

Short Paper

# Identification of Aerodynamic Sound Source with a Compact Green's Function

Iida, A.\*<sup>1</sup>, Mizuno, A.\*<sup>1</sup> and Kato, C.\*<sup>2</sup>

\*1 Department of Mechanical Engineering, Kogakuin University, 2665 Nakano-machi, Hachioji, Tokyo, 192-0015 Japan. E-mail: iida@fluid.mech.kogakuin.ac.jp

\*2 Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo, 153-8505 Japan.

Received 21 August 2006 and Revised 12 September 2006

## 1. Introduction

In the automobile and electric industries, aerodynamic noise is one of the most serious problems in the development of new products. The Mach number of the flow velocity for automotive and electric products is comparatively small, and the wavelength of the resulting aerodynamic sound is larger than the dimensions of these products. In this situation the radiated aerodynamic sound can be formulated by Lighthill-Curle's theory (Curle, 1955), which is generally known to be the most convenient theory currently available. Therefore, aerodynamic sound sources are conventionally investigated by using surface pressure fluctuation, which acts as a dipole source, as formulated in Lighthill-Curle's equation. However, Lighthill-Curle's theory gives us no information about the relationship between unsteady vorticity fluctuation and aerodynamic sound. That is, it only shows aerodynamic sound generated by the surface pressure fluctuation or aerodynamic forces. We therefore cannot obtain the vortex contribution to aerodynamic sound generation by using Lighthill-Curle's theory. From the aerodynamic point of view, even in a low-Mach-number wake, we have to consider the relationship between vorticity fluctuation and aerodynamic sound in order to reveal the origin of 'true aerodynamic sound source'. In this paper, we describe our work to identify the aerodynamic sound source around a circular cylinder by using the experimental results of the vorticity measurement and a compact Green's function method.

## 2. Experimental Methods

To identify the aerodynamic sound source around a circular cylinder, aerodynamic noise and vorticity fields were measured in a low-noise wind tunnel. The experiment was conducted at a mean flow velocity of 15 m/s and a Reynolds number of  $4.0 \times 10^4$ . The test cylinder had twelve pressure taps as shown in Fig. 1. The surface pressures were measured with microphones through the 1 mm pressure taps. To estimate the vorticity contribution to aerodynamic sound generation, vorticity fluctuation of  $\omega_z = (\partial v/\partial x - \partial u/\partial y)$  was also measured. Figure 2 shows a vorticity probe which has a parallel I-type hot-wire and an X-array hot-wire. The parallel array probe measures velocity fluctuation in the stream wise direction. This velocity is then used to calculate the cross-section gradient,  $\partial u/\partial y$ . The X-array probe measures the cross-stream component, which is used in Taylor's hypothesis to transform temporal derivatives into streamwise derivatives,  $\partial v/\partial x = -1/U_c \cdot \partial v/\partial t$ . The instantaneous span wise vorticity,  $\omega_z = (\partial v/\partial x - \partial u/\partial y)$  can be measured with this vorticity probe.

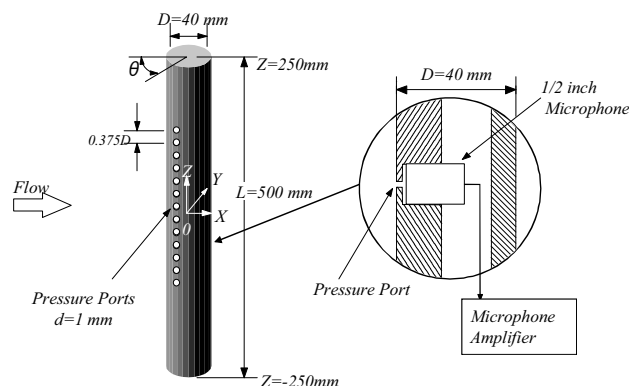


Fig. 1. Test cylinder and pressure pick-up.

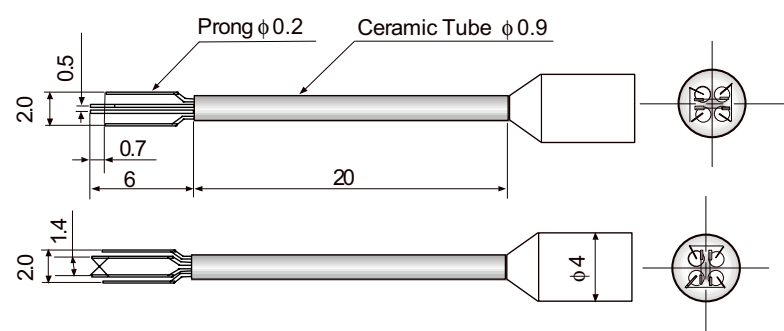


Fig. 2. Vorticity probe with four hot-wires.

In the case of a low Mach number wake flow behind a rigid body, aerodynamic sound,  $P_a$ , can be estimated with a compact body assumption suggested by Howe (Howe, 1998). That is, the aerodynamic sound equation can be written as follows:

$$P_a = -\rho_o \int \{ \boldsymbol{\omega}(\mathbf{y}, \tau) \times \mathbf{u}(\mathbf{y}, \tau) \} \frac{\partial}{\partial \mathbf{y}} G(\mathbf{x}, \mathbf{y}, t - \tau) d\mathbf{y} d\tau, \quad \mathbf{G}(\mathbf{x}, \mathbf{y}, t - \tau) = \frac{\mathbf{x}_j Y_j(\mathbf{y})}{4\pi a |\mathbf{x}|^2} \frac{\partial \delta}{\partial t} \Big|_{t - |\mathbf{x}|/a} \quad (1)$$

where  $\boldsymbol{\omega}$  and  $\mathbf{u}$  denotes vorticity and velocity vector.  $\mathbf{G}$  denotes a compact Green's function.  $Y_j$  is a velocity potential of incompressible flow past the bluff body. Then, the dipole sound can be calculated by coupling source term of  $(\boldsymbol{\omega} \times \mathbf{u})$  with a velocity potential  $Y_i$ , which is related to a compact Green's function  $\mathbf{G}$ , and  $Y_i$  can be given theoretically in the case of a (circular) cylinder placed in uniform flow.

### 3. Results and Discussion

The dipole sound source of the fundamental frequency ( $f = 75$  Hz) which correspond to Strouhal number of 0.2 is visualized by using the compact Green's function and the measured vorticity fluctuation as shown in Fig. 3(a). The dipole source is concentrated at  $XD = 1.5$  and  $YD = \pm 0.4$ . The vortex growth rate and  $\text{grad } Y_i$  are both large in this region. It is remarkable that the aerodynamic sound source is concentrated in a small area at  $YD = \pm 0.4$ . However, this area does not correspond to the vorticity concentration region; that is  $YD = \pm 0.6$ . The aerodynamic sound source lies near the center of the cylinder but the vorticity fluctuation is close to the side of the cylinder. In this region, the alternating vortices come from both sides of the cylinder, and the separated shear layer is stretched by this vortex motion. The separated shear layer therefore rolls up at the formation region of the Karman vortices. The result showed aerodynamic sound is caused by the vortices around the formation region in the wake of the cylinder, and then the separated shear layer seems to be the seed of the aerodynamic sound. Figure 3(b) shows the aerodynamic sound source which is calculated by coherent output power (COP) in terms of the vorticity and surface pressure fluctuation (Iida et al., 1999). The dipole source distribution calculated by the compact Green's function method is in good agreement with the COP. It is apparent that the compact Green's function reflects the vorticity contribution of the dipole sound generation. The conventional, Lighthill-Curle's method gives us no information about the vorticity contribution for the dipole sound generation. The compact Green's function method is useful to understand dipole sound generation. This method is therefore suitable for estimating the relationship between the dipole sound source and vorticity fluctuation.

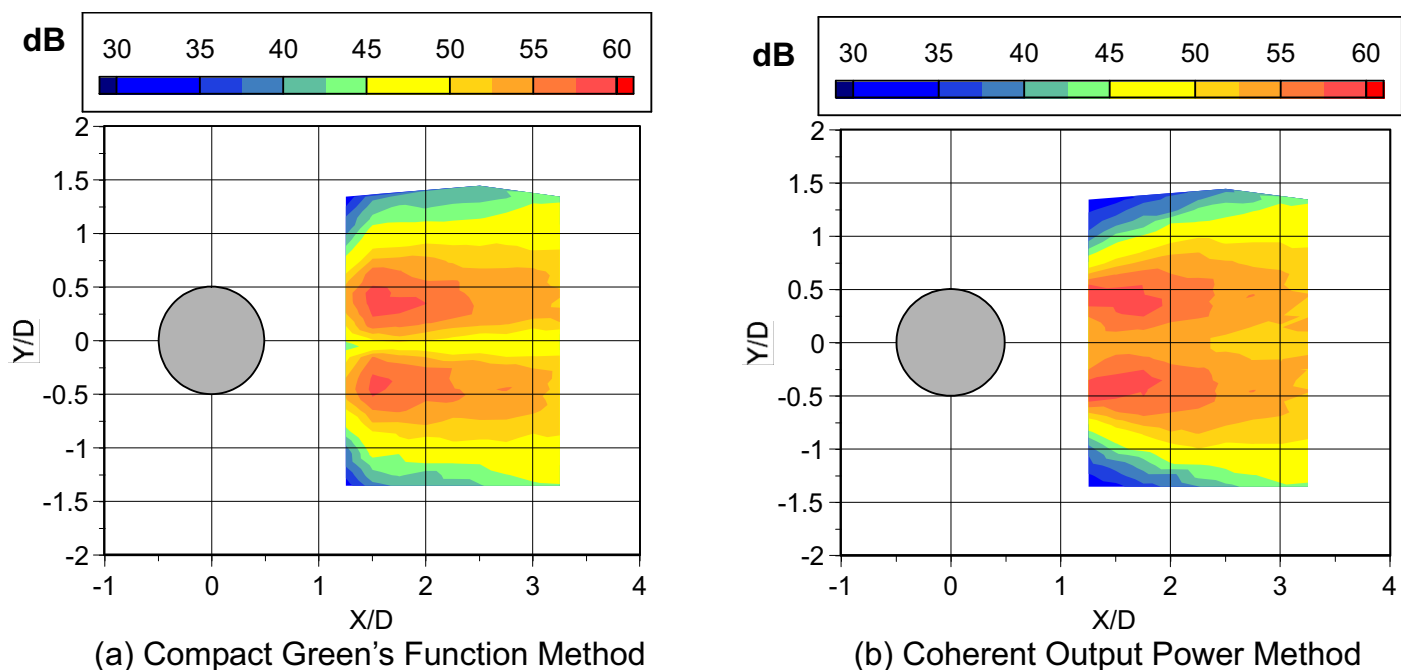


Fig. 3. Distribution of dipole sound source of the fundamental frequency in the wake of a cylinder.

### References

- Curle, N., The Influence of Solid Boundaries upon Aerodynamic Sound, Proc. Roy. Soc. London, A231 (1955), 505-525.  
 Howe, M. S., Acoustics of fluid-structure interactions, (1998), Cambridge University Press.  
 Iida, A., Otaguro, T., Kato, C. and Shimode, S., Analysis of Aerodynamic Sound Source with Measurement of Static-Pressure Fluctuation, JSME International Journal Ser. B, 42-4 (1999), 596-604.