Diagnosis of Airflow Characteristics in Wind Farm by Using the Unsteady Numerical Model RIAM-COMPACT

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We are developing the numerical model called the RIAM-COMPACT (Research Institute for Applied Mechanics, Kyushu University, Computational Prediction of Airflow over Complex Terrain). The object domain of this numerical model is from several m to several km, and can predict the airflow and the gas diffusion over complex terrain with high precision. The RIAM-COMPACT has already been marketed by certain tie-up companies. The estimation of the annual electrical power output is also possible now based on the field observation data.

In the present study, wind simulation of an actual wind farm was executed using the high resolution elevation data. As a result, an appropriate point and an inappropriate point for locating a wind turbine generator were shown based on the numerical results obtained. This cause was found to be a topographical irregularity in front of the wind turbine generator.

Key words : Wind risk evaluation, Complex terrain, CFD, LES, RIAM-COMPACT

1. Introduction

There exists a great and urgent need to reduce CO2 emissions as a way to combat global warming. Therefore, attention has focused on the development of environmentally friendly wind energy (natural energy). In Japan, the number of wind power generation facilities has increased rapidly from several WTGs (Wind Turbine Generators) to a large-scale WF (Wind Farm). The output of the WTG is proportional to the cube of the wind speed. Therefore, it is important that the windy region in which the WTG is installed be chosen carefully. The terrain in Japan is remarkably different from that of Europe and America, and thus it is extremely important to consider Japan's unique topographic effect on the wind, such as a local speed-up, separation, reattachment, and so on.

The social and technological requirements for wind power are strong. Concentrating on a space of several km or less, we are developing an unsteady, non-linear-type numerical simulator called the RIAM-COMPACT (Research Institute for Applied Mechanics, Kyushu University, Computational Prediction of Airflow over Complex Terrain) (1)-(3). The RIAM-COMPACT is a FORTRAN program based on the FDM (Finite-Difference Method), and adopts an LES (Large-Eddy Simulation) technique as a turbulence model. In an LES, comparatively large eddy structures are calculated directly, and only eddy structures that are smaller than the calculation mesh are modeled.

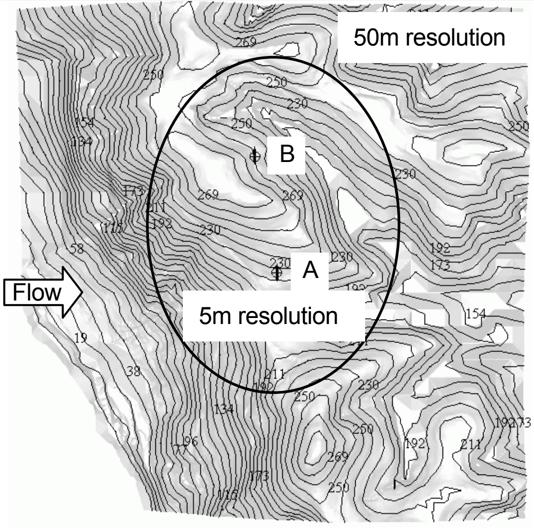
Up to now, most of the software that has been developed in Japan employs the time-averaged turbulence model called the RANS (Reynolds Averaged Navier-Stokes equation) from the problem regarding the necessary time required for calculation (4), (5). Computer performance has improved remarkably in recent years, and the problem regarding calculation time has been reduced dramatically. LES, a turbulence model of the space-average type, can simulate an unsteady flow field. If an unsteady flow field can be easily calculated, and the result reproduced in animation, the RIAM-COMPACT can provide an alternative tool for wind tunnel experiment. Consequently, it is expected to aid in practical design. We have been examining the practical use of the RIAM-COMPACT for several years from such a viewpoint. The RIAM-COMPACT has already been marketed by certain tie-up companies. Estimation of annual electrical power output is also possible now based on field observation data.

The main problem regarding the current WF is its low power output. It is thought that the main cause of this inefficiency is due to small geographical rises and depressions in the WTG site. It has been assumed that these irregularities mechanically generate wind turbulence. Therefore, a regular evaluation of flow characteristics is necessary in the WF during operation. We thus propose the use of the RIAM-COMPACT to diagnose the WF site's airflow characteristics. The high resolution elevation data of 10m or less that reflects the current state of land use is indispensable to this. We developed a technique for constructing high resolution elevation data of 10m or less based on a paper map and the CAD (Computer Aided Design) data in DXF (Data eXchange Format) form (6). In the present study, the numerical simulation for a WF during operation was executed by using elevation data of 5m resolution.

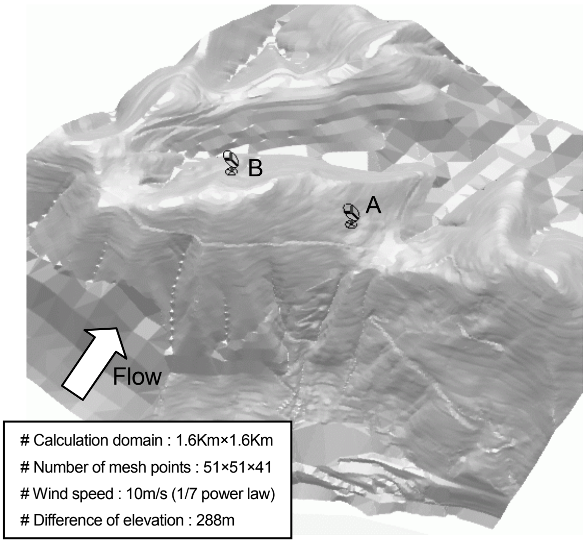
2. Numerical results and discussion

In the present study, the numerical simulation for a WF during operation was executed by using a generalized curvilinear collocated grid. Only the calculation for the prevailing wind direction was done in this research. Moreover, the geographical features handled for this research is used as an arbitrary place.

Fig.1 shows the geographical features around the WTGs and numerical conditions. In the present study, the surroundings of the WTGs sites were constructed from CAD data of the DXF form with 5m resolution. The surroundings were constructed with 50m elevation data provided by the Geographical Survey Institute. Thus, the high resolution elevation data originally constructed based on the paper map and the DXF file were merged with existing elevation data by using the GIS (Geographical Information System) technique.



(a)Top view

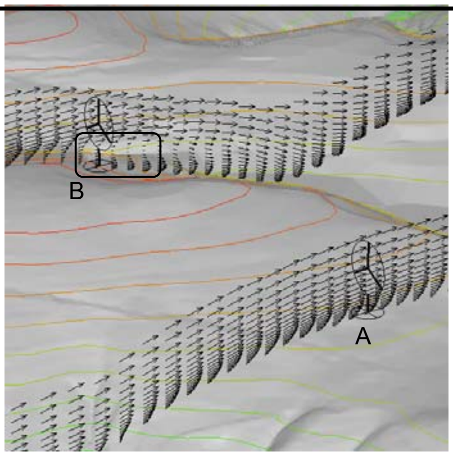


Calculation domain : 1.6Km×1.6Km
Number of mesh points : 51×51×41
Wind speed : 10m/s (1/7 power law)
Difference of elevation : 288m

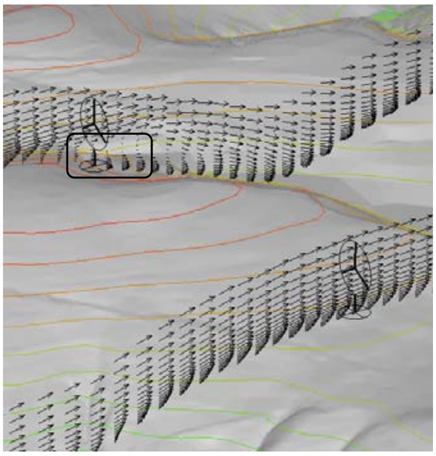
(b)Bird's-eye view

Fig.1 Geographical features around WTGs

The elevation data took several days to construct. The elevation data measured using a laser profiler, and free space shuttle elevation data (SRTM: Shuttle Radar Topography Mission data) is also used. In the RIAM-COMPACT, if the diameter of the rotor, the height of the hub, and the display color, etc. are set, and the location point is specified, the 3D line chart of the WTG can be inserted into the calculation result. The WTG in the present study has a rotor diameter of 52m, and a hub height of 44m. To clarify the topographic effect on the wind field near the ground, the surface roughness, such as a forest canopy, is not considered. The boundary conditions for the velocity field in the computational domain are as follows: 1/7 power law profile (inflow), free-slip condition (top and side boundary), convective outflow condition (outflow), non-slip condition (ground).



(a)Time=T_1



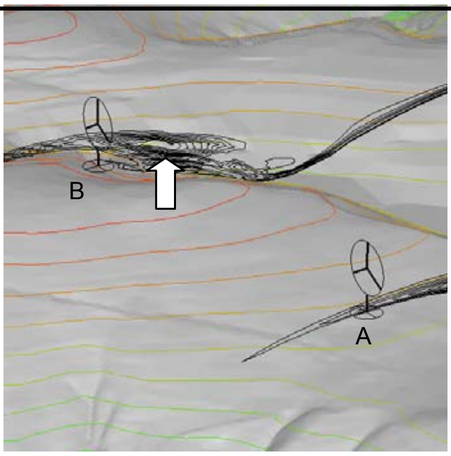
(b)Time= $T_1+\Delta T$

Fig.2 Time evolution of velocity vectors
in the vertical plane of each WTG

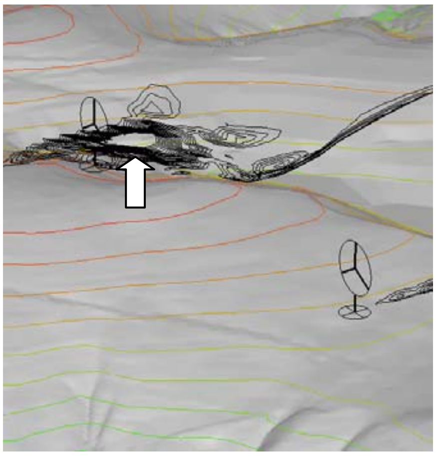
When the velocity vector and corresponding gust distributions in the vertical plane of each WTG are displayed, the difference of flow characteristics of both WTG-A and WTG-B becomes clearer. Fig.2 and Fig.3 show the results. In the case of WTG-A, it is understood that all rotor heights share almost the same speed distribution. In addition, a local speed-up due to geographical effects is confirmed. On the other hand, the separated flow is confirmed under the rotor center in the case of WTG-B, shown by the solid line in Fig.2. This is due to the turbulent flow mechanically generated from the topographical irregularity in front of WTG-B. That is, WTG-B is influenced by the turbulent flow generated by geographical features; this tower is located in a low point that shifts slightly from the hilltop. The flow phenomenon shown here cannot be reproduced if high resolution elevation data of 5m resolution is not used. The area in which wind speed varies greatly with time is confirmed by Fig.3 (see the arrow). If animation was made, and this was observed, it turned out to cause a similar phenomenon repeatedly. That is, a periodic vortex shedding was seen to be caused by the geographical irregularity in front of WTG-B (see Fig.4).

In the following, a more quantitative evaluation is performed. Fig.5 and Fig.6 show the time history of gust component $u'(=u-U_{ave})$ at the height of z^*=18, 44, and 70m. This is a physical quantity shown in Fig.3. The time scale of a horizontal axis is a dimensionless value normalized by the inflow wind speed and the difference of elevation in the calculation domain. The place where the time history was gathered is shown in these figures. In the case of WTG-A shown in Fig.5, the gust component is zero at all height levels. That is, the influence of wind turbulence is extremely small. On the other hand, at the height of especially 18m, sharp fluctuations are observed in the case of WTG-B shown in Fig.6. This corresponds to the periodic vortex shedding described in Fig.2 and Fig.3.

Fig.7 and Fig.8 show the vertical profiles of the sites of



(a)Time=T_1



(b)Time= T_1+⊿T

Fig.3 Time evolution of gust (=|u-U_{ave}|) in the vertical plane of each WTG

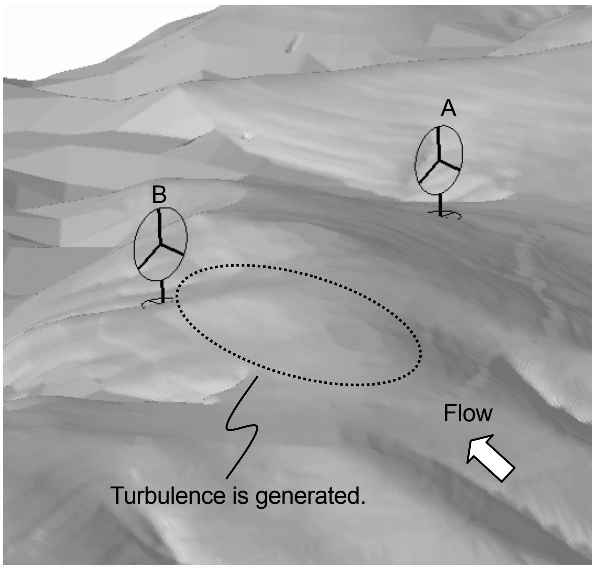
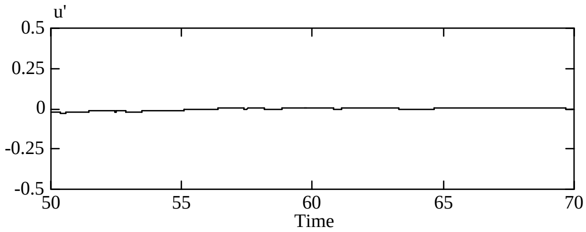
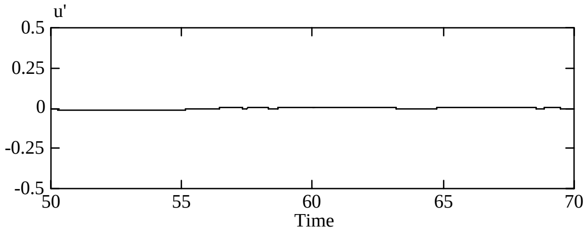


Fig.4 Closeup of geographical features around WTGs

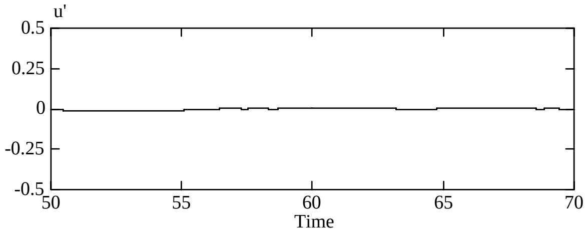
WTG-A and WTG-B. Fig.7 is a mean velocity profile. Fig.8 is a vertical profile of turbulence intensities. The vertical axis is a real scale distance from ground. The horizontal axis is a dimensionless value normalized by an inflow wind speed U_{in}. The rotor diameter is shown in the figure as well. In the case of WTG-A shown in Fig.7(a), it is understood to present almost the same speed distribution at all the height levels. In addition, a local speed-up by the effect of geographical features is confirmed at about 18m height. In the case of WTG-B shown in Fig.7(b), a strong vertical wind shear is clearly seen.



(a)z^*=18m

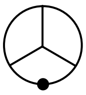


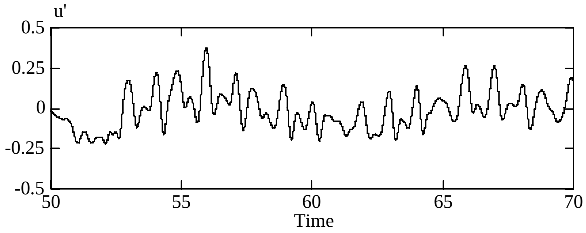
(b)z^*=44m (height of the hub center)



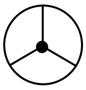
(c)z^*=70m

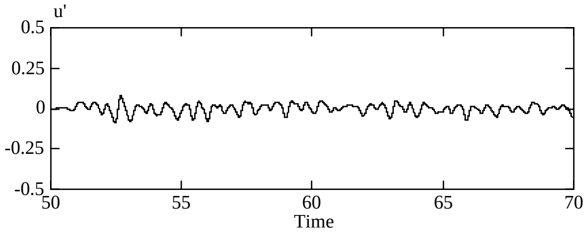
Fig.5 Time series data of u’ of WTG-A



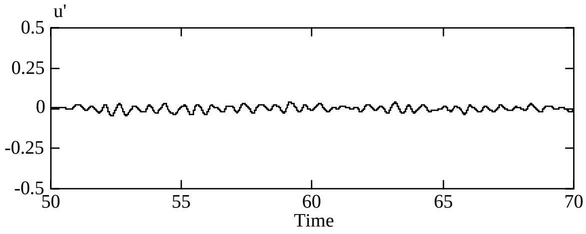


(a)z^*=18m



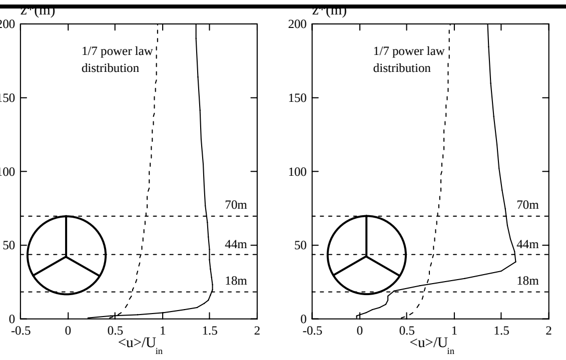


(b)z^*=44m (height of the hub center)



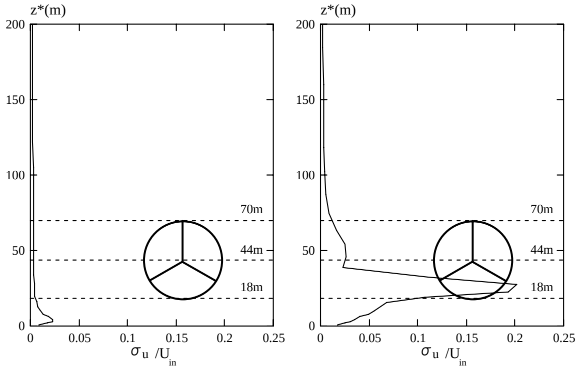
(c)z^*=70m

Fig.6 Time series data of u’ of WTG-B



(a)WTG-A (b)WTG-B

Fig.7 Mean velocity profile



(a)WTG-A (b)WTG-B

Fig.8 Vertical profile of turbulence intensities

3. Concluding remarks

In the present study, a numerical simulation for the WF during operation was executed by using elevation data of 5m resolution. An appropriate point and an inappropriate point for locating a WTG were shown based on the numerical results obtained.

In the WF diagnosis for which careful investigation is needed, it was shown that both a detailed constructing of current land use and the simulation of unsteady winds were necessary. Moreover, past techniques that depend only on the wind speed distribution in the horizontal plane at the height of the hub were shown to be insufficient. It is necessary to display the gust component and the turbulence intensities as well as their vertical distributions. It is also important to graph these quantitatively at the same time. Especially, it is expected that the display of the wind speed's vertical distributions and the turbulence intensities will become more important as the use of WTG grows. It is necessary to examine the time variation of the wind speed that negatively influences the power generation output, using numerical simulations, wind tunnel experiments, and field observations. These are problems to be solved in the future. Consequently, the criteria for determining the most effective sites for WTG have been established, leading to the construction of location risk maps. This will greatly contribute to the establishment of suitable wind power generation in Japan.

Finally, it is predicted that the wind power generation facilities of the future will be established in relatively rugged places such as mountainous districts. Therefore, it is necessary that the sites of wind power generation facilities be examined at a high level of accuracy. It is thought that WF site planning that uses the high resolution altitude data of 10m or less should be used in the preliminary investigation before the WTG is constructed.

References

[1] Uchida, T. and Ohya, Y., Numerical Simulation of Atmospheric Flow over Complex Terrain, J. Wind Eng. Ind. Aerodyn., Vol.81 (1999), pp.283-293

[2] Uchida, T. and Ohya, Y., Large-Eddy Simulation of Turbulent Airflow over Complex Terrain, J. Wind Eng. Ind. Aerodyn., Vol.91 (2003), pp.219-229

[3] Uchida, T. and Ohya, Y., Development of the Local Wind Field Simulator RIAM-COMPACT—Wind Field Assessment and Real Time Simulation—, J. Japan Society of Fluid Dynamics, (in Japanese), Vol.22, No.5 (2003), pp.417-428

[4] Murakami, S., Mochida, A., Kato, S. and Kimura, A., Development and Verification of Local Area Wind Energy Prediction System LAWEPS, J. Japan Society of Fluid Dynamics, (in Japanese), Vol.22, No.5 (2003), pp.375-386

[5] Ishihara, I., A Nonlinear Wind Prediction Model MASCOT : Development and Application, J. Japan Society of Fluid Dynamics, (in Japanese), Vol.22, No.5 (2003), pp.387-396

[6] Uchida, T., Ohya, Y., Araya, R., Tanabe, M. and Kawashima, Y., Construction of High Resolution Elevation Data from Paper Map for Numerical Model "RIAM-COMPACT", Reports of Research Institute for Applied Mechanics, Kyushu University, (in Japanese), Vol.129 (2005), pp.135-141