Tuning and Evaluating a High-Performance Domain Specific Language using the Taylor-Green Vortex Simulation Problem

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0.1 2D-TGV application

The 2D-TGV problem is a simplification of the 3D specification with $z = 0$. The problem has a time-dependent analytical solution derived from the incompressible 2D stream function [1]. We compare Saiph numerical output results with the time-dependent analytical solution given in terms of the vorticity as $\omega = \omega_{init} e^{-\frac{2}{Re}\frac{t}{t_c}}$. We test different spatial accuracies and time-integration methods available in Saiph and use the L2 norm as error measurement for the vorticity. The expression for the L2 norm is given below with ω_A and ω_N analytical and numerical values respectively and N the number of mesh points in each spatial direction,

$$||L2|| = \sqrt{\frac{\sum_{j=0}^{j=N} \sum_{i=0}^{i=N} (\omega_N(i,j) - \omega_A(i,j))^2}{N * N}}$$

Figure ?? reports the error results for two mesh sizes of 64×64 and 128×128 points, respectively, using simulation parameters from Table ?? and the configuration parameters from Table ?? corresponding to the 2D-TGV problem with a Reynolds number of 1600.

We do not report Euler's results in Figure ?? since their values are above the unit, out of the competitive range. Similarly, a second-order spatial accuracy does not meet a sufficiently lower error. In contrast, higher spatial accuracy combined with Runge Kutta integration methods preserves the symmetry of the solution for, at least, the first non-dimensional time stamp for both mesh dimensions. Overall, the finer-grained the mesh and higher the time accuracy, the lower the errors and longer the preservation of the symmetry solution. In contrast, a spatial accuracy increase does not imply better and more stable results; using a spatial order of 6 presents better results than those obtained with the spatial eight-order accuracy.

To refine the results, we ran the 2D-TGV application using a finer mesh of 400×400 points, combining the higher-order numerical methods and using an increased Reynolds number of 2000. Figure 1 shows the vorticity contours of the Saiph simulation output, and Figure 2 reports the errors obtained over the same quantity. Results show how around $t/t_c = 200$, the numerical solution becomes unstable and a similar error is obtained for the different accuracies. Saiph numerical accuracy and stability results are comparable with those found in the literature [1].

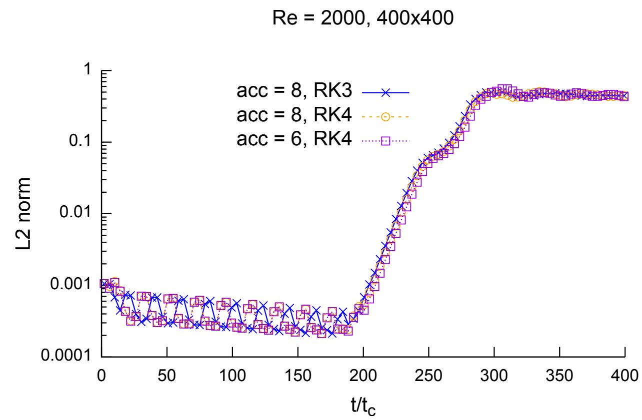

Figure 2: Saiph 2D-TGV vorticity error, using high-order methods

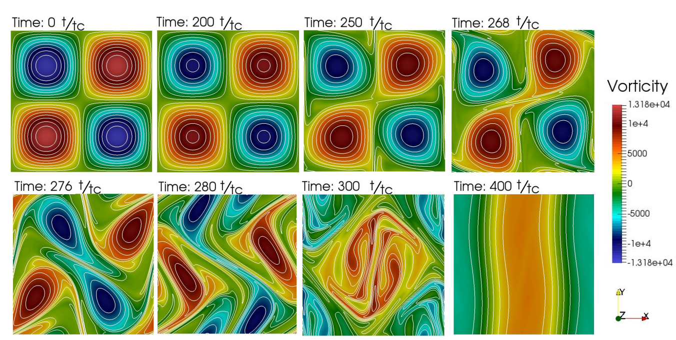

Figure 1: Saiph 2D-TGV vorticity contours at different time-steps using a RK3 time-integration method in a 400×400 mesh at $Re = 2000$

REFERENCES

[1] Nidhi Sharma and Sengupta. 2018. Non-linear instability analysis of the two-dimensional Navier-Stokes equation: The Taylor-Green vortex problem. *Physics of Fluids* 30 (05 2018), 054105. https://doi.org/10.1063/1.5024765

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