Comparison between objective and non-objective kinematic flow classification criteria

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Abstract: Turbulent flows present several compact and spatially coherent regions generically known as coherent structures. It is known that the dilution of an elastic polymer in a Newtonian solvent increases the size of such structures. The understanding of these structures is closely related to the concept of vortex, whose definition is still a subject of controversy within the scientific community. In particular, the role of objectivity (the invariance with respect to arbitrary changes of reference frame) in the definition of the vortex remains a largely open question. However, three usual kinematic criteria for flow classification, namely Q, Δ and λ_2, are non-objective since they all use the fluid's rate of rotation, which depends on the observer. In the present work, we propose an objective redefinition for these three classic criteria by using the concept of relative rate of rotation defined as the difference between the usual rate of rotation and the angular velocity of the eigenvectors of the strain rate tensor. We also explore two novel naturally objective flow classification criteria, which are obtained using the covariant convected derivative of the strain rate tensor. Preliminary analyses are performed with a 4:1 abrupt contraction and the analytical velocity field given by circular trigonometric functions that form the so called Arnold-Beltrami-Childress (ABC) flow. Then, all the criteria are applied to the instantaneous velocity fields obtained by direct numerical simulation (DNS) of both Newtonian and viscoelastic turbulent channel flows. The analysis will be carried out here for four frictional Reynolds numbers (Re_τ = 180, 395, 590 and 1000), emphasizing the difference between objective and non-objective identification criteria, as well as between Newtonian and non-Newtonian flows. Moreover, we try to obtain, from the results of flow classification criteria, information related to the polymer drag reduction phenomenon.

Keywords: Kinematic flow classification; viscoelastic fluid; objectivity; channel flow; DNS.