

Micro-siting Technique for Wind Turbine Generator by Using One PC -Introduction of the RIAM-COMPACT based on LES-

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Abstract It is highly important in Japan to choose a good site for wind turbines, because the spatial distribution of wind speed is quite complicated over steep complex terrain. We are developing an unsteady numerical model called the RIAM-COMPACT (Research Institute for Applied Mechanics, Kyushu University, Computational Prediction of Airflow over Complex Terrain). The RIAM-COMPACT is based on a LES (Large-Eddy Simulation) which is a kind of a turbulence model. The object domain of the RIAM-COMPACT is from several m to several km, and can predict airflow and gas diffusion over complex terrain with high precision. The RIAM-COMPACT is already sold from the Institute of Fluid Physics, Ltd. under cooperation of the Kyushu TLO (Technology Licensing Organization) Company, Ltd. in November, 2003. In the present paper, the feature and usage of the RIAM-COMPACT as a software package is described.

Keywords: Micro-siting, RIAM-COMPACT, LES, Complex Terrain

1. INTRODUCTION

A great reduction of CO₂ becomes an urgent problem because it combats global warming now. Therefore, attention has gathered in effective use for environment-friendly wind energy (natural energy). The number of wind power generation facilities increases rapidly from several wind turbines to a large-scale wind farm in our country. The output of the wind turbine is proportional to the cube of the wind speed. Therefore, it is important to choose a windy region adequately. Especially, the terrain in Japan is remarkably different from Europe and America. Under such a situation, it is extremely important to consider the effect of geographical features on the wind, such as a local speed-up, separation, reattachment, etc. as shown in Figure 1.

A social, technological request of the above-mentioned becomes strong. We concentrate on the space of several km or less, and are developing an unsteady and nonlinear type numerical simulator called the RIAM-COMPACT (Research Institute for Applied Mechanics, Kyushu University,

Computational Prediction of Airflow over Complex Terrain)¹⁾.

The RIAM-COMPACT is a FORTRAN program based on a FDM (Finite-Difference Method), and adopts a LES (Large-Eddy Simulation)²⁾ technique as a turbulence model. In LES, comparatively large eddy structures are calculated directly, and only eddy structures that are smaller than the calculation mesh are modeled. Up to now, the numerical model developed domestically employs the time-averaged turbulence model that is called the RANS (Reynolds Averaged Navier-Stokes equation) from the problem at the calculation time^{3,4)}. The improvement of the computer performance in recent years is remarkable. The problem at the calculation time is being canceled in dramatic form. LES that is the turbulence model of the space average type can simulate an unsteady flow field. Here is a point where RANS and LES are greatly different. Moreover, LES is an excellent technique in the tuning of the model parameter in generality compared with RANS. If an unsteady flow field can be easily calculated, and the result be reproduced in animation, it is possible to become an alternative tool of the wind tunnel experiment that requires a large sum of cost. Consequently, it is expected to become a help of a practicable design.

We have been examining the practical use of the RIAM-COMPACT for several years from such a viewpoint. The RIAM-COMPACT is already sold from the Institute of Fluid Physics, Ltd. under cooperation of the Kyushu TLO (Technology Licensing Organization) Company, Ltd. in November, 2003. In the present paper, the feature and usage of the RIAM-COMPACT as a software package is described.

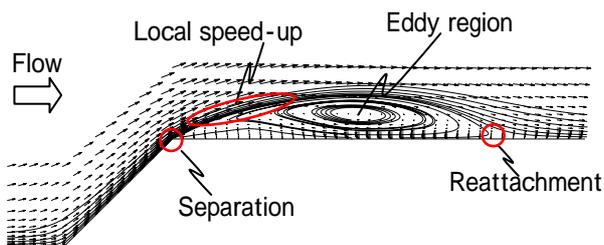


Figure 1 Flow pattern past a steep escarpment obtained by the RIAM-COMPACT

2. OPERATIVENESS AND GUI ENVIRONMENT OF THE THE RIAM-COMPACT

The RIAM-COMPACT as a software is composed of three processes of pre-processing, solver and post-processing. Both of pre-processing and post-processing operate only on a Windows PC. Solver can be operated on a Windows PC and a Linux PC. We explain the outline here for each operation method.

2.1 Pre-processing

We explain the method of operating the pre-processing software FLElevgen that generates a computational grid necessary for the solver. The FLElevgen is a software using OPEN GL (OPEN Graphics Library). The computational grid is generated based on 50m resolution data of Geographical Survey Institute. In the latest version, the data of 10m resolution of the HOKKAIDO-CHIZU Ltd. offer can be used. In addition, we developed a coordinated technology with GIS (Geographic Information System). As a result, constructing the elevation data of an arbitrary resolution based on the paper map, and using this became possible. The short cut of the FLElevgen.exe is made on desktop of a PC, and this is double-clicked and it starts. The FLElevgen is operated from pull-down menu of the window. Figure 2 shows the window screen where altitude numerical data (473000.MEM, 473001.MEM, 473010.MEM, 473011.MEM) is input. User can operate the expansion reduction, the translation, and the rotation, etc. with the mouse for the window screen.

The grid data is generated as follows. A cross and white line appears on the window screen after the altitude data is input. A horizontal range of a computational domain is specified by the mouse operation (see Figure 2). It is also possible to specify the horizontal range by the numerical value (the unit is m). A series of work can be repeatedly done. Three dimensional structured grid that fits the shape of geographical features is automatically generated (see Figure 3 and Figure 4).

In the FLElevgen, the width of the mesh of both in the horizontal and vertical direction can be edited. Here, we explain the edit of a vertical direction. In general, it is necessary to concentrate the grid toward the grand to reproduce the effect of geographical features on the wind with high accuracy. Figure 4

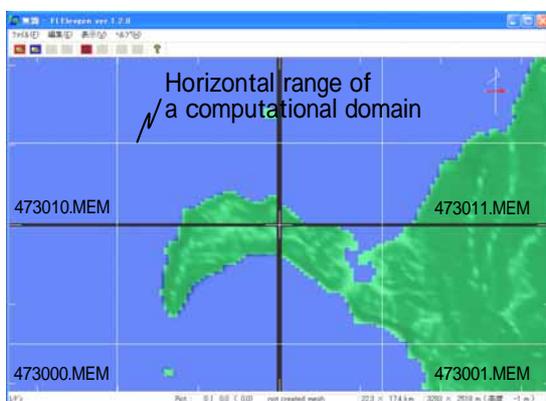


Figure 2 Window screen of the FLElevgen (Example of the Noma cape in Kagoshima prefecture)

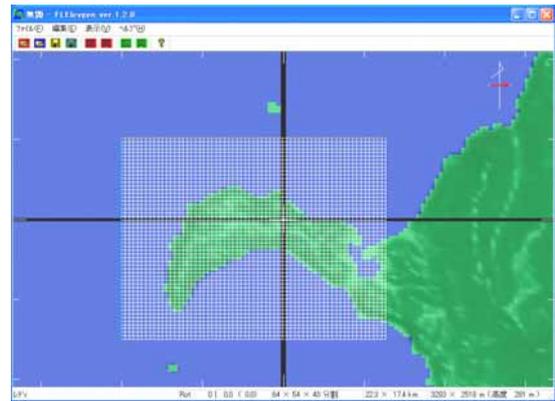


Figure 3 Top view of an initial grid

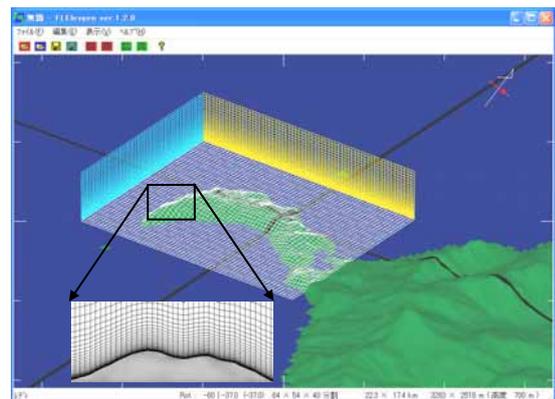


Figure 4 Bird's-eye view of a computational grid edited in the vertical direction

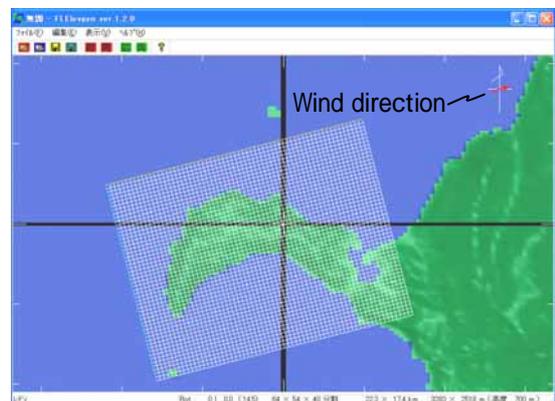


Figure 5 Top view of a rotated computational grid
An upper right arrow means a wind direction.

shows the computational grid after the editing work in a vertical direction is done. User can do a similar operation interactively repeatedly by the mouse operation.

The setting for an arbitrary wind direction is also possible in the FLElevgen. That is, the grid can be arbitrarily rotated to geographical features. As a result, the simulation for all the wind directions becomes possible. Figure 5 shows the example of rotating the grid. The arrow displayed in the upper right of the window screen shows the wind direction.

The elevation data in the computational domain can be compulsorily adjusted to 0m by the mouse operation. This is

effective to examine the influence of the interaction of geographical features.

2.2 Solver

The main feature of the RIAM-COMPACT is shown below. Please see the homepage of <http://www.riam.kyushu-u.ac.jp/windeng/uchida> or <http://www.ifpj.com/venture.html>, if you want to hear of a detailed content.

- 1) When complex terrain is reproduced based on altitude numerical data of Geographical Survey Institute, a collocated grid based on a sigma coordinate system is adopted. In addition, a highly accurate numerical simulation has been achieved by using an excellent difference scheme.
- 2) In the RIAM-COMPACT based on a non-uniform orthogonal staggered grid, a flow around the buildings or the urban area can be simulated. This is reported at another chance.
- 3) Because the RIAM-COMPACT is based on a LES, the flow unsteadiness over complex terrain can be reproduced in animation. It is also possible to investigate the mutual interference of plural wind turbines and the inflow turbulence acting on a turbine blade. Moreover, it is also possible to forecast the amount of power generation based on a power curve and a thrust coefficient that is the characteristic value of the wind turbine.
- 4) The calculation that considers various atmospheric stability levels (neutral or unstable or stable) is possible. Especially, wind power generation using local strong wind such as "Oroshi-kaze" and "Dashi-kaze" will be paid to attention in the future. If the RIAM-COMPACT is used, a highly accurate numerical simulation of local strong wind is possible.
- 5) It is possible to cooperate with the meso-scale meteorological model that is called the CSU-RAMS (Colorado State University, Regional Atmospheric Modeling System)⁵⁾. That is, the output result of the CSU-RAMS can be used as an inflow boundary condition of the RIAM-COMPACT. As a result, a real-time simulation of the micro-scale becomes possible. This is extremely effective to the power generation amount forecast system after the large-scale wind farm is constructed.
- 6) In relation to an atmospheric environmental assessment and a risk assessment, gas diffusion can be simulated under various atmospheric stabilities.
- 7) DNS (Direct Numerical Simulation) or LES of a flow past a bluff body such as a wind turbine is possible by the change of input data and the boundary conditions.

We explain the method of executing solver. Solver is executed from the command line. User only has to specify several parameters. Concretely, two files of file name "infile.dat" and "para.dat" are edited. In "infile.dat", the file name of the mesh data generated with the FLElevgen and the file name of necessary field data for the continuance calculation are specified. The parameter shown in Table 1 is set in "para.dat". If the command named "go" is input, the calculation is begun, after the edit of two files of "infile.dat" and "para.dat" ends.

UVEC	Wind speed(m/s)
BEKI	Index number of power law
NSTEP	Step number of calculation
NSOR	Interval which outputs the progress situation of calculation to a display
ICON	The parameter which shows beginning calculation from the first stage, or whether it continues
I PROG	The output interval of the data for inputting into the visualization soft FLScope

Table 1 Various parameters inputted into the solver

2.3 Post-processing

Here, we easily explain the feature and the operation method of the post-processing software FLScope that visualizes the calculation result output from the solver.

The FLScope is a software based on OPEN GL as well as the FLElevgen of the pre-processing tool. The start procedure and the operation method are basically the same as the FLElevgen. This tool specializes in the post-processing of CFD (Computational Fluid Dynamics), and the load to the computer is also extremely small. The FLScope is operated from the pull-down menu of the window as shown in Figure 6. In the FLScope, the visualization techniques such as the velocity vector, contour line, color shading, contour surface, stream line, streak line, time line, path line, particle passing, surface pass rendering, and volume rendering are covered. Moreover, a lot of display options (for instance, change in the opening angle of the velocity vector) are prepared. User can freely make the calculation result visualize according to the purpose. The FLScope can be interactively operated as well as the FLElevgen by a mouse operation and an easy keyboard operation. That is, the RIAM-COMPACT is a software that has an user-friendly GUI (Graphical User Interface) environment.

In the following, we take up the Noma cape (maximum above sea level 143m) located in Kagoshima prefecture as an example, and introduce a typical visualization result using the FLScope. In the Noma cape, ten wind turbines of Kyushu Electric Power Co., Inc. are set up, and the proof examination is done (see Figure 7).

If the passive particle tracking method shown in Figure 8 is

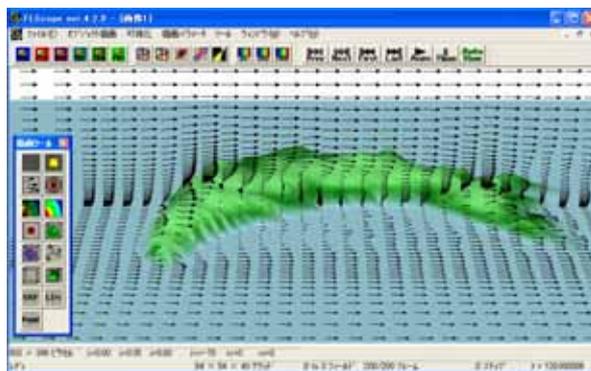


Figure 6 Window screen of the FLScope

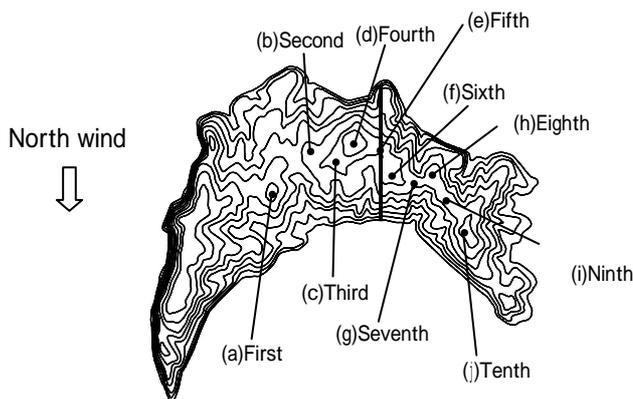


Figure 7 Installation position of the wind turbines in the Noma cape (Kagoshima prefecture)

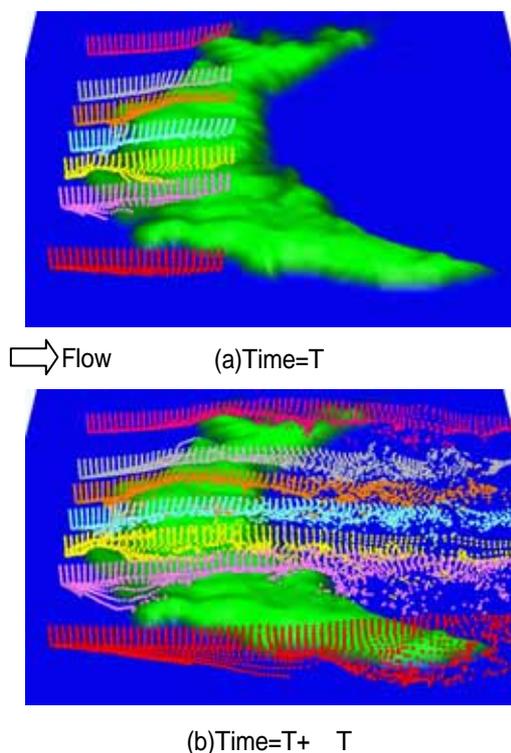


Figure 8 Bird's-eye view of the passive particles simulation (Flow is from the left to the right)

used, it is understood that the unsteady wind characteristics are reproduced at one view. In Figure 8, the complex phenomenon including the effect of geographical features on the wind such as the flow impingement, the flow separation, the flow attachment, and the backflow is clearly reproduced. In addition, the local speed-up is clearly observed. If animation is made and looked at, the presence increases in addition. Animation is extremely useful for the understanding of the wind characteristics. Software that can make animation is not found in another. Animation can be easily made in the FLScope, and these can be used effectively as a presentation material.

Figure 9 shows the velocity vector in a vertical section including the solid line shown in Figure 7. The position of the wind turbine is displayed in this figure. A decrease in the wind

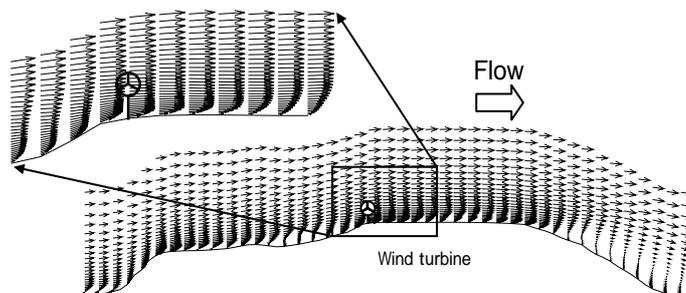


Figure 9 Velocity vector for the time-averaged flow field in a vertical plane including the fifth plant

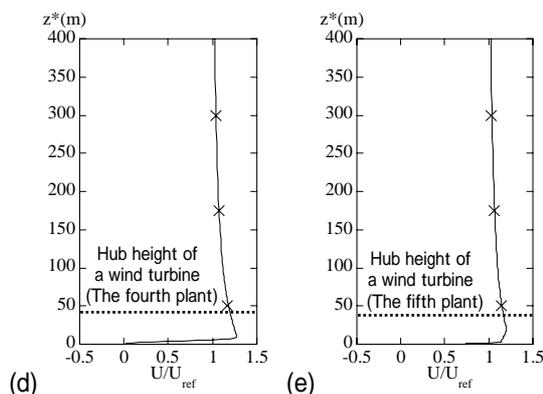


Figure 10 Comparison of the mean velocity profile, Line : RIAM-COMPACT, Symbol : Experiment

speed near the wind turbine is not seen. It is understood that the position where the wind turbine is set up is appropriate.

Figure 10 shows the comparison between the numerical simulation by the RIAM-COMPACT and the wind tunnel experiment by a SFP (Split-Film Probe) at the wind turbine installation position (see Figure 7). Only two points ((d) and the (e) point) are shown here. The vertical axis displays the height level from the grand (the unit is m). The numerical simulation (solid line) and the wind tunnel experiment (symbol) show an excellent agreement at all the height levels. Especially, both of the numerical simulation and the wind tunnel experiment show a local speed-up in the vicinity of the hub height.

3. CONCLUSION

In the present paper, the feature and usage of the RIAM-COMPACT as a software package is described, and an actual application example is shown. Because the local change in the wind can be reproduced in animation in the RIAM-COMPACT, it is expected to use the RIAM-COMPACT as a preliminary investigation tool of the construction of the wind farm.

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