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# GLOBAL FRICTION OF HETEROGENEOUS ROUGH SURFACES

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## INTRODUCTION

Turbulent flows over natural as well as over technical surfaces are often exposed to heterogeneous roughness, a famous example being the flow over a ship hull overgrown with barnacles. The prediction of the related global friction coefficient is of high interest, but remains challenging [1]. In particular, it is not clear how to incorporate roughness heterogeneity into existing predictive frameworks [4]. Classically, global drag prediction relies on the determination of an equivalent sandgrain roughness (and the related roughness function) which is evaluated in the fully rough regime; i.e. a flow regime in which the drag coefficient only depends on the roughness geometry and not on Reynolds number. In order to understand whether the drag over heterogeneous rough surfaces can be predicted with existing tools, reference data for the global drag behaviour is required. To widen the data basis of the friction coefficient of such surfaces, we investigate surfaces with alternating smooth and rough parts in a broad Reynolds number range.

## INVESTIGATED SURFACES

In order to initiate a systematic study of heterogeneous rough surfaces we consider the drag of roughness strips aligned in the streamwise direction. The investigated surfaces consist of alternating smooth and rough strips of $4\delta$ width which are made out of P60 grit sandpaper. As depicted in figure 1, the surfaces are produced such that the mean height of the sandpaper is at the same position as the smooth surface part. Similar surfaces with strip width of $1\delta$ and $2\delta$ have previously been investigated by our group [3] and are used to complement the present data set. The geometrical dimensions of all surfaces can be found in table 1.

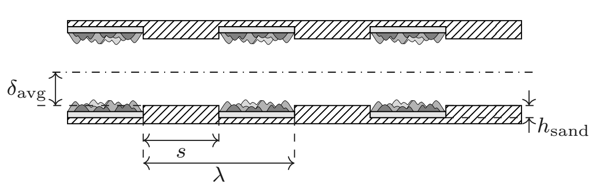


Figure 1: Sketch of the investigated surfaces and the geometric definitions.

| name surface | $\delta_{avg}$ mm | $h_{sand}$ mm | $s$ mm | $\lambda$ mm |
|---|---|---|---|---|
| submerged rough 4 delta | 12.692 | 0.67 | 50 | 100 |
| submerged rough 1 delta | 12.71 | 0.67 | 12.5 | 25 |
| submerged rough 2 delta | 12.66 | 0.67 | 25 | 50 |

Table 1: Geometrical dimensions of the different surface configurations.

## EXPERIMENTAL SET-UP

The experimental investigation of the surfaces is performed in the open-circuit blower wind tunnel depicted in figure 2. The test section has a channel half-height of $\delta = 12.6$ mm and a width of $W = 300$ mm resulting in an aspect ratio of $AR = 12$. The test section has a length of $314\delta$ whereof the last third is equipped symmetrically with the investigated surfaces.

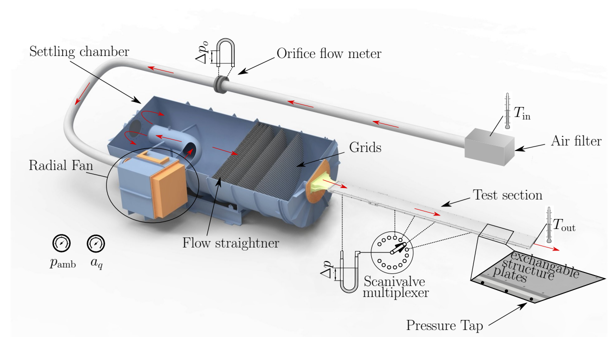


Figure 2: Scheme of the blower wind tunnel with the measurement equipment (adapted from [6]).

The pressure gradient $\Pi$ along the surface is measured using 21 pressure taps located on both sides of the test section. In conjunction with the mass flow rate $\dot{m}$ measured with an orifice flow meter in the inlet pipe, the bulk Reynolds number $Re_b$ and the global friction coefficient $C_f$ can be calculated by

$$Re_b = \frac{2\delta_{avg}U_b}{\nu} = \frac{\dot{m}}{\rho\nu W} \tag{1}$$

and

$$C_f = \frac{2\tau_w}{\rho U_b^2} = \frac{8\Pi\rho\delta_{avg}^3 W^2}{\dot{m}^2}, \tag{2}$$

respectively, with the bulk velocity $U_b$, and the air's density $\rho$ and kinematic viscosity $\nu$.

## RESULTS

Figure 3 includes the results for all three strip widths and also the reference curves for the homogeneous cases, i.e. smooth and homogeneous rough. The smooth-wall reference is in very good agreement with the correlation suggested by Dean [2]. The homogeneous rough curve reaches a quasi-constant value at high Reynolds numbers depicting a fully rough regime for this surface configuration.

Two main observations can be made for the heterogeneous rough surfaces. First, their global drag curves differ even

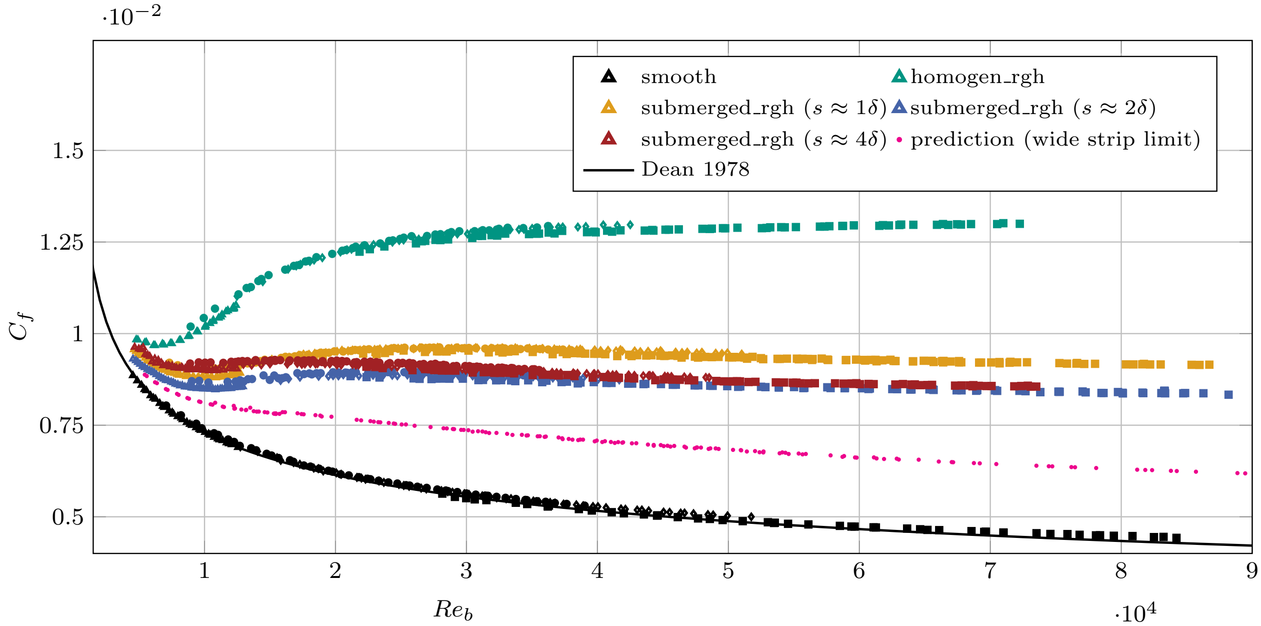


Figure 3: Results for the heterogeneous rough surfaces in comparison with the homogeneous reference cases and the wide strip limit [5].

though all of them have a 50 % surface-coverage with sandpaper. Second, all curves indicate a continuous decline at the highest Reynolds numbers covered by our facility. At relatively low $Re_b$, which corresponds to the transitionally rough regime of the homogeneous rough surface, the $C_f$ curves of the rough strips reach a flat local maximum. In this $Re_b$-regime a constant friction factor appears to be present over a limited Reynolds number range in all cases. As no fully rough regime is reached at high Reynolds numbers, no equivalent sandgrain roughness can be defined for the surfaces.

One alternative approach to predict the global drag of the heterogeneous rough surface is the use of an averaging procedure that employs data of the homogeneous smooth and rough case [5]. This model relies on the assumption that the flow above rough and smooth surface parts is in equilibrium with the wall condition, and the related predicted drag curve is added in figure 3. Even though good agreement of the model prediction with DNS results for low Reynolds numbers and small roughness has been shown in previous work [5], the model does not provide a good prediction of the global drag curve of the present P60 sandpaper strips at high $Re_b$. It also does not capture the intermediate flow regime in which a constant $C_f$ is found for all measured data. Due to the assumption of equilibrium flow conditions, the model is inherently not capable to resolve differences in the strip width. In addition, the prediction clearly underestimates the measured global $C_f$ for all considered cases.

In the conference contribution, the differences between the three measured global drag curves and potential reasons will be discussed in detail. In addition, an improved version of the predictive tool will be presented which can capture the general shape of the global drag curves and allows to distinguish different strip widths.

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