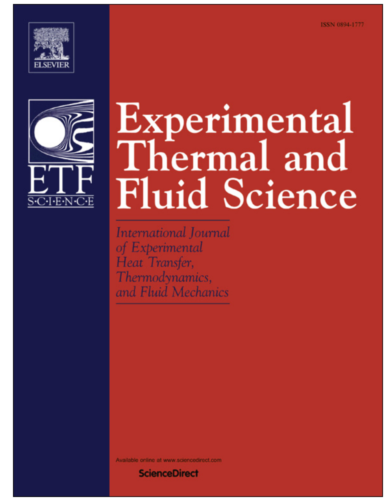

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Three-dimensional measurement of turbulent flow over a riblet surface

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Abstract

Measurement of three-dimensional (3D) turbulence over riblet surfaces is challenging due to the small size of the grooves and the requirement for measurement in the inner layer. The capability of two-dimensional (2D) and 3D particle image velocimetry (PIV) and particle tracking velocimetry (PTV) for characterization of the 3D structure of turbulent flow over a riblet surface with groove spacing of 750μm at $Re_\tau = 147$ (based on friction velocity and half channel height) is investigated. The 2D measurements were carried out using standard planar PIV and high-magnification long-range microscopic PTV (micro-PTV). The investigated 3D techniques include tomographic PIV (tomo-PIV) and 3D-PTV. The results are evaluated in comparison with measurement over a smooth surface and also with direct numerical simulation (DNS) of channel flow by Tsukahara *et al.* [1] at $Re_\tau = 150$. The reflection of the laser light from the smooth and riblet surfaces is significantly different in spite of the wall-parallel illumination. This resulted in biased near-wall ($y/H < 0.05$) measurement using planar PIV. The shortcoming was fulfilled by micro-PTV which could measure the mean velocity profile within the linear viscous sublayer ($2 < y^+ < 5$) and showed a 6.1% reduction of the skin-friction over the riblet surface. Micro-PTV also accurately measured the location of the $\langle u^2 \rangle$ peak and its magnitude reduction over the riblet surface compared with planar PIV. The Planar PIV measured $\langle v^2 \rangle$ peak which is further away from the wall at $y/H = 0.15$ and also the $\langle uv \rangle$ profile in the outer layer. The $\langle uv \rangle$ profile showed 7.4% reduction of wall shear stress over the riblet surface. 3D-PTV showed a 9.4% reduction of the $\langle w^2 \rangle$ peak and attenuation of v and w fluctuations over the riblet surface compared to the smooth surface through quadrant analysis. The three components of fluctuating vorticity measured by tomo-PIV showed negligible variation over the two surfaces due to the random noise and lack of spatial resolution. Quadrant analysis using planar PIV showed attenuation of the sweep and ejection events near the riblets, which indicates weaker streamwise vortices. Two-point correlation of PIV measurement also demonstrated increase of the coherence of the low and high-speed steaks over the riblets.

Keywords

Turbulent channel flow; Riblet surface; Particle image velocimetry; Particle tracking velocimetry

1. Introduction

Wall-normal momentum transport in turbulent flows causes larger skin-friction and more energy consumption in many applications including pipeline, marine, and aerospace industries. Among the methods for reduction of the skin-friction, only a few have short-term potential to be applied in practice. A riblet surface is a simple passive drag reduction (DR) technique that was inspired by the texture of the sharkskin. The surface has been replicated as microgrooves aligned in the streamwise direction [2]. Riblets are known to modify the structure of the near wall turbulence and reduce the skin-friction up to about 10% [3,4].

The performance of a riblet surface depends on the groove spacing relative to the scale of the near wall turbulence. According to Walsh and Lindemann [3], DR over riblets at different Reynolds numbers can be expressed in terms of dimensionless riblet spacing, $s^+ = s / (u_\tau / \nu)$, in which s is the lateral riblet tip spacing, ν is the kinematic viscosity, and u_τ is the friction velocity over the smooth surface exposed to the same bulk flow velocity. DR is quantified as DR $= (\tau - \tau_0) / \tau_0$ where τ is the wall shear stress over riblet surface and τ_0 is wall shear stress over the smooth surface. One of the earliest experimental works by Walsh [5] indicated that DR occurs only for $s^+ < 30$ and the maximum reduction is observed at $s^+ = 15\text{-}20$ for riblets with both sharp and curved shapes. Bechert et al. [4] provided a thorough set of DR measurements for riblets of various shapes and dimensions. Their results for small s^+ showed the riblet protrusion is immersed only in the viscous sublayer and the outer layer behaves the same as the flow on smooth wall [6]. This *viscous regime*