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Geometrical properties of the vorticity vector derived using large-eddy simulation

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Abstract

In this paper, the geometrical properties of the resolved vorticity vector $\bar{\omega}$ derived from large-eddy simulation are investigated using a statistical method. Numerical tests have been performed based on a turbulent Couette channel flow using three different dynamic linear and nonlinear subgrid-scale stress models. The geometrical properties of $\bar{\omega}$ have a significant impact on various physical quantities and processes of the flow. To demonstrate, we examined helicity and helical structure, the attitude of $\bar{\omega}$ with respect to the eigenframes of the resolved strain rate tensor $\bar{S}_{ij}$ and negative subgrid-scale stress tensor $-\tau_{ij}$, enstrophy generation, and local vortex stretching and compression. It is observed that the presence of the wall has a strong anisotropic influence on the alignment patterns between $\bar{\omega}$ and the eigenvectors of $\bar{S}_{ij}$, and between $\bar{\omega}$ and the resolved vortex stretching vector. Some interesting wall-limiting geometrical alignment patterns and probability density distributions in the form of Dirac delta functions associated with these alignment patterns are reported. To quantify the subgrid-scale modelling effects, the attitude of $\bar{\omega}$ with respect to the eigenframe of $-\tau_{ij}$ is studied, and the geometrical alignment between $\bar{\omega}$ and the Euler axis is also investigated. The Euler axis and angle for describing the relative rotation between the eigenframes of $-\tau_{ij}$ and $\bar{S}_{ij}$ are natural invariants of the rotation matrix, and are found to be effective for characterizing a subgrid-scale stress model and for quantifying the associated subgrid-scale modelling effects on the geometrical properties of $\bar{\omega}$.

Keywords: Turbulence; Vorticity; Vortex stretching; Enstrophy; Helicity; Large-eddy simulation; Subgrid-scale stress

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