LES-incorporated Vortex Particle Method for modeling unbounded flows

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ABSTRACT

Recent contributions to vortex particle methods for the computation of three-dimensional incompressible, unbounded flows are presented. A lightweight, dynamic Large-Eddy Simulation (LES) model with a dynamic procedure constructed under unbounded flow assumptions is proposed and tested. The LES subgrid scale model leverages the vorticity vector field alone to dynamically update the filter's constant, inspired by Winckelmans (1995). Anisotropy in the unbounded flow field is addressed by comparing the angle of the local vorticity vector to the mean vorticity angle, avoiding excessive dissipation of mean flow features (Cottet et al., 2003).

Since vorticity is the primary quantity transported by the vortex particles, the methodology is fully Lagrangian and relies on few auxiliary computations. A high-order algebraic kernel that allows for direct, analytic expressions of conservation laws and quadratic diagnostics, as originally proposed by Winckelmans and Leonard (1993), is adopted. Viscous diffusion is handled using the core-spreading methodology presented by Chorin (1973). Finally, the particle method is evaluated with respect to conservation laws of energy, helicity, and enstrophy for a Lamb-Oseen vortex, a vortex ring, and Leapfrogging vortex ring models. The particle dynamics are integrated using a 2nd-order Runge-Kutta scheme, which proved sufficient to keep dispersion errors at acceptable levels.

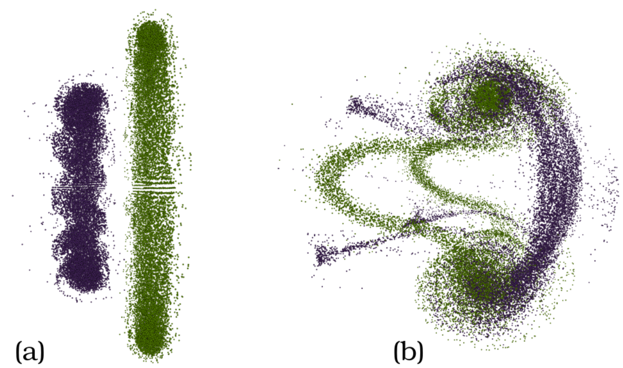

Figure 1: (a) Leapfrogging vortex rings at $t = 10$ and (b) during the reconnection process at $t = 20$ s.

Preliminary results reveal that the current methodology accurately captures the diffusion process of the Lamb-Oseen and vortex ring cores, with less than 1% error compared to analytical results for up to 25,000 computational time steps. A comparison of the Leapfrogging test case using the current, fully-Lagrangian methodology against results from other complex LES methodologies also reveals that the current LES approach accurately captures the reconnection of the vortex rings, as illustrated in Figure 1.

References

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