Consistent inlet and outlet conditions for ALE particle method

†Fangyuan Hu[1] and Seiichi Koshizuka[1]

[1]Department of Systems Innovation, Graduate School of Engineering, the University of Tokyo, Japan.
†Corresponding author: hfy8373@mps.q.t.u-tokyo.ac.jp

In computational fluid dynamics (CFD), the implementation of various boundary conditions plays a significant role in achieving convergent, accurate and stable results. The boundary conditions which define the interaction between the calculation domain and surrounding environment are also the most difficult part in a numerical method. This is particularly true for flows with inlet or outlet boundaries where the specification of how the fluid enters and leaves needs to be rational and consistent with the Navier-Stokes equations. An improper boundary condition may lead to excessive overall error or divergence since the error produced at the boundary is very likely to erode the whole calculation domain.

Inlet and outlet boundary conditions have a wide range of applications in engineering problems. They are commonly used in the simulation of arterial networks [1, 2], circular tube flow [3], heat transfer systems [4], combustion [5], micro-flow [6], etc. In the light of the above research, proper inlet and outlet boundary conditions are indispensable to numerical methods for solving real world problems.

In the present study, we propose simple and consistent open boundary conditions for viscous incompressible laminar flow calculation using an Arbitratry-Lagrangian-Eulerian (ALE) particle methods [7]. A pressure specified inlet/outlet condition, a velocity profile specified inlet/outlet condition and a fully developed flow outlet condition are proposed. We also proposed particle insertion and deletion technique for particles inlet and outlet particles. In our ALE particle method, a 2nd-order consistent spatial discretization scheme - a least squares moving particle semi-implicit method (LSMPS) [8] and the projection method to solve Navier-Stokes equations. A spring model and an upwind interpolation is applied to deal with the particle irregularity problem. We give the open boundary conditions that we proposed and their implementation. Numerical examples including a Poiseuille flow driven by specified pressure or specified velocity and a flow over a backward-facing step and a steady laminar flow in a 90 degree planar branch are calculated and compared with both experimental data and computational results by the FVM.

The inlet and outlet conditions for particle methods are validated. They are accurate and can be simply implemented.

References

[1] I.E.V. Clementel, C.A. Figueroa, K.E. Jansen and C.A. Taylor (2006) Outflow boundary conditions for three-dimensional finite element modeling of blood flow and pressure in arteries, *Computer Methods in Applied Mechanics and Engineering* **195**, 3776-3796.

[2] V.L. Rayz, S.A. Berger and D. Saloner (2007) Transitional flows in arterial fluid dynamics, *Computer Methods in Applied Mechanics and Engineering* **196**, 3043-3048.

[3] V.O. Shestopal and O.Ya. Shestopal (1981) Flow of metal in high-temperature extrusion, *Computer Methods in Applied Mechanics and Engineering* **25**, 85–99.

[4] M. Niemann and J. Fröhlich (2016) Buoyancy-affected backward-facing step flow with heat transfer at low Prandtl number, *International Journal of Heat and Mass Transfer* **101**, 1237-1250.

[5] F.O.C. González, E.E.S. Lora, H.F.V. Nova, L.J.M. Neto, A.M.M. Reyes, A. Ratner and M. Ghamari (2017) CFD modeling of combustion of sugarcane bagasse in an industrial boiler, *Fuel* **193**, 31-38.

[6] M. Hirschler, P. Kunz, M. Huber, F. Hahn and U. Nieken (2016) Open boundary conditions for ISPH and their application to micro-flow, *Journal of Computational Physics* **307**, 614-633.

[7] F. Hu, T. Matsunaga, T. Tamai and S. Koshizuka (2017) An ALE particle method using upwind interpolation, *Computers and Fluids* **145**, 21-36.

[8] T. Tamai, S. Koshizuka, Least squares moving particle semi-implicit method, *Computational Particle Mechanics* **1**, 277-305.