Analysis of Vortical Structure over a Sinusoidal Riblet by Dual-Plane Stereoscopic PIV

K. Yamaguchi¹, M. Sasamori¹, H. Mamori¹, K. Iwamoto¹,*, A. Murata¹

1: Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, Japan

* Corresponding author: iwamotok@cc.tuat.ac.jp

Keywords: Turbulent Control, Drag Reduction, Riblet, Dual-Plane Stereoscopic PIV, Turbulent Channel Flow

Skin friction drag in turbulent flows decreases due to grooves on walls, i.e., riblet surfaces. Bechert et al. confirmed 10% of drag reduction rate by an optimized two-dimensional riblet surface. The term of 'two dimensional' means that a lateral spacing of the riblet keeps constant in the streamwise direction. In contrast, Sasamori et al. shows 11.7% of drag reduction rate by means of a sinusoidal riblet surface. The lateral spacing of the sinusoidal riblet surface varies sinusoidally in the streamwise direction. In order to discuss the mechanism of the drag reduction effect, we focus on vortical structures over the sinusoidal riblet surface. Vortical structures are identified by the second invariant tensor of the velocity deformation tensor which is obtained by a dual-plane stereoscopic PIV (referred as DPSPIV, hereafter) measurement.

The DPSPIV measurement consists of two individual stereoscopic PIV systems and two laser light sheets. Note that the optical system to generate two laser sheets is the same as that by Tanahashi et al. In order to separate the scattered light onto the other plane, two double pulsed lasers are polarized in both the vertical and horizontal directions and separated by beam splitters installed in front of cameras. The alignments of laser sheets and cameras are shown in Fig. 1. The horizontally polarized laser sheet is aligned at the center of the sinusoidal riblet, while another one is separated 0.5mm in the spanwise direction. All cameras are adjusted in backward scatter configuration satisfying a Schieimpflug condition.

Since all instantaneous velocity components are acquired on both the planes, all nine velocity gradients can be calculated. Therefore, the second invariant of the velocity deformation tensor $Q = (\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y})$ can be provided. A local and negative peak of the second invariant is known to correspond to a core of a quasi-streamwise vortical structure $*$. Here, the superscript of plus denotes a wall unit.

The DPSPIV measurement is done in a turbulent channel flow at Re = 150, where the skin friction Reynolds number $Re$ is defined by a channel half width $a$, a kinematic viscosity $\nu$, and a friction velocity $u_*$ on the smooth surface. Figure 2 shows an instantaneous flow field near the riblet surface. The gray-scaled contour shows the distribution of the Reynolds shear stress and the white lines are isoline of $Q = 0.01$. Vortical structures are observed and large positive Reynolds shear stress is found around them. Because it is difficult to find differences between the flow fields for the smooth and riblet surfaces (not shown here) from the instantaneous field, we employed a conditional sampling method: the velocity field around the local minimum of the second invariant is extracted; the averaged flow fields are shown in Fig. 3. The $Q$ value and the rms value of the spanwise velocity are found to decrease in case of the riblet surface as compared with that of the smooth surface, indicating that the quasi-streamwise vortical structures are attenuated due to the riblet surface.

![Fig. 1 Schematic of the shape of the riblet surface (top view) and alignment for laser sheets and cameras.](image1)

![Fig. 2 Instantaneous distribution of the Reynolds shear stress over the riblet. The white line is the isoline of $Q^\ast = 0.01$.](image2)

![Fig. 3 Conditional sampled $Q^\ast$ and $\text{rms}$ of (a) the smooth and (b) the sinusoidal riblet surfaces.](image3)


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