Modeling and LES group

There are five papers in the modeling and large-eddy simulation (LES) group. Three of the studies had the common objective of introducing spatially non-local information into single-point closures. The papers by Laurence & Durbin and Demuren, Lele & Durbin use the elliptic relaxation idea. Durbin (JFM, 1993) introduced non-local effects in his models of pressure-strain rate correlation by an elliptic differential operator. This approach has been very successful in predicting wall-bounded flows without ad-hoc damping functions and explicit use of the distance to the wall. In his full Reynolds stress closures, Durbin had used a rather simple linear isotropization (IP) model for the pressure-strain correlation as input to the elliptic relaxation operator. The non-linear model of Craft & Launder has been shown to be superior to the IP models in a variety of flows. Laurence's project was to combine the elliptic relaxation idea with the Craft & Launder model. He also conducted a detailed analysis of the Reynolds stress budgets, which revealed the importance of the elliptic relaxation part. That is, near the wall, the homogeneous solution of the elliptic relaxation operator was dominant and led to significantly improved agreement with the direct numerical simulation data irrespective of the basic pressure-strain model.

Demuren used the elliptic relaxation idea to develop a non-local pressure-diffusion model for use with the $k - \epsilon$ equations. In practice the pressure-diffusion term is usually combined with the turbulent diffusion, and their combination is modeled by gradient-diffusion. This practice appears to be reasonable except near a turbulent/non-turbulent interface such as those at the edges of boundary layers and jets and wakes. The symptom of its failure is a very rapid and unphysical drop of turbulent kinetic energy and eddy viscosity near the free-stream edge, which, at the very least, casts doubt on the prediction of the free-stream turbulence effects on shear layers and boundary layers. The elliptic relaxation leads to a more gradual transition near the free-stream edge by transporting more turbulent kinetic energy from the turbulence core to the free-stream.

Non-local information can also be introduced in the framework of one-point closures by including variables that involve the derivatives and integrals of flow quantities in the formulation. One such variable is the vector stream function; the Reynolds stresses can be extracted from the derivatives of its two-point correlation function, evaluated at zero separation. Oberlack, Rogers & Reynolds developed a new model for the two-point correlation of the vector stream function and compared it with the DNS data of homogeneous shear flow. The model coefficient was chosen to minimize the $L2$ norm of the difference between the model and the DNS data. The model predicts the two-point correlation function accurately. Since the derivatives of the two-point correlation function were not calculated, it is difficult to judge the ability of the model to predict the Reynolds stresses. The rapid part of the pressure strain predicted by this model is evidently deficient. It consists of the familiar linear model, with its well-known deficiency in reproducing the effects of rotation.

In recent years several models have been introduced to account for the effects of compressibility on turbulence. The dilatation dissipation model introduced by Zeman and Sarkar is known to be effective in the prediction of free-shear flows, but its impact in boundary layers has been insignificant. The pressure-dilatation term in the turbulent kinetic energy equation is expected to be important in the shock/turbulence interaction problem. Brankovic & Zeman incorporated Zeman's pressure dilatation model into a Pratt & Whitney code for computation of complex flows and used it to compute a compression corner flow. Although they found some improvement in the prediction of the mean velocity profiles, the experimentally reported unsteadiness in the separation bubble was not predicted even when the code was run in a "time accurate" mode. This failure may be attributed to the turbulence models used, but the effects of numerical dissipation in the code can not be dismissed.

The only LES project in this Summer Program was initiated by Meneveau. His objective was to test an alternative formulation of the dynamic subgrid-scale model. His alteration addresses a well-known numerical difficulty which appeared in its early formulations: The dynamic model produces negative eddy viscosity in some regions of space. In the past this problem has been addressed either by spatial averaging of the eddy viscosity or by the variational formulations of Ghosal, Lund & Moin (CTR Annual Res. Briefs, 1992). Meneveau Lund & Cabot point out that if averaging is to be performed, it is more physically appropriate to perform it in a Lagrangian frame following the turbulence structures. Moreover, in complex three-dimensional flows, where there are no directions of flow homogeneity, it is virtually impossible to carry out spatial averaging. They formulated a dynamic model with Lagrangian averaging and successfully tested it in isotropic turbulence and turbulent channel flow. Surprisingly, the model is computationally efficient and does a good job of predicting the flows considered. However, this formulation does introduce new model parameters, which is contrary to the key advantage of the dynamic model where all parameters are computed dynamically. It remains to be seen whether this model is more accurate and robust than some of the recently developed dynamic localization models.

Parviz Moin