DIRECT NUMERICAL SIMULATION OF TWO-FLUID SYSTEM AND ITS APPLICATION TO AIR-WATER TURBULENT FLOWS WITH DEFORMED INTERFACES

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From a macroscopic point of view in hydrodynamics, the immiscible multiphase flows phenomena are often observed in every river and ocean, as wind-induced waves flows and oil-contaminated water flows in lakes and ocean, and so on. In these flows, the complicated scalar and vector transfer phenomena are so much associated with the corresponding flows across the largely deformed interface. For example, recently, gas transfer phenomena across the air-water interface, such as CO_2, O_2, NO_x and SO_x greatly have attracted the vigorous researchers, because of the serious earth environmental problems. Thus, it is considered that the immiscible multi phase flows should be intensively studied well for the prediction of the material transport phenomena accompanied with experimental and numerical approaches. However, the dynamics of multiphase flows have not been sufficiently clarified in the field of computational fluid dynamics (CFD) because of numerical difficulties. So far, CFD have treated the multiphase flows with low numerical accuracy.

Recently, some numerical studies on the dynamics of flows with the free surface have been vigorously conducted in order to make clear the related transport phenomena. Lam and Banerjee (1992) made a first attempt to conduct a numerical simulation on open-channel flows with no sheared free surface, utilizing the spectral method. Furthermore, the numerical simulation of the air-water two-phase flows have done with the pseudo-spectral method by Lombardi *et al.* (1996) in which the air-water interface was fixed with no water waves. Moreover, it is important to investigate the turbulent behavior of liquid and gas flows at a free surface in comparison with that of the motions at the solid boundary. Kunugi (2002) carried out the DNS for the turbulent free surface flow with a shear wind by means of a coupled gas-liquid flow solution, i.e., MARS (Multi-interface and Advection and Reconstruction Solver). In his study, the turbulent characteristics near the free surface, such as surface-shape, velocity fluctuation and the budget of turbulent kinetic energy, were investigated. According to the computational flow visualization in his study, the carbon-dioxide gas was transferred by the low-speed streaks and was transport by the vortexes from the free surface to the bottom in the water region.

Figs.1 a) ~ c) show the interface shapes in air-water co-current flows at $t_{0a}^+ \equiv t_0 U_{*a}^2 / \nu_a \cong$ 1600 from the initial condition. In the figures, η indicates the elevation from the still water level, U_{*a} denotes the friction velocity on the surface in the air layer, and ν_a is the kinetic viscosity of air. It is known in the figures that the interface shapes seems to be composed of 2-dimensional gravity waves, and that the wave height of the wavy interface is about 1 % of the water depth in a scale. This computational result is in relatively good agreement with the experimental one (Yoshida, *et al.*, 2003). Figs.10 a) and b) show the horizontal velocity vectors in the $x - z$ plane near the interface both in the air region and in the water one. It is notified that the streak structure shows up near the interface in the air-sheared boundary layer of the air side on the free surface, however, the corresponding structure is not clearly found in the water side on the surface. This is because the Reynolds number is relatively low and the computational domain in the spanwise direction is not large enough to capture the streaky structures (Robinson, S. K., 1991).

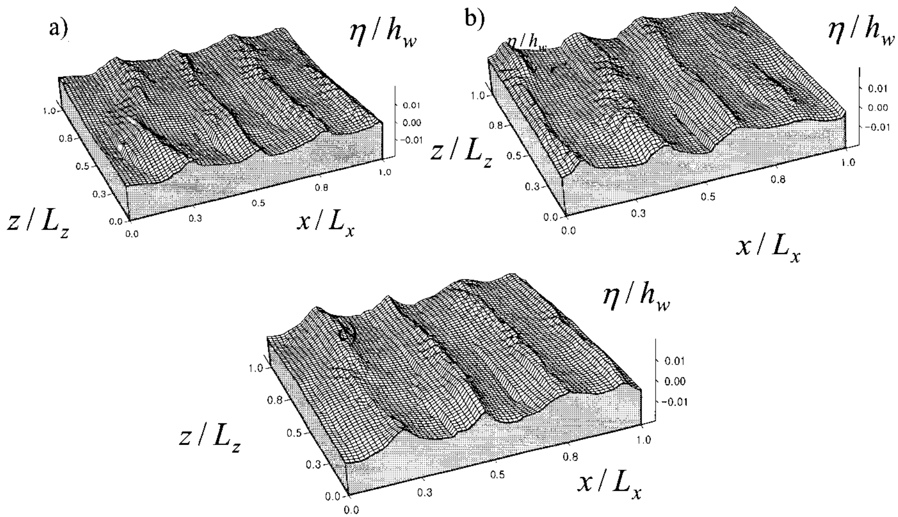

Fig.1 Interface Shapes (a; t_0 sec, b; t_0+0.25 secおよびc; t_0+0.5 sec, $t_{0a}^{+} \cong 1600$)

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