Title of Project： Innovative CFD simulation for multiphase flows including free surfaces

AOKI, Takayuki
(Tokyo Institute of Technology, Global Scientific Information and Computing Center, Professor)

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Keyword：multiphase flow, free-surface flow, non-Newtonian fluid, fluid film, AMR

【Purpose and Background of the Research】

Whereas the field of fluid dynamics has matured, and computational fluid dynamics (CFD) has been well-developed, however the study has been behind with simulations for multiphase flows including free surfaces for a long time. It is especially difficult to describe gas-liquid interfaces because of their large density jumps and dynamic deformations. These difficulties come from computational method, modeling and implementation on supercomputers.

For incompressible (low Mach number) multiphase flows including free surfaces, we introduce a weakly compressible fluid computational method and many techniques of high-performance computing, adaptive mesh refinement (AMR), dynamics load balance, GPU computing and so on. In this project, we study the following three topics over an extremely wide range from nanometers to kilometers, (1) natural disasters of flows including a lot of floating debris, (2) dynamics of liquid film and formation-collapse of foams, and (3) motions of low water-containing slurry in a solid-liquid-gas dispersed system. We reveal macroscopic features of the flows directly solving the detailed models and obtain new findings in the fluid dynamics of multiphase flows.

Figure 1 Gas-liquid two-phase flow simulation using a weakly compressible computational method.

【Research Methods】

We simulate multiphase flows by solving compressible fluid equations with a fully explicit time integration. The numerical method consists of finite volume method (FVM) and finite difference method (FDM) to compute the sound wave propagation accurately. Since the time step (□t) is determined by the sound speed, we artificially reduce it for 10-30 times the flow speed (Mach number 0.1-0.03) and accept weak compressions.

We introduce an AMR method adapting fine meshes to the region near free surfaces and solid bodies. In addition, dynamic domain partitioning for complex AMR mesh structures makes their large-scale computation efficient on supercomputers.

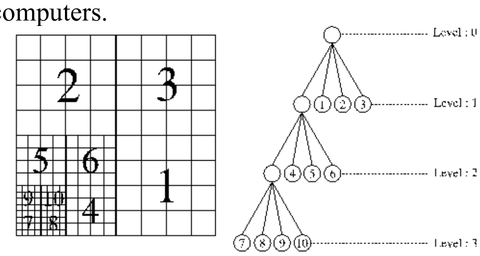

Figure 2 Recursive mesh refinement based on algorithm of tree data structure.

【Expected Research Achievements and Scientific Significance】

(1) In heavy rain or slope disasters, large-scale simulations taking account of the detailed interaction of free-surface flow and a lot of floating debris are used to understand debris trapping, impact to building structures, damage area and so on. We can also expect contributions to disaster prevention.

(2) Very high-resolution gas-liquid two-phase flow simulations make it possible to understand the stability of liquid films and foams. Furthermore, the heat transfer and material transportation through liquid film will be solved.

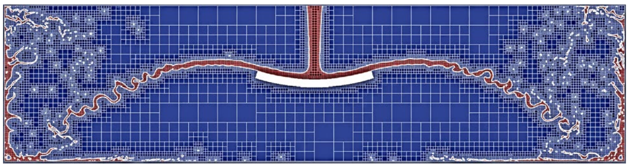

Figure 3 Liquid film generated by a spoon with AMR.

(3) We can construct a non-Newtonian macroscopic viscoelasticity model for low water-containing slurry by directly simulating liquid bridges among solid particles.

【Publications Relevant to the Project】

・S. Matsushita, T. Aoki: A weakly compressible scheme with a diffuse-interface method for low Mach number two-phase flows, J. Comput. Phys., 376, pp.838-862, 2019

・Y. Sitompul, T. Aoki: A filtered cumulant lattice Boltzmann method for violent two-phase flows, J. Comput. Phys., 390, pp.93-120, 2019

【Term of Project】 FY2019-2023

【Budget Allocation】 149,700 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.sim.gsic.titech.ac.jp/