DNS OF TURBULENT FLOW WITH TEMPORAL ACCELERATION

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Abstract Turbulent flows subject to temporal acceleration is considered in this study. Direct numerical simulations of accelerated turbulent wall-bounded flow were performed to study the response of the turbulent structures to temporal acceleration. The simulations were started with the fully-developed turbulent channel flow at an initial Re number, and then a constant temporal acceleration was applied. During the acceleration, the Reynolds number of the channel flow, based on the half-height and the bulk-mean velocity, increased linearly from $Re = 3500$ to 15000. The conditionally-averaged flow fields associated with changes in turbulent structures were analysed. It is found that the temporal acceleration initially weakened the flow structures before new turbulence was generated later in the near-wall region.

INTRODUCTION

Unsteady turbulent wall-bounded flows are frequently encountered in engineering applications such as turbo-machinery and heat exchangers, and also in biomedical applications such as airflow in the human lungs and blood flows in large arteries. In addition to the practical implications of achieving a better understanding of flows of this type, the study of unsteady turbulent flows provides insight into the underlying physics of turbulent boundary layers. Most studies have considered the periodic turbulent flow, where the pressure gradient (or the mass flow rate) changes periodically in time. However, unsteady turbulent flows with temporal acceleration have received relatively little attention despite their importance [1, 2, 3, 4, 5]. Numerical studies on the transient turbulent flow with temporal pressure gradient are particularly scarce. Chung [3] performed a direct numerical simulation (DNS) of a decelerated turbulent channel flow subjected to a sudden change of pressure gradient, and found that there are two different relaxations in the decelerated flow: a fast relaxation at the early stage and a slow one at the later stage. In the present work, a series of DNS of an accelerated turbulent flow were performed to study the response of the near-wall turbulence.

RESULTS AND DISCUSSION

In the present study, the simulations were started from a fully-developed turbulent channel flow at $Re = 3500$ (or $Re_\tau \approx 210$ based on the friction velocity, u_τ) [4, 5]. The acceleration parameter, $f = 0.2$, was kept constant throughout the simulations, so the mass flow rate increased linearly to the final Reynolds number of $Re = 15000$ (or $Re_\tau \approx 800$). All statistics were obtained using plane and ensemble averaging. Simulation parameters used in the present DNS are shown in Table 1. Wall units are calculated using u_τ at the final Re number.

$L_x \times L_y \times L_z$	$N_x \times N_y \times N_z$	Δx^+	Δy^+_{min}	Δy^+_{max}	Δz^+
$12h \times 2h \times 4h$	$768 \times 384 \times 640$	12.5	0.4	9.7	5.0

Table 1. Simulation parameters used in the present study based on the final Re number of $Re_\tau = 800$.

Turbulent structures are displayed in Figure 1 with iso-surfaces of λ_2 [6]. It is clearly seen that turbulent structures become weakened initially with temporal acceleration, and gradually disappear from a large area. The area with active turbulent structures (based on λ_2) has been calculated, and is shown in Figure 2a. At $Re = 12000$, more than half of the channel wall is devoid of active turbulent structures. The remaining *old* turbulent structures at this Re number have much weaker ($u_{i,rms}$ and $\omega_{i,rms}$) strength than in the steady flow (see Figure 2b). The generation of *new* turbulence is evident for $Re > 12000$, and the process is almost completed at $Re = 15000$. This turbulence generation process appears to be much faster (and stronger) than the destruction process. The strength of the new turbulent structures is almost the same as the one from the steady flow (not shown here). The characteristics of the new turbulent structures are found to scale with the local u_τ, while the old turbulent structures scale with the initial u_{τ_0}.
At the ETC14, the characteristics of the old and new turbulent structures will be presented in more detail using a conditional averaging technique, in particular, the interaction between the new and old structures.
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References

[1] S. He and J. D. Jackson. A study of turbulence under conditions of transient flow in a pipe. *Journal of Fluid Mechanics*, 408:1–38, 2000.
[2] D. Greenblatt and E. A. Moss. Rapid temporal acceleration of a turbulent pipe flow. *Journal of Fluid Mechanics*, 514:65–75, 2004.

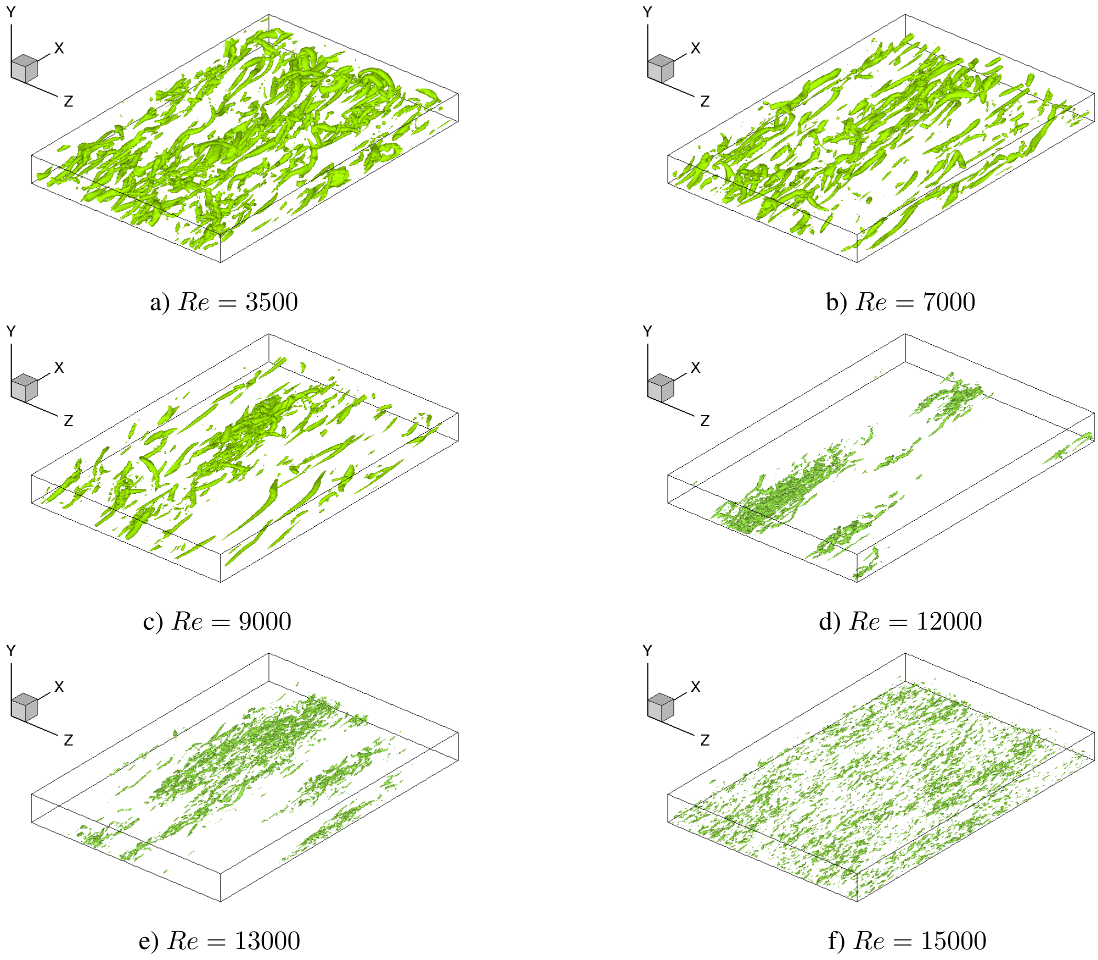

Figure 1. Iso-surfaces of λ_2 at different stages of acceleration.

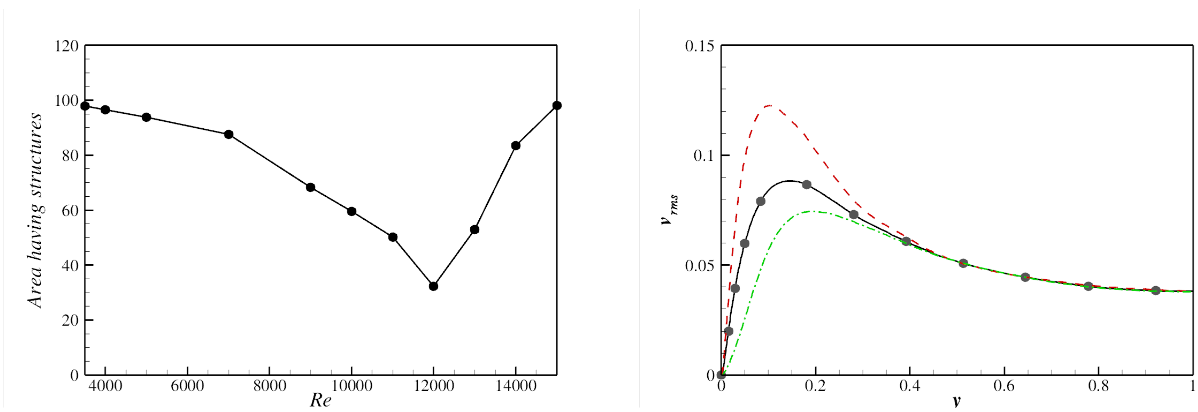

Figure 2. a) Areas for active turbulent structures at different stages of acceleration, and b) conditionally averaged v_{rms}. Red is for active vortices area, green is for non-active area, and symbols for the plane averaged.

[3] Y. M. Chung. Unsteady turbulent flow with sudden pressure gradient changes. *International Journal for Numerical Methods in Fluids*, 47(8-9):925–930, 2005.

[4] Y. M. Chung. Response of near-wall turbulent flow to temporal acceleration. In *7th European Fluid Mechanics Conference*, volume 1, page 165, Manchester, U.K., 2008.

[5] Y. M. Chung. Turbulent flow with temporal acceleration: A numerical study on turbulent structures. In *11th International Conference on Pressure Surges*, 24-26 October, Lisbon, Portugal, 2012.

[6] J. Jeong, F. Hussain, W. Schoppa, and J. Kim. Coherent structures near the wall in a turbulent channel flow. *Journal of Fluid Mechanics*, 332:185–214, 1997.