I. Small turbulence scales group

Inclusion of the study of small scales in the 1992 Summer program was, in part, motivated by the recent resurgence of interest in large eddy simulation of turbulent flows which in turn was brought about by the development of the dynamic subgrid scale model during the 1990 Summer Program. In contrast to the 1990 Program where several models were developed and tested, this year's studies mostly focused on fundamental questions about the small scales. The eight papers in this group can be divided into three parts: structure and kinematic properties of small scales (Lundgren; Jimenez *et al.*; Soria *et al.*; Antonia & Kim), nature of energy cascade and interaction among scales (Meneveau, Lund & Chasnov; Kida *et al.*), and parameterization and predictability (Meneveau, Lund & Moin; Shtilman & Chasnov).

Lundgren revisited his earlier theory in which he had shown that a model of small scale turbulence consisting of randomly orientated axially strained spiral vortices generates Kolmogorov's $k^{-5/3}$ spectrum. A numerical formulation of his model provided some flexibility for experimentation with parameters of the model that was not possible in his earlier analytical work. For example, he showed that the results are insensitive to the time dependence of the strain rate imposed on the vortices. Lundgren also gained new insight into his original model by noting that, in the inviscid limit, it gives a self similar enstrophy spectrum which is the key for obtaining the Kolmogorov energy spectrum.

Jimenez, Wray, Saffman & Rogallo conducted a comprehensive study of the celebrated tube-like intense vortical structures in homogeneous turbulence at several Reynolds numbers. The diameter of the tubes scale with the Kolmogorov scale and their lengths with the integral scale. Since these structures, also known as "worms", have been observed only in forced isotropic turbulence calculations, there was some concern that they may be artifacts of the forcing. Jimenez *et al.* present evidence that the worms are robust and occur without forcing. The worms apparently form from the roll-up of vortex sheets in the regions where two large scale structures come in contact. They occupy a smaller fraction of the flow volume with increasing Reynolds number and are not significant contributors to the flow dynamics. The worms are the primary contributors to the intense events manifested in the tails of the probability distributions of functions of velocity gradients. The tails get longer with increasing Reynolds number with no apparent sign of convergence, a result which supports multifractal models of turbulence.

Soria *et al.*, in a continuation of their study during the 1990 Summer Program, investigated the topology of the dissipating motions in turbulent mixing layers. Three incompressible mixing layers with different initial conditions were considered. The objective was to study the effect of initial conditions and Reynolds number on flow scaling and the topology of dissipating motions. Interesting observations were made on the evolutionary changes of structures in different flow regimes, but the underlying mechanisms remain for future investigations.

The concept of local isotropy in turbulent flows with mean strain or shear has been contested in some recent studies. Antonia & Kim investigated this issue using fully developed turbulent channel data at relatively low Reynolds numbers. They demonstrated that the isotropic relation for temperature derivatives and vorticity (both of which have significant contributions from small scales) is approximately satisfied as the channel centerline is approached. It was found that the criterion for local isotropy suggested by Corrsin (and Uberoi) is too restrictive although the parameter involved, which is the ratio of the Kolmogorov time scale to the time scale of mean shear, is appropriate. As long as this parameter is less than about 0.1, local isotropy is satisfied independent of Reynolds number.

The nature of interactions among different scales of turbulence has been a central one to turbulence research due to its fundamental role in the cascade of energy from large to small scales. Kida *et al.* studied the locality of the interactions using quasi-normal theories and data from highly resolved numerical simulations of forced isotropic turbulence. Whereas in the inertial range local triad interactions are dominant, in the dissipation range nonlocal triad interactions are dominant. Moreover, the nonlocality of the interaction was related to the form of the energy spectrum in the far-dissipation range.

The locality of the energy cascade was also studied by Meneveau, Lund & Chasnov in both physical and Fourier spaces. A novel Lagrangian space-time analysis of isotropic turbulence data provided evidence that fluid elements in a given energy band are better correlated with smaller eddies of nearly the same energy content at a later time than with eddies of the same spatial scale. This of course, supports the classical energy cascade phenomenology that large eddies break into smaller eddies as they decay.

The practical problem of parameterization of subgrid scale stresses in terms of the large scale data was considered by Meneveau, Lund & Moin using the projection pursuit algorithm. This is a powerful regression technique for many-dimensional parameter spaces which was originally developed to analyze experimental data in particle physics. The objective was to identify large-scale flow quantities that could be used in the modeling of subgrid-scale stresses. For isotropic turbulence, the search algorithm led to the strain rate tensor which is used in eddy viscosity models. For homogeneous shear flow and channel flow, more complex relationships in terms of other tensors were identified which resulted in some improvement of the correlation between the model and modeled terms. Overall, the improvements were not as high as expected, and it's unclear whether the new models will impact future large eddy simulations.

Shtilman & Chasnov performed a detailed study of the statistical predictability of LES calculations. They found good agreement between several statistics of an LES field and the corresponding statistics of a filtered DNS field in forced isotropic turbulence. These results are encouraging, providing evidence for the accuracy of large eddy simulations.

Parviz Moin