LES Numerics

By S. Scott Collis

In the 1990's, the advent of the dynamic procedure led to the application of large eddy simulation (LES) to an increasingly wider range of problems within the research community. Likewise, the success of LES on research type problems has encouraged industry to explore the use of LES for particularly difficult and important flow problems that cannot be accurately predicted with RANS models. As LES has moved out of the researcher's computational box to the world of industrial applications, a number of challenges with regard to accuracy, robustness, and practicality have been revealed. Discretizations, such as global spectral methods, that had before been the norm were replaced with low-order numerical methods and the interaction of numerical errors with subgrid scale models, especially when using a dynamic procedure, can prove disastrous. Practical issues that heretofore had not been of primary concern — such as grid generation, robustness, and software supportability — also become important when LES is used as a predictive tool for engineering applications. In essence, all the issues raised above are the bailiwick of *LES numerics* and the three projects in this section each strive to expand the domain of LES to more complex situations.

One approach to extend LES to complex flows is to take an existing industrial flow code that is primarily used for RANS simulations and modify it to support LES. This is the direction explored by Benhamadouche, Mahesh, and Constantinescu who have modified a collocated finite-volume code for use in LES. To overcome the excessive dissipation associated with the low-order, upwind discretizations commonly used for industrial RANS codes, Benhamadouche et al. modified their code to support a convective flux treatment that is approximately energy conserving and found that this approach leads to significant improvements in robustness and accuracy critical for use in LES. They also considered the influence of time discretization errors as well as errors that arise due to the use of a fractional-step procedure for enforcing incompressibility. By application of the modified code to a range of test problems, including a coaxial combustor, they demonstrate that, with modest changes, an existing industrial finite-volume code can be made suitable for LES in complex geometries using unstructured grids.

The opposite approach is taken in the second project, by Collis, who has developed a new flow solver specifically designed to support high-accuracy turbulence simulations in complex geometries using unstructured meshes. This approach utilizes a relatively new discretization, at least for turbulence simulation, called discontinuous Galerkin (DG) that offers potential advantages that can be utilized to make turbulence simulation more practical. In particular, a DG discretization provides high-order (spectral) accuracy on unstructured meshes, local *hp*-refinement, weak imposition of boundary conditions, local conservation, and orthogonal hierarchical basis that support multiscale turbulence modeling. Collis has implemented this DG method in an object oriented software environment that offers supportability and flexibility that are not commonly found in research codes but that are of key importance for industrial applications. This implementation is applied to vortex shedding from a circular cylinder as well as fully developed turbulent channel flow where it is shown that the weak imposition of wall boundary conditions that naturally arises in the DG method may have significant advantages in the context of wall modeling for LES.

In the third project, Pascarelli, Iaccarino, and Fatica also extend the class of flows for which LES can be applied by developing numerical methods to support LES for submerged objects near a free surface. They accomplish this by constructing linearized boundary conditions at the free surface that are coupled with the Navier–Stokes equations for the flow variables while the submerged object is represented using an immersed boundary method. Doing so, yields a numerical method that allows for both fully and partially submerged objects and the technique is demonstrated for both flow over a submerged hydrofoil and flow over a partially submerged square cylinder. While both these demonstration cases are at low Reynolds numbers, future work will apply these same techniques for turbulent flows using LES.