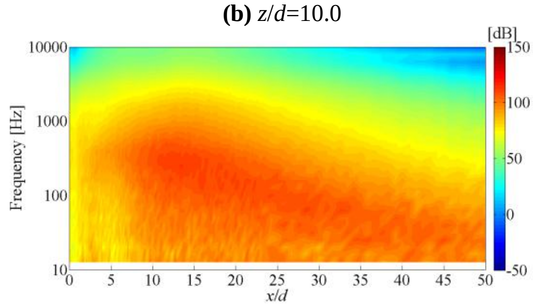
Figure 3.5 The spectrum of velocity fluctuation normal to the flat plate



(a) *z*/*d*=3.3



(b) *z*/*d*=10.0



(c) *z*/*d*=20.0

Figure 3.6 The spectrum of velocity fluctuation parallel to the flat plate

4. CONCLUSIONS

This study experimentally studied effects of the hole diameter *d*, dimensionless hole spacing *L/d*, and distance *z* between the perforated plate and the flat plate with constant total hole area and constant flow velocity at the hole.

(1) The flow-induced noise level decreased with the increase in the distance between the perforated plate and the flat plate at frequencies higher than 100 Hz but increased at frequencies lower than 100 Hz.
(2) The partial overall level of the sound pressure at frequencies higher than 100 Hz depended on *z*/*d* but was almost independent of *L*/*d* and *d*. The results of flow velocity and velocity fluctuation suggest that the strong turbulence in the center part generated by each jet issued from each hole and impinging on the flate plate induced pressure fluctuation on the plate, resulting the impingement noise at frequencies higher than 100 Hz.
(3) The partial overall level at frequencies lower than 100 Hz depended on *z/d*, *L*/*d* and *d*. The results of flow velocity and velocity fluctuation suggest that the turbulence generated by developed eddies in the peripheral shear layer of the multi-jets interacting with the paralle direction flow induced pressure fluctuation on the plate, resulting the impingement noise at frequencies lower than 100 Hz.

5. REFERENCES

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