Experimental setup

DNS integration domain

Timetraces at 1–spike stage

Localized disturbance generation

Timetraces at 3–spike stage

Shear–layer structure at 1–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.

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

Comparison of the streamwise disturbance velocity at a spanwise position approx. 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

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.