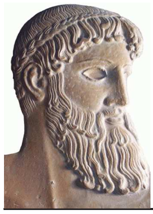
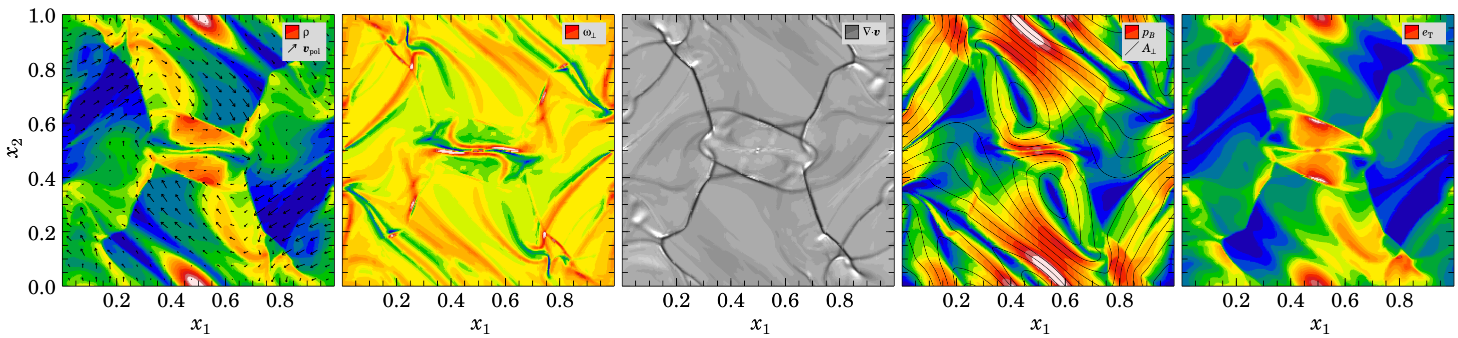


ZEUS-3D 2-D Gallery #6: The Orszag-Tang Magnetic Vortex



animate ρ animate $\omega_\perp$ animate $\nabla \cdot \vec{v}$ animate p_B animate $e_{\rm T}$

The Orszag-Tang magnetic vortex (1998, J. Fluid Mech., 90, 129) has become a standard 2-D test problem for MHD codes. Shown above from left to right are: (*i*) density with velocity vectors superposed; (*ii*) the normal component of the vorticity, $\omega_\perp$; (*iii*) the velocity divergence, $\nabla \cdot \vec{v}$, useful for mapping out shocks; (*iv*) magnetic pressure (p_B) with magnetic field lines superposed; and (*v*) the total energy density, $e_{\rm T}$. Links to the respective animations are provided below each image.

The simulation was done on a 256×256 Cartesian grid with periodic boundary conditions using `CMoC`, `FIT` (*Finely Interleaved Transport*) using the conservative total energy equation, artificial viscosity `qcon=1` and `qlin=0.1`, second order (van Leer) interpolation (`iord=2`), and Courant number `courno=0.75`.

In developing `FIT` (`trnvrsn=1`), this test problem was instrumental in determining what density had to be used in evaluating the *emfs*. In using Legacy transport (`trnvrsn=0`), which lacks consistency when the primitive variables are updated, there was often a battle to suppress unwanted behaviour in various test problems which occasionally led to seemingly arbitrary algorithmic design. In particular, when the old `MoC` algorithm was introduced into *ZEUS-2D* by Stone & Norman (1992, ApJS), the *emfs* had to be evaluated using the density *before* the transport step, lest unwanted oscillations be excited in test problems such as this. Indeed, the original `MoC` was a combined Eulerian-Lagrangian algorithm with the Lorentz force update being the only portion done in a Lagrangian frame of reference for similar reasons.

In hindsight, this was because of the coarseness of the operator splitting in *ZEUS* at the time, and the sequence in which certain operations were performed. While I didn't realise it then, the development of `CMoC` (Clarke, 1996, ApJ) where I was able to make the MHD algorithm fully Eulerian was the beginning of the resequencing of the operator splitting in *ZEUS* that ultimately led to `FIT`. More recently when the benefit of consistently using updated primitive variables was appreciated (see the 2-D advection page for a discussion), the requirement of using the pre-transport density disappeared. In fact, the O-T problem was the first test problem I found to be sensitive to what density was used in computing the *emfs*. Once the main principle of `FIT` was adopted, namely that velocity and magnetic field be updated as soon and often as they can be, the O-T vortex made it clear that the density had to be fully updated as well.

Finally, looking carefully at the $\nabla \cdot \vec{v}$ and $\omega_\perp$ animations, one can see one very brief time in each where highly localised low-level oscillations are triggered, then disappear. Whether these are glimmers of the "shear instability" discussed on the Kelvin-Kelmholtz instability page is unclear. First, the shear instability was very prominent in animations of *primitive* variables such as the density; here it is only apparent and only very briefly in variables constructed from *differences* of primitive variables, which poses a very stringent test on the numerics. At this point, I am not particularly concerned with these oscillations.