Overview of research by the stochastic decomposition/chaos/bifurcation group

This group consisted of four loosely inter-related projects with the common objective of understanding the mechanics of wall-bounded turbulent flows. All projects used the un-processed channel flow database (Kim, Moin, Moser 1987) or the velocity two-point correlation tensor computed from it (Moin & Moser 1987).

The invited participants were:
Professor Ronald J. Adrian (University of Illinois)
Dr. Nadine Aubry (Cornell University)
Dr. Julian C. R. Hunt (University of Cambridge)
Professor Javier Jimenez (Universidad Politecnica, Madrid, & UAM-IBM, Spain)

The local participants were:
Dr. Laurence R. Keefe (Center for Turbulence Research)
Professor Parviz Moin (Stanford University & NASA Ames)
Dr. Robert D. Moser (NASA Ames)

Hunt's self-similarity hypothesis for velocity correlations states that the two-point correlation of normal velocity v, when normalized by the intensity $\overline{v^2}$ at the point furthest from the wall is of the form $f(y/y_1)$. Using numerically generated correlations, this hypothesis was shown to be valid throughout a large portion of the boundary layer. A similar collapse was obtained for R_{uv} in the log layer. Hunt and coworkers had already shown that f is linear in shear free boundary layers. Comparison with their results clearly shows that shear reduces the correlation length of the normal velocity, in the normal direction. The variation of eddy scales in the spanwise direction was also investigated, and a strong dependence on shear was found. These results should be very useful in turbulence modeling and in other applications where two-point correlation data are used (e.g, see below).

The eigenfunctions of the spatial two-point correlation tensor were used in Aubry's dynamical systems representation of wall layer turbulence. In their previous work Aubry, Holmes, Lumley & Stone (1986) used eigenfunctions obtained from the experimental measurements of Herzog (1986) in the near wall region of a turbulent boundary layer. Employing these eigenfunctions, which appeared physically as roll-cells, they obtained a highly truncated solution of the Navier Stokes equations and used methods of dynamical system theory to analyze the results. The results exhibited intermittency which was associated with the bursting events in the sublayer. A similar analysis was performed at the CTR using the eigenfunctions computed from simulation databases (Moin & Moser 1987). The results were different from those of Aubry et al. In particular, limit cycle behavior was observed just prior to intermittency, rather than the fixed point behavior found previously. As a result the character of the intermittency is different and it is significantly more sensitive to the bifurcation or eddy viscosity parameter. In view of the significance of this work in relating dynamical systems theory to the structure of turbulence, further work is required to determine the sensitivity of the results to various computational parameters and other inputs.

Two-point correlation data was also used to extend, to three dimensions, the work of Moin, Adrian & Kim (1987) on stochastic estimation of conditional eddies. The previous work applied only in planes transverse to channel flow. With stochastic estimation, one approximates conditional averages using the two-point correlation tensor. In addition, the theory was extended to include specification of conditions at more than one point. An important result of this investigation was the verification that linear stochastic estimation indeed provides an accurate representation of conditional eddies. It was also shown that two-point stochastic estimates of the conditional eddies provide reasonable representations of the instantaneous flow structures. This technique is capable of generating the asymmetric structures that occur in the instantaneous flow field. Using conditions obtained from shear layers in the instantaneous field (see below), a simplified model of the shear layers was proposed which consisted of inclined vortical structures surrounding each shear layer.

Perhaps the most dramatic observation in this group was the discovery that turbulent channel flow contains a high density of strong, and highly visible, shear layers. The shear layers are regions of strong spanwise vorticity protruding from the wall region into the outer layers. Apparently the dominance of these shear layers, at least for the low Reynolds numbers considered here, has been overlooked previously. More importantly, the patterns of these shear layers, depicted in contour plots of spanwise vorticity in planes normal to the wall, and in the flow direction, strongly resembled those in Jimenez's (1987) two-dimensional numerical solutions. Although in channel flow these shear layers are three dimensional, the generation mechanism appears to be the same as in the two-dimensional case. The shear layers were followed in time and this generation process was observed directly. Based on these observations a simple model was proposed to explain vorticity ejection from the sublayer and the production of the shear layers. This model is essentially equivalent to the mechanism responsible for the instability of 2-D Tollmien Schlichting waves. Finally, by reducing the size of the computational box, futile attempts were made to study the dynamics of one shear layer in isolation (in the absence of complex interactions with other structures). One of the by products of this latter study was an interesting numerical solution which displayed three-dimensional turbulence on one side of the channel, and essentially two-dimensional flow on the other. The average wall shear stress of the turbulent layer falls between the values characteristic of the 2-D non-linear solutions and the 3-D turbulent solutions.

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