Overview of Research by the Reynolds Stress Modeling Group

It is well recognized that full turbulence simulations will be limited for the forseeable future to simple fundamental flows. In order to compute flows of engineering interest, turbulence models will have to be used in formulating the governing equations. These models are a pacing item in the development of a computational fluid dynamics capability. Traditional model development had relied on formulating a closure model, then the model is used in a simulation to assess its validity. No direct experimental measurements are available for the pressure-strain, because of the difficulty in measuring these terms, and therefore no direct assessment of the models was possible. Direct simulation data can be used to compute the terms that need to be modeled and direct comparison with closure formulas can be achieved. This process should lead to a more systematic way of testing models. The objectives of the Turbulence Modeling Group were to develop and test closure models.

The invited participants in the modeling group were:
Prof. P. Bradshaw (Imperial College)
Prof. J. G. Brasseur (Clemson University)
Dr. J. Y. Chen (Sandia National Laboratories)
Prof. H. Ha Minh (IMF-CNRS)
Prof. J. C. Hunt (Cambridge)
Prof. C. G. Speziale (ICASE; NASA Langley)
Prof. D. Vandromme (CORIA-CNRS)
Dr. J. Weinstock (NOAA/ERL/Aeronomy Laboratory)
Prof. M. Wolfshtein (Technion)

The local participants were:
Dr. M. J. Lee (NASA Ames)
Dr. S. Lele (NASA Ames)
Dr. N. N. Mansour (NASA Ames)
Mr. U. Piomelli (Stanford University)
Dr. M. W. Rubesin (NASA Ames)
Mr. K. Shariff (NASA Ames)
Dr. T.-H Shih (Center for Turbulence Research)
Dr. J. R. Viegas (NASA Ames)

As expected, most of the work was devoted to the assessment of existing turbulence models. While some of this work had already been carried out by investigators at Ames (e.g. Mansour, Kim and Moin, 1987, to appear in J.F.M.) for the model of Launder, Reece and Rodi (1975), the summer school provided an opportunity for various other modelers to test their models against full turbulence simulation data.

Weinstock & Shariff evaluated the theory of Weinstock (1981, 1982, 1985) for the slow term. They found that many of the features of the slow term are reproduced by the theory. The data indicates that the "Rotta" coefficient varies between component and changes significantly with strong temporal variations of the kinetic energy; these features are well predicted by the theory.

Wolfshtein & Lele studied the structure of two-point correlations (velocity-velocity, velocity-scalar, and scalar-scalar) with view towards improving turbulence models. They tested the linear two-point correlation model of Naot, Shavit & Wolfshtein (1973) and found that it is necessary to relate the two-point correlations not only to the Reynolds stresses, but also to all mean velocity and mean scalar gradients.

Shih, Mansour & Chen evaluated non-linear models for the return and the rapid pressure-strain terms (Shih and Lumley, 1985, and Shih, Mansour & Moin, 1987, to be published). In general, the models of the pressure strain term performed well for the cases of homogeneous turbulence under axisymmetric contraction, but all models were marginal for the cases of homogeneous turbulence under plain strain.

In addition to testing the models by direct comparison, Shih, Mansour & Chen used Reynolds stress models to predict the homogeneous shear case of Rogers, Moin and Reynolds (1987). Rubesin, Viegas, Vandromme, and Ha Minh coded a Reynolds stress model to compute channel flows at different Reynolds numbers. It was found that existing models that are linear in the anisotropy tensor perform poorly for these cases, while second-order models perform well for the homogeneous shear case but were not tested for the channel cases.

In addition to model testing, efforts were devoted by Bradshaw, Mansour, & Piomelli to testing certain approximations to the pressure strain term. In particular, the usual approximation to the rapid term where the local mean velocity gradient is used outside the integral solution of the Poisson equation was tested using the channel data. It was found that away from the wall this approximation works well, but close to the wall it will fail. The reason for the failure is attributed to the fact that close to the wall the velocity gradient varies rapidly as compared to the correlation length of the fluctuating velocity gradients.

A detail study of a homogeneous shear flowfield was carried out by Brasseur, & Lee where the intercomponent energy transfer by pressure-strain-rate was investigated. It was found that the rapid and slow parts of the turbulent pressure were uncorrelated; providing strong justification for current modeling procedures. In addition, instantaneous events of high transfer regions were studied in details. These events were found to be highly localized in space and are imbedded in regions of concentrated vorticity.

In order to gain insight into the effects of rotation on the dissipation rate, Speziale, Mansour & Rogallo carried a direct numerical simulation of decaying isotropic turbulence in a rapidly rotating frame. It was found that the primary effect of rotation is to shut off the energy transfer so that the turbulence dissipation is substantially reduced. It was found that the anisotropy tensor remains essentially unchanged while the energy spectrum underwent a pure viscous decay. Rapid distortion theory analysis reveals that the rate of change of the vorticity field is $O(\Omega)$ so that no Taylor-Proudman reorganization of the flow to a two-dimensional state was observed. Suggestions are made towards including the effects of rotation on the dissipation rate.

Finally, a recent mixing length formula proposed by Hunt et al. (1987) was tested by Hunt, Spalart & Mansour, for a wide range of turbulent wall-bounded shear flows. It was found that the formula works well for all y^+, but fails in the neighborhood of regions where $dU/dy = 0$.

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