Exploiting the symmetries of the Taylor-Green (TG) flow in the case of coupling to a magnetic field

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Scientific context  Astrophysical and geophysical flows are highly turbulent, with strong coupling between a wide range of spatial and temporal scales. The complex behavior of such flows is far from understood, and their study through direct numerical simulation (DNS) in three space dimensions is limited to modest scale separation, even at the largest resolution achieved today. We propose sets of initial conditions for magnetohydrodynamics (MHD) in which both the velocity and the magnetic fields have spatial symmetries that are preserved by the dynamical equations as the system evolves. When implemented numerically, they allow for substantial savings in CPU time and memory storage requirements for a given resolved scale separation.

The ideal case  The non-dissipative case is studied up to the equivalent of 2048\textsuperscript{3} grid points for one of these flows. The temporal evolution of the logarithmic decrements $\delta$ of the energy spectrum remains exponential at the highest spatial resolution considered, for which an acceleration is observed briefly before the grid resolution is reached. Up to the end of the exponential decay of $\delta$, the behavior is consistent with a regular flow with no appearance of a singularity. The subsequent short acceleration in the formation of small magnetic scales can be associated with a near collision of two current sheets driven together by magnetic pressure. It leads to strong gradients with a fast rotation of the direction of the magnetic field, a feature also observed in the solar wind (see Fig. 1, left and middle) (1). A higher resolution ideal run on an equivalent grid of 4096\textsuperscript{3} points encounters some difficulties with simple precision computations, leading to the (expected) need of modifying the code, a useful feature as we prepare for petascale.

The dissipative case  In the presence of dissipation at high Reynolds number and for a unit magnetic Prandtl number, again on grids equivalent to 2048\textsuperscript{3} points, we take as initial condition the TG flow which is globally non-helical and with equal kinetic and magnetic energies and concentrated in the large scales. The energetics of this dissipative flow are studied up to a magnetic Taylor Reynolds number of $\sim 1700$. We find that the global temporal evolution is accelerated, compared to the corresponding neutral fluid case. We also observe a sizable interval of time during which the flow is semi-stationary with quasi-constant total dissipation, time during which statistical properties

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Figure 1: Left: Current density intensity in a $200 \times 200 \times 120$ subvolume of the $2048^3$ ideal run at $t = 2.5$. Note the two current sheets approaching each other. Middle: Magnetic field lines in the same structure (viewed from the back). The current intensity in a slice is given as a reference. To the right and left of the slice, the magnetic field is strong (purple color), whereas in the transition region it decreases to $\approx 1/6$ of the maximum (yellow), corresponding to a strong local drop in intensity. Note also the rapid spatial rotation of the field lines (in approximately 6 grid spacing) between the two current sheets (1). Visualization using VAPOR (3). Right: Energy spectra, averaged in the plateau of total dissipation, compensated by $k^2$ (red), $k^{5/3}$ (green) and $k^{3/2}$ (orange) corresponding respectively to weak turbulence, Kolmogorov and IK spectra; dissipative $2048^3$ run. Note that wave turbulence seems to dominate in this flow possibly at all scales (2).

are analyzed after averaging. An anisotropic investigation of energy spectra confirms the findings of a non-symmetric fully helical flow with a tendency toward (anisotropic) weak turbulence in the small scales (see Fig. 1, right), with a complex spatial structure of current and vorticity sheets and with possibly bursty reconnection events at later times (2).

This work supports the strategic priorities of NCAR by performing and analyzing very high resolution direct numerical simulations of fundamental flows, in preparation of petascale.

References

