Center for Turbulence Research
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LES and numerical simulations

The development and the test of new concepts in large-eddy simulation (LES) traditionally plays a central role in the CTR summer program. This year is no exception with not less than 10 participants, 4 hosts and 5 research projects in the LES group. It might appear surprising to keep such an important "fundamentals" activity while LES are applied more and more routinely in industrial applications and in many fields of physics and engineering as confirmed by its intensive use in other groups of this summer program. There is however still room for improvements in the LES techniques. As a sign of this search for a better LES formalism, participants from several groups – magnetohydrodynamics, solar turbulence and combustion – have chosen to be directly involved in research projects on LES fundamentals. The most striking property of the projects presented hereafter is the integrated approach adopted. The LES problem is treated globally, including the definition of the resolved field, the numerical method and the modelling strategy. The possible interconnections between these different aspects of LES are fully recognized and exploited in the development of the projects.

The first project is a perfect example of this integrated approach. Goldstein, Vasilyev & Kevlahan use the wavelet representation of the velocity field to propose a new LES formalism. Wavelet filters are able to capture energetic structures by simultaneously resolving them in physical and wave number space. A specific numerical scheme is proposed, the dynamically adaptive wavelet collocation (DAWC) method. It is able to track energetic structures without ad-hoc assumptions for the grid adaptation. Also, an eddy-viscosity model based on a dynamic procedure redefined in terms of two wavelet threshold filters is implemented and a fully adaptative LES simulation is achieved. This approach, named stochastic coherent adaptive large eddy simulation (SCALES), implies a direct coupling of the grid evolution to both the flow and the subgrid-scale model. Results in isotropic decaying turbulence show that this approach competes with traditional LES. Providing a local version of the dynamic procedure exploiting the intrinsically local character of the numerical method is the next challenge for the SCALES approach.

The idea that the definition of the resolved field, the numerical method and the modelling strategy have to be considered as a global issue in LES is also omnipresent in the second project by Oberai, Gravemeier & Burton. Ideal LES solutions are introduced to refer to the fields obtained by truncating direct numerical simulation (DNS) solutions. The Smagorinsky model performances are evaluated in an *a-priori* study of the transfer of energy from the resolved scales, split into coarse and fine resolved scales, to the subgrid scales. When the ideal solution is defined as a truncated Fourier representation of the DNS solution, the energy transfer from the fine resolved scales is the dominant contribution and the Smagorinsky model is overly dissipative in the coarse resolved scales. When the ideal LES solution is identified as the nodal interpolant on a coarse finite element mesh, contributions from both the coarse and the fine resolved scales are important and the model is found to perform reasonably well in both coarse and fine resolved scales. The variational multiscale formulation of LES in which different models are used for the fine and the coarse resolved scales could thus be justified in spectral codes but not necessarily in finite element cases.

In the third project, Debliquy, Knaepen, Carati & Wray propose a LES formalism based on sampling operators. Samplings have several attracting properties in LES. They directly transform continuous signal into discrete data and always commute with products. However, samplings never commute with spatial derivatives. A model is needed for this commutation error, which is the discretization error associated to the numerical scheme. Hence, here again, an integrated approach is proposed in which the definition of the resolved field, the numerical scheme and the model are treated simultaneously. A dynamic procedure, based on samplings on embedded grids, is proposed and tested in isotropic decaying turbulence. The Smagorinsky model is chosen and, despite its ability to represent discretization errors is questionable, reasonable results are obtained. As a by-product of this formalism, interpolation functions compatible with finite difference schemes have been proposed. These functions play the same role as the plane waves in the Fourier analysis.

In the fourth project, Nakayama, Hori & Street have focused their research on the definition of the LES velocity field close to a rough solid boundary. An explicit filtering is used to treat in a unified formalism all the effects due to the lack of resolution, both in the core flow and in the wall region. In addition to the traditional subgrid scale stress, the resulting LES equations contain extra stress-like terms that can be identified as subgrid-scale roughness contributions and that need to be modeled. Here again, the coupling between the definition of the resolved field, the resolved domain and modelling is thus fully acknowledged. Preliminary LES calculations have been conducted for turbulent channel flows over flat and wavy rough surfaces. It is suggested that the rough boundary effects may be modeled by boundary resistance and slip velocity effects. The results are obtained with pre-assigned values of the model constants. However, the formalism is compatible with a dynamic procedure which is presented in the report.

In the last project, Moureau, Vasilyev, Angelberger & Poinsot have investigated the importance of the temporal commutation errors (TCE) in LES. The coupling between the definition of the resolved field and the modelling is again the primary motivation of this work. When the filter is a function of time, the LES equations contain an unknown term due to the non commutation of the filter operator and the partial time derivative. A general form of TCE has been derived and the error magnitude has been estimated in a numerical square-piston experiment. In particular, the influence of the crank speed and the compression ratio have been studied. It has been shown that the magnitude of TCE remains small even for large values of these parameters. It is thus tempting to conclude that TCE can be neglected. It should be underlined however that in piston-engines the flow and the mesh deformation are generated by the same phenomenon: the piston motion. In some other cases with automatic local mesh refinement, TCE may be less correlated to the flow and may not remain negligible.

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