Spiral small–scale structures in compressible turbulent flows

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We investigate the spectral signature of the dynamics of small–scale structures for a fully developped compressible turbulent flow in three dimensions (3D).

We recall that a $k^{-5/3}$ behavior has been observed for velocity spectra in 3D numerical simulations of either forced or decaying compressible flows at unit *r.m.s.* Mach numbers [1]. We thus extend to compressible turbulent flows with a perfect gas law, the spiral vortex model of Lundgren [2] which links the dynamical and the spectral properties of incompressible flows providing a $k^{-5/3}$ Kolmogorov energy spectrum.

A compressible spatio-temporal transformation similar to that of Lundgren is derived, reducing the dynamics of 3D vortices stretched by an axisymmetric incompressible strain, into a two–dimensional vortex dynamics. This allows for writing the 3D spectra of the square velocity – Helmoltz–decomposed into its incompressible u_s and compressible u_c parts – in terms of, respectively, the 2D spectra of the enstrophy and the square velocity divergence, using a temporal integration.

Numerical results are presented stemming from direct simulations performed with 512^2 (*resp.* 1024^2) grid points. The *r.m.s.* Mach number is around 0.25, with local values up to 0.9, the Reynolds number is 700, (*resp.* 1,400), and $u_c^2/u_s^2 \sim 0.1$. A spiral vortex obtains, and the divergence field organises itself around it. The 3D spectrum of u_s is thus computed from the 2D enstrophy spectrum over a time span of a few acoustic times corresponding to the life–time of the vorticity in the spiral arms. The 3D spectrum of u_c is computed from the 2D spectrum of the square velocity divergence up to a characteristic time comparable to the acoustic time.

In that framework, a $k^{-5/3}$ inertial behavior is indeed observed for both the compressible and incompressible 3D spectra [3].

References

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[2] T.S. Lundgren, *Phys. Fluids,* **25**, *1982.*

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