Numerical Simulation of Unsteady Vortical Flows with a Grid-Free Vortex Method

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ABSTRACT

One of the crucial problems for turbulent flow analyses via computational fluid dynamics (CFD) is how to analyze the unsteady motion and deformation of vortical structures. The Navier-Stokes flow solvers with the finite element method, the finite difference method, or the finite volume method can capture the vortical structures explicitly, but when the computational grid is not sufficiently small, the vortices are diffused due to the numerical diffusion. In the vortex methods, vorticity distributions are represented by using discrete vortex elements. When compared to other schemes, vortex methods have the advantage that the nonlinear distortion of vortical structures is directly calculated without the numerical diffusion. The vortex methods are divided into two types. The first one is vortex-in-cell (VIC) method in which stream function is calculated on the fixed grid. Another is the grid-free vortex method, in which the velocity field is calculated by the Biot-Savart law, without using the computational grid. In the vortex methods, numerical resolution is dependent on the scale of the discrete vortex elements. The scale of the vortical structure is locally different especially in turbulence. Therefore, the local redistribution scheme is necessary for high strain regions. Cottet et al.[1] calculated fundamental turbulent flows by the VIC method with a grid-base redistribution model. The results indicated that the analysed energy spectra were close to DNS results. For the grid-free vortex method, Fukuda and Kamemoto[2] proposed a grid-free redistribution model. The model was applied to two vortex rings interaction. The results showed that the analyzed energy spectra were close to DNS and experimental results and the energy cascade mechanism was reasonably simulated. The great advantage of the method is that it can be easily applied to the flows with complex geometry because of its grid-free characteristic. The scheme has been applied into the various engineering problems (for example, [3]). However, there are few studies on the validation as DNS or LES scheme.

In this study, the method was applied to turbulent flows. Firstly, unsteady evolution of the vertical structure in the pipe was simulated. Figure 1 shows the mean velocity profile. The result showed the current result was in good agreement with the experimental data. The rms value of the axial velocity fluctuation is depicted in Figure 2. The present results showed that the overall profile of the rms value and the amplitude were close to the experimental data, even though the peak location of the calculated rms value slightly shifted to higher y+ region.

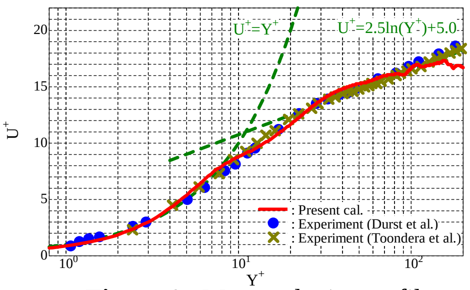

Figure 1: Mean velocity profile

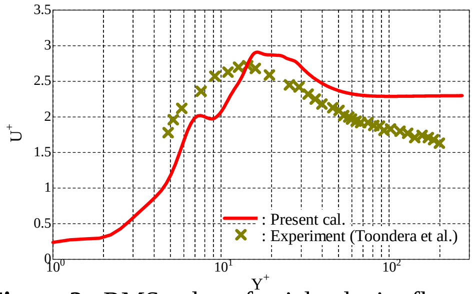

Figure 2: RMS value of axial velocity fluctuati

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