Application of the immersed boundary method to simulate flows inside and outside the nozzles

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Abstract

DNS of two phase flows remains a major topic of research. One of the main challenges is to capture the interface behavior in the nozzle vicinity with enough accuracy in order to well describe the primary breakup. A major task to achieve such a simulation is to handle jump conditions at the liquid-gas interface without artificial smoothing; this is made possible thanks to the Ghost Fluid method. The Level Set method is used to represent the interface and is coupled with the Volume of Fluid method to ensure mass conservation. This coupling already showed a good behavior for the simulation of primary jet breakups (Ménard et al [1], Shinjo and Umemura [2] for instance). In such situations, boundary conditions strongly influence the perturbation initiation on the liquid-gas interfaces. For instance, Berlemont et al [3] proposed a coupling between simulations of flows inside and outside the nozzle using different solvers where calculated velocity profiles at the nozzle outlet were used as initial condition for the jet primary breakup. Results were encouraging despite the fact that some information can be lost during the coupling.

The objective of the present work consists in a strong coupling between internal and external flows by keeping the same numerical tools. Here the walls which delimit the fluid volume inside the nozzle have to be accounted for. As the walls can have complex shapes, the chosen methodology needs to be able to perform simulations within the scope of regular Cartesian grids. The chosen approach is based on a discrete forcing immersed boundary method similar as the original Mohd Yusof's proposal [4]. The solid-fluid boundaries are represented by a level set function identical as the one already used to take into account the liquid-gas interfaces. The major difference concerns the physical conditions to be written at the solid-fluid boundary. As far as numerics are concerned, a projection method is used to solve incompressible Navier Stokes equations. A uniform staggered grid is used, spatial discretization is carried out with a WENO scheme for convective terms, second order Runge Kutta method is used for temporal derivatives. Poisson equation is discretized with a second order central scheme and solved with a BICGSTAB method. Finally, specific care has been carried out to improve simulation capabilities with MPI parallelization.

In a first part of the paper, we present in details the methodology to impose physical conditions on the immersed body. The second part of the paper presents the validation of the method on two 2D test cases. First the equilibrium of a droplet on a solid surface is investigated and validated thanks to analytical results. Second, the simulation of an injection event is presented and it is showed that the velocity fluctuations created inside the nozzle directly affects the liquid/gas interface downstream the injector tip.

References

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