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ORIGINAL

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Identification of vortex cores of three-dimensional large-vortical structures

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Abstract In this paper, we propose a nonlocal method to identify vortex cores in three-dimensional flows as a complement to the existing list of local and nonlocal methods of the bibliography. The method is based on the vector field of the instantaneous rotation of a particle around a center. This center is defined using the Darboux vector field along the path-particle lines; the vortex core is detected using their Frenet–Serret frame. We illustrate the application of the method to identify the core of large-vortical structures in analytical and numerically simulated laminar and turbulent natural convection flows.

Keywords Flow visualization · Vortex · Structure of the flow

1 Introduction

There are several techniques available in the literature to reveal the vortical structures of the flows (Jeong and Hussain [1]; Roth and Peikert [2]; Haller [3]). These methods of identification of vortical structures perform local analyses of the flow, based on the velocity gradient tensor. On the other hand, the nonlocal methods are based on quantities averaged over a certain region of the flow or a certain period of time that are associated with the vortical motion of the fluid particles. The identification of this vortical flow structures is of importance, for example, because they are commonly responsible for mixing processes and for large rates of momentum and heat/mass transfer.

A nonlocal method for two-dimensional flows was proposed by Michard et al. [4] and Graftieaux et al. [5]. This method is based on the calculation of the normalized angular momentum function f:

$$f(x_p) = \frac{1}{V} \int\limits_{x \in V} \frac{(x - x_p) \times \overrightarrow{v}(x)}{\left\| x - x_p \right\| \left\| \overrightarrow{v}(x) \right\|} \mathrm{d}V, \tag{1}$$

where V is a volume around the point x_p, $\overrightarrow{v}(x)$ is the velocity vector at point x, and $\times$ is the vector product. The modulus of $f(x_p)$, $\left| f(x_p) \right|$, ranges between 0 and 1. In two-dimensional cases, if V tends to a very small volume, then $\left| f(x_p) \right|$ tends to a characteristic function that is zero everywhere except in the vortex center, where it attains the value of 1.

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