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SOUND GENERATION FROM TAPERED CYLINDER

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Abstract

The aeolian tones generated from the tapered cylinder were investigated for several inclined angles experimentally. The diameter of the tapered cylinder is varied from 10 mm to 40mm. The tapered cylinder was inclined from –40 to 40 degree. It is obtained some interesting results in relating to the aeolian tone and the unsteady flow characteristics. The aeolian tone is large not at the zero angle, but at negative and positive angles. When the side of the large diameter is set downstream at the negative inclined angle, the aeolian tone becomes large compared with the positive angle. The wake vortex generates even at the large inclined conditions. At the case of the zero inclined angle, the peak frequency is constant in the span direction, even though the diameter varied. At the case of large inclined condition, it is emerged the swelled peak and the peak frequency of the velocity fluctuation is varied in span direction. The peak level of the fluctuating velocity is large near the middle of span at the zero degree compared with the large inclined case. But the aeolian tone is fairly low at zero degree compared with the large inclined angle. It is indicated that the aeolian tone is governed not only with the strength of the flow fluctuation in the wake, but also with the position of the rolling up to the wake vortex.

INTRODUCTION

The aeolian tone by the wake vortex shedding has been investigated for many years. In the two-dimensional condition, the relationship of the characteristics between the wake vortex and the sound source is fairly cleared [1]-[4]. The sound source concentrates near the separation point. But the three dimensional structure of the wake vortex and of the sound source are not cleared well.

There are only some researches in relating to the three dimensional structure of the wake vortex. It is shown for the inclined cylinder that the flow turns to the normal

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direction to the circular cylinder. This turning flow might have much influenced on the wake vortex generation [3],[5]-[7]. But it is not cleared the relationship between the aeolian tone and the three-dimensional wake vortex. We have been researched the characteristics of the three dimensional coherent structure of the wake vortex and the relationship between the wake vortex and the aeolian tone with the inclined flat plate [8]. It is cleared that the aeolian tone becomes large not at the two-dimensional flow condition, but at the slightly inclined condition. When the aeolian tone becomes large, the wake vortex is not strong, but the span-wise correlation length becomes large. And the aeolian tone is generated from not only the strengthen wake vortex, but also the large scale one in span direction. We pointed out the importance of the three dimensional structure of the wake vortex for the aeolian tone.

In the paper, the aeolian tones generated from the tapered cylinder and the characteristics of the wake vortex for the cylinder in uniform oncoming flow were investigated experimentally. The tapered cylinder was inclined in the flow direction. The characteristics of the wake vortices may be varied in span location, because the diameter of the tapered cylinder is varied in each position. And the wake vortex has the three-dimensional structure especially at the inclined case. It was found out that the aeolian tone becomes large not at zero inclined angle but at large angle. The tone is closely relating to the location of the rolling up.

EXPERIMENTAL APPARATUS AND METHOD

Experiments were carried out with the open type wind tunnel. Figure 1 shows the schematic diagram of the test section. The air blows from the nozzle outlet of 230*230mm section. The oncoming velocity to the model can be varied from 19m/s to 50m/s. In this experiments, the uniform flow is set 30m/s. The Reynolds number is 47000 at mid span. The turbulence level at the nozzle outlet is under 0.25% of

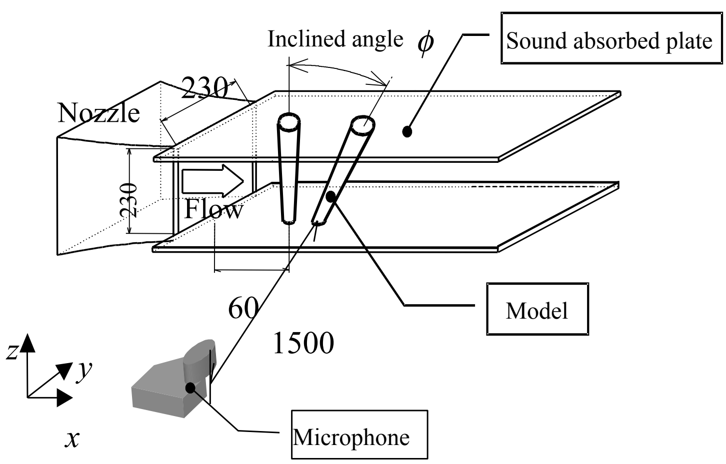
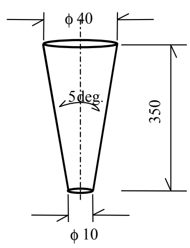
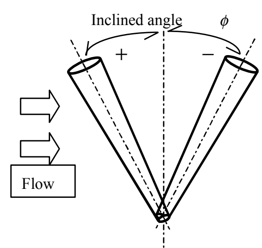


Figure 1 Experimental apparatus



(a) Geometry of test cylinder



(b) Inclined setting condition

Figure 2 Geometry of Test Model and Setting Condition oncoming flow. The upper and lower walls were set with the absorbed material to avoid the interaction of the shear flow from the edge of the nozzle and the model and to avoid the reflection of the sounds from the walls.

The aeolian tone was measured at 1.5m apart from the model. The velocity fluctuation were measured with hot-wire anemometers. The signal of the anemometers were analysed with the spectrum and the correlations. The spatial correlations in the wake were measured in each shear layer from the cylinder.

Figure 2 shows the test model. Figure (a) is the sketch of the model. The diameter of the model is varied from 10mm to 40mm. Then the tapered angle is 5 degree. The span length is 350mm, but the 230mm length of the middle part is bone in the flow. Figure (b) shows the definition of the inclined angle. The inclined angle is varied from –40 to 40 degree. When the angle is set positive, the part of the large diameter is set upstream.

RESULTS AND DISCUSSION

Characteristics of Aeolian Tone

Figure 3 shows the variation of the sound pressure level(SPL) of aeolian tone with the inclined angle. It can be seen that the OverallSPL level slightly increases with the inclined angle at positive angle. The OverallSPL level at negative inclined angles becomes very large between the –20 and –40 degree. That is, the SLP level becomes minimum at zero inclined angle.

Figure 4 shows the spectrum distributions of the sound pressure level for the inclined angle –30, 0 and 30 degrees. There are some peaks at the

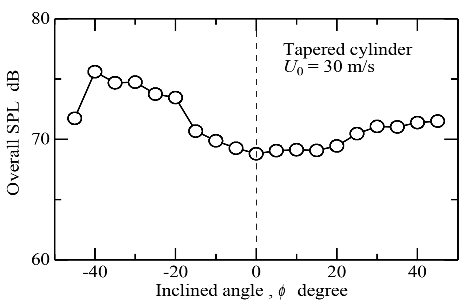
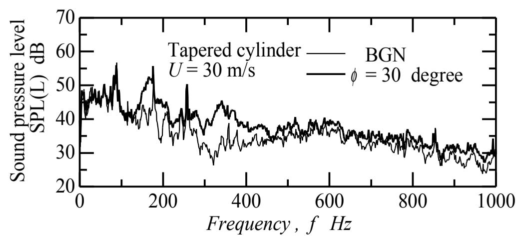
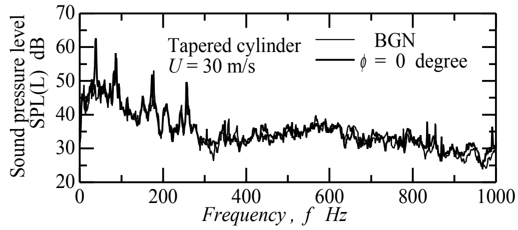


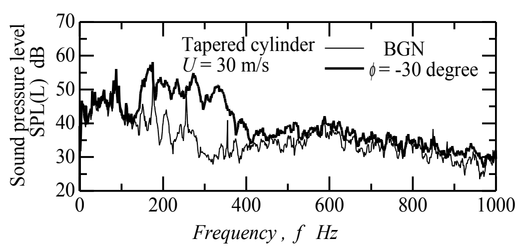
Figure 3 Variation of SPL with inclined



(a) Inclined angle ϕ =30 degree



(b) Inclined angle ϕ = 0 degree

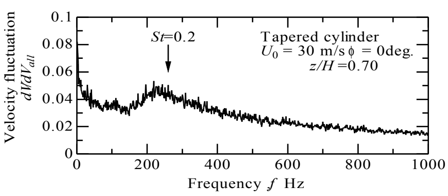


(c) Inclined angle ϕ =-30 degree

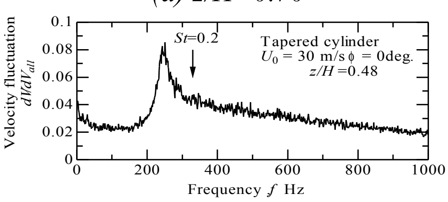
Figure 4 Spectrum distribution of Sound pressure level inclined angle –30 and 30 degree. These peaks are the aeolian tone from the tapered cylinder. Especially, it can be seen the remarkable peaks between 150-400Hz at ϕ=-30 degree. However it cannot be seen the peak at zero inclined angle. Then the overall SPLs are increased at negative and positive inclined angle.

Characteristics of Wake Flow

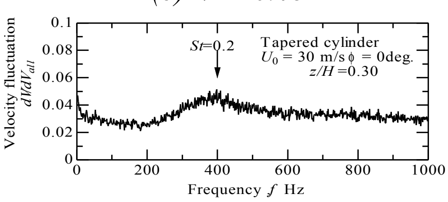
Figure5 shows the spectrum distribution of velocity fluctuation in the wake at each span-wise location at zero inclined angle. Figure (a) is the location of z/H=0.7. It can be seen the swelled peak near the f=230Hz. The peak distribution is spread in the wide frequency range. The frequency of Karman Vortex shedding St=0.2 is f=260Hz at this location. So the peak frequency of the velocity fluctuation is a little lower than the Karman vortex frequency. Figure (b) is the location of z/H=0.48 near the mid span. There exists the sharp peak near f=250Hz. The level of it is very large compared to other locations. It shows that the wake vortex shedding occurs at this location. The frequency of the Karman vortex is 330Hz. The frequency of the fluctuation is fairly low compared with Karman vortex. Then it is indicated that the strong wake vortex rolls up near the mid-span, but the characteristics is different from the two dimensional Karman vortex. Figure (c) is the location of z/H=0.30. It can be seen the swelled peak near the 400Hz. The fluctuating frequency is about coincided to the Karman vortex frequency. From figure (a) to (c), the frequency of the fluctuation in the wake is gradually decreased with the span location because the diameter of the cylinder increases with the span location, but the frequencies are fairly different from



(a) z/H=0.70

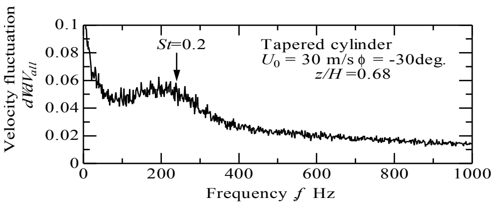


(b) z/H=0.48

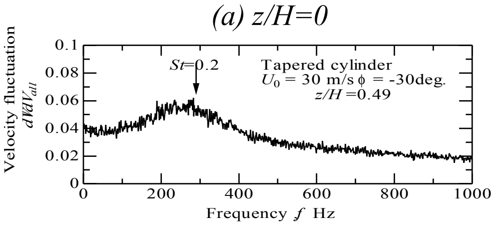


(c) z/H=0.30

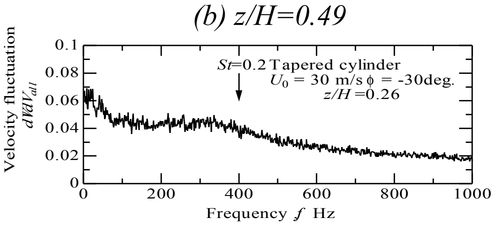
Figure 5 Spectrum distribution of velocity fluctuation at each span location at ϕ=0



(a) z/H=0



(b) z/H=0.49



(c) z/H=0.26

Figure 6 Spectrum distribution of velocity fluctuation at each span location at ϕ=–30 the Karman's frequency especially near the mid-span. The frequency is lower than the Karman's one.

Figure 6 shows the spectrum distributions of velocity fluctuations in the wake at each span location at ϕ=–30degree. Figure (a) is the location of z/H=0.68. It can be seen the swelled peak near the 200Hz. The peak distribution is spread the wide frequency range. The level of it is not large because of the frequency of the fluctuation varied in time with wide range. The frequency of Karman Vortex shedding from St=0.2 is f=240Hz. The peak frequency of the velocity fluctuation is a little lower than the Karman vortex. Figure (b) is the location of z/H=0.49 near the mid span. The swelled peak also exists near 270Hz. The peak level of it is low compared to the zero angle. The frequency of the Karman vortex is 290Hz. The frequency of the fluctuation is almost same to the Karman's frequency. Figure (c) is the location of z/H=0.26. It can be seen the swelled peak near the 300Hz. But the swelled peak is fairly small. The frequency of the Karman vortex is 400Hz. The fluctuating frequency is fairly lower than the Karman's frequency. The distributions of the spectrum of velocity fluctuation are distributed to the wide frequency range at all span locations. And the peak frequency is little varied in span location.

Figure 7 shows the distributions of the peak level of velocity fluctuation in the span location. It can be seen the large level during z/H=0.35 – 0.5 at zero inclined angle. This large level is corresponding to the sharp peak in figure 5(b). This indicates that the remarkable peak at zero angle is restricted near the mid-span. The level at –30 degree is almost constant in all span locations. The level of it is fairly small compared to the zero degree. Because the level is corresponding to the swelled peak with wide frequency range as shown in figure (a) and (c). This distribution indicates that the fluctuating flow in the wake at –30 degree is occurred in wide span-location compared to zero inclined degree.

Figure 8 shows the coherence and the cross-spectrum phase of velocity fluctuations in the wake. The span-wise locations of these results are obtained near the mid-span. The two velocity fluctuations in the wake were measured at each side of the separated shear layers at x/D=1.5. Figure (a) and (b) are the case of zero inclined angle. Figure (a) is the coherence. There exists the large coherence in the frequency f=200 – 300 Hz. It is indicated that the fluctuating flow of each shear layer is closely relating each other. Figure (b) is the phase distribution of cross spectrum. It can be seen that the phase is about –180 degree in f=200 – 300 Hz where the

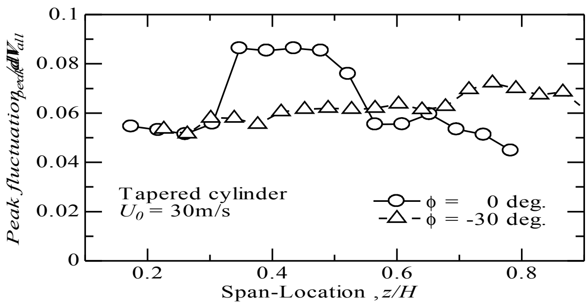
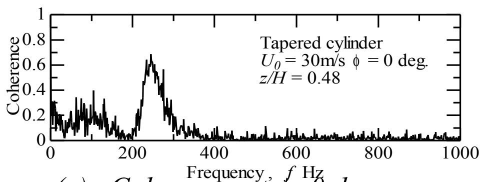


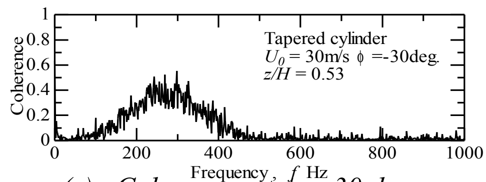
Figure 7 Distribution of peak level of velocity fluctuation to span direction

coherence is large. This means that the wake vortices roll up alternatively from each shear layer, that is, it is generated the Karman vortex shedding. Figure (c) and (d) is the case of the –30 degree. Figure (c) is the coherence. There exists the swelled peak in the range of *f*=100-400Hz and the peak is about *f*=260Hz. It can be seen in figure (d) that the phase of coherence is about 180 degree. This also means the alternate rolling-up to Karman vortex shedding. That is, the rolling up of the shear layer to the wake vortex occurs alternatively even at a large inclined angle.

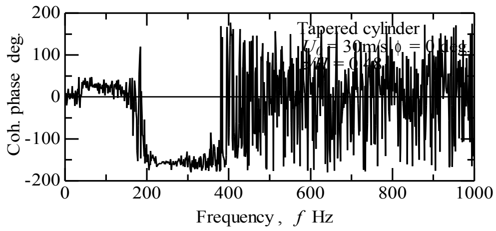
Figure 9 shows the distributions of the time averaged velocities in the wake. The direction *Y/D* is the normal to the stream- and span-wise directions. Figure (a) is the case of zero inclined angle. It is shown that the low velocity region exists at *Y/D*= -0.5 – 0.5 which is corresponding to the dead air region. Each edge of this region is the shear layer that is not yet rolling up to the wake vortex. The distributions are coincided each other. This indicates that the large dead air region generates at zero inclined angle. Figure (b) is the case of –30 degree.The velocity distribution is fairly different to the case of zero degree. There does not exit the dead air region. The velocity distribution is varied in flow direction. So it indicates that the dead air region is fairly small.

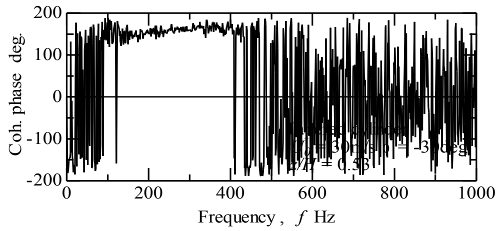


(a) Coherence at ϕ=0 degree



(c) Coherence at ϕ= -30 degree

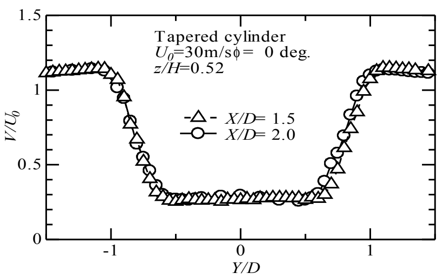


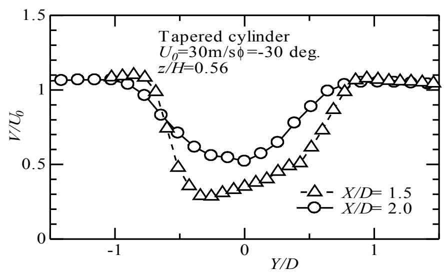


(b) Phase at ϕ=0 degree

(d) Phase at ϕ= -30 degree

Figure 8 Alternate vortex shedding characteristics in the wake





(a) f=0 degree

(b) f=-30 degree

Figure 9 Velocity distributions of the wake at mid-span

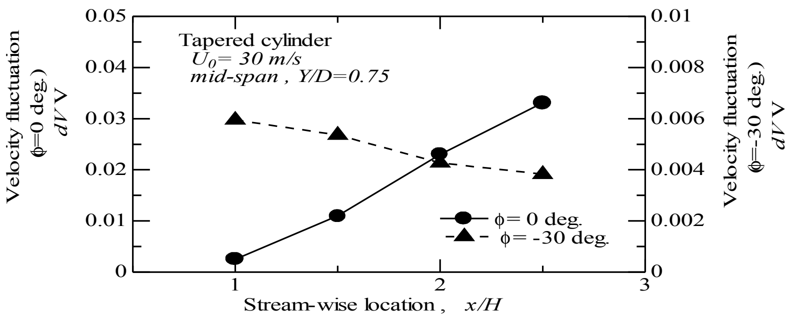


Figure 10 Variation of velocity fluctuation in the wake to the stream-wise direction

Figure 10 shows the variation of the velocity fluctuation to the stream-wise location. These levels are corresponding to the peak of the spectrum distribution. At the case of ϕ=0 degree, the level is very small near the cylinder. And the fluctuation is rapidly increased downstream. This is corresponding to the formation of a large dead air region (figure 9). And the rolling up to the wake vortex is occurred at fairly far from the cylinder. Then it is little influenced on the flow on the cylinder. Figure (b) is the case of the f=-30degree. The fluctuation level is large near the cylinder and it is gradually decreased to the downstream. It is indicated that the rolling up of the shear layer to the wake vortex shedding is occurred just downstream of the cylinder and is influenced on the flow on the cylinder. It is cleared that the scale of the dead air region is greatly affected to the aeolian tone, because the position of the rolling up to the wake vortex are varied.

Coherence of the wake flow and aeolian tone

Figure 11 shows the coherence between the aeolian tone and the velocity fluctuation at each span location. Figure (a) is the case of *z/H*=0.2. There exists a large coherence at f=260Hz and the large coherence is extended to the high frequency at ϕ= -30 degree. There is no coherence between aeolian tone and velocity fluctuation at zero degree. Figure (b) is the case of *z/H*=0.5. There exists the large coherence at f=250Hz in –30 degree. The frequency region of the large coherence is a little biased to the low

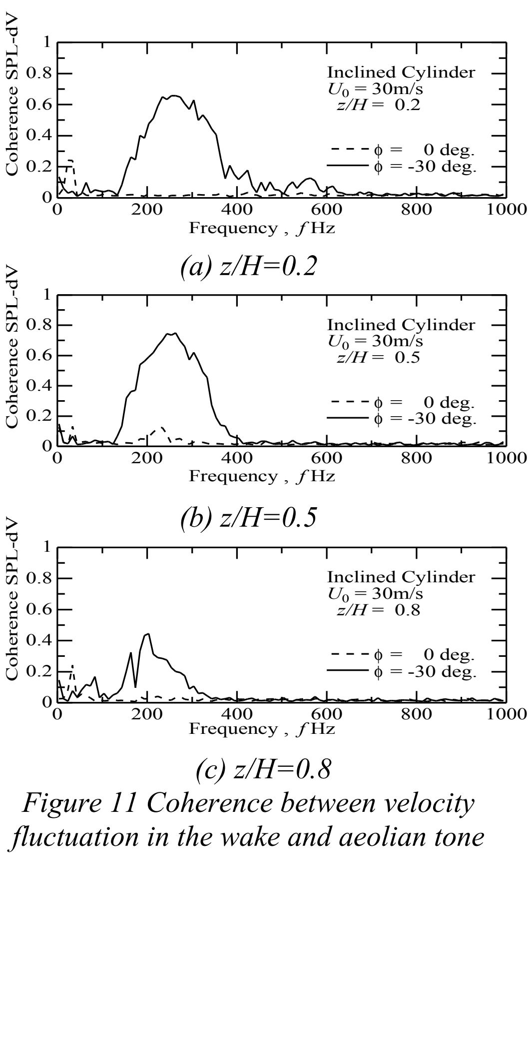


Figure 11 Coherence between velocity fluctuation in the wake and aeolian tone

frequency compared to figure(a). At zero angle, There is very small coherence at f=230Hz. Figure (c) is the case of z/H=0.2. There exits the peak at f=200Hz at –30 degree inclined angle. But there does not exit the large coherence in the case of zero degree. Then it is cleared that the aeolian tone at –30degree has the large correlation with the velocity fluctuation.

CONCLUSIONS

The aeolian tones generated from the tapered cylinder were researched with the inclined conditions experimentally. The following results are obtained.

1. The sound level of aeolian tone is little at zero inclined angle, but large at the large positive and negative inclined angles.
2. The alternative vortex shedding is generated not only at the zero angle, but also at the large inclined angle.
3. The location of the rolling up to the wake vortex is far from the cylinder at zero inclined angle, but is close to the cylinder at large angle.
4. The position of the rolling up of the wake vortex is closely relating to the level of aeolian tone. When the position is close to the body, the sound level of it becomes large.

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