EFFECT OF THE THRESHOLD ON THE DETERMINATION OF THE TRANSITIONAL INTERMITTENCY FACTOR

Ondřej Hladík, Pavel Jonáš, Václav Uruba
Institute of Thermomechanics AS CR, v.v.i.

The transitional intermittency is describing the flow development along the surface in stream wise direction during the process of laminar / turbulent transition. It relates to the generation and propagation of turbulent spots. The transitional intermittency factor $\gamma(x)$ is one of the key parameters in recognition of the transitional boundary layer state. This factor computed by means of direct method is defined as time ratio of turbulent flow occurrence time over whole measurement time. Direct method of determination of the intermittency factor is very effective in detecting the start and the end of transition with proper choice of parameters for signal processing and analysis. A lot of methods of determination γ is available [1] but only the TERA (Turbulent Energy Recognition Algorithm) method [2] was chosen in this case. The analysis of the skin friction record, made during the research of the flat plate boundary layer by-pass transition (by means a wall-proximity hot wire probe) is presented as an example of this method application. The flat plate boundary layer was investigated experimentally in the close circuit wind tunnel of the Institute of Thermomechanics AS CR. The boundary layer develops itself on the aerodynamically smooth plate 2.75m long and 0.9m wide in the working section with the cross-section (0.5 x 0.9)m^2. Free stream turbulence was controlled by plane grid with cylindrical rods and square mesh holes placed across the incoming flow in proper distance upstream the plane. The grid produce free stream turbulence with turbulence level $Iu_e = 3$ percent and dissipation length parameter $L_e = 5.9mm$ in the leading edge plane, more information is given in [3]

The TERA method consists of several consecutive steps which are shown in the Figure 1-6. At the first, the raw voltage signal from CTA anemometer, proportional to skin friction, is filtered by Butterworth filter with low pass frequency 1 kHz to eliminate noise from the signal. At the second step the Detector function $D(t)$ (Figure 3) 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

$$D(t) = \left| u \frac{\partial u}{\partial t} \right|, \tag{1}$$

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 $K(t)$ (Figure 4) created; details are presented in [4]).

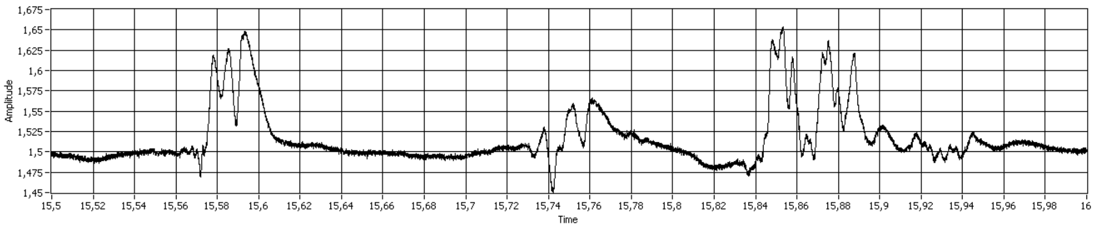

Fig. 1 Raw voltage signal from CTA in duration 0,5s

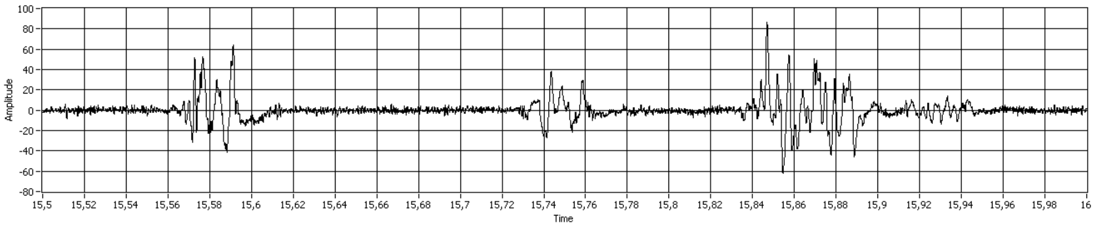

Fig. 2 Filtred and derivative signal

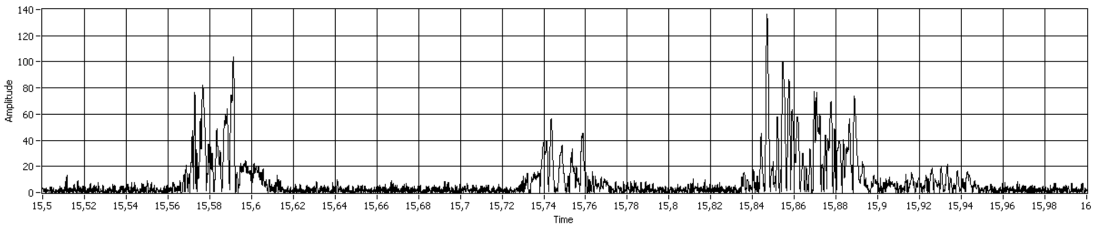

Fig. 3 Detector function $D(t)$

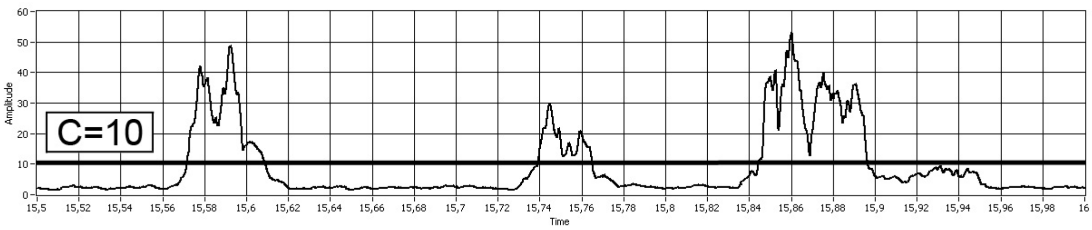

Fig. 4 Criterion function K(t) with threshold C=10

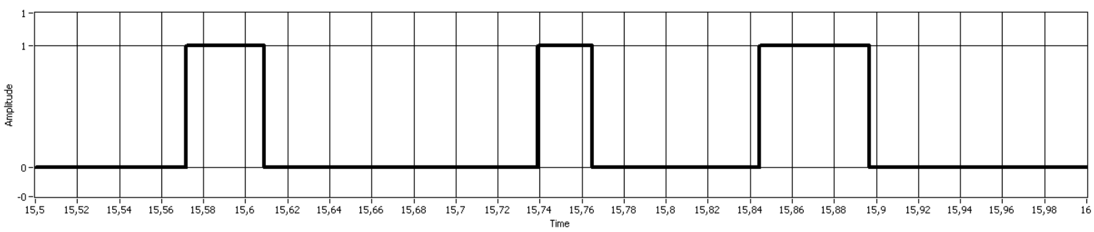

Fig. 5 Indicator function $I(t)$

Next step is the determination of a quantity that can be used to distinguish between the non-turbulent and turbulent portions of signal. The Indicator function $I(t)$ (Figure 5) meets this task. It is defined as follows

$$\begin{aligned} K(t) \le C &\Rightarrow I(t) = 0, \\ K(t) > C &\Rightarrow I(t) = 1, \end{aligned} \tag{2}$$

where C is dimensionless threshold constant for the given criterion function. The formula (2) should be interpreted that 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. Having determined the indicator function $I(t)$ the intermittency factor γ can be calculated and the conditional analysis of skin friction can be made that allow a deeper insight into the flow structure. The intermittency factor γ is 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. So it is impossible to exceed the value 1 of intermittency factor. It is define by

$$\gamma(x) = \sum_{i=1}^{N} \frac{I(x,t_i)}{N}; \qquad \textit{where} \quad I(t_i) = \begin{cases} 1 & \textit{turbulent} \\ 0 & \textit{non-turbulent} \end{cases} \qquad (3)$$

$i = 1,2,...N \geq 750000$

The threshold constant C, which distinguishes between the non-turbulent and turbulent nature of the signal, is of key significance. This threshold constant should be “properly“ chosen. The choice depends on the experiences and knowledge of the fundamental turbulence relations. In Figure 4 the criterion function with threshold value C=10 is shown. The indicator function is classified as 1 (turbulent portion) in the portions where criterion function is bigger than the threshold and in the remainder portions it is classified as 0 (non-turbulent portion).

The stream wise distributions of the transitional intermittency factor in the flat plate boundary layer under turbulent external flow calculated by means of this method are shown in Figure 6. The correct distribution has been found with the threshold value C=4. Because the flow is fully turbulent up to the wall at x=0, then the intermittency factor $\gamma(x) = 0$ after definition. Next the boundary layer is growing and simultaneously the turbulence disturbances from outside are damped by the viscous actions in the boundary layer in the stream wise direction. Thus, initially the intensive damping of turbulence eddies manifest itself by decreasing γ in the downstream direction. After minimisation of turbulence disturbances inside the layer the minimum value of intermittency factor is achieved. Then the transitional process begins and the intermittency factor grows monotonically from $\gamma(x) = 0$ up to the end of the transitional region $\gamma(x) = 1$ where a self-sustaining turbulent boundary layer develops.

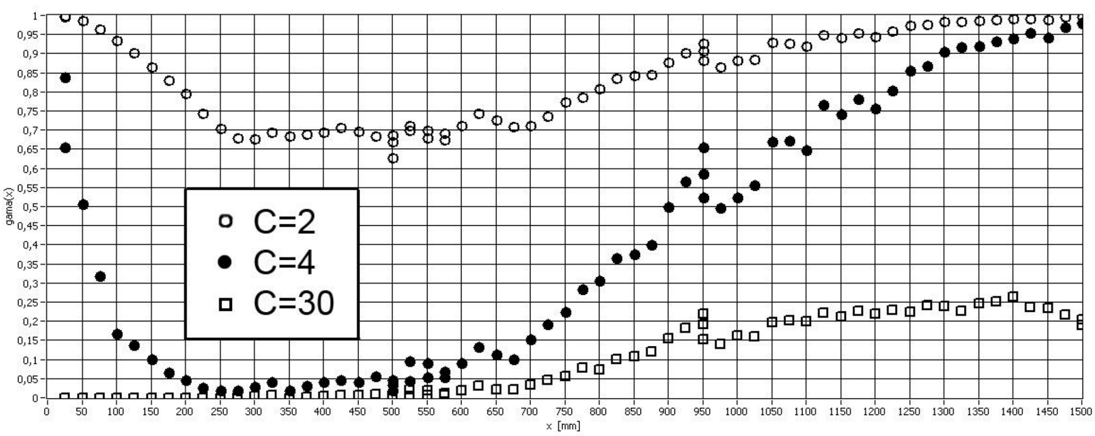

Fig. 6 The distributions of intermittency factor along the plate

In Figure 6 there are shown that too low threshold value causes the distribution of intermittency factor approaching the constant value 1, which is its limiting case and on contrary at very high value of the threshold the $\gamma(x)$ distribution decreases markedly.

Acknowledgements
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