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A PARALLEL SECOND-ORDER CUT-CELL METHOD : VALIDATION AND SIMULATION AT MODERATE REYNOLDS NUMBERS.

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To improve the discretization in the near-cylinder region, a new cut-cell method that ensures conservation properties (mass and kinetic energy) and directly enforces no-slip Dirichlet boundary conditions on an immobile obstacle is proposed in [1]. We focus here on a parallel version based on MPI which has been recently developped.
The staggered arrangement of the velocity components is adapted to the cut-cell geometry (triangle, trapezoid, rectangle, pentagon). However, the pressure node is placed at the centre of the Cartesian cells for both fluid-cells and cut-cells. These locations of the unknowns induce specific discretizations in mesh cells located in the neighbourhood of the solid boundary. As a consequence, the linear systems are non-symmetric.
The parallel version is based on a splitting of the datas among processes along the horizontal axis, namely each process works with a vertical band of the computational domain. As usual in local discretization methods, the parallel computation of the explicit terms, such as the nonlinearity, requires very few communications. The only tricky part concerns the non-symmetric linear systems. They are efficiently solved by a direct method based on the capacitance matrix method (see [1] for details) : the presence of the obstacle is treated as a perturbation added to the standard five-point stencil scheme obtained when the computational is fully filled by a fluid. Schematically, the algorithm consists in three steps. First, a linear system with n_1 unknowns (n_1 = number of cut-cells which is much smaller than the total number of unknowns) is solved on one dedicated process of the MPI communicator. The involved matrix has been factorized during a preprocessing step performed once for all before time iterations. Then, a penta-diagonal linear system (similar to the system obtained without any solid obstacles) is solved. As each MPI process contains datas located on vertical bands, discrete Fourier transforms can be applied in the y-direction resulting in a collection of independant tridiagonal systems, for which the right-hand sides are splitted among MPI processes. A parallel direct solver based on the

divide and conquer approach has been implemented. Finally a linear correction is applied in order to account for the presence of the obstacle in the computational domain. The parallel code reaches a good level of performance : less than 10% (in the worst cases) of the CPU time is spent in communications between processes. The sequential part performed on one process represents a negligible amount of CPU time. The computations presented here have been performed on a DELL cluster using 32 cores of Xeon processors. A low latency bandwith network connects the cluster nodes.
Recently, in [2], we used a validation tool to investigate the numerical errors associated with this immersed boundary method. The assessment procedure is based on a reference solution [3] for the classical problem of the flow over a circular cylinder at Reynolds number $Re = 40$. The velocity and pressure convergence is illustrated in Figure 1. A simulation of the flow over a circular cylinder at $Re = 9500$ has been performed on a $4\,096^2$ mesh up to the time $t = 20$. Good agreement with experimental results have been found. Streamlines isocontours at $t = 5$ are shown on Figure 2.

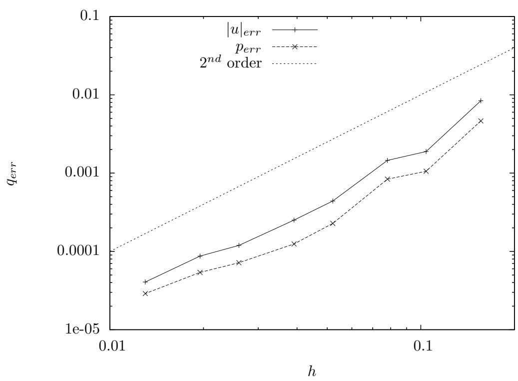

Figure 1: Decrease of velocity and pressure errors in L^2-norm with the spatial resolution.

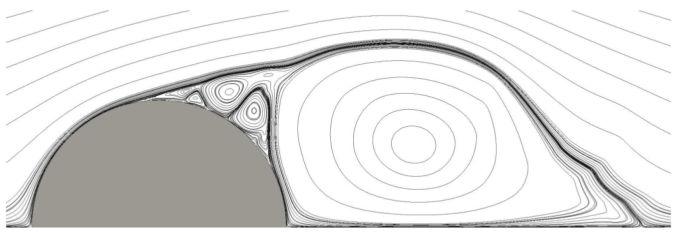

Figure 2: Streamlines isocontours for the flow over a circular cylinder at $Re = 9500$ and time $t = 5$.

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