Numerical Analysis of Karman Vortex Street in the Wake of the Jeju Island

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ABSTRACT: From late autumn to the beginning of the spring, the phenomena like the Karman vortex street have been frequently observed in the wake of Mt. Halla in the Jeju island. Research revealed that the necessary conditions for development of these vortex clouds are a strong low-level inversion of temperature and a persistent wind speed of 5 to 13 m/s. After the cloud is formed, the vortex clouds are shed from alternating sides of Jeju island and move downwind with main flow. The Karman vortex street in the wake of the Jeju island was one of the interesting topics in Meteorology. In this study, CFD using LES turbulence model was used to investigate the Karman vortex street and the results of CFD had a good agreement with whether data.

KEYWORDS: Karman Vortex Street, Large Eddy Simulation, Jeju Island, Vorticity, Froude Number.

1 INTRODUCTION

When the northwest wind blows, the vortex flow like the Karman vortex street is formed in the wake of Jeju island. (Figure 1) For a long time, research about the Karman vortex streets in the wake of Jeju island has been one of the interesting topics in meteorology. But there are a few research papers. The study on Karman vortex streets in the wake of Jeju island have been performed by Hubert (1965) and Tsuchiya (1969). They explained the creation process of a vortex street applying the theory of Von Karman (1912) and Tsuchiya analyzed the condition at appearance using parameter's limit value. Using the weather data acquired through artificial satellite, Lee (1983) carried out theoretical research about stable structure of Karman vortex. Oh (2005) investigated characteristics of vortex through an experiment and presumed critical values about the occurrence condition of the Karman vortex street. The purpose of this study is to investigate the Karman vortex street in the wake of the Jeju Island and to confirm it using the numerical method.

Fig. 1 The Satellite image of Karman vortex street
2 NUMERICAL MODEL AND METHOD

The LES turbulence model was applied to simulate the Karman vortex street because the previous research showed that the results by the LES turbulence model were more accurate than other models, for example RNG k-ε turbulent model and laminar model. Figure 1 shows the schematic diagram for this study.

In LES turbulence model, Smagorinsky subgrid-scale model was adopted. And a spatial discretization is based on Finite volume method of the 2nd order accuracy. The 2nd order Crank-Nicolson method is applied for time-marching. Also the time-step is determined by the explicit time-marching scheme and the temporal resolution by LES. Also, considered time step should be satisfied with CFL (Courant-Friedrichs-Lewy) condition for stability of unsteady calculation. The time step size for this calculation is 30[sec] calculated by CFL condition.

3 COMPUTATIONAL GRID SYSTEM AND BOUNDARY CONDITION

From now on, we show the process to generate the computational grid system. At first, we get the GPS (Global Positioning System) data through an artificial satellite. And then, we transform GPS data into a coordinates system. Finally, we generate a computational domain to simulate a flow motion using this coordinates system.

After the computational domain is obtained, the computational grid system is generated. The number of grid to be used is 2,200,000(200*100*110). The grid is concentrated in the vicinity of Jeju island, because the Karman vortex street is created in the wake of Jeju island and more grid points are needed around that area to have accurate calculation results.

To simulate Karman vortex streets, the boundary layer profile of the 1/7 power is used for inlet boundary condition and the pressure outlet boundary condition is adopted for outlet boundary condition. In this case, the pressure is atmospheric pressure. Last, the no-slip condition is used on the bottom.

4 RESULTS AND DISCUSSION

The results of this study are shown at fig.3 to 5. Figure 3 shows the vorticity contours at the height 1100[m] according to the time step. In this figure, we can see that the oscillating flow pattern in the wake of Jeju island is well reproduced by numerical analysis.
Figure 3 shows the flow structures of Karman vortex streets according to the height. Through these results, it is found that the Karman vortex streets are generated at all positions according to the height. The Karman vortex street is found at the near top of the Mountain Halla as shown in fig. 4(d). But the phases of starting oscillating vortexes are different due to difference of diameters at each height. In addition, the structure of Karman vortex street become stable when the height increases.

Generally, it is well known that the ratio of length of vortex row and interval of each vortex is about from 0.28 to 0.52. In this case, the ratio is 0.422. So, we can say that this vortex street is stable.

As shown in fig. 5, it is found that the flow is recirculating over the hill and is oscillating in downward direction in a perpendicular section. In the previous research studied by William Froude, it was reported that this phenomenon is associated with the Froude Number which is the ratio of the wave length of wind and wind speed. When the Froude Number is 1.0, the flow generates the rotating flow as follows. In this case, the wave length is similar to the depth of mountain and the Froude number is about 1.0. The fact that flow circulation is generated in the wake of mountain is well fit for above theory.
5 CONCLUSIONS

By using Large Eddy Simulation, we have investigated the wake of Jeju island and obtained following conclusions.

1) The Karman vortex street in the wake of Jeju island can be well reproduced by LES and the result is a good agreement with weather data obtained by an artificial satellite.
2) The Karman Vortex street is generated at every height and the structure of vortex is getting stable as the height increases.
3) The perpendicular flow pattern of wind in the wake of Jeju island is oscillating and the rolling flow pattern is also generated over the hill.

6 REFERANCE