Tue1.1 Grinstein

On implicit large eddy simulation for turbulent flows

Fernando F. Grinstein

IGPP, MS C305, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
fgrinstein@lanl.gov

Large Eddy Simulation (LES) is an effective intermediate approach between DNS and RANS, capable of simulating flow features which cannot be handled with RANS such as significant flow unsteadiness and strong vortex-acoustic couplings, and providing higher accuracy than RANS at reasonable cost but still typically an order of magnitude more expensive. In the absence of an accepted universal theory of turbulence, the development and improvement of subgrid scale (SGS) models has been unavoidably *pragmatic* and based on the rational use of empirical information. Classical approaches have included many proposals ranging from, inherently-limited eddy-viscosity formulations, to more sophisticated and accurate mixed models, e.g., [1]. Their main drawback relates to the fact that *well-resolved* (discretization-independent) LES becomes prohibitively expensive for the practical flows of interest at moderate-to-high Re.

Recently, many researchers have abandoned the classical LES formulations, shifting the focus directly to the SGS modelling *implicitly* provided by non-linear stabilization achieved algorithmically, through use of a particular class of numerical schemes, or based on regularization of the discretization of the conservation laws, [2]. Most numerical discretization schemes can potentially provide built-in or implicit SGS models enforced by the discretization errors if their leading order terms are dissipative. However, not all implicitly implemented SGS models are expected to work: the numerical scheme has to be constructed such that the leading order truncation errors satisfy physically required SGS-model properties, and hence non-linear discretization procedures are required. The analogy to be recalled is that of shock-capturing schemes designed under the requirements of convergence to weak solution while satisfying the entropy condition. Nonoscillatory finite-volume (FV) numerical schemes can likewise be viewed as relevant for *nonlinear* implicit LES (ILES) of turbulent flows [3], if we propose to focus on two distinct inherent *physical* SGS features to be emulated:

the anisotropy of high-Re turbulent flows in the high-wave-number end of the inertial subrange region (characterized by very thin filaments of intense vorticity and largely irrelevant internal structure, embedded in a background of weak vorticity),

the particular nature of laboratory observables (only finite fluid portions transported over finite periods of time can be measured).

We thus require ISSM to be based on FV numerics having a *sharp velocity-gradient capturing capability* operating at the smallest resolved scales. In the Monotonically Integrated LES (MILES) approach [3], the effects of the SGS physics on the resolved scales are incorporated in the functional reconstruction of the convective fluxes using locally-monotonic FV Flux-Corrected Transport methods. The MILES performance has been demonstrated in many fundamental applications ranging from canonical to complex flows; other proposed ILES approaches are discussed in [2].

Challenges for ILES to be addressed in the presentation include developing a common appropriate mathematical and physical framework for its analysis and development, further understanding the connections between implicit SGS model and numerical scheme, and in particular, building physics into the numerical scheme to improve on the implicitly-implemented SGS dissipation & backscatter features. Moreover, additional (explicit) SGS modelling might be needed to address inherently small-scale physical phenomena such as scalar mixing and combustion – which are actually outside the realm of any LES approach: how do we exploit the implicit SGS modelling provided by the numerics, to build efficient "mixed" (explicit/implicit) SGS models ?

[1] Sagaut P.; 2002, "Large Eddy Simulation for Incompressible Flows",Springer, New York.

[2] Grinstein, F.F. & Karniadakis, G.Em, Editors, Alternative LES and Hybrid RANS/LES; 2002, *J. Fluids Engineering,* 124, 821-942.

[3] Fureby C. & Grinstein F.F.; 2002, "Large Eddy Simulation of High Reynolds Number Free and Wall Bounded Flows", *J. Comp. Physics*, 181, p 68; see also AIAA Paper 2003-4100 (2003).

*Orson Anderson Distinguished Visiting Scholar; on Sabbatical leave from LCP&FD, NRL, Washington DC, USA.