THE 5 ASIAN COMPUTATIONAL FLUID DYNAMICS
BUSAN, KOREA, OCTOBER 27 ~ 30, 2003

Unsteady Turbulent Flow with Sudden Pressure Gradient Change

Yongmann M. Chung

Fluid Dynamics Research Centre, Department of Engineering, University of Warwick,
Coventry CV4 7AL, U.K.

Corresponding author : ***Y. M. Chung***

ABSTRACT

Direct numerical simulations are performed for a turbulent flow subjected to a sudden change in pressure gradient. The calculations are started from a fully-developed turbulent channel flow at $Re_\tau = 180$. The pressure gradient of the channel flow is then changed abruptly. The responses of the turbulence quantities (*e.g.*, turbulence intensities, Reynolds shear stress, and vorticity fluctuations) and the near-wall turbulence structure to the pressure gradient change are investigated. It is found that there are two different relaxations: a fast relaxation at the early stage and a slow one at the later stage. The early response of the velocity fluctuations shows an anisotropic response of the near-wall turbulence.

Keyword: *Turbulent, channel flow, DNS, unsteady, pressure gradient*

1. Introduction

Turbulent flows subject to sudden changes in boundary conditions, *e.g.*, pressure gradient, wall temperature, roughness, curvatures and wall blowing/suction, are frequently encountered in engineering applications. When a fully-developed turbulent flow is subjected to a step change in wall boundary conditions, there is an initial relaxation toward an equilibrium state after the step change of perturbation [1, 2]. A spatial or temporal relaxation occurs depending on the nature of the disturbance. For example, when boundary conditions are changed as the flow goes downstream, a spatial relaxation is followed. On the other hand, if boundary conditions are changed in time, a temporal relaxation accompanies. Most works have been focused on the *spatial* relaxation and extensive reviews are found in Smits and Wood (1985) and Bushnell and McGinley (1989). In contrast, the temporal relaxation associated with a sudden change has received less interest and the relaxation process is not fully understood yet. There are only a few studies on the temporal relaxation. It was found that non-equilibrium turbulent flows have different characteristics from the equilibrium state and could not be predicted accurately using turbulence models.

In this study, the temporal relaxation of turbulent flow caused by a sudden pressure gradient change are considered. The direct numerical simulation technique is employed to investigate the modifications on the near-wall turbulence structures. Preliminary results were presented in Chung and Luo [3].

2. Results and Discussion

Direct numerical simulations are performed for a fully developed planar channel flow that was subjected to a sudden pressure gradient change. The calculations are started from a fully-developed turbulent channel flow at $Re_\tau = 180$. The initial pressure gradient is $\partial P/\partial x = -\tau_w/\delta$, where τ_w is the mean wall shear stress in the unperturbed channel and δ the channel half-width. The subsequent calculations are performed with a new pressure gradient $\partial P/\partial x = -A\tau_w/\delta$. Two values of A are considered ($A = 4/9$ and $25/36$), which correspond to $Re_\tau = 120$ and 150, respectively. Results are averaged in the homogeneous directions (x and z).

Figure 1(a) shows the time history of the friction velocity u_τ. u_τ for the unperturbed case are also included for comparison purposes. Although the pressure gradient change is abrupt, the adjustment of

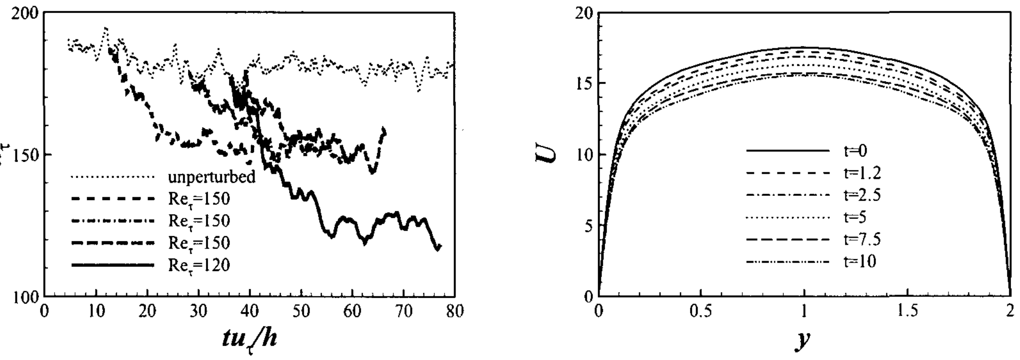

Figure 1: (a) Time history of friction velocity u_τ and (b) streamwise velocity at several time instants.

the near-wall turbulence is gradual. From the figure, it is found that there are two different relaxations: a fast relaxation at the early stage and a slow one at the later stage. The value A appears to play an important role in the early fast relaxation, while the second relaxation is almost independent of A. After the sudden changes in the pressure gradient, u_τ decreases gradually. The centreline velocity U_c shows a similar trend (now shown here).

The streamwise velocity profiles are shown at several instants during the relaxation in Fig. 1(b). The mean velocity begins to decrease as soon as the pressure gradient is changed. It is interesting that the log-law is not affected during the relaxation while the velocity profiles are changed significantly in global units. Especially, in the viscous sublayer, virtually no effect is shown.

The turbulence intensities are also analysed (not shown here). The effect of the pressure gradient change appears first in the u_{rms} distributions. This feature is attributed to the decrease in the production term, $-\overline{uv}\frac{\partial U}{\partial y}$. In contrast, v_{rms} and w_{rms} are not decreased immediately and show a little delayed response after the pressure gradient change. The slow response of the transverse velocity fluctuations is explained by the redistribution terms in the Reynolds stress transport equations, $\phi_{ij} = \frac{1}{\rho}\overline{p\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)}$. The maximum values of v_{rms} and w_{rms} show a gradual decrease after the pressure gradient change. The early response of the streamwise velocity fluctuations u' is found to be faster than that of other components (not shown here), indicating an anisotropic response of the near-wall turbulence. The delayed response of ω_y indicates that the (strength of the) low-speed streaks are not affected immediately by the pressure gradient change.

In the final manuscript, the temporal relaxation after a sudden pressure gradient change is analysed in detail. The modulation of the low-speed streaks, especially the streak spacings are analysed. The near-wall turbulence structures affected by the new pressure gradient are analysed. The quadratic analysis is also performed to examine the effect of the pressure gradient change on the ejection and sweep events.

References

[1] Chung, Y. M., and Sung, H. J., " Initial relaxation of spatially evolving turbulent channel flow subjected to wall blowing and suction," *AIAA Journal*, Vol. **39**, No. 11, (2001), pp. 2091–2099.

[2] Chung, Y. M., Sung, H. J., and Krogstad, P.-A., "Modulation of near-wall turbulence structure with wall blowing and suction," *AIAA Journal*, Vol. **40**, No. 8, (2002), pp. 1529–1535.

[3] Chung, Y. M., and Luo, K. H., "DNS of a turbulent flow with sudden change in pressure gradient," *Advances in Turbulence IX*, edited by I. P. Castro, P. E. Hancock, and T. G. Thomas (CIMNE, Barcelona), (2002), pp. 842.