Late–Stage Transitional Boundary–Layer Structures. Direct Numerical Simulation and Experiment.

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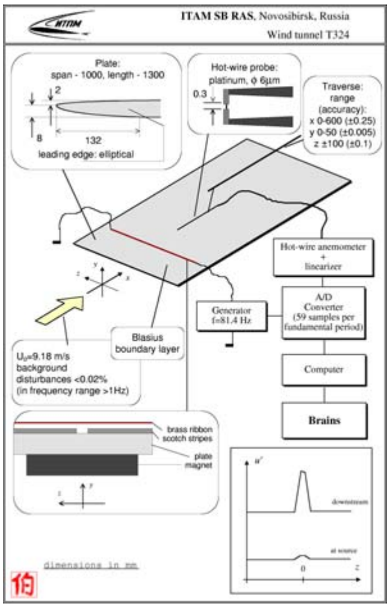
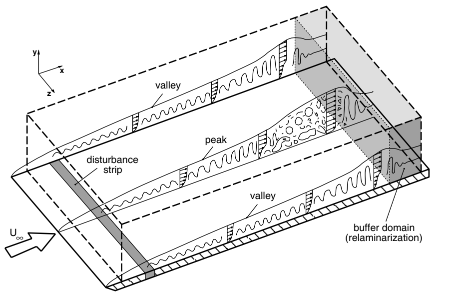
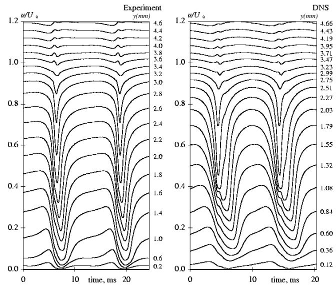
Experimental setup



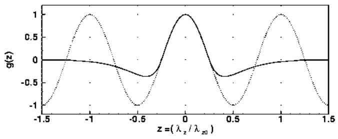
DNS integration domain



Timetraces at 1–spike stage



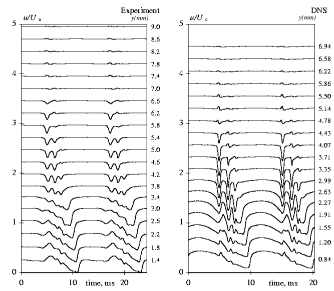
Localized disturbance generation



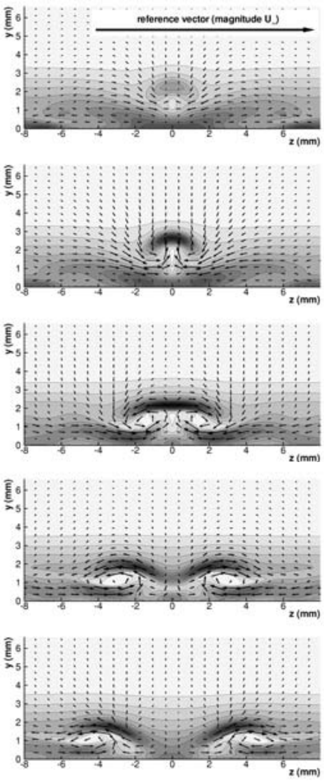
- simulation of K–type breakdown using the full Navier–Stokes equations for incompressible fluid (spatial model)
- 2D Blasius baseflow ($Re_{\delta 1}[x0]=580$)
- controlled disturbance generation by suction and blowing:

  2D TS–wave (3–4%, 98.4 Hz) and 3D oblique waves generated by a steady modulation in spanwise direction
- localized disturbance in spanwise direction in order to avoid mutual interaction of the vortices in adjacent peak planes
- disturbance waves grow downstream and give rise to the development of vortical structures in the flow field

Timetraces at 3–spike stage

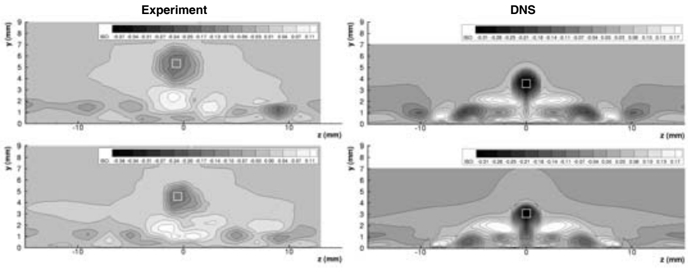


Shear–layer structure at 1–spike stage

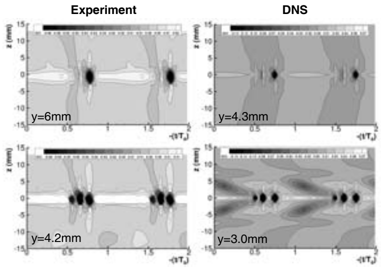


Velocity gradient and velocity vectors in yz–plane at 5 time instants (DNS).

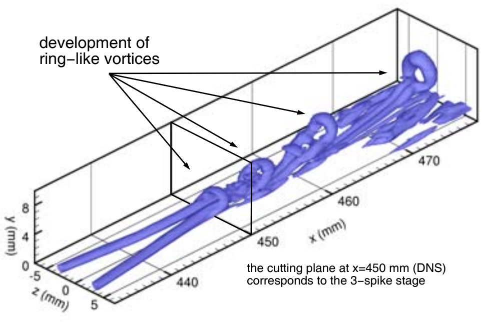
Ring–like vortices and the near–wall disturbances at 3–spike stage



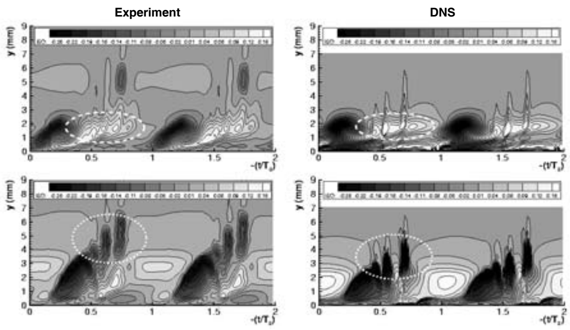
Streamwise component of disturbance velocity. Time instants of the occurrence of the first (top) and second (bottom) spike which are generated by a ring–like vortex moving through the cutting plane depicted below. The spike positions are marked with small rectangles.



Streamwise velocity disturbance at two different distances from the wall.

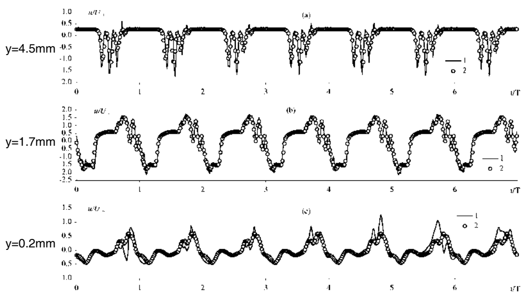


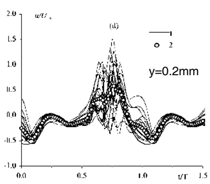
Vortex visualization of DNS data.



Comparison of the streamwise disturbance velocity at a spanwise position appr. 2mm off–peak (top), with the peak position (bottom). The spikes (dotted lines) are located in the center of the ring–like vortex. The induced positive velocity fluctuations in the off–peak plane are marked with dashed lines.

Flow randomization observed in experiment





1: instantaneous data (solid lines)

2: averaged data (circles)

Flow randomization due to instabilities in the near–wall region occurring at first close to the wall where positive velocity disturbances are induced by the ring–like vortices.

Conclusions

- **A detailed quantitative comparison between experiment and DNS was performed for the late non–linear stages of the boundary–layer transition process.**
- **A very good agreement between the measured and the simulated development of the flow field was observed for the periodic (deterministic) components of the streamwise velocity and the spanwise vorticity fields.**
- **In experiments as well as in simulations it was found that the ring–like vortices (which generate the well–known spikes) induce intensive positive velocity fluctuations in the near–wall region below the ring–like vortices. These fluctuations have the same temporal and spatial scale as the ring–like vortices and propagate downstream with the same high (almost free–stream) speed. Thus, a new high–shear layer evolves in the near–wall region.**
- **In experiments the induced near–wall perturbations have a significant irregular component. These non–periodical motions play an important role in the process of flow randomization and in the final transition to turbulence which starts below the ring–like vortices in the vicinity of the peak position.**

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