Drag of heterogeneous rough surfaces in internal flows

Bettina Frohnapfel*, Carola Schmidt*, Jonathan Neuhauser*, Davide Gatti*

The drag-prediction for rough surfaces classically relies on the assumption that the surface roughness is isotropic and homogeneous. Both assumptions have been challenged in the last years and it is known that the global drag prediction for anisotropic and heterogeneous rough surfaces cannot be directly based on existing models.

One important step for the development of new models is the availability of reference data over a wide range of Reynolds number. The present contribution presents an experimental facility in which reference curves for internal turbulent channel flows in terms of friction coefficient as a function of Reynolds number can be measured and discusses the challenges in the corresponding data evaluation.

In the experiments, the surface heterogeneity is realised by alternating smooth and rough wall sections, where the roughness is realised with sandpaper and inserted in such a way that the mean height of the roughness corresponds to the location of the smooth wall. The terminology of a 'heterogeneous' rough surface is not uniquely defined. In the present work, we consider surfaces in which the smooth and rough surface parts have length scales that are of the order of the boundary layer thickness or larger. The measured drag curves for such surfaces are discussed in comparison to drag measurements of a fully smooth or a fully rough surface. An interesting question is to which extent the drag curves for the heterogeneous rough surfaces can be predicted based on the fully rough and fully smooth references. One underlying assumption that one may take in this context is the one that the flow above each roughness and each smooth patch is in local equilibrium with the boundary condition. This allows to formulate a global drag prediction based on an averaging procedure between the rough and the smooth wall drag.[1] [2]

The corresponding predictions (and variations thereof) will be compared to the measurement data for streamwise aligned roughness strips recently presented in Frohnapfel el al.[3] By the time of the conference we plan to be able to show additional drag measurements that include wider roughness strips and patchy roughness (in a checker-board pattern) composed of smooth and sandpaper sections. Preliminary results of complementary direct numerical simulations of patchy roughness with squared patches of corner length 4δ in a turbulent channel flow indicate that local equilibrium is not reached over these patches. This appears to be primarily related to the streamwise change in boundary condition which induces an internal boundary layer. [4] In addition, no secondary motions of Prandtl's second kind are found for this surface. These large scale flow structures are a prominent feature in turbulent flows over streamwise-aligned roughness strips[3]. A streamwise extent of 4δ apparently is not sufficient for the development of secondary motions. Interestingly, the global drag of the checker-board pattern is lower than for the streamwise-aligned roughness strips while both surfaces have a roughness surface coverage of 50%. We aim to discuss these simulation results which rely on a simple roughness model[1] and are carried out at low Reynolds number in comparison with new experimental data obtained over a broad Reynolds number range.

*Karlsruhe Institute of Technology (KIT), Institute of Fluid Mechanics (ISTM), Kaiserstr. 10, Karlsruhe, Germany

[1] Neuhauser et al., *Journal of Fluid Mechanics* **945** (2022)
[2] Hutchins et al., *Ocean Engineering* **271** (2023)
[3] Frohnapfel et al., *Journal of Fluid Mechanics* **980** (2024).
[4] Rouhi et al., *Journal of Fluid Mechanics* **866** (2019).