

## DISTRIBUTION OF INTERMITTENCY FACTOR ON ROUGHT WALL BOUNDARY LAYER

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### Introduction

The boundary layer was investigated in the closed circuit wind tunnel (0.5 x 0.9) m<sup>2</sup> on the flat plate (0.9 m wide and 2.75 m long) with the smooth surface and the surface covered by 60-grit sandpaper, typical height of the roughness elements was 0.435 mm. Mean flow velocity outside the boundary layer was 5.2 m/s ( $\pm 3\%$ ) in average. Free stream turbulence was controlled by means of a square mesh plane grid. The turbulence intensity was 0.3 % without the turbulence generator and 3 % with it, the dissipation length parameter was  $Le = 33.5$  mm in this case in the leading edge plane  $x = 0$ . For more details of the experimental facility and turbulence generators see e.g. [1].

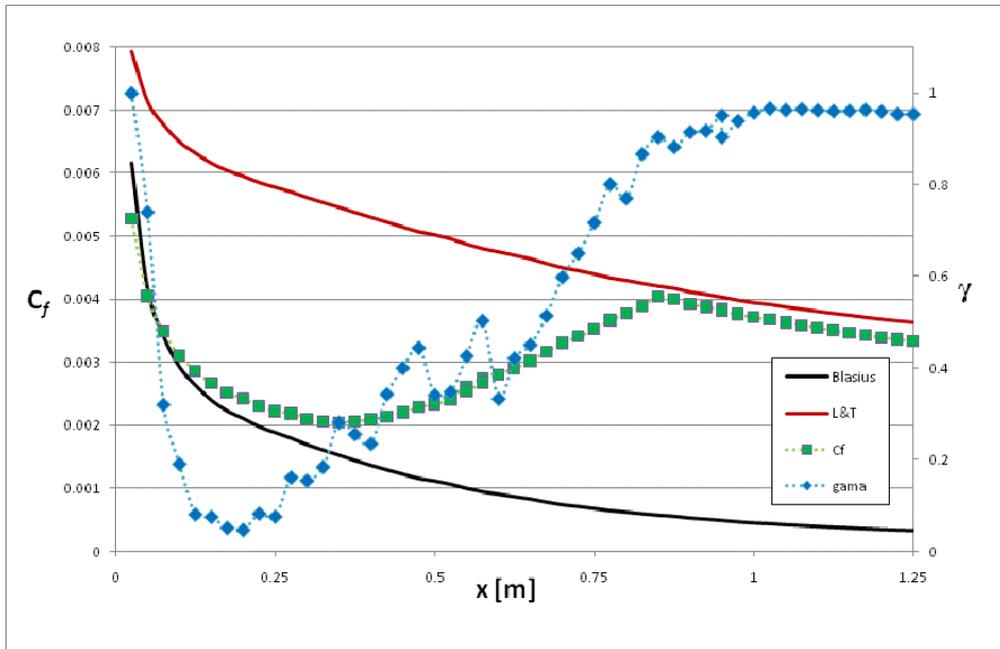
### Measurement and evaluation methods

Evaluation of the mean velocity profiles was based on the pressure measurements with a couple of the flattened Pitot tube and round nosed static pressure probe. The probes were moving together in the streamwise direction  $x$  and in the direction of the normal to the surface. Details on the measurement and evaluation techniques are given in [3]. The evaluated distributions of the time average skin friction coefficient  $C_f$  for various experimental setups are shown in Figures 1 to 3. The distributions of the time average skin friction coefficient  $C_f$  for various experimental setups were evaluated. These distributions follow the Blasius solution with laminar flow structure and the Ludwig and Tillmann formulae in turbulent boundary layer. Therefore it can be used for estimation of the onset and the end of the transitional region.

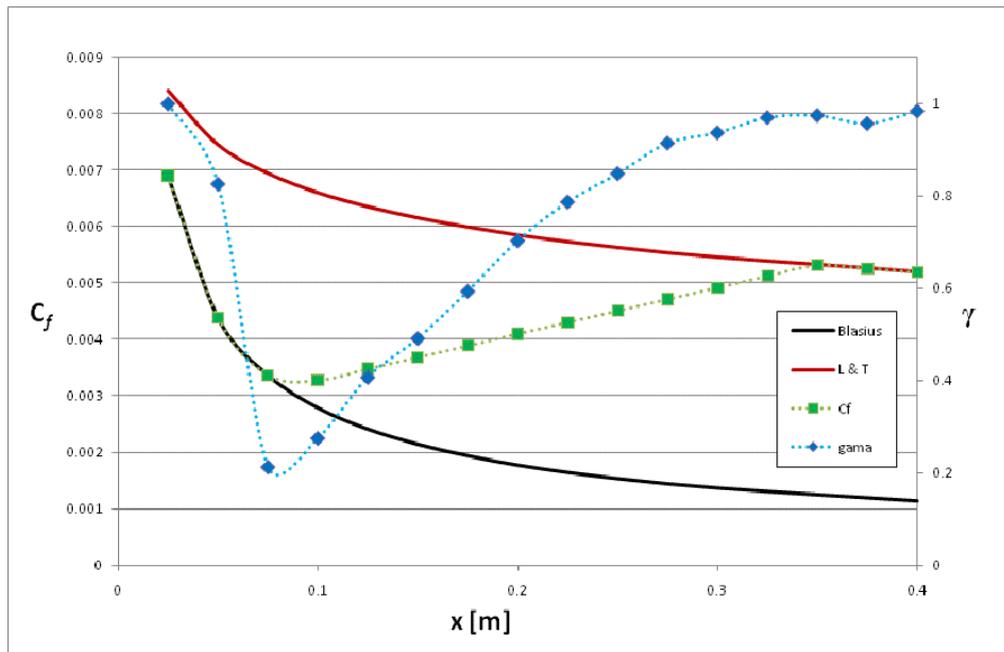
The measurement of instantaneous wall friction with hot wires was done. The probe with two heated parallel wires was mounted on device with wheels. This device was connected with the traversing system and has been dragged in the stream wise direction along a surface. The wall proximity corrections must have been applied on the HW readings, as the probe was moving in a close proximity along the surface. In principle, the implementation of some assumptions allows directly calculate the skin friction  $\tau_w$ , but in reality, an additional calibration of skin friction is necessary as the wall correction is not exactly known and the shift of the zero level was changed with moving the probe stream wise, in  $x$  direction. Therefore the distributions of the time averaged skin friction coefficient  $C_f$  evaluated from pressure measurements were applied during an indirect local calibration assuming  $\bar{\tau}_w = 0,5 \cdot \rho_e \cdot U_e^2 \cdot C_f = K_i \cdot \bar{U}_i$ ;  $i = 1, 2$ . Next the coefficients  $K_i$  are valid at the same boundary conditions as for the pressure measurement. The records of the instantaneous values of wall friction  $\tau'_w$  are then calculated from the records of the instantaneous velocities  $U_i$ :  $\tau'_w(t_j) = K_i \cdot U_i(t_j)$  where  $t_j$ ,  $j = 1, 2, \dots, 750000$  denotes instants of time of sampling (frequency 25 kHz).

This intermittent signal was analyzed to determine the intermittency factor  $\gamma$ . In literature a lot of methods of intermittent signal analysis could be found, a review of classical methods is given in [4], more recent methods are shown in [5]. In our case the TERA (Turbulent Energy Recognition Algorithm) method was chosen. The method consists of several consecutive steps. At the first obtained records of the instantaneous values of wall friction  $\tau'_w$  are filtered by Butterworth filter with low pass frequency 1 kHz to eliminate noise from the signal. At the second step the Detector function  $D(t)$  is derived as to emphasize the differences of the signal time behaviour during turbulent and non-turbulent periods. Here the detector function has been computed after the formula:  $D(t) = |u(\partial^2 u / \partial t^2)|$  where  $u$  is fluctuation of the stream wise velocity component. Then the detector function is smoothed to eliminate the scale much smaller than those we are going to recognize thus the Criterion function  $K(t)$  created; details are presented in [6]).

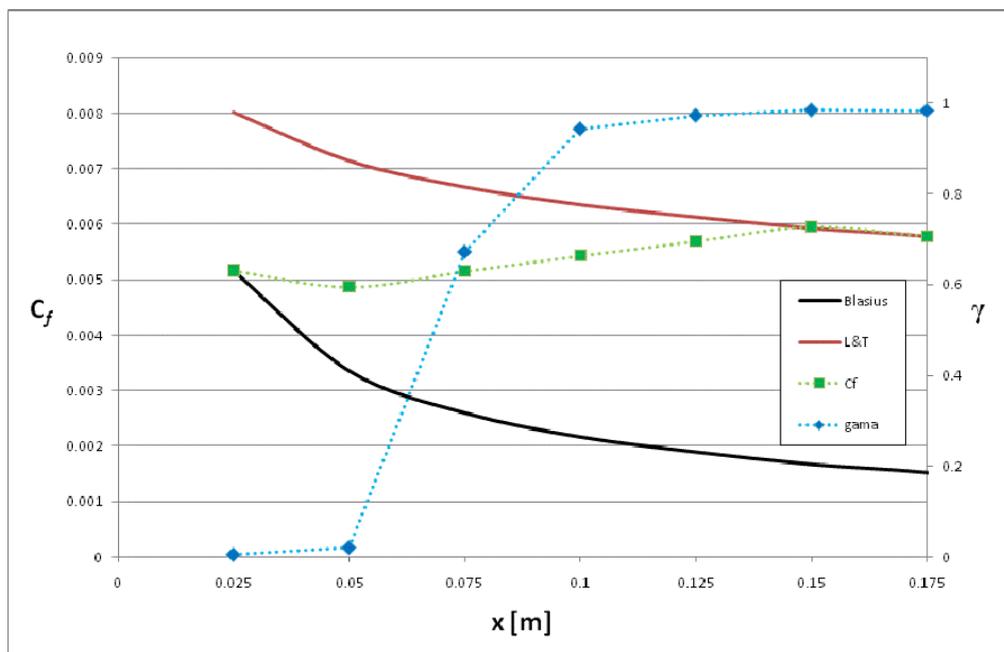
Next step is the determination of the indicator function  $I(t)$  that can be used to distinguish between the non-turbulent and turbulent portions of signal. It is defined as follows:  $K(t) \leq C \Rightarrow I(t) = 0$  and  $K(t) > C \Rightarrow I(t) = 1$ , where  $C$  is dimensionless threshold constant for the given criterion function. The indicator function  $I(t)$  is equal to 0 in the non-turbulent signal portion of the signal and equal 1 in the turbulent portion. Then the intermittency factor  $\gamma$  can be calculated as the long time average of the indicator function with the physical meaning as the probability that the turbulent flow will occur within the given flow field point. It is defined by  $\gamma(x) = \sum_{j=1}^N I(x, t_j) / N$ , where  $I(x, t_j) = 0$  for non-turbulent and  $I(x, t_j) = 1$  for turbulent. For analysis 750 thousand samples were acquired with frequency 25 kHz for each  $x$  position.



**Fig. 1** Distributions of skin friction and intermittency factor on flat plate affected by increased free-stream turbulence



**Fig. 2** Distributions of skin friction and intermittency factor on flat plate affected by surface roughness



**Fig. 3** Distributions of skin friction and intermittency factor on rough flat plate affected by increased free-stream turbulence

## Results

The streamwise distributions of the transitional intermittency factor in the flat plate boundary layer under joint action of surface roughness and external turbulence calculated by means of above described method as well as the distributions of skin friction coefficient are shown in Figures 1 to 3. The onset of transition process is characterized by departure of skin friction curve from Blasius solution and in the end approaches the Ludwig and Tillmann curve. In terms of intermittency curve, onset of transition corresponds to minimum of its value (ideally 0) and the end of transition region is indicated by  $\gamma \approx 1$ . Increasing value of the intermittency coefficient upstream the transition onset could be explained by disturbances penetrated from outside the boundary layer.

## Conclusion

Two methods of transitional region determination for various cases were shown. Position and length of transition region is strongly affected by surface roughness and free-stream turbulence, joint action increases the effect. The surface roughness significantly shortens the transitional region.

## Acknowledgements

This work was supported by the Grant Agency of the Academy of Sciences of the Czech Republic, IAA200760614 and by the Grant Agency of the Czech Republic, projects No. 101/08/1112.

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