SKIN-FRICTION MEASUREMENTS ON MATHEMATICALLY GENERATED ROUGHNESS IN A TURBULENT CHANNEL FLOW

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Abstract Engineering systems are affected by surface roughness, however, predicting frictional drag has proven to be challenging. The present work takes a systematic approach by generating and manufacturing surfaces roughness where surface statistics, such as rms, skewness and power-spectral density can be controlled. The frictional drag on these surfaces is measured in a turbulent channel flow facility.

INTRODUCTION

The surface conditions encountered in many technologically relevant flow systems experience some degree of surface roughness, which leads to a deterioration of the performance in the form of additional drag. One open question is how roughness topography, whether it is idealized 2D and 3D or irregular with multi-scale features, impacts the frictional drag. Flack and Schultz (2010) [2] provide a comprehensive review of the predictive methods available to determine frictional drag on flows over roughness. These methods rely on a range of roughness scales, including density and a shape parameter, for instance. Using an extensive number of experimental results available in the fully rough regime, the authors developed a new method to estimate frictional drag based on surface statistics. The objective of this work is to extend the method proposed by [2] by measuring the frictional drag on mathematically generated rough surfaces, where a systematic variation of the surface statistics, such as root-mean-square (*rms*), skewness, kurtosis and power-spectral density can be achieved. This systematic approach will help to identify the roughness scales that contribute most to frictional drag.

EXPERIMENTAL SETUP

The skin-friction measurements will be conducted in the high Reynolds number turbulent channel flow facility. This facility consists of a test section with 25 mm in height (h), 200 mm in width (w), and 3.1 m in length (l), yielding an aspect ratio, w/h, of 8. The flow is driven by two pumps operating in parallel and are capable of generating a bulk mean velocity, U_b, from 0.4 to 11 m/s inside the test section, and therefore resulting in a Reynolds number based on the channel height and the bulk mean velocity ranging from 10,000 to 300,000. In order to perform the skin friction calculations, pressure taps located between $90h$ and $110h$ downstream from the inlet of the test section measure the streamwise pressure gradient.

The surface roughness was generated using a similar approach to [1]. The roughness is produced using the random Fourier modes method with a power-law spectral slope, β. Therefore, the roughness generated by this method contains a multitude of scales that obeys the imposed power-law slope, and the surface elevation possesses a Gaussian probability-density-function (*p.d.f*). Figure 1 shows the effect of six different power-law spectral slopes, where the mean values have been removed and normalized to have a maximum peak of 0.2 mm. As the spectral slope decreases, longer wavelength roughness protrusions can be readily seen. However, the surface statistics remain essentially the same.

One important aspect that should be considered is how faithfully a high-resolution 3D printer can reproduce the surface details. Figure 2 illustrates a comparison between a 2.5 cm square roughness sample with power-law spectral slope of $\beta = -0.8$. The left panel shows the generated surface, whereas the right panel shows the printed counterpart as measured by a surface profiler with sub-micron resolution. This surface was 3D printed using a commercially available printer (Projet 3500 HDMax) capable of producing 16 μm deposition layer with 34 μm × 34 μm of lateral resolution. In a qualitatively sense, the printer does a very good job of reproducing the surface details. The finest scale features cannot be reproduced due to the limitations of the printer resolution. Consequently, the surface statistics are different between the generated and printer version. For example, $k_{rms} = 45\,\mu$m for the generated surface as compared to 34 μm for the printed surface. Nonetheless, a systematic change of surface features can be achieved. Currently, 20.3 cm × 15.2 cm tiles are being manufactured, and subsequently will be replicated using a mold/cast technique to cover the top and bottom surfaces of the flow channel.

The final paper will present skin-friction measurements for a range of surfaces similar to those shown in figure 1. The relevant scales for the prediction of frictional drag will be discussed.

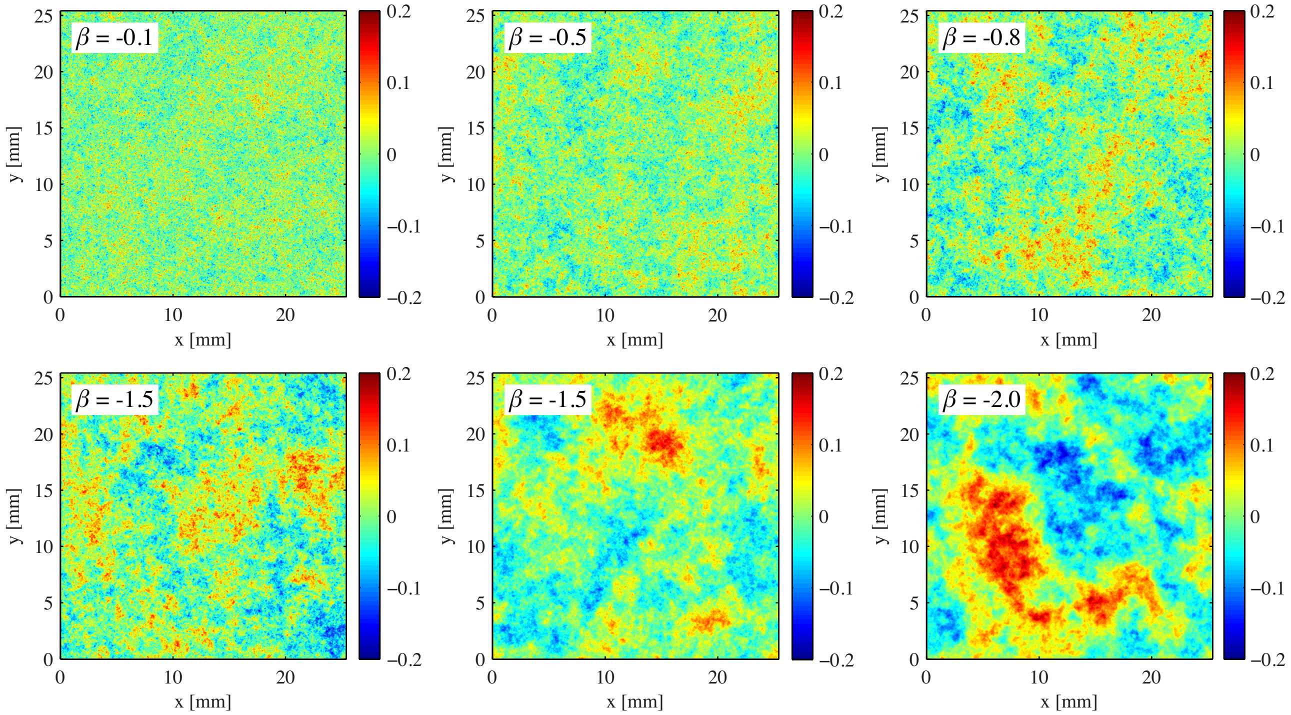

Figure 1. Effect of power-law spectral slope, β, on the surface roughness.

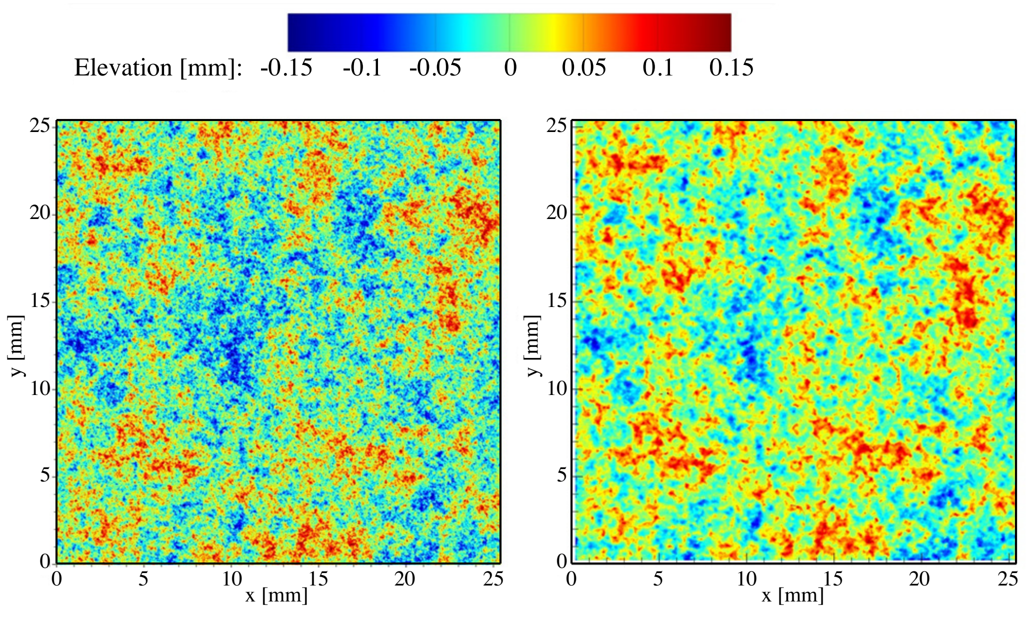

Figure 2. Comparison between the mathematically generated roughness (left panel) and the correspondent printed version (right panel), showing a good agreement of surface details. Contour maps represents surface elevation.

References

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