8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

Coupled Finite Element and Immersed Boundary Method for the Computation of Interaction of Multiple Deformable Particles/Structures with a Fluid Flow

*** Atsushi UEYAMA[1], Kousuke TAMURA[1], Shintaro TAKEUCHI[2] and Takeo KAJISHIMA[1]**

[1] Department of Mechanical Engineering
Osaka University
2-1 Yamada-oka, Suita-city,
Osaka 565-0871 Japan
E-mail: ueyama@fluid.mech.eng.osaka-u.ac.jp
tamura@fluid.mech.eng.osaka-u.ac.jp
kajisima@mech.eng.osaka-u.ac.jp

[2] Department of Mechanical Engineering
The University of Tokyo
7-3-1 Hongo, Bunkyo,
Tokyo 113-8656 Japan
E-mail: shintaro.takeuchi@fel.t.u-tokyo.ac.jp

Key Words: *Fluid-Solid Interaction*, *Elastic Object*, *Immersed Boundary Method*, *Finite Element Method*

ABSTRACT

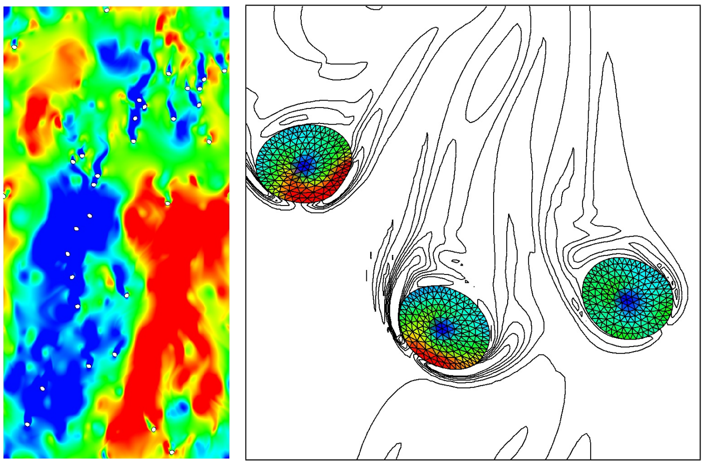
The authors have developed a new method for studying interaction between elastic object and fluid by coupling immersed boundary method (IBM) and finite element method (FEM).

The interaction at the fluid-solid boundary is represented by an IB technique of body-force type[1, 2], which has enabled simulation of interaction between a fluid and rigid spherical particles of a total number of $O(10^3)$ by a momentum-exchange technique through a volume-averaged velocity field of multiple phases.

In the present study, the interaction force in the IBM is incorporated into FEM. As the body-force (interaction force) in the above is designed to take non-zero values only in the computational cells embedded at the interface, the coupling of IBM and FEM is done by simply superimposing the interaction force over the solid internal force field. A method for approximating of volumetric fraction at the interface of a aspherical body[3] has been implemented to allow arbitrary geometric condition at the deformable interface. Fractional step method is applied for coupling of velocity and pressure fields. By this numerical procedure, the effect of the deformability of the solid material is successfully incorporated into the fluid-solid interaction process.

The uniqueness of the present approach also lies in the implementation of the inter-phase momentum exchange through the distributed force field shared by both Eulerian (fluid phase) and moving/deforming Lagrangian (solid phase) references, without interpolation of physical properties between the two references. Therefore, this IBM-FEM coupling method offers an efficient and robust computation, with no adjustable parameters, for the fluid including a large number of deformable objects.

The applicability of the present method is demonstrated through direct numerical simulation of a flow field including elastic particles in two-dimensional flow field employing the periodic boundary in both directions. Figure 1 shows some snapshots of the flow field and deforming particles due to hydrodynamic forces. The particles are deformed due to the interstitial flows and wakes developing between the particles. We discuss the effects of the aspherical and deformable natures on the behaviours of the particles. Particular attention is focused on the influence of microscopic particle-particle interactions on the clustering motion of the particles in the fluid. Another application of the present method is a deformable particulate flow field with elastic/rigid structures. Figure 2 shows an example of the numerical results of a flow field involving a soft particle bounded by elastic walls, and the result demonstrates the applicability of the present approach to the biological flows.



(a) (b)

Figure 1: Elastic particles sedimentation in an up-current flow (ellipticity: 1.2). (a) Particle distribution (white dots) and the intensity of the vertical components of fluid velocity (colour). (b) Mises stress distribution (colour) and vortical structures around particles (solid lines).

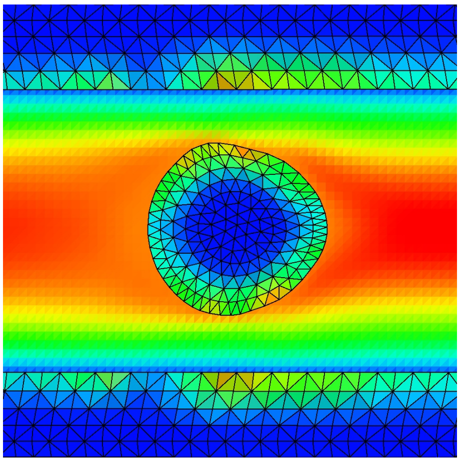


Figure 2: Fluid flow involving a deformable object through a passage bounded by elastic walls. Colour represents Mises stress distribution and the intensity of the horizontal components of fluid velocity.

Acknowledgement

One of the authors, Shintaro TAKEUCHI, gratefully acknowledges the financial support of the Suzuki Foundation for this study.

References

[1] Kajishima, T., Takiguchi, Hamasaki, S., and Miyake, Y., Turbulence structure of particle-laden flow in a vertical plane channel due to vortex shedding, *JSME Int. J. Ser. B*, **44**-4, pp. 526-535, 2001.

[2] Kajishima, T. and Takiguchi, S., Interaction between particle clusters and fluid turbulence, *Int. J. Heat and Fluid Flow*, **23** (5), pp. 639-646, 2002.

[3] Yuki, Y., Takeuchi, S. and Kajishima, T., Efficient Immersed Boundary Method for Strong Interaction Problem of Arbitrary Shape Object with the Self-Induced Flow, *J. Fluid Science and Technology*, **2**-1, pp. 1-11, 2007.