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The Flow Through a Row of Flat Plates and the Sound Generated

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ABSTRACT

The mean velocity and velocity fluctuations in the flow through a row of flat plates were measured by hot-wire technique. Wave forms of velocity fluctuations were compared with those of the sound generated. It was known that in the present experiment the stationary sound wave was generated between both side walls of the channel, being excited by pressure fluctuations due to the vortices in the wakes of plates. Therefore, the sound could be decayed by setting a piece of flat plate at the location of the node of the stationary wave.

INTRODUCTION

On the way of study on the interference between wakes of plates in the flow through a row of flat plates, it was found by Matsui et al. (1975) that for the row of flat plates with tapered trailing edges, sound was generated for the wind velocity higher than about 8 m/s, while for the row of flat plates with blunt trailing edges sound was not generated for the wind velocity up to about 20 m/s.

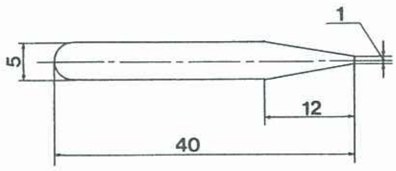
Studies on sound generation in the air flow through a row of flat plates were performed by many investigators, e.g. Parker (1966, 1967, 1968), Hiramoto et al. (1972) and Hara (1975). In those studies, however, the relation between the flow field and the sound field has not yet been clearly revealed and most of the experiments were performed for the row of flat plates with large pitch-thickness ratio. In this case, according to our previous experiments by Matsui et al. (1974, 1975), every plate has the same velocity distribution and the same frequency of velocity fluctuation in its wake. In the case of smaller pitch-thickness ratio, the wake flow behind every plate is not the same and the frequency of generated sound increases almost linearly with the increase in wind velocity. For larger pitch-thickness ratio, the frequency of generated sound does not necessarily increase with velocity increase, but the frequency has discreate values. In the present experiment, for the latter case the relation between the flow field and the sound field was studied and a method to prevent sound generation was tried.

EXPERIMENTAL APPARATUS

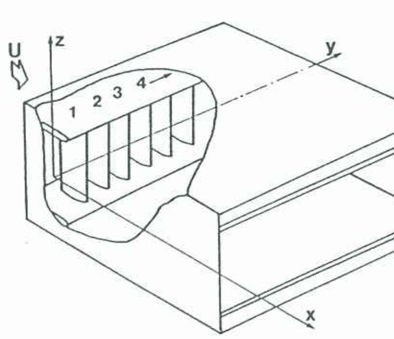
A row of flat plates was set in a wind channel with a rectangular cross-section of 300 mm   150 mm. A flat plate has the thickness of 5 mm and the length of 40 mm. The leading edge is a semi-circle of 2.5 mm radius, the rear portion is tapered in the range of 12 mm to have the thickness of 1 mm at the trailing edge. (See Fig. 1.) Twenty-five plates of this shape were arranged with a pitch of 12 mm, i.e. the clearance between neighbouring plates is 7 mm and the ratio of pitch to thickness of plate is 2.4, the open area ratio is about 0.58.

To avoid the effect of the boundary layer along the upper and the lower walls of wind channel on the flow through the row of flat plates, the upper and the lower end-plates supporting the flat plates are 15 mm distant from the upper and the lower walls of the channel. A ceiling plate and a floor plate are set to be attached to the trailing edges of the end-plates, according to the experimented results by Ishimoto and Matsui (1979).

Mean velocity and turbulence intensity were measured by hot-wire technique. The frequency of sound and sound pressure were measured with a condenser-microphone by the same method as that by Hiramoto et al. (1972). A static tube filled with steel wool was attached on the front side of a small condenser microphone, which was used to measure sound pressure distribution in a flow field.



a. A flat plate



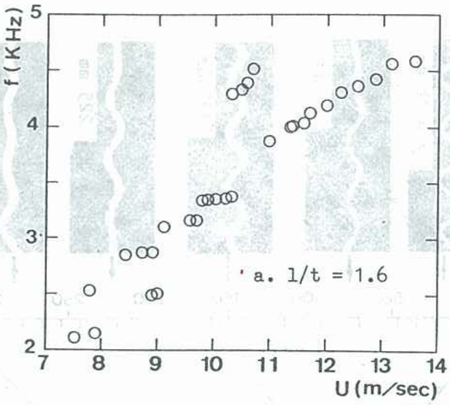
b. A row of flat plates

Fig. 1. Experimental arrangement.

EXPERIMENTAL RESULTS AND DISCUSSIONS

1. Mean velocity and the frequency of sound generated

For the pitch-thickness ratio of 1.6, i.e. $l/t = 1.6$, the sound frequency increases almost stepwise for lower velocities, but for higher velocities it increases to be approximately linear to the velocity, where l denotes the distance between the center lines of neighbouring flat plates and t denotes the thickness of a plate. For $l/t = 2.4$, the sound frequency changes stepwise 1625, 1125, 1625, 2075 and 2425 Hz with increase in velocity, in other words, sometimes decreases, sometimes increases with velocity increase, as shown in Fig. 2. Thus, the case for $l/t = 2.4$ may be simpler than that of $l/t = 1.6$. Then, the distributions of mean velocity and of turbulence intensity, wave form and frequency of velocity fluctuation and of sound were measured for $l/t = 2.4$.



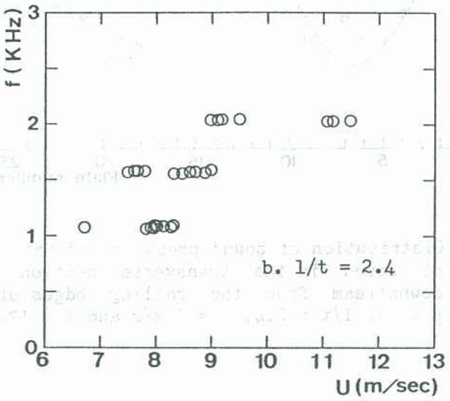


Fig. 2. Variation of sound frequency due to wind velocity.

2. Distribution of mean velocity and turbulence intensity

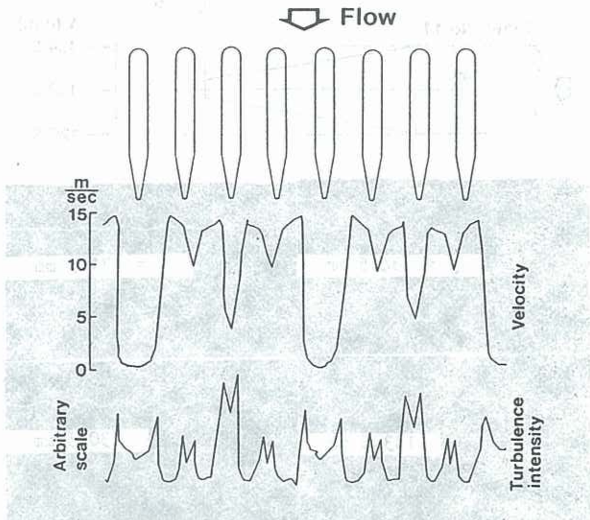
For 1/t = 2.4, sound was not generated for the wind velocity lower than 7 m/s. The mean velocity distribution has a remarkable periodicity in the transverse direction, that is, mean velocity in every wake behind every plate is not the same, but the velocity detect in the wake is, in turn, large, small, medium, small and large in the transverse direction. In other words, the mean velocity distribution has a wavelength of 41 in the transverse direction.

For the wind velocity of 8 m/s, sound of 1125 Hz was generated. In this case, the velocity defect of medium wake decreased and that of small wake increased. Thus, velocity defect of both wakes became almost the same, as shown in Fig. 3. The intensity of turbulence was also nearly equal in both wakes, and the characteristic frequency of velocity fluctuations in the small wake had the same value, 1125 Hz, as that of the generated sound.

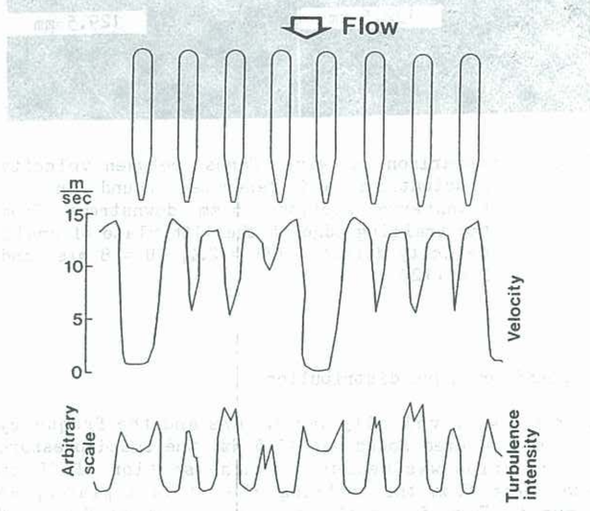
When the velocity was increased to 8.7 m/s, a sound of 1625 Hz was generated, and the velocity defect and the turbulence intensity in medium wakes were increased. The characteristic frequency of velocity fluctuations in the medium wake has the same value, 1625 Hz, as that of the generated sound.

3. Comparison of wave forms between velocity fluctuation and generated sound

In the case of wind velocity of 8 m/s, when the sound of 1125 Hz was generated, the wave forms of velocity fluctuations and of the generated sound were measured in the small wake behind the eleventh plate from a side wall in the transverse section of 5 mm downstream from the trailing edge of the plate. The locations of



a. U = 7 m/s. No sound generation.



b. U = 8 m/s. frequency of sound, f = 1125 Hz.

Fig. 3. Distribution of mean velocity and turbulence intensity for 1/t = 2.4.

measurement and the results obtained are shown in Fig. 4, in which the wave forms of velocity fluctuations are shown in the upper side, and those of sound measured outside of the channel are shown in the lower side. The frequency is seen to be the same both for the velocity fluctuation and for the sound, but the phase difference is 180 degrees at y = 134.5 mm, whereas both waves are in phase at y = 129.5 mm. The facts tells that the velocity fluctuations have 180 degrees phase difference between on both sides of the small wake. It is also seen in Fig. 3 that there are fairly strong shear layers on both sides of the wake. Therefore, it is suggested that there may be a remarkable vortex row like a Karman vortex street and the pressure fluctuations due to the vortices can be the origin of resonance between side walls.

For the velocity of 8.7 m/s, the vortices in the medium wake may be the origin of the resonance.

When the side walls were taken off, no sound was generated up to the velocity of 10 m/s. It can be concluded that the sound generated for wind velocity less than 10 m/s is due to the resonance between side walls.

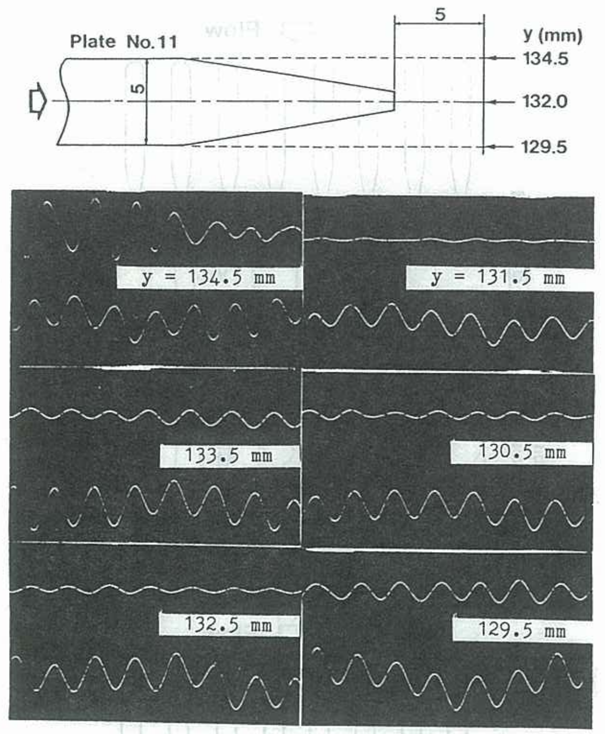


Fig. 4. Comparison of wave forms between velocity fluctuations and generated sound in the transverse section 5 mm downstream from the trailing edge of the 11th plate of small velocity defect. l/t = 2.4, U = 8 m/s and f = 1125 .

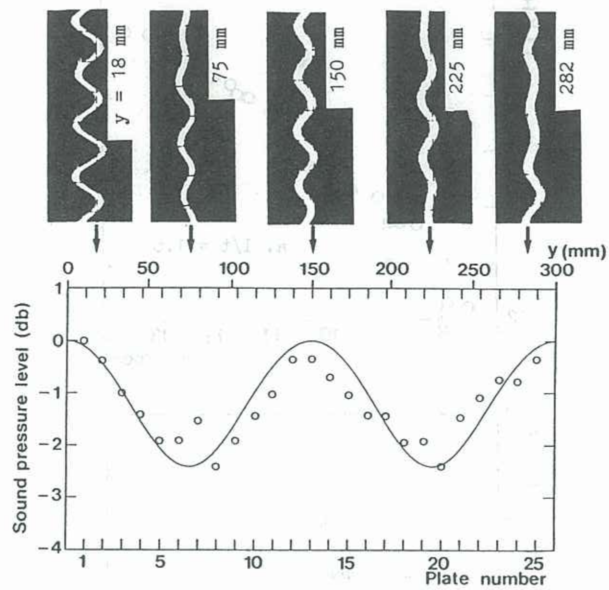


Fig. 5. Distribution of sound pressure and wave forms of sound in the transverse section 10 cm downstream from the trailing edges of flat plates. l/t = 2.4, U = 8 m/s and f = 1125 Hz.

4. Sound pressure distribution

When the wind velocity was 8.1 m/s and the frequency of the generated sound was 1125 Hz, the sound pressure distribution was measured in the section of 10 cm downstream from the trailing edge of flat plates, as shown in Fig. 5. In the same figure wave forms of sound are also shown at the locations corresponding to the maxima and the minima of the sound pressure. The sound pressure distribution has maxima on the center line of the channel and on both walls. Therefore, the sound pressure distribution may correspond to the secondary stationary wave between side walls.

If the sound is perfectly reflected on side walls, the sound pressure distribution is expressed by a cosine curve.

$$p \sim \cos(m \cdot \pi y/L), \qquad (m = 1, 2, 3, \cdots\cdots),$$

where L denotes the distance, 30 cm, between side walls. Wave length, λ, is 2L/m, and the frequency, f, is $a/\lambda = ma/2L$, where a denotes the sound velocity, which is about 337 m/s for dry air of 10 degrees centigrade. Now, the frequency of sound generated due to resonance with the stationary waves between the side walls is expressed as

$$f = m \cdot a/2\,L \quad (\text{Hz}).$$

The sound for m = 1 could not be measured in the present experiment. The sound for m = 2 has the frequency of 1124 Hz and the wave length is just equal to the distance between side walls, L. The measured frequency was 1125 Hz. The agreement between the experiment and the theory is very good.

For m = 3, the frequency of resonated sound is 1685 Hz, while the measured value was 1625 Hz. For m = 4, the frequency of sound is 2247 Hz, the measured value was 2075 Hz.

5. Prevention of sound generation

The origin of sound generation in this experiment may be the pressure fluctuation in the wake flows behind flat plates. For the pitch-thickness ratio of 2.4, the mean velocity distribution has a remarkable periodicity in the transverse direction for the oncoming flow velocity up to about 12 m/s. Wakes of flat plates arrange themselves in order of large, small, medium, small, and large velocity defects. Characteristic frequencies of velocity fluctuations in the wakes also vary in the same way. If one of the frequencies, e.g. the characteristic frequency in the wake with small velocity defect, has the same value as that of a mode of the stationary wave between side walls, then resonance occurs and the amplitude of the stationary wave is so much amplified that the sound of the frequency is generated. Accordingly, it is expected that the resonance will be prevented by inserting a piece of flat plate at the position of nodes of the stationary wave, that is, at the position of the minimum of sound pressure, as the stationary waves have loops on solid boundaries, where the perfect reflection is assumed. On the surface of the inserted plate, the sound pressure must be maximum and the original stationary wave will become unable to occur, and the resonance will be suppressed. If a piece of flat plate is inserted at the position of the loop, then the resonance will be amplified.

Pressure fluctuations in wakes of flat plates are caused mainly by vortex rows in the wakes. The vortices are generated in rather near wakes from the trailing edges of flat plates. Therefore, if a piece of flat plate is inserted in this region, sound generation will be effectively prevented. Now, a flat plate of the same shape as that of flat plates composing the row of flat plates was set in the way that the tapered edge of the plate was attached to the tapered trailing edge of a plate in the row, the trailing edge of the plate now being round. The experimental results thus performed will be described in the following.

When the sound of the frequency of 1125 Hz was generated for the wind velocity of 8 m/s, the wave form of the sound was measured with a microphone outside the channel, as shown in Fig. 6, a.

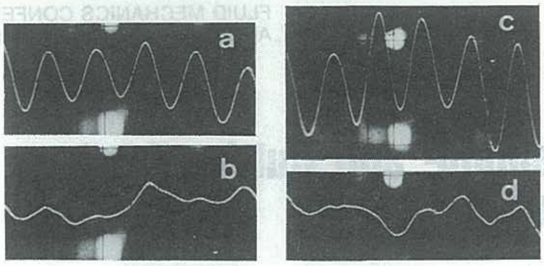


Fig. 6. Effects of a suppressing plate. l/t = 2.4, U = 8 m/s and f = 1125 Hz. a, without suppressing plate ; b, with a suppressing plate attached to the 7th plate ; c, to the 13th plate ; d, to the 20th plate.

Now a suppressing plate was attached to the trailing edge of the seventh plate, the position of which was nearly the position of the node of the stationary wave, as seen in Fig. 5. The wave form of the sound is shown in Fig. 6, b. In this case the amplitude is small, the wave form is irregular and the sound is not perceptible. Secondly, the suppressing plate was attached to the thirteenth plate corresponding to the loop of the stationary wave. The amplitude of the sound wave was increased as seen in Fig. 6, c, and the sound was intensified. Next, when the suppressing plate was set to be attached to the twentieth plate at the position of the other node, again the sound was not perceptible, as shown in Fig 6, d.

Thus, it was confirmed that in this case the sound was generated by resonance with the stationary wave between side walls because of the pressure fluctuations due to vortex rows in the wakes of flat plates. Also, a method was shown to prevent the sound generation.

CONCLUSIONS

When velocity defects in wakes of flat plates in a row of flat plates of small pitch-thickness ratio are not uniform, but arrange themselves in the transverse direction in order of large, small, medium, small and large velocity defects, and when the frequency of vortex generation in some wakes is equal to or nearly equal to the frequency of the stationary sound wave between side walls of the channel, the sound of the frequency is generated due to resonance, and the velocity defects and the intensity of velocity fluctuations in those wakes are increased.

When a suppressing plate is set at the positions of the nodes of the stationary wave, the sound is decayed; to the contrary, at the position of the loop, the sound is intensified.

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