Drag Reduction Mechanism in Turbulent Channel Flow Controlled by Traveling Wave-Like Blowing and Suction

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A traveling wave-like blowing and suction control in a fully-developed channel flow\textsuperscript{1} has some attractive advantages, e.g., a large drag reduction effect without using any sensors and positive control efficiency. Mechanism of drag reduction effect by this control in laminar channel flow has been explored by a detailed phase analysis\textsuperscript{2}. The present study is an investigation for drag reduction mechanism in turbulent channel flow by means of a direct numerical simulation, which is an extension of the previous study\textsuperscript{2}.

Figure 1(a) shows the flow configuration. The mean flow is driven by the mean pressure gradient to keep constant flow rate. The control input is the wave-like blowing and suction from the wall. The skin-friction drag coefficient is expressed as\textsuperscript{3}

\[ C_f = \frac{12}{Re_b} + 12 \int_0^1 2(1 - y) \left( -u'' \right) dy + 12 \int_0^1 2(1 - y) \left( -u''v'' \right) dy. \]  

(1)

The first term on the RHS is the laminar contribution. The second and third terms are periodic and random contributions, which are the integrations of the \( y \)-weighted periodic and random Reynolds shear stresses (referred to as RSSs), respectively.

Figure 1(b) shows the RSS profiles when skin-friction drag decreases. The periodic-RSS is negative in the region near the wall, while it is zero in the far-wall region. According to a phase analysis and a parametric study, viscosity in the region near the wall is found to induce a non-quadrature between streamwise and wall-normal velocities and this non-quadrature contributes to the change of periodic-RSS. This explanation is similar to that in laminar flow. On the other hand, the random-RSS is kept positive in the whole channel, while it is reduced from the uncontrolled level. An “indirect effect” due to the constraint of constant flow rate is found to explain the decrease of the random-RSS.

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\textsuperscript{1}Min et al., J. Fluid Mech. 558, 309-318 (2006).
\textsuperscript{2}Mamori et al., Phys. Rev. E 81, 046304 (2010).

Figure 1: (a) Traveling wave-like blowing/suction in channel flow. (b) Reynolds shear stress profiles in a drag reduction case.