COMMENT ON IDENTIFYING THE LOCATION OF TRANSITIONAL REGION IN BOUNDARY LAYER

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The laminar/turbulent boundary layer transition is an important phenomenon of fluid mechanics as well as in practise. A great amount of factors influencing the transition process is known e.g.

the shape and the properties of the surface or of the body with investigated boundary layer (2D or 3D, flat plate, shape of the leading edge next the surface: hydraulically smooth, completely rough, wavy, heated etc.);

the features of the incoming flow (steady-state flow; unsteady flow with deterministic/ random disturbances, homogeneous, shear flow etc.).

An important task of laminar/turbulent transition investigation is the determination of the onset and termination of transition region at various boundary conditions. Some useful experiences were gained during experiments on laminar/turbulent transition performed in the Institute of Thermomechanics AS CR (I.T.) since the ninetieth of the last century.

The investigated boundary layers (*grad* $P_e = 0$) were examined experimentally in the close circuit wind tunnel (0.5 x 0.9) m^2 in the I.T. They are developing either on the aerodynamically smooth flat plate (2.75 m long and 0.9 m wide) made from a laminated wood-chip board 25 mm thick in the primary configuration or on the thin plywood plate (7 mm thick) covered by sandpaper placed on the smooth flat plate. The primary plate has the leading edge designed by Kosorygin et al. [1]. The rough plate leading edge has an elliptic shape ($a \times b = 60 \times 20\ mm^2$) covering the primary leading edge. Presented results relates to the external mean flow velocity $U_e \approx 5$ m/s over the rough surface (60-grit sandpaper with the maximum size of grains s = 0.435 mm ± 0.014 mm). The free stream turbulence (FST) was either natural or created by square mesh plane grid (mesh M = 35 mm. rod's diameter d = 10 mm) placed across the flow upstream from the leading edge $x_G = -1{,}35$ m. Thus the FST intensity at the leading edge plane was either 0,3 percent or 3 percent of U_e. Pressure probes with accurate pressure transducers and the CTa measuring technique were employed for measurement of boundary layer characteristics distributions. More details of experimental set up are given in [2] and [3].

Three ways were applied in determining the start of transition region in the smooth wall boundary layer: the departure of the shape factor H_{12} from the value 2,6 and the departure of the skin friction coefficient C_f from the course specified by the Blasius solution of the flat plate laminar boundary layer [4]. Similarly, the drop of H_{12} to a constant value about 1,4 (depends on Reynolds number value) and the attachment of the measured C_f to the course in fully developed turbulent boundary layers e.g. the empirical curve proposed by Ludwieg and Tillmann [4]. Both procedures need quite detailed exact measurement of the mean velocity profiles, laborious evaluations of H_{12} and C_f. A surface roughness make more difficult their applicability as more unknowns enter into evaluation (velocity zero level, roughness function).

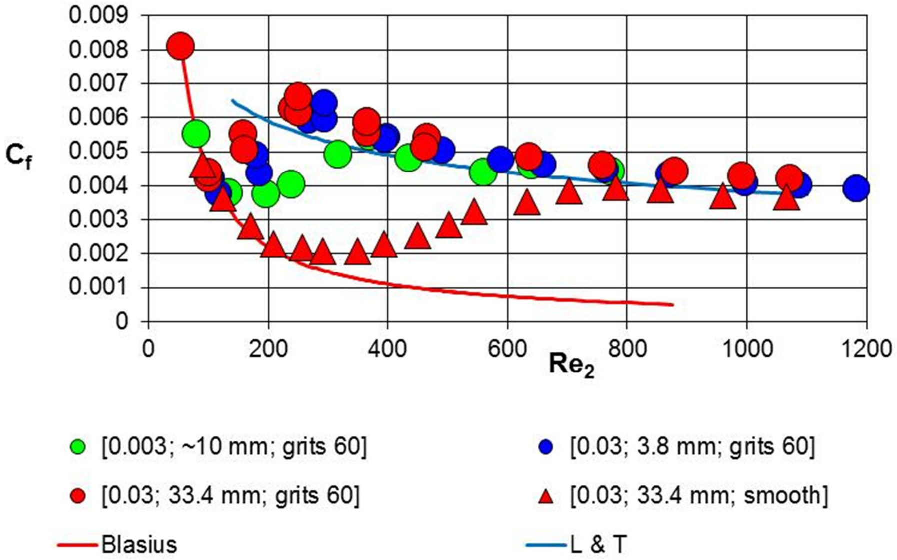


Figure 1. Example of the skin friction coefficients.

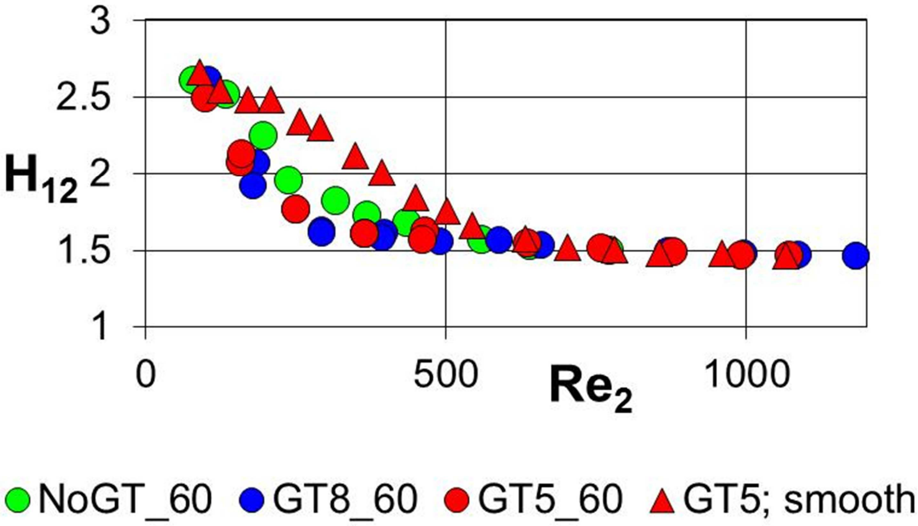


Figure 2. Example of the shape factor distributions.

The third applied method still checked out is measurement of transitional intermittency factor γ, the probability that the flow is in the turbulent state. For this purpose the CTA measurements, with the heated wire parallel and very close to the surface (the distance ~ 10^{-4} mm), were applied to obtain records of the output signal that was subsequently transformed to the instantaneous wall friction $\tau_w(t,x)$ records. Next the records were analysed by using the TERA method (Turbulence Energy Recognition Algorithm) and finally the transitional intermittency factor $\gamma(x)$ was evaluated. The method consists of several consecutive steps. At the first obtained records of the instantaneous values of wall friction τ_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 *D* has been computed by the formula:

$$D(t) = \left|\tau_w \left(\partial^2 \tau_w / \partial^2 t\right)\right| \tag{1}$$

Then the detector function is smoothed to eliminate the scales much smaller than those we are going to recognize, thus the criterion function *K*(*t*) is created (details are presented in [5]). The next step is determination of the indicator function *I*(*t*) that is used to distinguish between the non-turbulent and turbulent portions of signal. It is defined as follows:

$$K(t) \le C \Rightarrow I(t) = 0 \quad and \quad K(t) > C \Rightarrow I(t) = 1, \tag{2}$$

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 portions of the signal and it is equal to 1 in the turbulent portions. Having determined the indicator function *I*(*t*) the intermittency factor γ 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. The factor γ is defined by

$$\gamma(x) = \sum_{j=1}^{N} I(x, t_j) / N \tag{3}$$

where $I(x,t_j) = 0$ for the no-turbulent state and $I(x,t_j) = 1$ for the turbulent state. Apparently the procedure of γ-distribution is not simple but it is less laborious and more unbiased than the preceding methods. The adjustment of the threshold level plays a crucial role, but its choice is just in hands of experimenter. As to find a faster way to set the proper threshold level the distributions of central moments were studied, since they reflect the evolution of fluctuations in boundary layer. The central moments of a quantity e are defined as follows

$$Var\, e = \overline{(e')^2} \quad ; \quad S = \frac{\overline{(e')^3}}{\left[\overline{(e')^2}\right]^{3/2}} \quad ; \quad F = \frac{\overline{(e')^4}}{\left[\overline{(e')^2}\right]^{2}} \tag{4}$$

where $e' = e - \overline{e}$ are fluctuations of either wall friction τ_w [Pa] or of the detector function *D(t)* (1). The obtained distributions are drawn in the Figures 3 and 4.

From the preliminary conclusions follow:
var *D(t)* is more convenient to estimate the position of termination of transition region than the instantaneous wall friction proportional to the CTA output signal (Figure 3)
the maximum values of var *D(t)* correspond to maximum value of $\gamma(x)$ and maxima of *S* and *F* correspond to the minimum of $\gamma(x)$ (Figure 4).

Therefore the subsequent examples shown in Figures 5 and 6 present characteristics of the detector function *D* (1). They are in accord with the preliminary conclusions. It should be mentioned that the demonstrated procedure can help by selection/construction of another type of the detector function.

GT5_60_D(t) and τ_w

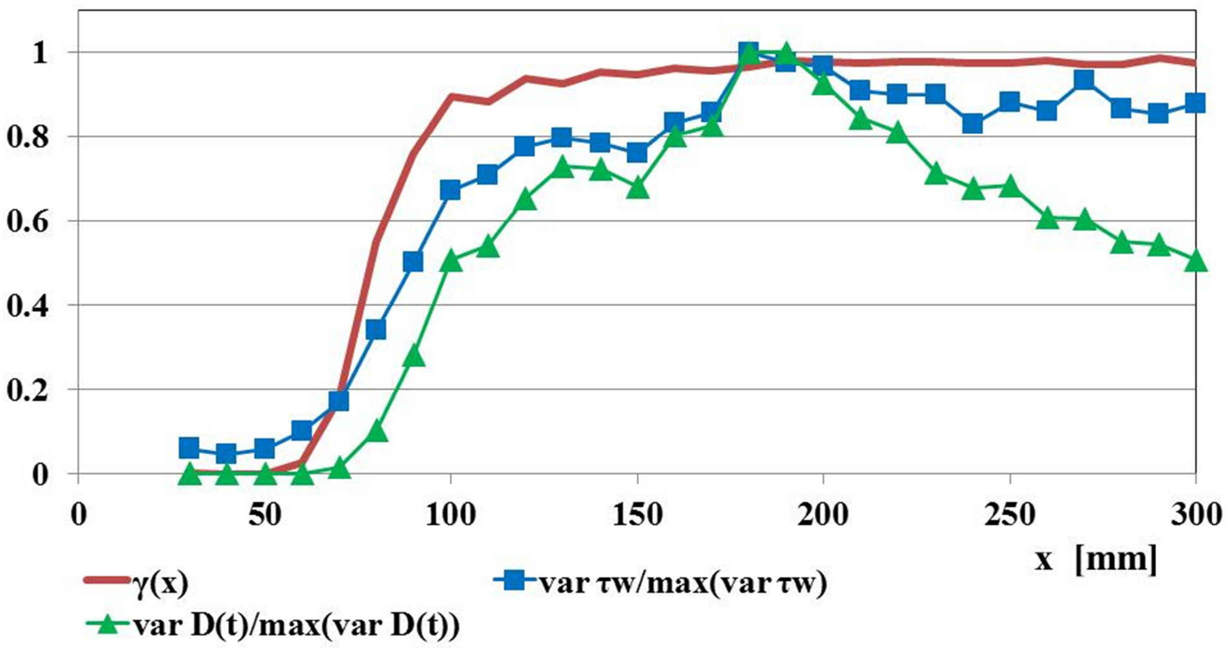


Figure 3. Distributions of $\gamma(x)$, var τ_w and var *D(t).*

GT5_60_D(t)

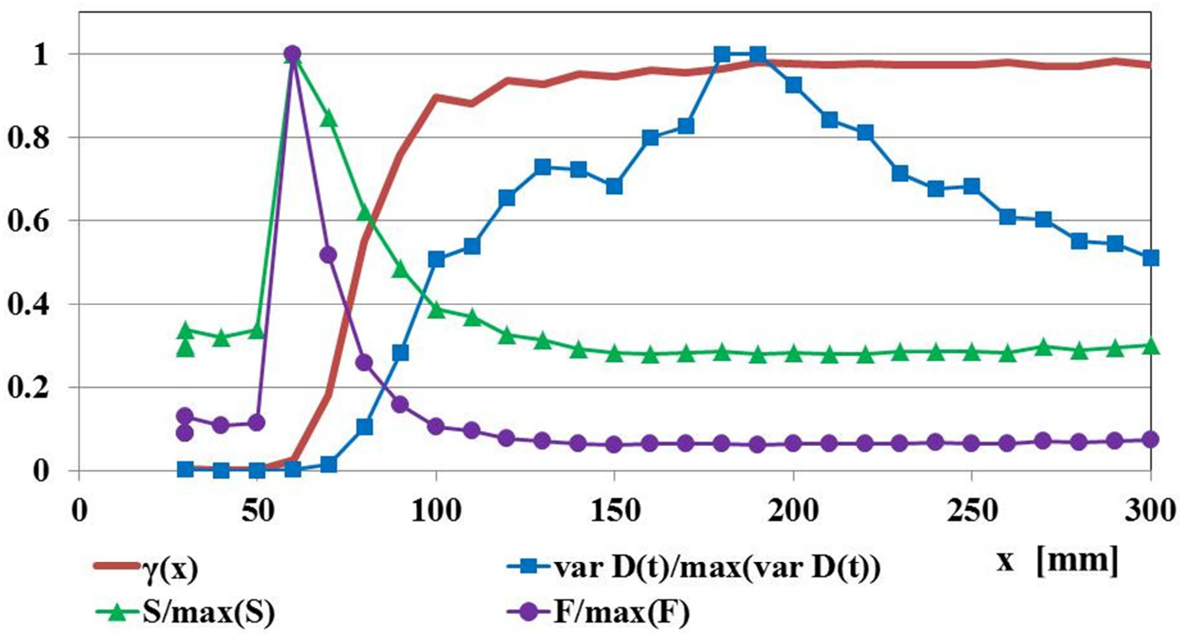
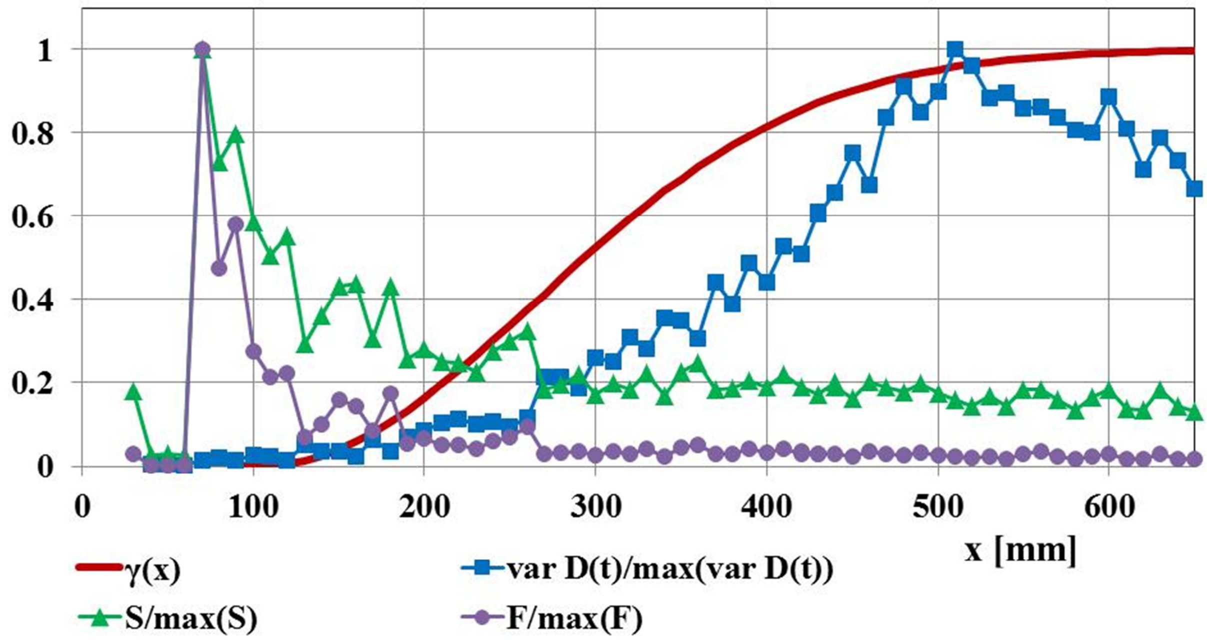
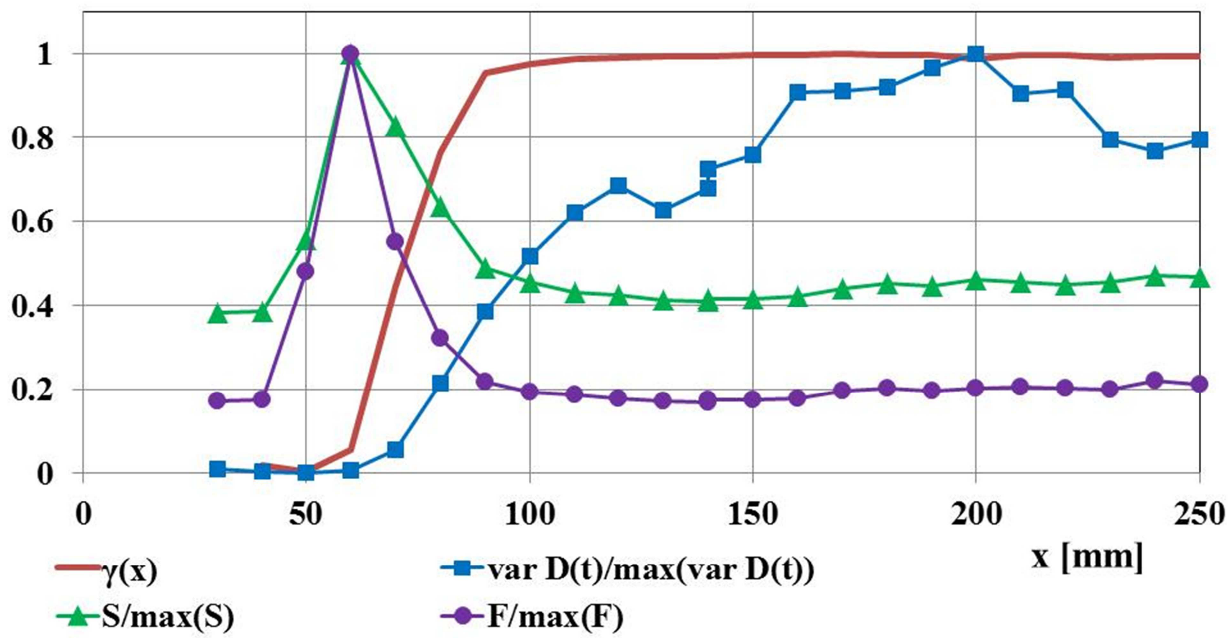


Figure 4. Distributions of $\gamma(x)$, var *D(t), S(D(t))* and *F(D(t)).*

NoGT_60_D(t)



GT5_60_D(t)



Acknowledgements

This work has been supported by the Czech Science Foundation, the projects GA101/08/1112 and GAP101/12/1271 and with the institutional support, projects AV0Z20760514.

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