TURBULENCE CHARACTERISTICS OF HIGH-REYNOLDS-NUMBER ROUGH-WALL PIPE FLOW

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Our purpose in this work is to experimentally investigate the turbulence structure of high-Reynolds-number rough-wall pipe flow. Understanding the physics of high-Reynolds-number flows is important because many engineering flows occur at high Reynolds numbers (for a thorough review see Gad-el-Hak and Bandyopadhyay [1]). For instance, high-Reynolds-number pipe flows exist in large natural gas pipelines and, as Lovins [2] notes, even small reductions in pipe friction can yield substantial reductions in fuel consumption and pollution. After decades of empirical analysis, any further decrease in friction will seemingly only come from a more advanced understanding of the fundamental physics of the flow structure. Furthermore, much of our current understanding of wall-bounded flows comes from scaling arguments that are based on high Reynolds number limits and therefore they should be tested at high Reynolds numbers. Here we focus on rough-wall high-Reynolds-number pipe flow, however, it is important to note the physical basis for the attached-eddy model we will consider have been developed for all wall-bounded flows.

All data are taken in the Princeton/ONR Superpipe facility. The Superpipe consists of a high-pressure vessel (21MPa) that holds a 26m-long 0.13m-diameter test pipe. Using compressed air as the working fluid, the facility can reach Reynolds numbers of $3 \times 10^3 < Re_D < 4 \times 10^6$ ($3 \times 10^3 < R^+ < 1 \times 10^5$). The facility is described in detail in Shockling [3]. The roughness in the test pipe was created by honing and has $k_{rms} = 2.5$ μm with an equivalent sand grain roughness, $k_s \simeq 3$ μm. Over the given Reynolds number range, the ratio of the equivalent sand grain roughness to the viscous length scale varies $0.17 < k_s^+ < 44$ while $k_{rms}/R = 1 \times 10^{-3}$. With this facility we are able to obtain smooth, transitionally-rough and rough-rough wall flows. All instantaneous velocity measurements are obtained with conventional single-component hot-wire anemometry procedures.

We compare the streamwise turbulence intensities and one-dimensional spectra at varying wall-normal positions from the rough-wall pipe to the corresponding statistics from the smooth wall pipe as shown in Morrison *et al.* [4]. This allows us to study any effects of the wall roughness over a variety of Reynolds numbers. We also compare these statistics to the suggested forms given by the attached eddy model of wall-bounded turbulence.

References

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