§ 43. Interaction between a Trailing Vortex and External Turbulence

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Interactions between intense columnar vortices and surrounding turbulent motions are often produced in engineering and environmental flows, and they occur naturally in most sheared turbulent flows, such as circular jet, plane jet, and mixing layer. These interactions are thought to play an important role in the three-dimensionalization of the flow fields. It is, also, of practical interest to estimate the lifetime of trailing vortices under the influence of atmospheric turbulence.

Melander and Hussain[1] performed a columnar (without an axial flow) embedded in random perturbation. They showed the followings, i.e. (1) azimuthal alignment of small-scale vorticity, (2) merger and axisymmetrization of these vortex rings (corresponding to the inverse energy cascade), and (3) excitation of long bending waves on the columnar vortex.

We investigate the interaction between a columnar vortex and external turbulence using direct numerical simulations. As the columnar vortices we consider the Lamb-Oseen vortex and the q-vortex with axial flow. The external turbulence (R_λ is about 120) is numerically produced turbulence by the Fourier-spectral method is used which Both the columnar vortex and fine scale structures (worms) can be extracted by the low pressure swirling vortex method[2].

As in Melander and Hussain[1], we can observe that worms wrapped around the vortex to form the spiral forms (deformed worms) around the Lamb-Oseen vortex (Fig.1). We find that the columnar vortex, which itself expands slightly. The energy dissipation increases considerably outside the vortex core. Using the two-point energy-spectrum tensors, we can capture such phenomena as the 'Blocking Effect' (fluid particles cannot penetrate into the vortex core) and the excitation of bending and axisymmetric vortex waves.

We also investigate the instability of the q-vortex ($q = -0.45$ and $q = -1.5$). In the q-vortex with $q = -0.45$, the linear unstable modes grows until the

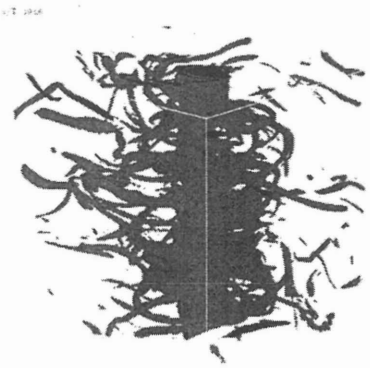

Figure 1: Iso-surface of the vorticity at $t/T \simeq 10$, $\alpha = 40$.

columnar vortex make one turn (Fig.2). Its growth

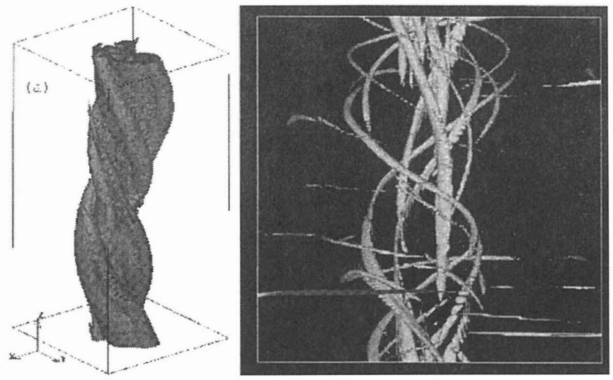

Figure 2: Isosurface of vorticity of q-vortex: (a) $q = -0.45$, and (b) $q = -1.5$.

rate agrees with that of the linear analysis[3]. After the vortex made two turns, the secondary instability is excited. It caused that the columnar q-vortex collapses and many fine scale vortices appear abruptly. In the q-vortex with $q = -1.5$, thin and strong spiral structure is formed inside the vortex core.

References

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[3] E. W. Mayer and K. G. Powell. Viscous and inviscid instabilities of a trailing vortex. *J. Fluid Mech.*, 245:91–114, 1992.