Vortex tubes, spirals, and large-eddy simulation of turbulence

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Abstract Progress in the quantitative modelling of turbulence using vortex-based models of the fine scales is reviewed. Recent work on the calculation of the spectrum of a passive scalar convecting and diffusing within a stretched-spiral vortex is briefly described. This is followed by a discussion of the application of ideas from the study of the vortex structure of the small scales of turbulence to the development of sub-grid models for the large-eddy simulation (LES) of turbulent flows at large Reynolds numbers. Examples are given including the LES of rotating and non-rotating plane channel flow and of the mixing of a passive scalar by forced isotropic turbulence.

A scalar transported by flow;
In a spiral of type that we know,
Itself becomes spiral,
Possibly chiral,
And its spectrum is found without woe.
—HKM 2001

Big eddies have plenty to spare;
But the little ones hardly do care,
For at scales small,
Dissipation is all,
If energy cascade is fair.
—DIP 2001

1. Introduction

The modelling of turbulence using ensembles of superposed local solutions to the Navier-Stokes and Euler equations appears to provide a viable approach to the calculation of some properties of turbulent small scales. Although Hill spherical vortices and Burgers vortices have been used as the basic elements for vortex-based modelling of turbulence (He et al. 1999; Kambe & Hatakeyama 2000; Pullin & Saffman 1998), the most interesting structure proposed to date has perhaps been the stretched-spiral vortex (Lundgren 1982). Its nearly axisymmetric vorticity may be viewed as tube-like on scales which are large compared with its cross-sectional dimension, and sheet-like on smaller scales. Experimental and numerical studies of turbulent flow have revealed the presence of vortex tubes (Porter et al. 1998) and spiral structures (S. Kida, this volume). Indeed, it may be argued that spirals are unavoidable once tubes are present. The formation mechanism for tubes/spirals,