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A MONOTONE, HIGHER-ORDER ACCURATE, FIXED-GRID FINITE-VOLUME METHOD FOR CONVECTION PROBLEMS WITH MOVING BOUNDARIES

*** Barry Koren[1,2] and Yunus Hassen[1,2]**

[1] Centre for Mathematics and Computer Science
PO Box 94079, 1090 GB Amsterdam, the Netherlands
Barry.Koren@cwi.nl

[2] Faculty of Aerospace Engineering, TU Delft
PO Box 5058, 2600 GB Delft, The Netherlands
Yunus.Hassen@cwi.nl

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ABSTRACT

The goal of this research is to develop an immersed-interface method to be applied to incompressible Navier-Stokes problems with moving and deforming boundaries. In the present paper we still restrict ourselves to pure convection problems and linear scalar equations only. This model-equation approach allows us to perform thorough analyses and to do numerical experiments with exact reference results.

The spatial discretization considers a finite-volume method that is standard in cells away from the immersed interfaces: a monotone (flux-limited), higher-order accurate, cell-centered finite-volume method. For cell faces in the neighborhood of an immersed interface, several different local flux formulae are derived and analyzed. The analyses are rigorous and detailed, and concern both accuracy and monotonicity. Tailor-made non-equidistant limiters and corresponding monotonicity requirements are derived for the fluxes in the neighborhood of immersed interfaces.

For the temporal discretization a third-order accurate, explicit, three-stage Runge-Kutta method is employed. It combines perfectly fine with the limiter, both away from and near the immersed interfaces. Monotonicity of the solution imposes a condition on the time step. Near the immersed interfaces this condition differs from that away from the immersed interfaces. A special property of the time discretization is that it is locally adaptive. Near each immersed interface, time steps are split depending on the crossing of finite-volume walls by an immersed interface.

Two test cases are considered; both differ in their initial solution. For all immersed-interface methods derived and analyzed in this paper, numerical computations are performed on a family of three grids, and for both initial solutions. The numerical results obtained are in perfect agreement with the theoretical findings. Some of the immersed-interface methods show an astonishingly good accuracy and monotonicity behavior, without requiring much computational overhead. These methods are currently being extended to linear, scalar convection-diffusion problems. Of these last methods, the best one will be selected, and carried over and applied to the incompressible Navier-Stokes equations.