ON RELATIONSHIP BETWEEN INSTANTANEOUS AND STATISTICAL PROPERTIES OF THE DETERMINISTIC TURBULENCE

V.I. Borodulin[1], Y.S. Kachanov[1] & D.A. Mischenko[1]
[1] *Institute of Theoretical and Applied Mechanics of SB Russian Academy of Sciences, Novosibirsk, Russia*

Abstract Multiple reproduction of instantaneous structure of the deterministic post-transitional turbulent boundary layer is performed experimentally at different, fully controlled initial-disturbance conditions. Every particular realization of the instantaneous flow structure was produced by a particular set of signals used for excitation of the primary laminar boundary layer. The particular instantaneous flow structure was reproduced many times (up to three hundred thousand times in one set of measurements) by means of a precise reproduction of the initial disturbance conditions. The independence of statistical characteristics of the flows, produced by different initial signal realizations, from the particular instantaneous-flow structure is analyzed.

INTRODUCTION

The deterministic turbulence found and studied in [1, 2] represents a post-transitional wall-shear flow that is turbulent according to the generally accepted statistical characteristics but possesses, meanwhile, a significant degree of determinism, i.e. reproducibility of its instantaneous structure. The deterministic turbulence can occur in those cases when transition is caused by convective-type instabilities. Some detailed recent experimental and numerical studies of late stages of transition (see e.g. references [3, 4]) have not revealed any definite mechanisms of the final flow 'randomization' occurred, as believed, at late stages of the boundary-layer laminar-turbulent transition. Therefore, the question appeared: "Is it possible that the instantaneous structure of transitional flow would remain deterministic, reproducible (at repetition of the same initial conditions) at super-late, final stages of transition and even in the post-transitional fully turbulent boundary layer?" The positive answer to this question was obtained recently in [1, 2]. However, a question remained: "Whether the deterministic turbulence corresponds exactly to the ordinary random turbulent flow or not?" If the answer is affirmative, the stochastic properties of such turbulence (such as mean-velocity profiles, disturbance amplitude profiles, spectra of turbulent fluctuations, etc.) must be: (*i*) independent of particular realization of the deterministic turbulent flow and (*ii*) identical to those of the ordinary (stochastic) turbulence. *The present study is devoted to investigation of the answer to the point (i) indicated above.*

One has to note that the investigation of the deterministic turbulence is very important because, in particular, it represents a powerful tool for both applied and fundamental research. Indeed, the first practical application of the deterministic turbulence method, performed in [5, 6], has been demonstrated its great efficiency. The instantaneous flow field of a deterministic turbulence was documented in detail in those experiments in a boundary layer. Then a Large-Eddy-Break-Up (LEBU) device was installed at a position, where the boundary layer was already practically turbulent, and the same instantaneous flow field was documented again. Detailed comparison of two flow fields allowed us to see very clearly the physical mechanism of the LEBU device affect on the turbulent boundary layer.

SOME RESULTS OF MEASUREMENTS

The present experiments were performed in a laminar boundary layer at fully controlled disturbance conditions at free-stream speed of about 9 m/s. The laminar-turbulent transition and the deterministic turbulence were produced due to a natural development of Tollmien-Schlichting (TS) waves. Fig. 1 demonstrates the neutral stability curve for the studied flow. The uncontrolled background velocity disturbances were less than 0.03% of incident flow velocity (in the frequency range above 1 Hz). The controlled initial disturbances were produced by a generator of TS-waves. The streamwise evolution of them started from their linear amplification, through nonlinear stages, and ending with the fully turbulent flow. An example of results of measurements of one of realizations of instantaneous structure of the deterministic turbulent flow is presented in Figs. 2 and 3. The two figures are obtained by a single hot-wire probe after scanning (point by point) the flow field in the (y, z, t)-space. Thus, all plots represent just several cross-sections of one array of experimental data related to one particular streamwise position x = 520 mm, which corresponds approximately to the beginning of the post-transitional turbulent region. The figures display contours of constant values of the instantaneous streamwise velocity component within the deterministic turbulent boundary layer. Shown in Fig. 2 are three different sections of the instantaneous flow field displaying effectively some plan views, obtained at wall-normal coordinates y = 1.0, 4.2, and 6.5 mm. The instantaneous flow structure is seen to be rather different at these distances. Two cross-sections of the same instantaneous flow field by planes perpendicular to the wall and parallel to the mean-flow direction presented in Fig. 3 are obtained for the spanwise coordinates z = −0.5 and +4.5 mm. The general character of flow structures is similar at these particular spanwise locations, while the exact shapes and positions of the regions of enhanced and reduced instantaneous flow velocities are significantly different.

There are the following main conclusions drawn based on the results of the present experimental study. It is found that variation of initial disturbance conditions changes significantly the instantaneous structure of the post-transitional deterministic turbulent flow. However, the most important statistical characteristics of all studied flow realizations turned out to remain practically the same and are typical to those of the regular (stochastic) turbulent boundary layer.

The study is partly supported by the Russian Foundation for Basic Research (grant No 13-01-00479 a).

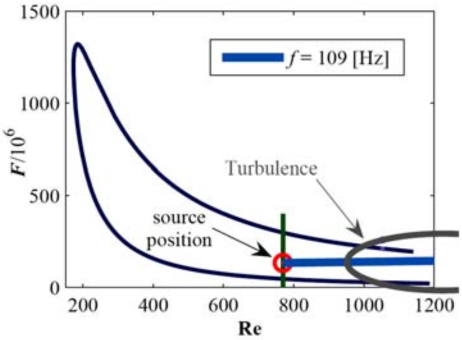

Figure 1. Neutral stability curve for experiments [1], [2] and the present one. Initial disturbances represent superposition of 2D Tollmien-Schlichting wave at 109 Hz and broadband noise which is random in time and space.

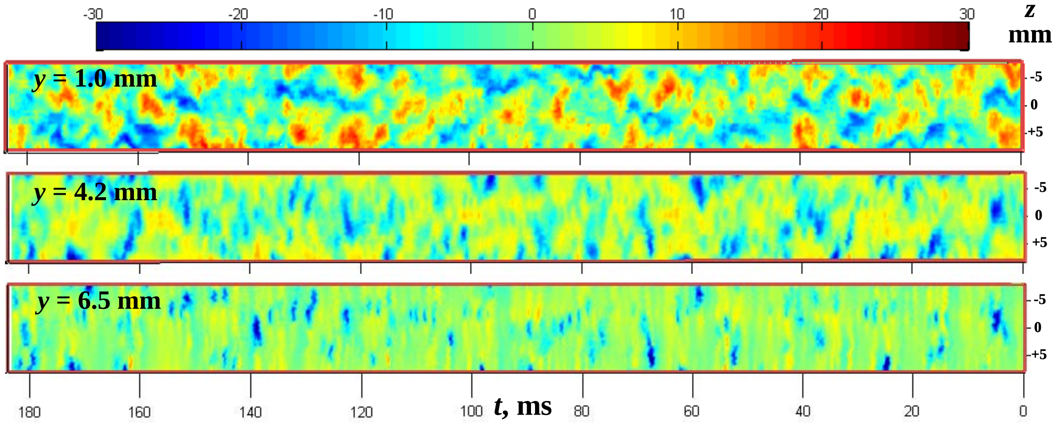

Figure 2. Example of three plane-view sections of an instantaneous streamwise-velocity field measured in the deterministic turbulent flow at three wall-normal locations for one particular case of boundary-layer excitation by controlled perturbations. x = 520 mm.

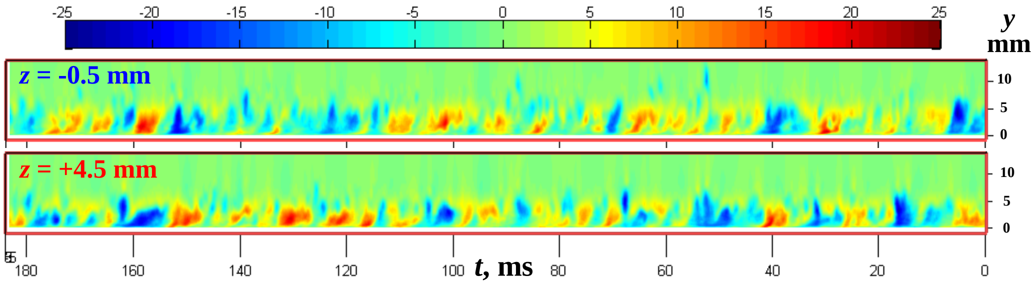

Figure 3. Example of two side-view sections of the instantaneous streamwise-velocity field shown in Fig. 2 measured in the deterministic turbulent flow at two spanwise locations: z = −0.5 and +4.5 mm. x = 520 mm.

References

[1] V.I. Borodulin, Y.S. Kachanov, and A.P. Roschektayev. The deterministic wall turbulence is possible. In: *Advances in Turbulence XI*. Proceedings of 11th EUROMECH European Turbulence Conference, June 25–28, 2007, Porto, Portugal (J.M.L.M. Palma and A. Silva Lopes, eds.) – Heidelberg: Springer, 2007, pp. 176–178.

[2] V.I. Borodulin, Y.S. Kachanov, and A.P. Roschektayev. Experimental detection of deterministic turbulence. *J. Turbulence*. **12**, N 23:1–34, 2011.

[3] V.I. Borodulin, V.R. Gaponenko, Y.S. Kachanov, D.G.W. Meyer, U. Rist, Q.X. Lian, and C.B. Lee. Late-stage transitional boundary-layer structures. Direct numerical simulation and experiment. *Theoret. Comput. Fluid Dynamics.* **15**: 317-337, 2002.

[4] V.I. Borodulin, Y.S. Kachanov, and A.P. Roschektayev. Turbulence production in an APG-boundary-layer transition induced by randomized perturbations. *Journal of Turbulence.* **7**, N 8: 1-30, 2006.

[5] V.I. Borodulin, Y.S. Kachanov, and A.P. Roschektayev. Investigation of LEBU-device effect on turbulent boundary layer structure by means of 'deterministic turbulence method'. In: *XIV International Conference on Methods of Aerophysical Research*. June 30 − July 6, 2008. Proceedings (Ed. V.M. Fomin) — Novosibirsk: ITAM SB RAS, 2008, 10 pp.

[6] V.I. Borodulin, Y.S. Kachanov, and A.P. Roschektayev. Application of the deterministic turbulence method to study of LEBU-device mechanism. In: *Advances in Turbulence XII.* Proceedings of the 12th EUROMECH European Turbulence Conference, Springer Proceedings in Physics. Vol. 132 (B. Eckhardt, ed.) – Springer: Berlin, Heidelberg, 2009, pp. 313–316.