Active gust generation and its application to bluff body aerodynamics

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ABSTRACT: The authors developed a gust generator. The effects of gusty wind to structural models were investigated. In this paper, active gust generation techniques and its advantages are summarized and one of the experimental studies for bluff body aerodynamic problems using the advantages is presented. The experimental study includes the estimations of aerodynamic admittance functions and indicial response functions of bluff bodies. And flutter derivatives in turbulent flows of bluff bodies are extracted.

KEYWORDS: Active gust generator, Aerodynamic admittance function, Bluff body aerodynamics, Flutter derivatives, Turbulence

1 INTRODUCTION
For an accurate estimation of aerodynamic responses in natural wind, it may be more reasonable to measure aerodynamic properties (Ex. static and dynamic aerodynamic forces, flutter derivatives etc.) in a turbulent flow similar to natural wind. We have developed an active gust generator to simulate turbulent flow similar to natural wind for two-dimensional wind tunnel testing [1]. Experimental studies of bluff body aerodynamics have been carried out using the generation devices. In this paper, active gust generation techniques and its advantages are summarized and one of the experimental studies is introduced.

2 ACTIVE GUST GENERATION
2.1 Active simulating procedure of wind gust
Fig.1 shows an outline of the active gust generator. The active gust generator consists of arrays of plates and airfoils, which play role on horizontal and vertical wind gusts.

Time history of a wind gust with target power spectra and phase angles is simulated by simulation using Fast Fourier Transformation. Also, time history may be obtained from direct scaling of the observed wind velocity at a bridge construction site.

The simulated time history is transformed into the voltage data to drive AC servomotor. The servomotor drives plates or airfoils. The motion of the plates or airfoils gives time varying wind velocity. At the first try, the generated wind velocity doesn’t agree well with the target ones. Considering to the differences in power spectra and phase angles between the target and the measured wind velocity, the target power spectra and phase angles are modified. Modified time history is calculated from the modified power spectra and phase angles. The modified time history is also transformed into the voltage data for the second process of simulation. The above process is repeated several times until the measured power spectra and phase angles get close to the target ones. Of course, turbulence intensity and turbulence length scale also agree with the
target ones.

Fig.1 Outline of active gust generation in an Eiffel type wind tunnel of Ritsumeikan University

2.2 Wind tunnel testing of active gust generation

Wind tunnel testing is carried out in a Göttingen type wind tunnel with a working section of 2000~3000 mm$^2$ in the research center of Hitachi Zosen. Experimental facilities are similar to the active gust generator in Fig.1. The fluctuating vertical and horizontal components of the flow were measured by hot-wire anemometers at the center of sectional model placed 1680 mm downstream from the trailing edge of the airfoils.

The active gust generation was applied to simulate turbulence of Von Kármán’s spectrum as target spectrum (target values: $L_u=10\%$, $I_w=5\%$, $L_u=200\text{cm}$, $L_w=50\text{cm}$) in the wind tunnel. Fig.2 shows the target and the measured time history of wind gust. The measured time history agreed well with the target ones. Moreover, the measured turbulence intensity and turbulence length scale also agreed well with the target ones.
3 APPLICATION TO BLUFF BODY AERODYNAMIC PROBLEMS

Table 1 shows the advantage of active gust generation and the experimental studies for bluff body aerodynamic problems considering the above advantages. In this paper, experimental estimations of complex aerodynamic admittance functions and flutter derivatives of bluff structures in turbulent flows are introduced.

Table 1 Advantage of active gust generation and application to bluff body aerodynamic problems

<table>
<thead>
<tr>
<th>Advantage of active gust generation</th>
<th>Application to bluff body aerodynamics</th>
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<tbody>
<tr>
<td>Generation of large scale turbulence</td>
<td>Fundamental study on turbulent effects on aerodynamic behavior [2,3,4]</td>
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<tr>
<td>Control of turbulence properties</td>
<td>Measurements of fundamental aerodynamic response functions using sharp edged gust or sinusoidal wind gust [5]</td>
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<td>Generation of the wind gust with fundamental function such as step change function or sine wave</td>
<td>Measurement of flutter derivatives in a turbulent flow [6]</td>
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<td>Repeatability of simulated wind gust</td>
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<td>Generation of two dimensional wind gust</td>
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3.1 Complex aerodynamic admittance functions of bluff bodies

Complex aerodynamic admittance functions of NACA0012 airfoil section and the rectangular cylinder with B/D ratio = 7.5 were measured. It is necessary to measure fluctuating wind velocity at the model position (as the input) and aerodynamic forces (as the output) at the same time to estimate complex aerodynamics admittance functions. Because the gust generator can provide the same time history at each test case, we can identify the wind velocity at just leading edge or the center of the model for the previously generated data. Thus we can obtain fluctuating wind velocity and aerodynamic forces under the wind gust with same time.

Fig.3 shows experimental results for moment forces. Küssner’s function was calculated by inverse Fourier transformation of complex aerodynamic admittance function. For the airfoil section, the measured values are in agreement with Sears’ function and Küssner’s function. For the rectangular cylinder, the measured values have different tendency with Sears’ function and Küssner’s function. The Küssner’s function has overshoot transiently before convergence to quasi-steady value (=1.0). The overshooting of transient aerodynamic moment might be related to growth of separation bubbles from the leading edges.

<table>
<thead>
<tr>
<th>Section</th>
<th>Aerodynamic admittance</th>
<th>Complex admittance</th>
<th>Equivalent Küssner’s function</th>
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<tr>
<td>NACA0012</td>
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<td>B/D=7.5</td>
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Fig.3 Measurement of complex aerodynamic admittance functions for aerodynamic moment
3.2 Flutter derivatives of bluff bodies in a turbulent flow

Effects of upstream gust on flutter derivatives of rectangular cylinders were studied. Flutter derivatives in turbulent flows were measured using forced vibration method. Aerodynamic forces were measured in a fixed and a sinusoidal moving model. On each model the same time history of wind gust was applied. Subtracting the aerodynamic forces acting on the fixed model from that on the moving model, we could get the aerodynamic forces due to the body motions alone.

From comparison between the flutter derivatives in the smooth and the turbulent flows (see Fig.4, 5), it was found that the upstream gust has different effects on the flutter derivatives according to sectional shapes. It was concluded that the flutter derivative of the rectangular cylinders with larger vortex separations from the leading edges are especially subjected to the effects of the upstream gust.

![Fig.4 Turbulent effects on flutter derivatives _A_2^* of rectangular cylinders with and without fairing](image1)

![Fig.5 Turbulent effects on flutter derivatives _A_2^* of rectangular cylinders with different B/D ratio](image2)

4 CONCLUSIONS

The gust generator can repeatedly produce accurate time history. This feature is main advantage of this gust generator. This advantage was effectively used in the experimental estimations of aerodynamic admittance functions and experimental extractions of flutter derivatives in turbulent flows.

5 REFERENCE