Low Order Methods for Simulation of Turbulence in Complex Geometries

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Due to overly restrictive constraints on the mesh and boundary conditions, classical spectral methods can not be used to simulate turbulence in complex geometries. Spectral element methods can handle these types of problems, but only with a hefty increase in algorithmic complexity. While discrete methods (e.g. finite volume) are often chosen as a simpler alternative, the associated numerical error is a real concern for a broad-band phenomenon such as turbulence. Numerical dissipation is especially harmful to turbulence since it incorrectly damps the intermediate-and small-scale motions, thus interfering with the turbulence energy cascade process. In response to this fact, the turbulence simulation community has spent much effort developing higher order schemes which attempt to minimize both dissipation and dispersion errors. Experience has shown that the coding complexity increases appreciably while the computational efficiency and parallel amenability drop as the order is increased. It is also nearly impossible to eliminate dissipative error for schemes higher than second order.

The prospect of petascale computing allows us to rethink the choice of a numerical algorithm for complex turbulent flow simulation. In particular, there exists a class of second order methods which are surprisingly well-suited to the task as computer resources increase. These so-called “kinetic energy conserving” schemes have no numerical dissipation, are extremely easy to code, and produce highly efficient parallel algorithms. The purely dispersive numerical error can be controlled to an acceptable level by simply increasing the number of mesh points. There is a growing body of evidence which suggests that the largest turbulent length scales (which mainly control the dynamics) are insensitive to dispersion errors at the very small-scale end of the spectrum. We simply need to provide a wide separation between the integral scale and the mesh spacing, and petascale computing affords us this luxury.

The talk will describe the second order kinetic energy conserving schemes and will quantify their dispersion error. Several examples will then be given where these methods are applied to a variety of turbulent flow simulations. Comparisons with higher order methods will demonstrate the potential of the second order schemes.