Effects of large-scale turbulence on the mean flow past a circular cylinder

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An actively controlled wind tunnel equipped with multiple fans was utilized to generate the turbulent flow with large integral scale, within which the effects of large-scale turbulence on the vortex shedding from a circular cylinder were investigated. The results show that the mean characteristics of the vortex shedding behavior in the large-scale turbulence approaches to that in the smooth flow.

1. Introduction

Vortex shedding from a bluff body is sensitively affected by the oncoming turbulence, however, the physical mechanism of the interaction of the separated shear layer with the oncoming turbulence is not fully understood [1-4]. It has been realized from the past researches that the flow around a bluff body can be characterized by two basic flow modules, one is the boundary layer separation and reattachment, and the other is the karman vortex street. According to this, Nakamura et al. suggested that there are two basic length scales relevant to the bluff body flow, one is the thickness of the separated shear layer, and the other is the distance between the two separated shear layers, or more simply, the body size. Based on this, Nakamura et al suggested further that the flow past a bluff body in the turbulent flow is dependent not only on the value of the turbulent intensity, $I_t (I_t = u'/U, u': standard deviation of the velocity fluctuation, U: mean velocity)$ of the oncoming turbulence, but also on the ratio of the turbulent integral scale to the body scale, $L_e/h$, where $h$ is the representative scale of the bluff body and $L_e$ is the measure of the average size of turbulent eddies of the flow, defined as $L_e = \frac{U^2}{\overline{u'^2}} \overline{R_{uu}(\tau)}$ with Taylor's frozen hypothesis be applied, where $\overline{R_{uu}(\tau)}$ is the auto covariance function of the velocity fluctuation at a given point. Nakamura et al. produced several kinds of grid turbulence, with the turbulent integral scale varied with the grid space. They showed that vortex shedding behavior form a bluff body changed with the turbulent integral scale indeed, and finally they predicted that the turbulence effects will be negligible if the integral in the world for this purpose [7]. This wind tunnel is an open-circuit one with 99 fans of 270mm in diameter at the front, arranged in a 9 wide by 11 high matrix. Each fan is driven by an individual AC servo motor with fast frequency response. The rotational speed of all the servo motors is controlled through a computer within the frequency range of approximately 0-25.0Hz, thus achieving fluctuating air flow in the test section. Since 99 fans can be programmed independently to deliver variable flows, phase shifts can be introduced among them, allowing transverse and vertical turbulence to be generated. With adding compulsorily the turbulence energy at the low frequency region, turbulence with long region of inertial subrange as well as large integral scale of the turbulence is large enough compared with the representative body scale. But this prediction has not yet been proved by wind tunnel studies, because large-scale turbulence, which requires the realization of a long inertial subrange region in power spectrum, is almost impossible to be generated in a conventional wind tunnel.

In atmospheric turbulent flows the integral scale changes from several meters to over hundred meters according to the terrain roughness and the height of the measurement point. Turbulence intensity also varies with the height. Current acknowledge of the turbulence effects is that the turbulence induces earlier transition of the shear layers separated from a circular cylinder and increases the entrainment, resulting in increase of drag. This conclusion was drawn without considering the effects of large-scale turbulence. The investigation of the large-scale turbulence on the vortex shedding from a bluff body is thus very important for both basic fluid physics and engineering application studies.

A unique actively-controlled wind tunnel has been established in Miyazaki University, Japan, with which large-scale turbulence can be generated. In this study, the effects of the large-scale turbulence on the mean flow around a circular cylinder are investigated.

2. Experimental setup

Great efforts have been made by many researchers to generate large-scale isotropic turbulence with passive [5] or active devices [6]. We put forward the first multiple-fan turbulence wind tunnel scale can be obtained. The test section of the wind tunnel is 1550mm long, 2600mm wide, and 1800mm high. In order to investigate the effects of large-scale turbulence on the vortex shedding from the bluff body, the mean pressure distribution around a circular cylinder of 110mm in diameter was measured. Totally number of 72 pressure tappings is provided on the cylinder surface with an angle increment of 5 degree. The mean pressure coefficient $C_p$ defined as $C_p = (\overline{p} - P_\infty)/\frac{1}{2} \rho U_\infty^2$, where $P_\infty$ and $U_\infty$ are the static pressure and mean velocity of the upstream flow unaffected by the cylinder, are measured with a pressure transducer with range of 0-500Pa. Endplates are supplied on the two sides of the cylinder. The
blockage ratio is 6.1%, and the aspect ratio is 8.0. Reynolds number, based on the mean velocity of the oncoming flow and the cylinder diameter is controlled to be $3.6 \times 10^5$, belonging to subcritical Reynolds number region, for all experiments.

3. Results and Discussions

Smooth flow and seven kinds of large-scale turbulent flow were generated in the multiple-fan wind tunnel. The turbulent intensity of the smooth flow in this wind tunnel is large as 1.6%, because it was built to generate the turbulence with strong intensity and large scale, and no facility is equipped to reduce the turbulence intensity. The turbulence intensity varies from 1.6% to 8.52%, including the smooth flow condition. Fig.1 shows the example of the velocity histories of the generated turbulence, whose turbulent intensity of 8.52%, 8.08% and 6.19% in the stream-wise, transverse and vertical directions, respectively. The relation, $v u / v v = 1.05$, is comparable to the general acknowledge for isotropic turbulence. Fig.2 presents the power spectrum of the stream-wise velocity fluctuation. Good agreements with karman type spectrum are obtained. A long inertial subrange region can be noticed in the power spectrum. Its turbulent integral scale is about 1.8m, about 16.0 times the diameter of the test cylinder. Fig.3 shows the variation of the mean base pressure coefficient with the turbulent intensity. The effects of blockage and aspect ratio are not corrected. Mean base pressure coefficient is almost unchanged with the intensity. Fig.4 compares the distribution of mean pressure coefficient around the cylinder at the smooth flow ($I_u = 1.6\%$) and turbulent flow with large-scale turbulence ($I_u = 8.5\%$). It can be found that the pressure distribution is also same. These results shows that the large-scale turbulence has not significant influence on the pressure distribution, in other words, the vortex shedding.

Thus, for turbulence with very large $L_u/h$ ratios, longitudinal velocity fluctuations will be perceived as slow changes in mean velocity. Under this condition quasi-steady approximations can be applied.

4. Conclusion

Vortex shedding from a circular cylinder placed at large-scale turbulence is investigated. The results show that the vortex shedding behavior in the large-scale turbulence approaches to that in the smooth flow.

Reference