A checkerboard-free symmetry-preserving conservative method for magnetohydrodynamic flows

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A checkerboard-free symmetry-preserving conservative method for magnetohydrodynamic (MHD) flows is presented in this work. Simulation of MHD flows at high Hartmann numbers and low magnetic Reynolds numbers are of high interest for the design of a nuclear fusion breeding blanket. Conservative schemes are of special interest in this case, as the delicate balance between the generated Lorentz force and the high pressure drop needs to be preserved. Furthermore, accurate depiction of the motion of flow at any scale is required for the prediction of transitional and turbulent regimes present under these circumstances. Conservative schemes are essential in maintaining these physical qualities, while at the same time warranting unconditional stability.

One of the aspects of this method is the use of predictor values for both the Poisson equation for pressure and electric potential. By using a predictor value, the dependence on time step of the order of accuracy of the pressure error shifts from Δt to Δt^2, greatly reducing the numerical dissipation seen during simulation. This method, however, can lead to increased occurrence of oscillatory solution fields, known as the checkerboard problem. This work introduces a method to quantify and deal with the checkerboarding in both fields during run-time, using a normalised, global, non-dimensional, time-step independent indicator. This value provides a negative feedback on the inclusion of the predictor values, effectively diminishing oscillations by dynamically introducing the necessary numerical dissipation.

This method is implemented in the open-source software OpenFOAM and tested using several laminar, transitional and turbulent cases. The results are compared to widely-used methods available in literature, that form the accepted standard to perform such simulations.