Massively Parallel CFD and Moving Boundary Methods for Industrial Problems

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ABSTRACT

High-Performance Computing(HPC) frameworks for the fluid-structure interaction problems with complicated geometry have been developed, considering its application to applied aerodynamics and industrial problems. Two frameworks are considered here; one is based on the unstructured mesh system, and the other is based on the hierarchically structured grid system.

For the fully unstructured finite volume method developed here, arbitrary Lagrangean-Eulerian (ALE) method together with solving the governing equations on the non-inertial reference of frame was adopted to track the complicated motion of rigid body in fluids. The method was specially tuned on the K computer, and so far it can treat up to ten billion unstructured meshes for the coupled fluid-solid motion problems. The advantage of this framework is its accurate prediction of aerodynamic forces acting on the complicated geometry by optimizing the unstructured meshes near the wall, especially in the case flow is in turbulence state. On the other hand its disadvantage is its workload required for the pre-processing including dirty CAD treatment and mesh generation. This problem in fact prevents its spread and utilization in industrial process.

To overcome this problem, alternative framework based on the hierarchically structured finite volume method was developed, in which both the fluid motion and structure deformation are solved in Eulerian manner. To achieve higher computational efficiency of parallelization and scaling on the massively parallel environment, Building Cube Method (BCM) proposed by Nakahashi[1] was adopted. In the method, numerical domain is first decomposed into cubic sub-domains based on the Octree method. Then the same number of numerical grids is allocated to each cubic subdomain. In the simulation framework, the solid surface with complicated geometry is represented by the immersed boundary method (IBM). In the fluid-structure interaction problems with structure surface in motion, accurate representation of the immersed body is indispensable. Thus Lagrangian description for tracking the moving solid body surface is adopted in the Eulerian framework of solving fluid and structure motions. One of the drawbacks of the hybrid Lagrangian-Eulerian approach is its difficulty to achieve higher load balancing among processors on the massively parallel environment. Thus a multi-constraint based load balancer to simultaneously balance the load of Lagrangian particles and the BCM mesh. The parallel scalability of the numerical method and the efficacy of the load balancer were evaluated through simulation with up to 32,768 cpu cores on the K-computer. So far, the framework can handle maximum of tens of billions of numerical meshes using hundreds of thousands of CPU cores on the K-computer.

In this study, applications of these massively parallel CFD and coupled problems are introduced, some of them include aerodynamics and flight path of sports balls, full-scale road vehicle aerodynamics considering its six degrees-of-freedom motion and wheels rotation, and prediction of wind load on high rise buildings in Tokyo area.

REFERENCES

[1] K. Nakahashi, Building-Cube Method for Flow Problems with Broadband Characteristic Length, in: Com-625 putational Fluid Dynamics 2002, Springer Berlin Heidelberg, pp. 77–81, (2003).