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Drag-Reduction Effect of Sinusoidal Riblets in Turbulent Channel Flow by Direct Numerical Simulation

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Skin-friction drag significantly increases in wall turbulence. Riblet surfaces, which are micro-grooves aligned in a streamwise direction, are known to decrease the skin-friction drag and are expected to contribute effective energy use.

Miki *et al.*(1) experimentally confirmed the drag reduction effect in the turbulent channel flow by a zigzag riblet surface. The zigzag riblet surface is different from ordinary two dimensional riblet surfaces(2), i.e., the lateral spacing of the riblet surface varies in the streamwise direction while that of the ordinary ones does not. The drag reduction rate of the zigzag riblet is comparable to the ordinary ones. As an extension of Miki *et al.*'s study, Sasamori *et al.*(3) performed a sinusoidal riblet surface of which lateral spacing is designed to vary in the streamwise direction sinusoidally aiming to decrease the pressure drag. The drag reduction rate of the sinusoidal riblet is higher than that of the zigzag riblet surface. In the present study, we perform a direct numerical simulation (DNS) of the turbulent channel flow over the sinusoidal riblet surface to clarify the influence on the drag reduction effect. As compared with the experimental study made by Sasamori *et al.* (3), the present DNS is possible to show the influence of the parameters of the riblet shape and to obtain the flow field in detail.

Figure 1 shows the geometry of the channel flow and the sinusoidal riblet surface. The riblet surface is installed on both the channel walls. The governing equations are incompressible continuity and Navier-Stokes equations. The riblet surface is expressed by using an immersed-boundary method(4). The base flow is driven by a constant mean pressure gradient and a friction Reynolds number, based on the skin friction velocity of the flat surface u_τ and the channel half height δ, is set to be Re_τ =110. Due to the constant pressure gradient, the bulk velocity increases if the drag-reduction effect appears. Thus, the drag reduction

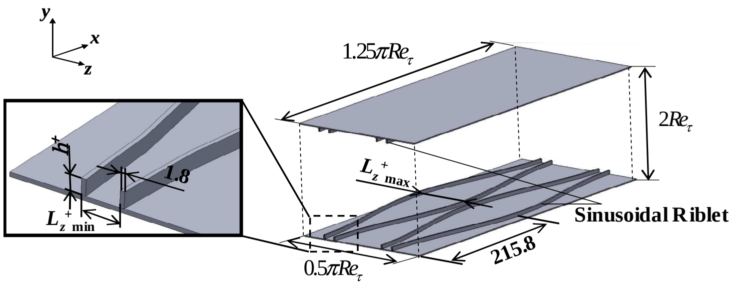

Fig. 1 Schemetic of channel flow and the sinusoidal riblet surface.

Table. 1 Parameters of sinusoidal riblet.

	$L_{z\,max}^+$	$L_{z\,min}^+$	h^+
Case1	71.58	12.95	7.5
Case2	71.58	12.95	3.75
Case3	52.80	31.46	7.5
Case4	49.76	35.54	7.5

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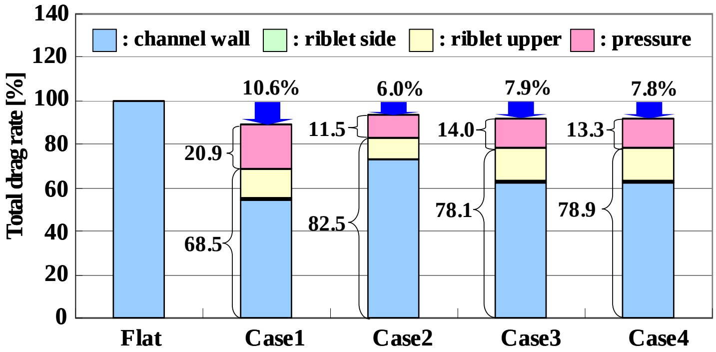

Fig. 2 Contribution to the total drag.

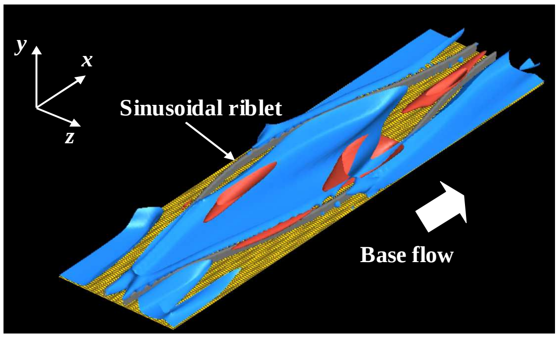

Fig. 3 Visualization of instataneous flow field.

effect is determined by using an empirical formula for the skin-friction coefficient(5) with the same bulk Reynolds number. Table 1 summarizes the parameter sets of the riblet surface. Here, the superscript of plus denotes a wall-unit (i.e. nondimensionalized by u_τ and the kinematic viscosity ν.). Case 1 is the reference case and Case 2 is the shorter height of the riblet wall. Cases 3 and 4 are cases of the smaller amplitude of the sinusoidal shape as compared with Case 1.

Figure 2 shows the contribution to the total drag: the total drag consists of the skin-friction drag on the wall of the channel, the side and the top surfaces of the riblet, and the pressure drag. The total drag in all the cases is found to decrease. The maximum drag reduction is obtained in Case 1, where the skin-friction drag decreases 68.5% as compared to the flat case while the pressure drag increases 20.9%. In Case 2, the pressure drag decreases while the skin-friction drag increases as compared with Case 1, resulting in slight increase of the total drag. In Cases 3 and 4, the skin-friction drag increases and the pressure drag decreases. As decreasing the amplitude of the sinusoidal riblet, the geometry of the riblet asymptotically approaches to a two-dimensional riblet.

Figure 3 shows a visualization of instantaneous flow field over the sinusoidal riblet in Case 1. The blue surface represents the isosurface of the wall normal velocity v^+ = -0.1 and the red surface represents the isosurface of the Reynolds sheer stress $-u''^+v''^+$ = -0.1. The superscript of the double prime denotes the fluctuation. In the regions where the lateral spacing of the riblet increases, the blue isosurface is found to dominate, indicating the generation of the downward flow. On the other hand, the red isosurface is found at the regions where the lateral spacing of the riblet decreases, which correspond to the regions where the upward flow is induced (not shown here).

In the presentation, we will discuss the mechanism of the drag reduction effect by the sinusoidal riblet according to the investigation for the detailed flow field.

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