The turbulent Taylor-Couette flow: A benchmark for implicit LES

Bruno Blaisr[1] & Laura Prieto Saavedra[1] & Peter Munch[2]
1 CHAOS laboratory, Department of Chemical Engineering, Polytechnique Montreal, Montreal, Quebec, CANADA
2 Institute of Mathematics, Technical University Berlin, Strasse des 17. Juni 136, 10623, Berlin, GERMANY

The turbulent Taylor-Green Vortex (TGV) is a commonly used flow case for validating CFD software capable of Direct Numerical Simulation (DNS) or Large-Eddy Simulation (LES). Researchers utilize the TGV to compare the kinetic energy dissipation rate with enstrophy, assessing both the level of artificial dissipation introduced by CFD solvers and the extent to which this dissipation mimics physical dissipation. While the TGV is a very valuable test case, it lacks certain features present in many real-world flow problems, such as curved boundaries and boundary layers.
In 2021, Wang *et al.* proposed a benchmark based on the canonical turbulent Taylor-Couette (TC) flow at Re = 4000. In their original study, enstrophy as a function of time was primarily used to evaluate the capabilities of their high-order flux reconstruction scheme. In this work, we investigate the Taylor-Couette benchmark to assess the performance of the high-order matrix-free solver available in Lethe. Lethe is an open-source, high-performance software that leverages the finite element capabilities of the deal.II framework. By utilizing its matrix-free implementation, Lethe scales up to a billion cells over thousands of cores.
First, we analyze the evolution of enstrophy over time as a function of mesh refinement and finite element polynomial order. Using vorticity and Q-criterion visualizations, we highlight the key turbulent structures that emerge in the Taylor-Couette flow at this Reynolds number. Through an energy balance analysis, we quantify the level of artificial dissipation over time and evaluate the impact of mesh resolution and finite element order on numerical dissipation. Finally, we discuss the challenges in determining an appropriate level of artificial dissipation and explore the potential extension of this work to intensified chemical processes, such as spinning disk reactors.

Email address for correspondence: *bruno.blais@polymtl.ca*