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SOME NEW RESULTS ON THE INFLUENCE OF TURBULENCE SCALE ON BY-PASS TRANSITION IN A BOUNDARY LAYER

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Abstract

The external turbulence causes an earlier laminar-turbulent transition of the flow in a boundary layer which consequently leads to an increase of skin friction. It is possible to characterize the turbulence by its two main measures: intensity and scale, usually related to a velocity along an average stream line. The influence of turbulence intensity on transition is quite well learned, but there are still very few investigations relating to the influence of the turbulence scale on laminar – turbulent transition. In his review, Mayle (1991) suggested the transition appears earlier when the mesh of the grid is greater (what implies a greater length scale). Also Jonas (2000) implied the turbulence scale dependence on the inception and transition length. Unfortunately their results were not dimensionalized. They both claim themselves that the use of their corerelations are rather limited.

Key words: turbulence scale, turbulence intensity, boundary layer, by – pass transition, grid turbulence

INTRODUCTION

Experimental results of Jonas (2000) indicate the laminar – turbulent inception moves downstream with the decreasing of turbulence scale; the length of transition also becomes shorter. For larger values of dissipative length scale, *Lu*, the laminar – turbulent transition process ends earlier. Unfortunately, there are not made non-dimensional values for turbulence scale in the literature. Besides, the authors of the two papers claim themselves that the use of their correlations are rather limited. In the other author's opinion (e.g.: Epik, 2001) it seems to be quite opposite; the reducing of turbulence scale should provide an earlier inception, i. e. the lower momentum thickness Reynolds number, Re_t^{**}. That is why, the previous investigations require some revision.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The investigation was carried out in the subsonic wind tunnel of low level of turbulence, Tu<0.08% and velocity up to 100 *m/s.* The sketch of the working section and the detail of the leading edge is shown in Fig. 1. The enhanced level of turbulence was generated by four grids of following dimensions:

1) d=0.3 *mm*, M=1 *mm*,
2) d=0.6 *mm*, M=3 *mm*,
3) d=1.6 *mm*, M=4 *mm*,
4) d=3.0 *mm*, M=10 *mm*

(named appropriately Grid 1, 2, 3 and 4), where *d* is a diameter of the rod and *M* is a grid mesh size. Grids were placed at the different distances upstream of the leading edge of plate: L_s=450, 410, 370 and 330 *mm*. Also four different incoming velocities were used: *U*= 6, 10, 15 and 20 *m/s.*

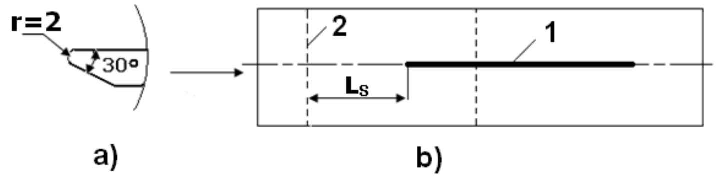

Fig. 1: Working section of wind tunnel: a) shape of leading edge, b) plate (1), grid (2) at distance L_s upstream

The coordinates systems for the turbulence intensity and scale measurements is fixed to the grid with *x* coordinate parallel to the mean velocity of flow. The coordinate system for boundary layer measurement is fixed to the leading edge of plate and the distance between the grid and leading edge of plate is equal to L_s as mentioned above.

The velocity and turbulence measurements were carried out by means of the StreamLine termoanemometry system (DANTEC) with the software Stream-Ware 3.41.20 and the hot-wire probe 55P15 of DANTEC suitable for measurements in boundary layer. The data was sent to the computer by means of the acquisition card NI 6040E.

First the measurements of the turbulence decay behind grids was carried out, then velocity profiles in the boundary layer of a flat plate in different section from the leading. To avoid separation at the leading edge the plate was set at the incidence angle i = -1.63° therefore a rather small velocity gradient along the plate was measured. A value of acceleration coefficient (1) was approximately equal to: $K \approx 2.7 \cdot 10^{-7}$.

$$K = \frac{\nu}{U^2}\frac{dU}{dx} \tag{1}$$

SCALES OF TURBULENCE

In the article from 2001, Barrett and Hollingsworth describe few longitudinal scales of turbulence, although the authors report there are more than ten. We can distinguish the integral scales – those associated with the largest eddies in the flow, microscales and dissipation scales. The longitudinal integral scales can be defined as follows:

$$\Lambda_I = U\int_0^\infty R(\tau)\,d\tau \tag{2}$$

where $R(\tau)$ is a time correlation coefficient, or:

$$\Lambda_{II} = U\,E_1\{0\}/(4u'^2) \tag{3}$$

where the one – dimensional energy spectrum function $E(k_1)$ is extrapolated to the wave number k_1=0.

The measure of the average size of small turbulent eddies involved in fluid motion, is the spatial micro-scale of turbulence, called the Taylor microscale. Under condition that the spatial correlation function $R_{ii}(r)$ is symmetric, we can describe this scale as follows:

$$\lambda_{ii} = \left(-\frac{1}{2} \frac{d^2 R_{ii}}{dr^2} \bigg|_{r=0} \right)^{-1/2} \tag{4}$$

Two another length scales (5) and (6) are associated with the turbulent kinetic energy dissipation. Assuming that the turbulence is isotropic, and knowing that the dissipation of energy causes the decreas of the velocity fluctuations, we get dissipative length scales:

$$Lu = -\langle u^2 \rangle^{3/2} / \left(U \frac{\langle \partial u^2 \rangle}{\partial x} \right) \tag{5}$$

$$Le = \frac{3}{2} \frac{u'^3}{\varepsilon} \tag{6}$$

Finally, the measure of the smallest eddies in the flow, can be describe as:

$$\eta = \frac{1}{k_\eta} = \left(\frac{\nu^3}{\varepsilon} \right)^{1/4} \tag{7}$$

It is called the Kolmogorov length scale and k_η is the wave number corresponding to that scale; ν is a kinematic viscosity, and ε – the time rate of dissipation of turbulence kinetic energy into internal energy per unit mass.

In our investigation the dissipative length scale (5) was used. At the fig. 2 different kinds of turbulence scale are presented, for the Grid 3, the velocity of the flow U=10 *m/s* and the grid distance L_s=450 *mm* from the leading edge of the plate.

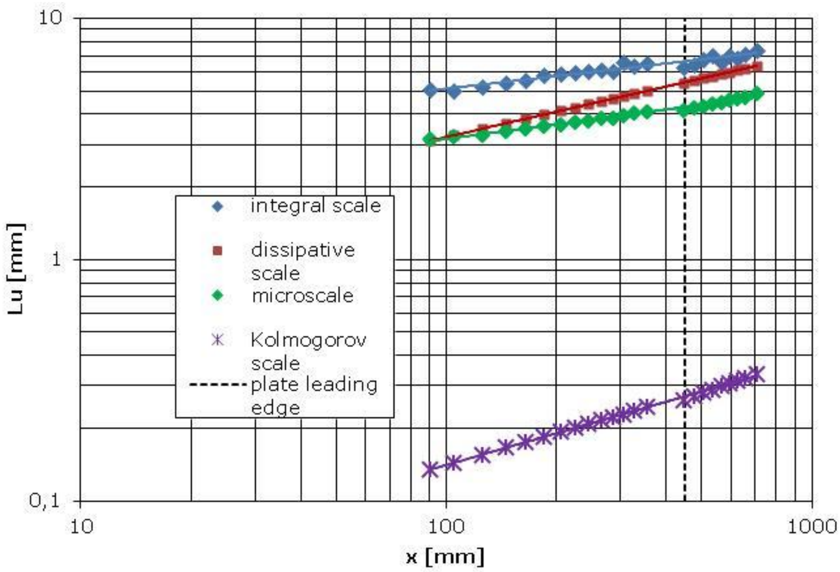

Fig. 2. Scales of turbulence for mean velocity U=10*m/s* and grid dimensions: d=1.6*mm*, M=4*mm*.

INVESTIGATION RESULTS

The results of present investigations seem to confirm the results of Jonas, but only if we make correlation for all grids together (Fig. 3). But when we look at every grid separately, the result seems to be quite opposite. The momentum thickness Reynolds number Re_t^{**}, from formula (8), for every grid apart increases as Lu increases. Besides, higher values of d (diameter of the grid wire) and M (the mesh size), gives higher values of the coefficient k and the exponent m.

$$\mathrm{Re}_t^{**} = kLu^m \tag{8}$$

The turbulence scale at the formula (8) can be made non – dimensional by the use of grid wire diameter d, (9):

$$\mathrm{Re}_t^{**} = k\left(\frac{d}{Lu}\right)^m \tag{9}$$

Fig. 4 shows the results of Re_t^{**} as a function of d/Lu, for grids of different dimensions. Coefficient k=156.7 and exponent m=−0.464. These results seem to confirm the Epic's assumption.

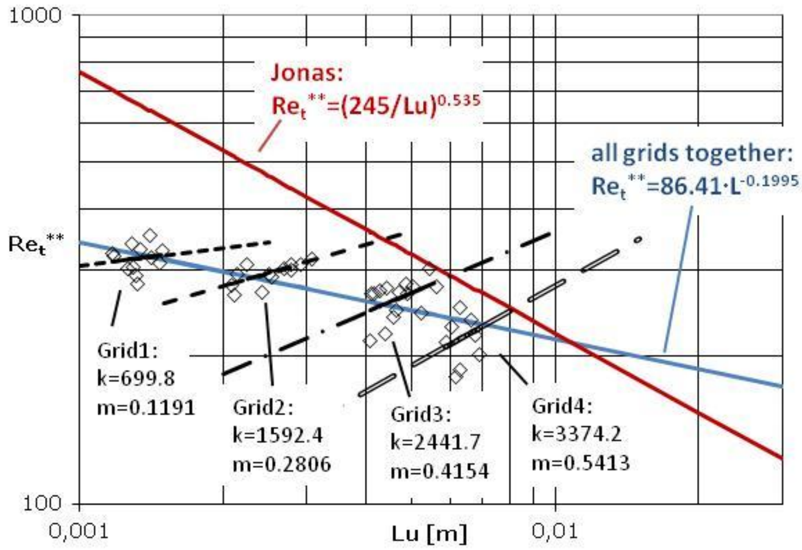

Fig. 3. Momentum thickness Reynolds number at the onset of transition as a function of turbulence scale

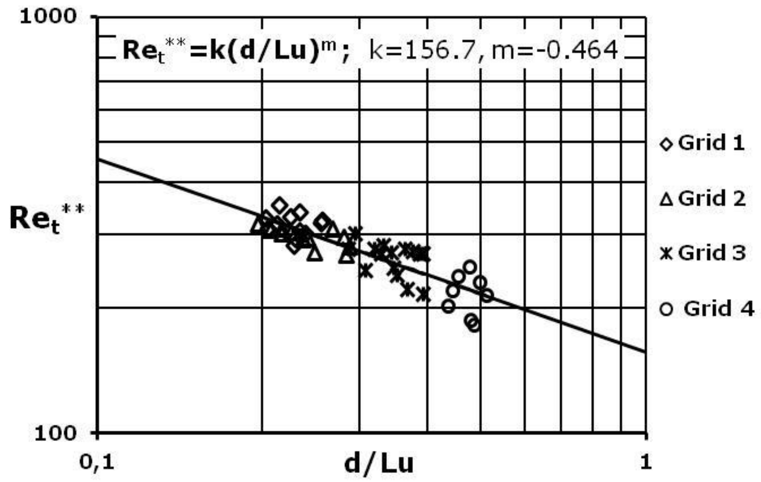

Fig. 4. Momentum thickness Reynolds number at the onset of transition as a function of d/Lu; correlation coefficient r=-0.86

CONCLUSIONS

To investigate the phenomena of turbulence generated by grids, longitudinal scales of turbulence were measured. The influence of the scale on the laminar – turbulent by – pass transition on a flat plate was searched. For this purpose, the momentum thickness Reynolds number, Re_t^{**}, was calculated.

Present investigations seem to confirm the results of Jonas, but only if we make correlation (as Jonas did) for all grids together. But when we look at the single grid, the result seems to be quite opposite.

Dividing the turbulence scale by the grid wire diameter, non – dimensional formula was obtained. Finally, we can say, the investigation seems to indicate that the reducing of turbulence scale provide an earlier inception, i. e. the lower momentum thickness Reynolds number. These results seem to confirm the Epic's assumption.

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