Linear Analysis of Drag Reduction in Channel Flow by Wall Heating/Cooling

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Reduction of the skin friction drag in turbulent flows is of significant importance for effective energy utilization. In fully developed channel flows, the increment of the skin friction drag from the laminar value (ΔD) is expressed[1] as

$$\Delta D = \frac{3}{2}\mathrm{Re}\int_{-1}^{1}(-\overline{u'v'})(-y)dy. \quad (1)$$

Here, Re is the Reynolds number based on the laminar centerline velocity and the channel half-width, and $-\overline{u'v'}$ is the Reynolds shear stress.

Recently, Min et al.[2] have reported that a traveling wave-like surface blowing and suction can reduce the skin friction drag by producing a negative Reynolds shear stress in the region near the wall. Similar effect can be expected with body forces. The objective of this study is to make a linear analysis on the possibility of drag reduction by using a traveling wave-like surface heating and cooling.

The linearized and Fourier-transformed continuity, Navier-Stokes and energy equations can be expressed as matrix equation, i.e., $\mathbf{A}\hat{\mathbf{q}} = \mathbf{b}$. Here, $\mathbf{A}$ is the system matrix discretized by using the Chebyshev collocation, $\hat{\mathbf{q}}$ contains the discretized velocity, pressure and temperature, and $\mathbf{b}$ is the vector including the boundary condition. From the solution, $\hat{\mathbf{q}}$, the velocity and temperature fluctuations and the Reynolds shear stress distribution can be determined.

Figures 1 and 2 are sample results obtained by the present analysis. Increment of drag (ΔD) is shown in Fig. 1 as a function of c, where c is the wavespeed of the traveling wave. It shows that ΔD is negative when the wave travels downstream ($0 \le c \le 0.47$). Figure 2 illustrates this mechanism. The buoyancy force is created by the temperature distribution from surface traveling wave (Fig. 2(a)), and the velocity fluctuations are induced so as to make the Reynolds shear stress nominally negative in the region near the wall (Fig. 2(b)).

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[1]K. Fukagata et al., *Phys. Fluids* **14**, L73-L76 (2002).

[2]T. Min et al., *J. Fluid Mech.* **558**, 309-318 (2006).

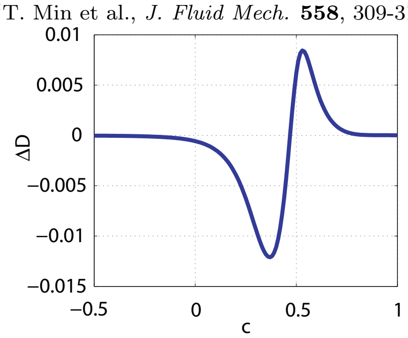

Figure 1: Increment of friction drag, ΔD, by surface heating and cooling.

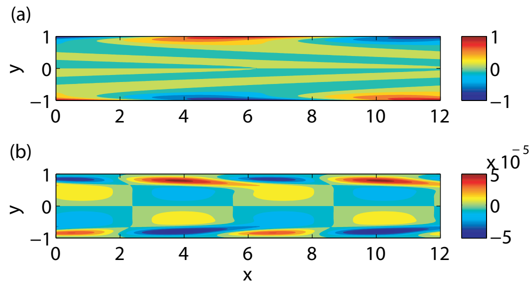

Figure 2: Distribution of fluctuation: (a) temperature; (b) Reynolds shear stress.