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Spectral Vanishing Viscosity Stabilized LES of the Ahmed Body Turbulent Wake

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Abstract. The paper addresses the Large-Eddy Simulation (LES) of the turbulent wake of the Ahmed car model. To this end we use a Fourier-Chebyshev multi-domain solver and the LES capability is implemented through the use of the Spectral Vanishing Viscosity (SVV) method, completed with a near-wall correction. A "pseudo-penalization" technique is used to model the bluff body. Comparisons of the present SVV-LES results with the experiments and also with a more classical Finite Volume LES are provided.

AMS subject classifications: 76D25, 76M22

Key words: Large-eddy simulation, spectral vanishing viscosity, spectral methods, wakes, turbulence.

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1 Introduction

When computing turbulent flows, the computational grid is generally too coarse to capture the smaller scale phenomena, so that to prevent a numerical crash using a stabilization technique becomes necessary. This is especially true when high order methods are concerned, because the numerical scheme is then definitively not dissipative enough to stabilize the computation. This stabilization may result from a Sub Grid Scale (SGS) model, which aim is to provide an approximation of what happens at the "non-resolved scales", giving then rise to the usual Large-Eddy Simulation (LES) methodology (see, *e.g.*, [38]). Thus, the celebrated SGS Smagorinsky model completes the Navier-Stokes equations with an additional dissipation term, which diffusion coefficient is proportional to a norm of the strain rate tensor (symmetric part of the velocity gradient tensor).

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The spectral vanishing viscosity (SVV) method was developed to handle hyperbolic 1D scalar problems, typically the Burgers equation, with standard Fourier or Legendre spectral methods [27,39]. The main goal was to provide stability together with preserving the so-called spectral accuracy, *i.e.*, the exponential rate of convergence of the numerical approximation. Basically, the method relies on the introduction of some artificial viscosity only in the high frequency range of the spectral approximation. This idea has appeared very useful in the frame of the LES of turbulent flows, resulting in the development of the so-called SVV-LES by extending to the incompressible Navier-Stokes equations ideas first developed for the Burgers equations [17,18].

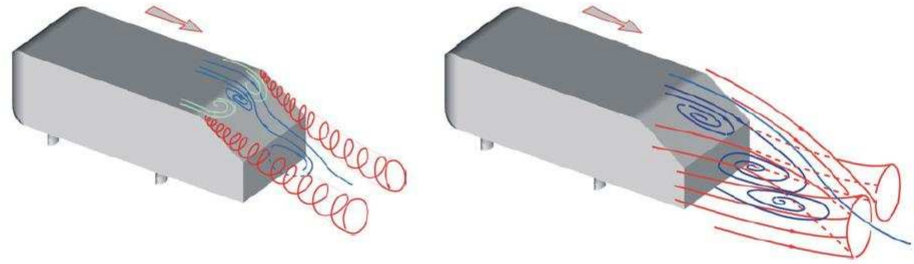

Figure 1: Car model and schematic of the flow for two slant angles (courtesy H. Lienhart): 25^o and 35^o (change of topology for 30^o).

Here we want to outline the efficiency of the SVV stabilization by addressing a challenging benchmark: the turbulent wake of the Ahmed car model [1]. As shown in the schematic of Fig. 1, the model is very crude, since essentially characterized by its length, height and width and by the length and inclination of the slant. However, for a Reynolds number, based on the height of the vehicle and on the incoming air velocity, equal to $Re=768000$, the flow is already very complex. Especially, depending on the slant inclination angle, the flow may show different topologies: For angles greater than a critical value of 30^o, then one observes a large detachment whereas for smaller angles there is a reattachment on the slant and the development of trailing vortices from its edges. Associated to this change in the flow topology, one observes a drag crisis, with a sudden decrease of the drag coefficient [1]. The Ahmed problem is presently not accessible to the Direct Numerical Simulation (DNS), *i.e.*, to the numerical integration of the Navier-Stokes equations, the Reynolds number being too high. Moreover, for the subcritical slant angle Reynolds Averaged Navier-Stokes (RANS) approaches fail to predict the correct behavior of the flow, see *e.g.* [13,28], and the LES methods must use a large amount of grid points to get valuable, but still far from fully satisfactory, results.

Another difficulty of this wake flow problem comes from the complexity of the geometry, much more complex than those accessible to standard spectral methods. This problem is addressed by using a volume penalization method, namely the *pseudo-penalization method* [35]. Here we revisit this approach, first for the paper to be self contained and second because the approximation of the obstacle is strongly linked to the treatment and