Design of a hybrid Lattice-Boltzmann/Navier-stokes solver for aerodynamic and aeroacoustics simulations

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In the field of aeronautics, numerical simulations often involve turbulent flows, complex geometries and complicated non-linear interactions between aerodynamics and acoustics. The design of a hybrid LBM/Navier-Stokes solver is motivated by the fact that, depending of the flow region, optimal efficiency might be reached with a different solver.

It is well known that LBM has better acoustic properties and lower computational cost than traditional Navier-Stokes methods [1] thanks to its simple algorithm which scales well in parallel execution. However, due to its cartesian mesh constraint and explicit time-stepping, the resolution of turbulent boundary layers within the Lattice-Boltzmann framework remains costly or inaccurate as wall modeling errors still need to be quantified [2]. Therefore, solving the Navier-Stokes equations (by finite differences or finite volumes) might outperform LBM in near-wall regions benefiting from body-fitted meshes or implicit time-stepping.

The proposed coupling strategy relies on a zonal decomposition where each method is applied in specific flow regions. Following the idea of Albuquerque and Latt [3, 4], it relies on a thorough understanding of the meso/macroscopic relations where the Chapman-Enskog expansion is used to reconstruct the missing velocity distribution functions. In order to achieve stable and accurate results, a regularized collision operator is applied [5] and temporal interpolation between LBM and explicit multi-step Runge-Kutta is studied in depth.

Some canonical numerical tests are conducted. Results are in good agreement with theoretical values and indicate that the advantages of each method are preserved. Especially, dispersion and dissipation properties of the hybrid solver are obtained and compared to those of the individual methods.

References

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