NUMERICAL STUDY ON CORRELATION BETWEEN AEROACOUSTIC SOURCES ON UNIFORMLY LINED CYLINDRICAL BODIES PLACED IN A STATISTICALLY UNIFORM FLOW

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ABSTRACT

Our goal is to establish a numerical prediction system for aeroacoustic noise from building subsidiaries in windy environments like an exterior balustrade. To reduce computational resources required for CFD computation, the authors present a method to estimate the noise from a row of cylinders like balusters by computing its part. The idea is to extrapolate the sound pressure obtained by partial computation using correlation function of the phase angles of fluid forces at each frequency between the cylinders. A computation of a balustrade with eight balusters with the method applied is attempted, where correlation is hardly observed even at the Karman frequency. Thus further investigation is required to confirm the validity of the method.

1. INTRODUCTION

The authors are working on numerical prediction of aeroacoustic noises from building exterior subsidiaries such as balusters or louvers in windy environments, which sometimes annoy inhabitants. Prediction of the noise from a complex body such as a balustrade, however, requires too much computational resources to analyze the whole body. As the subsidiaries usually have shapes of equally spaced cylindrical bodies, the sound sources on each body are considered to have some correlation to each other if statistically uniform approaching flow is given. Using the correlation, noises from all bodies are expected to be estimated from the analysis of a part of the subsidiary. In the present paper, the estimation method is presented and computation is attempted as the primary step to verify the method.

2. NUMERICAL METHODS

2.1 Overview

The computational approach for prediction of aeroacoustic noise is, on the whole, based on a classic two-step Lighthill analogy method. The flowfield around sound source objects is solved to determine aeroacoustic sources using a large eddy simulation with the standard Smagorinsky subgrid-scale model applied, and then the radiated far-field noise is calculated using an integral based on Curle's extension to the Lighthill analogy theory over the sound source (see reference [1] for details). The estimation method will be appended between the two steps.

2.2 Estimation Method of the Noise Using Part of the Analysis

The following method is derived from a discrete analogy of spanwise total sound pressure estimation described in the reference [2] based on the reference [3].

Let us consider *N* cylinders of identical shape uniformly aligned with equal spacing in statistically uniform flow and an observation point ***y*** shown in Fig. 1. We assume that *M* of *N* bodies will actually be included in the computational domain in a CFD computation.

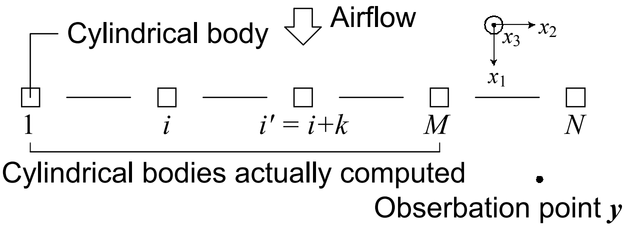

Fig. 1: Schematic of a row of cylindrical bodies.

Time-averaged acoustic intensity radiated from the sound sources on *M* bodies $\bar{I}_s(f)$ which reach the observation point ***y*** is obtained as follows, by excluding the parameters regarding relative positions of the source and the receiver, and by assuming the amplitude of the sound sources on each body is identical.

$$\bar{I}_s \propto \sum_{i=1}^{M} \sum_{k=1-i}^{M-i} g(i,k,f), \qquad (1)$$

$$g(i,k,f) = e^{j[\Theta(i+k)-\Theta(i)]}, k = i'-i$$

where i and i' denote the i-th and i'-th bodies of the cascade respectively and $\Theta(i)$ denote the phase of the fluid force on the body i at the frequency f. The end effects of the cascade and the retarded time are neglected. Then the correlation function of fluctuating fluid forces between the two bodies of k-bodies distance from each other is defined as the following.

$$\gamma(k) = \frac{1}{M-k}\sum_{i=1}^{M-k} g(i,k,f) \tag{2}$$

It is assumed that γ obeys the exponential function as to k and correlation distance $l(f)$.

$$\gamma(k) \approx e^{-\frac{k}{l}} \tag{3}$$

By substituting Eqs. (2, 3) for the inner summation of Eq. (1) and executing analytical integral for continuous analogy of the outer summation, a function h to which $\bar{I}_s$ is proportional is obtained.

$$\bar{I}_s \propto h(M,l), \tag{4}$$

$$h(M,l) = 2l\left[M + l\left(e^{-\frac{M}{l}} - 1\right)\right] \tag{5}$$

Here l is determined through curve-fitting Eq. (3) to Eq. (2) using a least square estimation technique. If the flowfield is statistically uniform l should be constant to M and N, which means that the acoustic intensity from all N bodies $\bar{I}$ is proportional to $h(N,l)$. Thus the sound pressure from all bodies, $\bar{p}(\mathbf{y},f)$, is derived as follows from the sound pressure from the M bodies in the computational domain which is directly computed using a Curle integral, $\bar{p}_s(\mathbf{y},f)$.

$$\begin{aligned}\bar{p}(\mathbf{y},f) &= q(N,M,l)\bar{p}_s(\mathbf{y},f),\\ q(N,M,l) &= \sqrt{h(N,l)/h(M,l)}\end{aligned} \tag{6}$$

3. ANALYSIS

The sound sources from a balustrade with 8 square section balusters with cross-sectional length 21mm placed in a uniform airflow is computed. The computational conditions and the computational domain are shown in Tab. 1 and Fig. 2 respectively. The computation is conducted from nondimensional time T = 0 to 220 and used the data after T = 40 for the following analyses where the flowfield became periodic steady-state. The computation was performed on a Hitachi SR8000 supercomputer (8Gflops) and took about 18 days.

Tab. 1: Computational parameters.

Cross-sectional length of a baluster L = 21mm, wind velocity U = 12m/s, number of computational cells (x_1, x_2, x_3) = (131, 828, 20), minimum cell width = 0.018L, time scale T = 0.00175s, time step ΔT = 0.001T, Reynolds number Re = 16000, observation point $\boldsymbol{y}$ = (500L, 500L, 0) from the center of the balustrade.

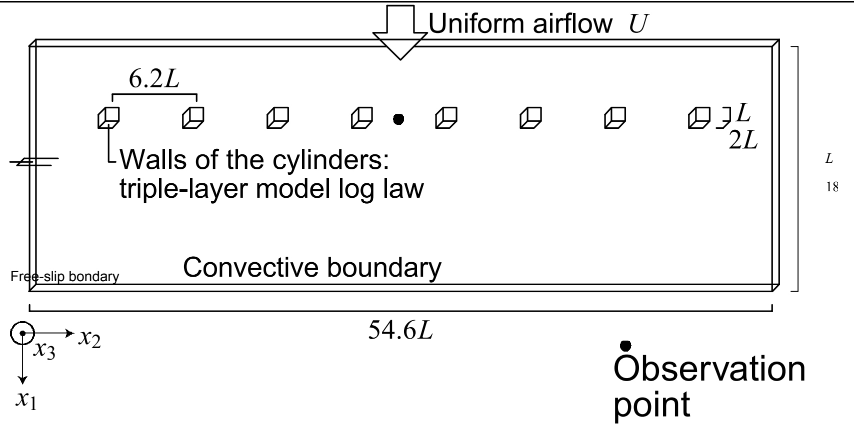

Fig. 2: Computational domain for flowfield analysis.

3.1 Correlation Function

Fig. 3 and 4 show the x_1- and x_2-directional correlation functions γ obtained from the phase of fluctuating fluid force on the bodies. One can read roughly exponential distributions of γ for both components. The x_2-component of fluid force, however, does not show strong correlation at the Karman frequency, 90Hz, which is a different behavior from the cases of spanwise estimation [2]. The x_2-directional correlation function between the neighboring bodies (k = 1) tends to be negative at around 5kHz or above.

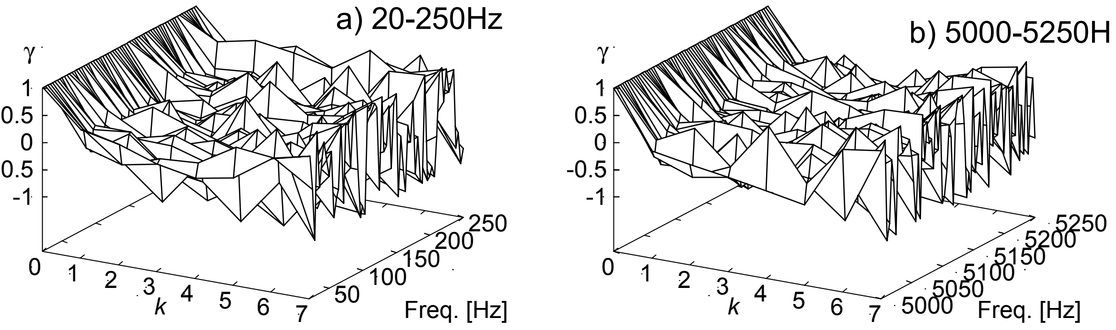

Fig. 3: Correlation function γ for x_1-component of fluid force at a) 20-250Hz and b) 5000-5250Hz.

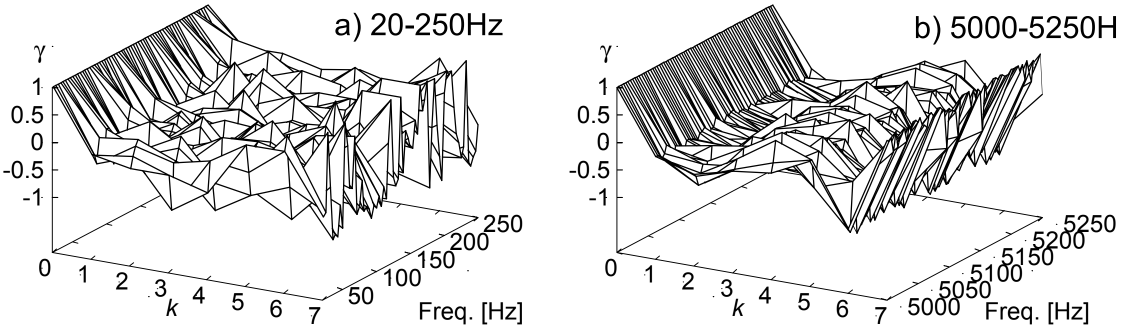

Fig. 4: Correlation function γ for x_2-component of fluid force at a) 20-250Hz and b) 5000-5250Hz.

3.2 Correlation Distance

Fig. 5 shows the correlation distance obtained through fitting the correlation functions shown in Fig. 3 and 4 to exponential function. The correlation distances are at most the spacing of the balusters except at few frequencies. No strong peak around the Karman frequency is observed.

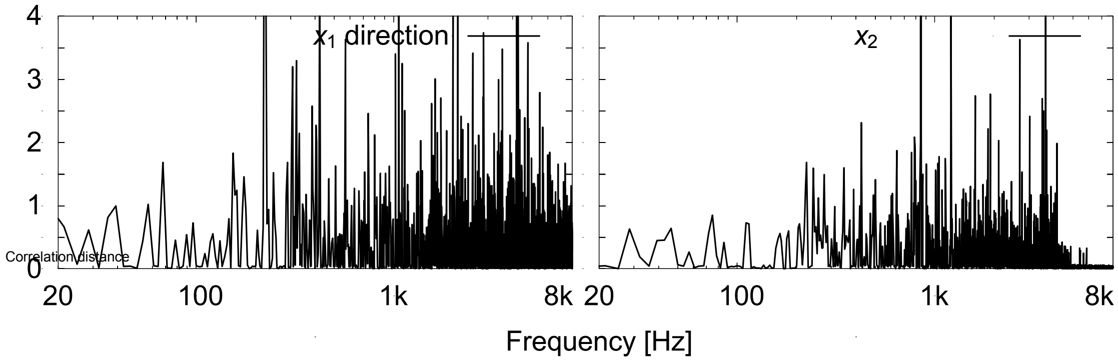

Fig. 5: Correlation distances $l(f)$ for x_1- and x_2-components of fluid force.

3.3 The value of function *q*

From Eq. 5, *h* takes the following values as to the relationship of *l* an *M*.

$$h(M,l) \approx 2Ml(l << M), \quad \approx M^2(l >> M)$$

Assuming the total number of bodies N = 24 for example, the values of q obtained from Eq. 6 should be as follows.

$$q \approx \sqrt{N/M} = \sqrt{3}(l \to 0), \quad \approx N/M = 3(l \to \infty)$$

From the comparison of the values above and Fig. 6 where q as function of frequency is plotted, the correlation of the sound sources is barely observed for almost all frequencies of x_1-and x_2-components of the fluid force.

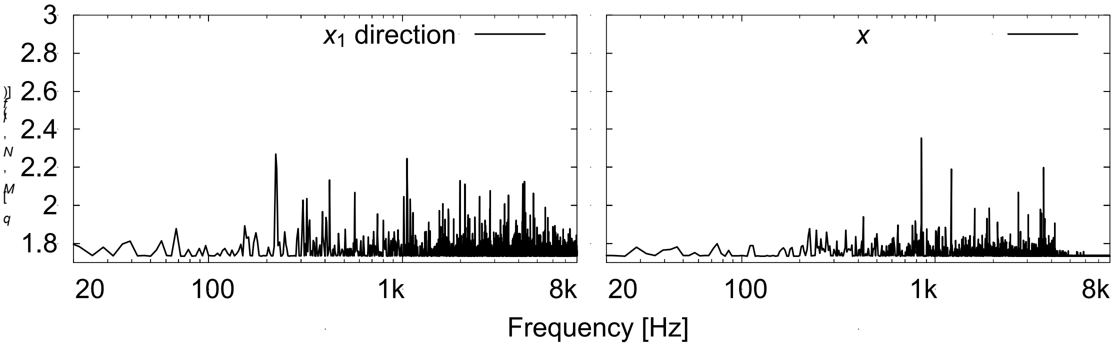

Fig. 6: Values of function q for x_1- and x_2-components of fluid force.

3.4 The Sound Pressure Levels

The 1/3-octave-band averaged sound pressure level received at the observation point is shown in Fig. 7, calculated with the method applied and with the assumption of no correlation between the bodies (+3dB = double the source). As expected from the values of correlation distances, both of the results are almost identical. In such case the assumption of no correlation would suffice and estimation method need not be necessarily applied. Thus it turned out that to prove the effectiveness of the method, a case where one can observe stronger correlation should be formed, such as by narrowing the spacing of the balusters.

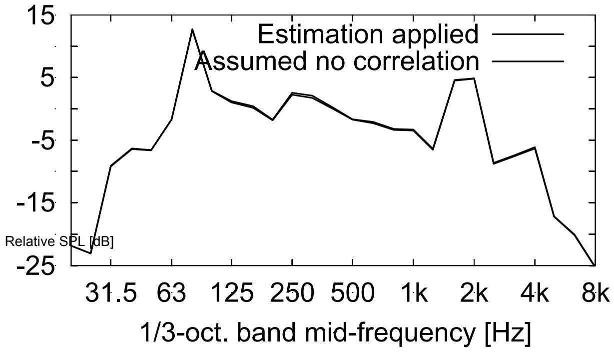

Fig. 8: 1/3-octave-band averaged sound pressure levels obtained by applying the method and by assuming no correlation.

4. CONCLUSION

An estimation method of the total sound pressure radiated from a row of cylindrical bodies is presented and a computation is attempted. The results tell that the correlation of the fluid force between the balusters is not dependent on the Karman frequency. Validity of the method, however, could not be confirmed because the computational setup of the balustrade was not adequate and should be further investigated.

ACKNOWLEGEMENT

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