A Coupled Lagrangian-Eulerian Approach for the Moving Boundary Method and its Application to Applied Aerodynamics Problems on Massively Parallel Environment

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ABSTRACT

High-Performance Computing(HPC) framework for the fluid-structure interaction problems with complicated geometry has been developed, considering its application to applied aerodynamics and industrial problems. Both the fluid motion and structure deformation are solved in Eulerian manner on the unified hierarchically structured grids. 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). Concerning the forcing approach of continuous or discrete way[2], the former[3] was adopted considering its robustness and versatility to the treatment of complicated surface geometry. 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, this simulation framework was applied to a full-scale road vehicle aerodynamics simulation in six degrees-of-freedom motion including wheel rotation and front wheel's steering action. The vehicle geometry was reproduced from the real digital data provided by a road vehicle company and every detailed geometry of the real vehicle is considered. As far as we know, this is the world-first and largest aerodynamics simulation of a real road vehicle in dynamic cornering motion.

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