MAGNETOHYDRODYNAMIC INSTABILITIES OF ASTROPHYSICAL JETS

Hubert Baty*, Rony Keppens**, Pierre Comte***
**Observatoire Astronomique, 11 Rue de l'Université, 67000 Strasbourg, France*
***FOM-Institute for Plasma Physics Rijnhuizen, Association Euratom/FOM, P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands*
****Institut de Mécanique des Fluides et des Solides, 2 Rue Boussingault, 67000 Strasbourg, France*

Summary We present the main findings of recent studies using high-resolution magnetohydrodynamic (MHD) simulations of compressible shear flow layers, with the aim to investigate configurations representative of astrophysical jets. We show how initially weak magnetic fields control the non linear dynamics of Kelvin-Helmholtz instabilities, through magnetic reconnection events and stabilizing mutual interaction with magnetic instabilities.

Astrophysical jets are collimated flows that are observed to propagate over large distances with respect to their radial extents. This is the case of jets emanating from young stellar objects and active galactic nuclei. It is to date an open question how these supersonic jets survive MHD instabilities (Ferrari 1998). Indeed, in high-resolution three dimensional (3D) hydrodynamic simulations, Kelvin-Helmholtz (KH) instabilities are seen to disrupt the flow with a strong turbulent transition. The characteristic time scale of the disruption is too fast by more than one order of magnitude to account for the observations. However, the astrophysical jets are believed to be magnetized although the dominant contribution to the jet energy is the kinetic one. Thus, we investigate the role played by the magnetic field with the aim to examine the issue of large-scale flow coherence and survival.

To that end, we use the Versatile Advection Code (VAC) initiated by Tóth (1996), to solve the full set of non linear MHD equations as an initial value problem. VAC and its recent grid-adaptative variant AMRVAC (Keppens et al. 2003) are general finite-volume based schemes, making use of a second order accurate shock capturing method and employing a Roe-type approximate solver.

In order to model the interface separating the jet from the surrounding medium, we first consider a single two dimensional (2D) shear flow layer embedded in a weak uniform magnetic field that is aligned with the flow (in the longitudinal x direction). We assume periodicity along the longitudinal direction, and we use free outflow boundaries on the lateral sides. Thanks to AMRVAC, we have followed the initial growth of many KH vortices initiated by a white noise perturbation. A strong process of large-scale coalescence is found. It proceeds through continuous pairing/merging events between adjacent vortices up to the point where the final large-scale vortice structure reaches the domain dimensions. This coalescence is also accompanied by small-scale magnetic reconnection events that partially disrupt the vortices at different stages of the evolution, thus releasing a non negligible part of the perturbed energy. The extension of these results (Baty et al. 2003) to a 2D slab jet is actually under current investigation.

Second, we consider a 3D magnetized cylindrical jet configuration. The flow is axial, sheared in the radial direction with an hyperbolic tangent form, and is embedded in an helical magnetic field. We take an axial length equal to the linearly dominant axial wavelengths (the large-scale coalescence is excluded), and the jet surface is perturbed at $m = \pm 1$ azimuthal mode numbers. As predicted by a stability analysis, a $m = -1$ KH mode develops at the interface (dominating the $m = 1$ KH counterpart), while the jet core is affected by the growth of a $m = -1$ magnetic instability that is driven by the electrical current. This simultaneous development of the two types of modes is illustrated in Figure 1. As time proceeds, the magnetic field deformation induced by the current-driven (CD) mode provides a stabilizing effect on the further KH development. The subsequent disruptive effect on the flow (due to a magnetic reconnection process) is shown to be weaker than in magnetized configurations without CD mode (in particular with an axial magnetic field), as illustrated in Figure 2 (see also Baty & Keppens 2002).

We have presented two examples of configurations in which initially weak magnetic fields ultimately control the non linear dynamics of unstable shear flow layers. The long-term disruptive effect on the flow is thereby weaker compared to a 3D purely hydrodynamic configuration, in particular when the jet is embedded in an helical magnetic field. These results provide important clues to understand astrophysical jets survival.

This work was supported in part by the European Community's Human Potential Program under contract HPRN-CT-2000-00153, PLATON.

References

[1] Baty H., Keppens R.: The Astrophysical Journal **580**, 800, 2002.
[2] Baty H., Keppens R., Comte P.: Physics of Plasmas **10**, 4661, 2003.
[3] Ferrari A.: Annual Review of Astronomy and Astrophysics **36**, 539, 1998.
[4] Keppens R., Nool M., Tóth G., Goedbloed J. P.: Computer Physics Communications **153**, 317, 2003.
[5] Tóth G.: Astrophysical Letters and Communications **34**, 245, 1996.

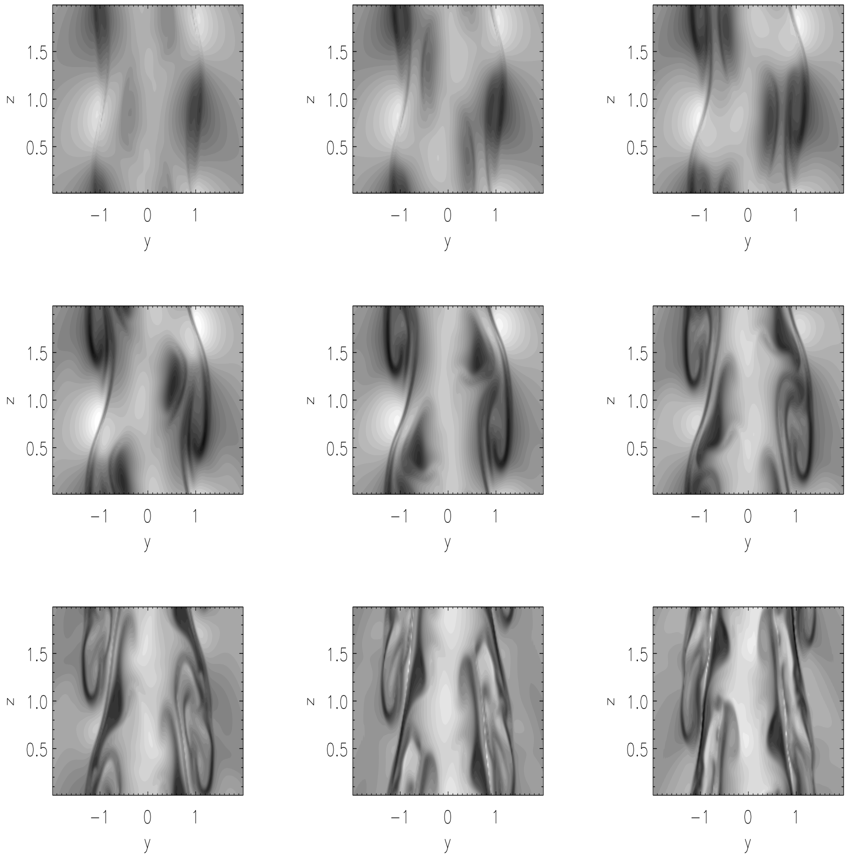

Figure 1. Grey-scale images of the density distribution of a magnetized jet simulation with an helical magnetic field (using VAC), in the $y-z$ plane (using a 2D cut at $x=0$). The times are running from left to right and top to bottom. Dark regions correspond to low values.

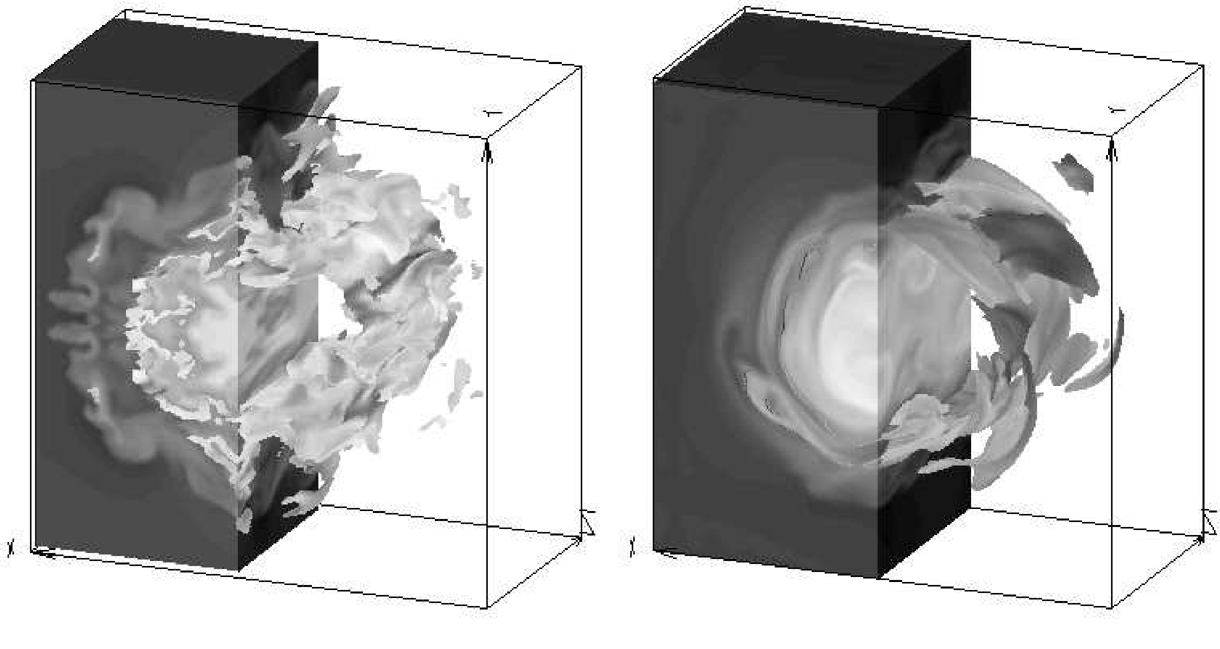

Figure 2. The 3D jet structure at the end of the simulations for magnetized jets in a pure axial (left), and in helical (right) magnetic field. Shown is the axial velocity V_z on various cross-sections, and an isosurface $V_z = 0$ corresponding to the jet boundary.