REMARKS ABOUT THE CONTROL OF THE GRID GENERATED TURBULENCE DECAY

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Abstract
The results of preliminary experiments to slow down the decay of the grid generated turbulence are presented. The effects were testing of a moderate mean velocity lateral gradient and of the distribution of velocity disturbances sources distribution.

Introduction

When investigating the evolution of a two-dimensional boundary layer attached to a flat plate it is necessary to create a two-dimensional external homogeneous flow, parallel to the plate. The research of flow phenomena occurring in technological applications requires modelling of deterministic and random flow disturbances in the free stream. Special attention is paid to the effect of free stream turbulence on boundary layer laminar-turbulent transition, friction drag, flow separation and miscellaneous interactions of shear layers in different stages of evolution. Passive turbulence generators make a good approximation of homogeneous isotropic turbulence (screens, square mesh plane/ biplane grids) or some sort of un-isotropic turbulence (e.g. many fluttering small flags bounded to a grid). The evolution of turbulent kinetic energy in such flow is described by the equation

$$\frac{Dk}{Dt} = P - \varepsilon\,, \quad k = \left(\delta_{ij}\,\overline{w_i w_j}\right), \quad P = -\overline{w_i w_j}\,S_{ij}, \quad \varepsilon = -\nu\overline{s_{ij}s_{ij}},$$

$$S_{ij} = \frac{1}{2}\left(\frac{\partial \overline{W}_i}{\partial x_j} - \frac{\partial \overline{W}_j}{\partial x_i}\right); \quad s_{ij} = \frac{1}{2}\left(\frac{\partial w_i}{\partial x_j} - \frac{\partial w_j}{\partial x_i}\right)$$

which implies the rate of change of turbulent kinetic energy equals to difference of the energy production P and to the dissipation ε. Following notation is applied: Cartesian coordinate system with x_1 as the main stream direction $(x_1.x_2,x_3)$, kinematic viscosity ν, Kronecker delta δ_{ij}. The common feature of all above mentioned passive turbulence generators is a rather fast

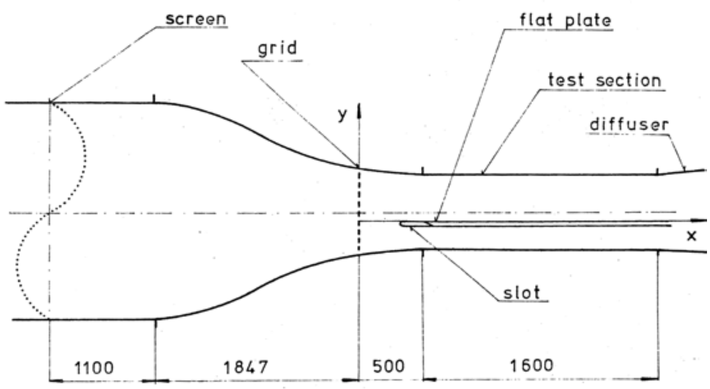

Figure 1: Experimental arrangement – control of grid turbulence by shear flow.

stream wise decay of turbulent fluctuations because there is no production – mean velocity gradients are missing. Preliminary studies on a possibility to introduce some additional turbulence sources into a steady flow were done formerly [1 and 2]. The revised and supplemented results are presented in this paper.

Control by a shear flow

With the aim to slow down the decay of the grid generated turbulence it was decided to produce a mean shear flow in the test section (0.5x0.9x1.5m^3) of the close type wind-tunnel IT AS CR. A fine screen built in the form of the letter “S” across the channel is able to create the mean shear flow

$$\frac{\partial \overline{W}_x}{\partial y} = \frac{d\overline{W}_x}{dy} > 0$$

The arrangement is shown in the Figure 1. The location and the shape of the S-profile were calculated after Elder [3] with the regard to the wind-tunnel lay out and with the pursuit of maximal mean velocity gradient [1]. Cartesian coordinate system (x, y, z) is introduced as shown in the Figure 1 with the origin at entry to the test section. After Elder [3] a linear mean velocity profile $\overline{W}_x(y)$ can be modelled by means of a homogeneous screen with cylindrical shape placed across the wind-tunnel channel. The generating lines are parallel to z-axes. The profile of the screen is described generally by the equation

$$\frac{x(y)}{L} = \frac{\lambda}{\pi^2 B E}\left[-0.915\pi\left(y/L\right) + \pi^2\left(y/L\right)^3/B + \pi^5\left(y/L\right)^5/60 + ...\right]$$

that is derived from formulas (7.1) and (7.3) presented in Elder (1959). Intervals of the variables *x/L* and *y/L* are determined by the height of the channel *L* and from the magnitude of the S-shape deflection – the location of maximum *(x/L)* is placed at *y/L* = ±0.294. Constants B and E describe changes in the tangential component and the normal one of momentum flow

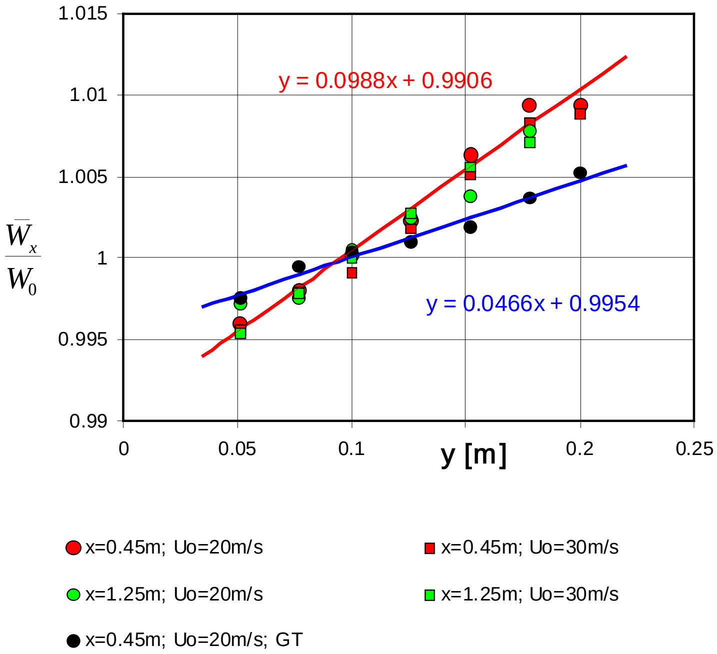

Figure 2: Mean velocity dimensionless profiles.

through the screen. Having in mind the aim "to reach maximum" of *dW/dy* and comply with the space limitations, the screen (CSN 153120, porosity 31%) was inserted upstream from the entry to the contraction nozzle and its shape was designed in form

$$\frac{x(y)}{L} = 0.303\left[-2.875\left(\frac{y}{L}\right) + 10.4\left(\frac{y}{L}\right)^3 + 5.07\left(\frac{y}{L}\right)^5\right]$$

The investigations of the modelled shear flow were done by Pitot-static probes and by a single hot-wire CTA-anemometer. Presented results relate to the relative velocity W_0 = 20 m/s (exceptionally 30 m/s) in the section 0.25 m downstream the entry of the working section.

The dimensionless profiles of the mean velocity in planes x = 0.45 m (circles) and x = 1.25 m (triangles) are shown in the Figure 2. Red symbols denote undisturbed flow downstream the "shear generator" at the section x = 0.45 m (green at 1.25 m). The black circles describe results taken downstream the "flags turbulence generator" inserted between the "shear generator" and the cross section x = 0.45 m. (The "flags turbulence generator" is a net of oscillating flags about 0.02 x 0.05 m^2, producing non-isotropic turbulence of intensity 14 percent at x ~ 0.4 m). Statistical estimates of the slopes of straight lines are 0.099 in case without turbulence generator and 0.047 downstream the flags generator. Apparently the increased turbulent diffusion results in the attenuation of the mean flow shear.

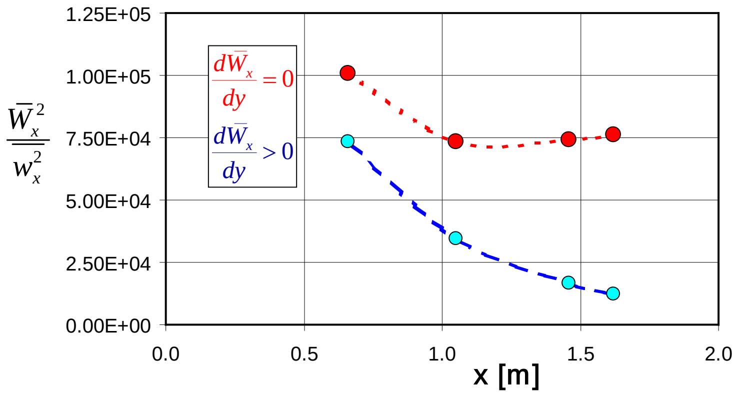

Figure 3: Comparison of the natural turbulence level development (red symbols) with turbulence development downstream of the „shear generator".

The course of natural turbulence level i.e. neither turbulence generator nor the shear generator were inserted upstream the test section (red circles) and with the shear generator inserted across the channel (blue circles) are shown in Figure 3. Obviously natural turbulence level, about 0.3 percent increases downstream up to about 0.4 percent in the case of $grad\,\overline{W} = 0$. Modelling the shear flow, the turbulence level increases about twice between x = 0.6 m and 1.6 m up to about one percent at the end of the test section.

Results on the grid turbulence decay, plotted in Figure 4, illustrate the effect of tested shear flow on turbulence amplification. The values corresponding to the uniform flow are marked by red symbols and the relevant data measured in the shear flow are marked by blue symbols. The distributions valid in the uniform flow demonstrate that the grid turbulence was in the developing state. Evidently the modelled shear flow contributes to turbulence production. The delayer decay (lower slope of blue lines) and at least suppressed decay (constant course) prove the stabilizing effect of shear flow.

As partial conclusion: modelling homogeneous shear flow (in z- direction) generates an additional turbulent energy supply into a dissipating turbulent flow e.g. grid turbulence. It induces the increase of turbulent intensity and the reducing the damping rate.

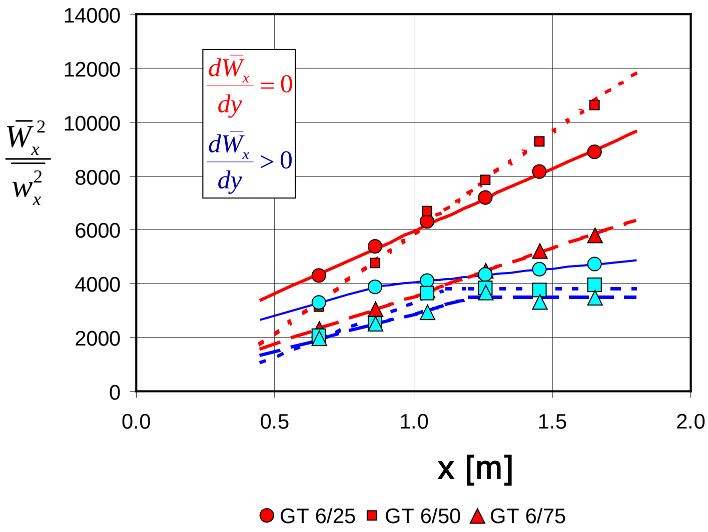

Figure 4: Decay of grid turbulence in the uniform flow (red symbols) and in the shear flow (blue symbols).

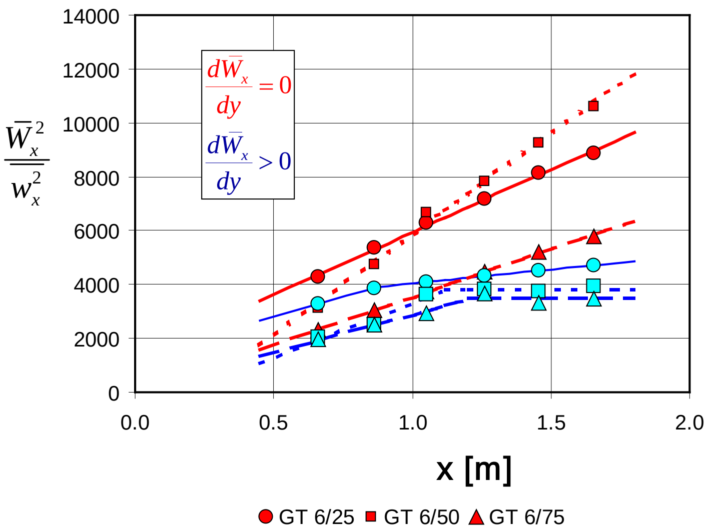

Figure 4: Decay of grid turbulence in the uniform flow (red symbols) and in the shear flow (blue symbols).

Control by layout of disturbances sources

The principal idea of this preliminary study [2] was to reduce the decay of grid turbulence by means of a distribution of disturbances sources in the flow field. The sources distributed regularly downstream from a grid are producing turbulent kinetic energy that might compensate, to some extent, the dissipation losses. The tested experimental set up in the close type wind-tunnel IT AS CR is shown in the Figure 5.

Due to the relatively short test section (1.5 m) the square mesh bi-plane grid (cylindrical rods: diameter = 10 mm, mesh = 25 mm) is fixed perpendicularly to the tunnel axis 0.5 m upstream from the outset of the working section, in the section x = -0.5 m. The "fence channel" (0.28 x 0.28 x 1.5 m^3) is inserted in the test section, fastened to the grid and

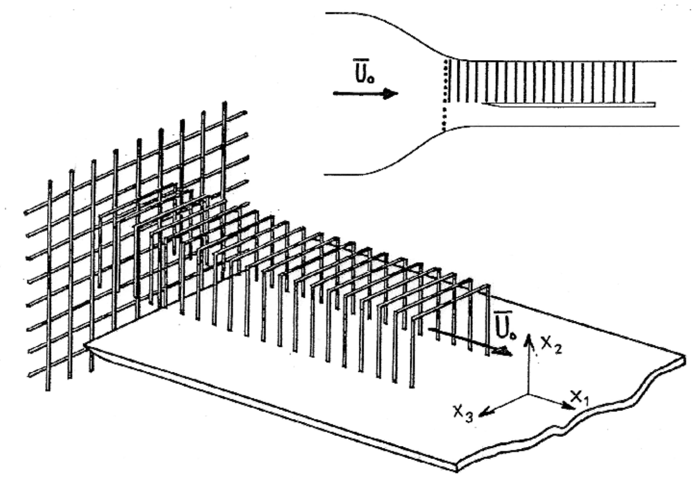

Figure 5: Experimental arrangement of the "fence generator" of turbulence.

placed on the flat plate. The scheme of this set up is shown in Figure 5. The upper wall and the side ones of the "fence channel" are created by the system of parallel square rods (10x10 mm^2) with the spacing 25 mm. The lower wall constitutes the smooth flat plate with an investigated boundary layer. The leading edge of the plate is identical with the z-axis (x = 0). This configuration was designated the "fence generator" of turbulence.

The mean velocity was measured by means of a Pitot-static tube in the plane (x, y) at a height y = 0.05 m. The single wire CTA-anemometer The turbulent fluctuations of the longitudinal velocity component were measured in similar locations.

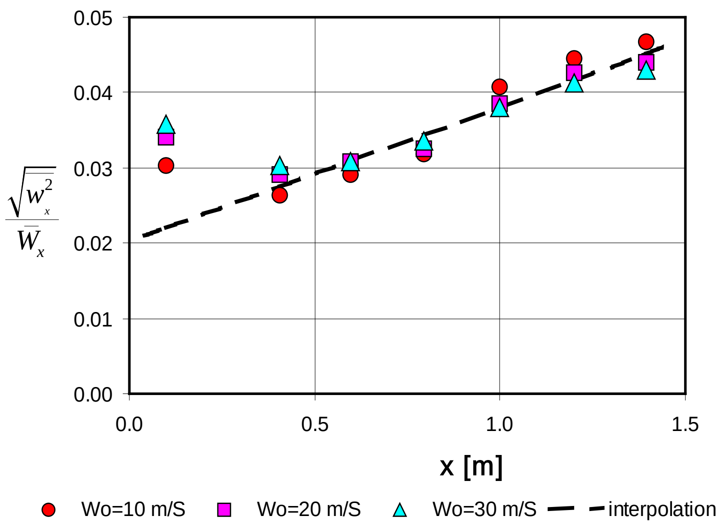

Figure 6: Distributions of turbulence intensity inside the fence channel downstream the grid 10/25.

The distribution of the mean velocity inside the “fence channel” was found out uniform in the limits of measuring accuracy for x > 0.1 m. Note, the “fence channel” has no bottom from x = -0.5 m up to the leading edge of the plate. As follows from the distribution of turbulence intensity shown in Figure 6, the intensity of longitudinal fluctuations begun moderately grow from the distance x ~ 0.3 m. Turbulent disturbances generating due to the action of pickets represent production of additional turbulence. Thus turbulence production prevails the dissipation. It was found from exploratory measurements that the cross section of the “fence channel” and the spacing of the side fences control the ratio of production to dissipation.

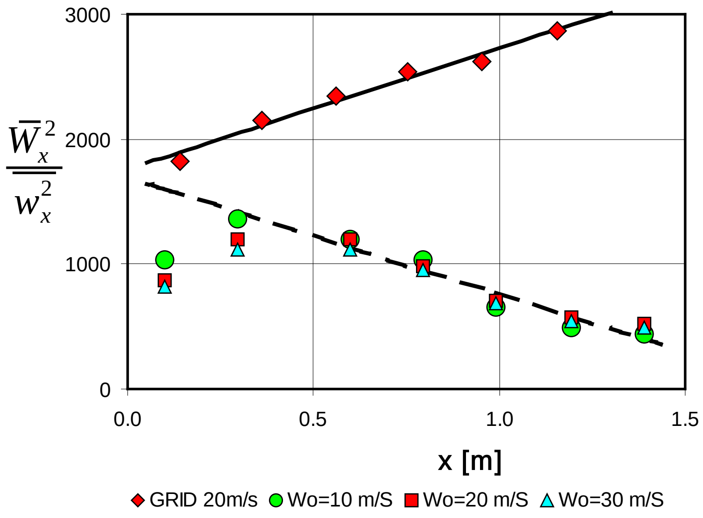

Figure 7: Decay of the longitudinal component of velocity fluctuations downstream of the grid 10/25 (rhombus) and inside the fence channel attached to the same grid.

The comparison of two examples of turbulence decay development is shown in Figure 7. The first example (rhombus) is the decay downstream the isolated grid 10/25 (across the working section, 0.5 x 0.9 m^2) and the second ones are the decay measurements at different relative velocities inside the “fence channel” connected to the original grid. Dissipation prevails the production only on small piece of the channel length, say up to x = 0.25m. Next the turbulence production predominate the dissipation.

Interesting knowledge was also received from the measurement of the skewness factor *Su* and the flatness one *Fu*. Small negative values of *Su* indicate a turbulent transport of kinetic energy from the rod walls to the core of flow in the channel. The flatness *Fu* equals three with a small scatter. The value of the longitudinal integral scale of generated turbulence was estimated between 16 mm up to 18 mm from the autocorrelation measurements with using the Taylor’s hypothesis.

A similar method of inserting the net of singular turbulent disturbances sources was realized in the small high-speed wind tunnel (0.1 x 0.1 m^2) [4]. Sidewalls of the working section were made from perforated plates (diameter of gaps 2 mm; a checkerboard pattern with mesh 3 mm). Two-dimensional mean flow with a long part of constant turbulence level was accomplished.

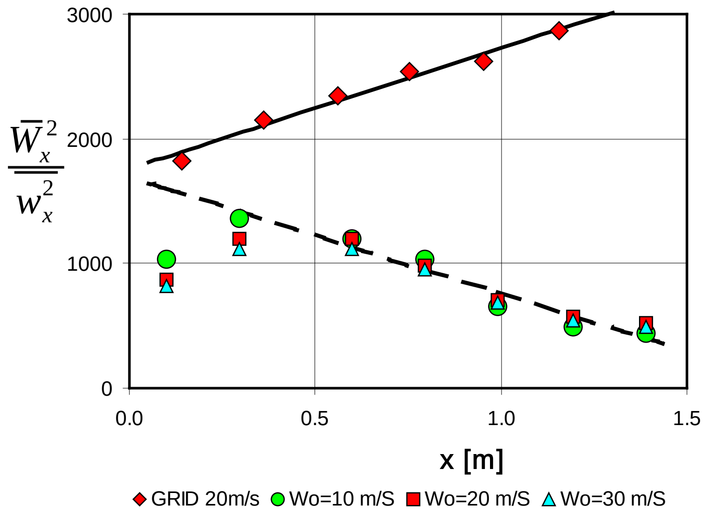

Figure 7: Decay of the longitudinal component of velocity fluctuations downstream of the grid 10/25 (rhombus) and inside the fence channel attached to the same grid.

Conclusions

Two methods of the grid generated turbulence control were checked out namely the modelling of the lateral gradient of the longitudinal velocity and the distribution of disturbances sources in the flow field.

Modelling homogeneous shear flow (in z- direction) generates an additional turbulent energy supply into a dissipating turbulent flow e.g. grid turbulence. It induces the increase of turbulent intensity and the reduction in the damping rate.

The sources of the flow disturbances (jet/wake) distributed regularly downstream from a grid are producing turbulent kinetic energy that can compensate, to some extent, the dissipation losses.

The accomplishment equilibrium between turbulence production and dissipation in a given part of the working section depends on the possibility to match up the dimensions of wind-tunnel lay out with the selected equilibrium region. After the received experiences this represents laborious hard task.

Acknowledgements

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