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The structure and dynamics of coherent vortex tubes in rotating shear turbulence of zero-mean-absolute vorticity.

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The effect of the system rotation on shear flow turbulence is one of the central issues of fluid mechanics in relation to geophysical and astrophysical phenomena as well as engineering applications such as turbo machinery, so is still being vigorously investigated. If a turbulent shear flow is rotated as a whole about the axis parallel to the mean-shear vorticity, the flow structure is significantly influenced by the magnitude and direction of vorticity associated with the mean shear relative to those of the system rotation. The flow field is called either cyclonic or anti-cyclonic accordingly as vorticities associated with the mean shear and the system rotation are parallel or anti-parallel. Turbulence has a tendency to keep its two-dimensional structure along the system rotation both for cyclonic and for an anti-cyclonic regions for rapid system rotation, whereas the two-dimensional structure is unstable and easily broken down to three-dimensional in an anti-cyclonic region if the system rotation is relatively slow to the mean-shear vorticity.

If the flow field is anti-cyclonic and the mean-shear vorticity cancels out that of the system rotation, the mean absolute vorticity is zero in the flow field, and then it is called the zero-mean-absolute-vorticity state (ZAVS). ZAVS, which is neutral to the above-mentioned instability, is observed in many rotating shear flow turbulence. One of the most remarkable features of ZAVS turbulence is the generation of very coherent quasi-streamwise vortex tubes which are not observed in other cases of rotating or nonrotating turbulence. Though the importance of the role of vortex tubes in shear flow turbulence is generally recognized, it is not easy to study their dynamics due to the interactions between vortex tubes and vortex-shear layers which are generated from the background mean-shear vorticity. In ZAVS, on the other hand, it is rather easy to investigate vortex tubes in turbulence because they are stable and long-lived without the interactions associated with the background mean-shear vorticity.

In the present study, the structure and dynamics of coherent vortex tubes in ZAVS are investigated by direct numerical simulations in order to work out the roles of coherent vortex tubes in a fully development rotating shear flow turbulence. It is found that a coherent vortex tube consists of two parts; end parts and an intermediate part between them. Two end parts are crucial to keep the direction of the vortex tube against the tilting mechanism by the mean shear flow and to rotate themselves from the direction of the mean-shear vorticity at their birth period to that of the system rotation as time proceeds. This change in the direction of the vortex tubes may contribute to the stabilization of the whole turbulent flow field. During the rotation, vortex tubes are deformed and flattened, which leads to the decay of the tubes. This suppresses the growth of the turbulence kinetic energy and stabilize turbulence. Many types of the interaction between coherent vortex tubes is investigated in detail and find that the interaction between them strongly affects their motion and structure.