Accurate discretization of diffusion in the LS-STAG cut-cell method using diamond cell techniques

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Mots-clés : Navier-Stokes equations, Heat Transfer, Cut-Cell method, Gradient Discretisation.

In cut-cell methods for fluid flow in complex geometries such as the LS-STAG method [1, 5], mesh non-orthogonality near the immersed boundary makes inaccurate 2-point formulas for computing the face-normal gradients in diffusive fluxes. A way to improve the accuracy is to compute the whole solution gradient at the cut-cell faces, thus decomposing the flux as an orthogonal contribution (using a standard 2-point formula) and non-orthogonal correction (using data at cell vertices). The solution at cut-cell vertices is then interpolated from cell-centered data and boundary conditions. This gradient reconstruction technique is commonly denominated "secondary gradients" [4] in the CFD community and "diamond cell method" [2] in the applied mathematics community.
The diamond cell method is implemented in the LS-STAG code for cell-centered data (temperature equation in 2D geometries) and face-centered data (Navier-Stokes equations in 3D-extruded geometries) using various interpolation schemes for vertex reconstruction (inverse distance weighting, least-squares, Delaunay triangulation). The accuracy of the diamond cell discretization is firmly assessed on a series of 2D benchmark problems (Taylor-Couette solution, natural convection from a cylinder in an enclosure [3]) by inspecting the formal order of accuracy and the heat flux distribution at the immersed boundary. The impact of the cut-cell quality (smoothness, orthogonal quality) on the solution accuracy will also be thoroughly analyzed.
These computations illustrate the versatility of the diamond cell technique, which can be applied to other cut-cell methods. In a companion presentation by Brice Portelenelle, the diamond cell discretization will be employed to formulate a systematic discretization of the viscous fluxes of the Navier-Stokes equations in 3D cut-cells of arbitrary shape, which enables the design of an efficient and accurate cut-cell method for 3D flow computations.

Références

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