THESE

Lundi 22 Janvier 2018 à 15h00 - Salle AY0263 à l'ONERA Meudon

Study of high-order vorticity confinement schemes

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Vortices are flow structures of primary interest in a wide range of fluid dynamics applications including wakes, fluid-structure interaction, flow separation and turbulence. Albeit their importance, standard Computational Fluid Dynamics (CFD) methods very often fail to provide an accurate representation of vortices. This is primarily related to the schemes' numerical dissipation which, if inadequately tuned for the calculation of vortical flows, results in the artificial spreading and diffusion of vortices in numerical simulations. Among other approaches, the Vorticity Confinement (VC) method of J. Steinhoff allows balancing the baseline dissipation within vortices by introducing non-linear anti-dissipation in the discretization of the flow equations, but remains at most first-order accurate. At the same time, remarkable progress has recently been made on the development of high-order numerical methods. These allow reducing the problem of excess dissipation, but the diffusion of vortices remains important for many applications. The present study aims at developing high-order extensions of the VC method to reduce the excess dissipation of vortices, while preserving the accuracy of high-order methods. First, the schemes are analyzed in the case of the linear transport equation, based on time-space coupled and uncoupled formulations. A spectral analysis of nonlinear schemes with VC is performed analytically and numerically, due to their nonlinear character. These schemes exhibit improved dispersive and dissipative properties compared to their linear counterparts at all orders of accuracy. In a second step, third- and fifth-order accurate VC schemes are developed for the compressible Navier-Stokes equations. These remain conservative, rotationally invariant and independent of the baseline scheme, as the original VC2 formulation. Numerical tests validate the increased order of accuracy and the capability of high-order VC extensions to balance dissipation within vortices. Finally, schemes with VC are applied to the calculation of turbulent flows, in an implicit Large Eddy Simulation (ILES) approach. In these applications, numerical schemes with VC exhibit improved resolvability compared to their baseline linear version, while they are capable of producing consistent results even in complex vortical flows.

Composition du jury

Mme. Héloïse BEAUGENDRE	Inria Bordeaux - Sud-Ouest	Rapporteur
M. John STEINHOFF	University of Tennessee Space Institute	Rapporteur
Mme. Paola CINNELLA	Arts et Métiers ParisTech	Examinateur
M. Christophe CORRE	École Centrale de Lyon	Examinateur
M. Éric LAMBALLAIS	Institut Pprime, Université de Poitiers	Examinateur
M. Michel COSTES	ONERA Meudon	Examinateur
Mme. Subhashini CHITTA	Wave CPC Inc., Tullahoma	Membre invité
M. Yann DOUTRELEAU	DGA/MRIS, Paris	Membre invité