Large-eddy simulation

The six projects in this group aimed at developing or testing new concepts, as well as assessing existing approaches to the subgrid-scale modelling problem. Other projects in which LES is applied to complex flows or combustion and studies related to the coupling between numerics and LES modelling are reported elsewhere in this volume.

In the first project, He, Wang & Lele have evaluated the performance of several subgrid-scale models in terms of time correlations. In the past, such diagnostics have been limited to the study of the time history of pointwise quantities. Here, space-time correlations, which can be characterized by a two-time energy spectrum, have been computed in homogeneous turbulence for both DNS and LES fields. Correct predictions of the space-time correlations do not represent a purely theoretical challenge for LES since they are needed in the computation of turbulent sound sources. Various eddy-viscosity SGS models have been tested, and the results showed a systematic, though limited, over-prediction of the time correlations as compared to DNS results. This can be understood by the deterministic nature of the eddy-viscosity picture and indirectly supports the introduction of explicit random backscatter mechanisms to the models. However, Another solution is suggested by the authors: the use of a history-dependent eddy-viscosity. Although none of these approaches has been explicitly tested, the measurement of space-time correlations in turbulent fields is likely to become a new important assessment methodology in the LES community.

In the second project, Carati & Wray have explored LES formulations in which equations for nonlinear functions of the velocity are carried explicitly. Adding an evolution equation for the time derivative of the filtered velocity was first considered. This approach has however been abandoned, because the turbulence statistics appeared to depend strongly on the initial conditions chosen for the additional variable. Another, more promising, approach consisted in writing an additional equation directly for the subgrid-scale force, the divergence of the subgrid-scale stress tensor. The modelling effort is then postponed to the new equation. It contains an unknown subgrid-scale tensor for which a dynamic procedure has been developed. Preliminary runs are inconclusive as to whether this approach might be successful but tend to show that, in this formulation, the results are less sensitive to initial conditions. Interestingly, this framework could be used to implement a history-dependent eddy-viscosity as suggested in the first project.

The channel flow is the simplest LES test case of a wall bounded flow. It has been used extensively in two papers in this group. Gullbrand & Chow report on tests comparing LES of the channel flow with and without an explicit filter. In contrast to the subgrid-scale stress, which represents turbulent motions not captured on the numerical grid, the additional subfilter-scale stress generated by the explicit filter can theoretically be reconstructed exactly. In practice, however, this term is only reconstructed approximately using, for instance, the scale-similarity model or an iterative deconvolution method. Various numerical schemes have been used in this paper in order to better evaluate the effect of the numerical errors. Although the interaction of numerical errors with subfilter and subgrid models remains an open issue, a grid resolution adapted to each scheme has been determined. Comparisons between several models show that using an explicit filter improves the LES predictions as long as accurate reconstruction schemes, like high order iterative deconvolution methods, are used for the subfilter stress.

In the second paper using channel flow as a test case, Jeanmart & Winckelmans have performed a systematic study of LES predictions for a series of dynamic models including the Smagorinsky model, a regularized version of the multiscale model, a mixed viscosity and hyperviscosity approach and an eddy viscosity acting on a modified, enhanced, velocity field. This last model is very similar in nature to the 'mixed viscosity and hyperviscosity' approach but contains a single parameter to be determined dynamically. Special attention has also been paid in this study to the consistent implementation of the test filter in the wall-normal direction in the dynamic procedure, but without significant improvement in the results. Although no model simultaneously reproduces the velocity profile and all the components of the Reynolds stress, there is a systematic trend supporting a different modelling strategy for the very large scales and for the small, but resolved, scales in LES. In particular, both the multiscale model and the Smagorinsky model acting on an artificially-enhanced velocity field appear to produce more accurate predictions.

A hyperviscosity term has also been used by Caughey & Jothiprasad in an attempt to develop a tool for assessing LES accuracy for flows at high Reynolds number. For such flows, comparison with DNS of the Navier-Stokes equations with a viscous term is usually not possible. The authors have considered an alternative way of simulating flows at high Reynolds number by artificially increasing the separation between the energetic and the dissipative scales. For this purpose, they have replaced, in a fourth order-central-difference code, the physical viscous dissipation by an artificial hyperviscous dissipation mechanism acting more in the small scales and less in the large scales. Several turbulent flows, like the freely-evolving Taylor-Green vortex, the inhomogeneous Kolmogorov flow generated by a static force periodic in space, and homogeneous decaying turbulence have been considered. Numerical results obtained using the hyperviscous dissipation mechanism on relatively modest meshes show good agreement with higher-resolution DNS.

The concepts of ideal and optimal LES have been proposed recently as strategies to reach the best possible approximations for the LES fields. Both these approaches require explicit expressions for several turbulence statistics, which are computed in the optimal LES using a stochastic estimation procedure determined from DNS. Haselbacher, Moser, Constantinescu & Mahesh have investigated the extension of optimal LES to high-Reynolds number flows using a stochastic-estimation procedure based on turbulence theory. The method has been implemented in an unstructured finite-volume code. Some of the statistics necessary to implement the optimal LES require further theoretical investigation, and predictions for the energy spectra are not fully consistent with the underlying Kolmogorov theory. However, preliminary tests of this innovative approach, coupling statistical theories of turbulence and subgrid-scale modelling, have already been performed and show a reasonable agreement for global quantities such as the total energy decay in homogeneous turbulence.

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