VELOCITY STATISTICS OF ROUGH-WALL CHANNEL FLOW

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INTRODUCTION

The examination of the effects of very large roughness is not only important from a practical point of view, but it also brings into question the classical view of roughness (see, for example Townsend, [4]) in which it is accepted that local inhomogeneities arising from the specific roughness geometry are confined to a “roughness sublayer”, analogous to the viscous sublayer found over smooth walls, the thickness of which is generally accepted to be about 5 roughness heights. Under these assumptions, any effects of the roughness on the turbulence away from the wall relative to the smooth-wall case must necessarily be attributable to the increase in the wall shear stress, $\tau_w$, alone. One can therefore expect that an overlap region of mean velocity will exist (and therefore a self-similar log law) and that the outer-region flow (or at least the mean velocity deficit and second moment) will scale exclusively with the wall friction velocity $u_* = \sqrt{\tau_w/\rho}$, and $h$, the outer length scale.

In the present experiment, the effects of very-large roughness height using grit and mesh (respectively $k/h = 4\%$ and $8\%$) are examined. The streamwise and wall-normal velocity components in fully-developed turbulent channel flow are studied for these surfaces and compared with a smooth surface at comparable Reynolds numbers. The mean velocity profile over the grit surface exhibits a limited range of self-similarity (in the form of a logarithmic law) but the profile over the mesh surface exhibits only a small region with a slope tangential to log-law scaled on outer variables. However, in conformity with Townsend’s outer scaling, the mean velocity deficit and higher moments (up to the fourth order) all exhibit some degree of outer scaling over both surfaces. These results are reported by Birch and Morrison [1]. Here, the somewhat striking prevalence of very large-scale motions, with a circulation in the plane orthogonal to the mean flow is examined.

EXPERIMENTAL FACILITY

Experiments were carried out in rough channel flow with half-height $h = 50.8$ mm, width $W = 15h$ and a total streamwise fetch of $134h$. The interior, wetted surfaces of the channel were interchangeable, and could be fitted with either a grit-type roughness, a mesh-type roughness or smooth walls. The grit-type roughness was an industrial abrasive sheet with an isotropic but sparse grit pattern having a highly non-Gaussian distribution. The mesh-type roughness was an expanded metal sheet comprising twisted $2.36 \times 1.6$ mm rectangular elements forming a diamond-shaped pattern with a centreline spanwise-to-lengthwise aspect ratio, $L_z/L_x$ of 2.6. The rough surfaces were digitised using a laser surface profilometer; their geometries and probability distributions of $k$ are shown in Fig. 1, while the key roughness scale parameters are summarized in Table 1. For the purposes of comparison, all surfaces are described by the maximum roughness height, $k$. Hot-wire data were taken at Reynolds numbers $4780 \leq Re_\tau = h u_*/\nu \leq 5540$ for the grit surface, and $5230 \leq Re_\tau \leq 6270$ for the mesh surface. For more details see [1].

RESULTS

The two-point streamwise velocity correlation in the cross-flow plane (with spanwise separation $\Delta z$) is:

$$R_{11} = \frac{\overline{u(y,z)u(y,z+\Delta z)}}{\overline{u(y,z)^2}},$$

(1)
where $u$ is the streamwise velocity fluctuation, $y$ and $z$ are the wall-normal and spanwise locations of a fixed reference station. A reference probe was positioned close to the channel centre-line at $y/h = 0.14, 0.4, 0.8$, and a second probe was scanned through the cross-flow plane with a resolution of $0.02h$ along the spanwise axis. Fig. 2 shows the correlation with the expected “backflow region” described by Townsend and indicative of large-scale circulation in the $(y,z)$-plane. This result is similar to measurements of $R_{11}$ in a smooth-wall boundary layer [2] and those in a smooth pipe and a smooth channel [3]. Estimates of the “spanwise width scale”, $l_z$, from the data of Fig. 2 show that it is larger than corresponding data for smooth channels [3]: here, at $y/h = 0.8, l_z/h \approx 1.2$. Fig. 3 shows that, (a) the value of $\Delta z/h$ increases more or less linearly with $y/h$, and that (b), the minimum correlation occurs at $y/h \approx 0.3$.

**REFERENCES**


