# Transient growth induced breakdown and 'direct' breakdown.

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It is well known that in boundary layers exposed to strong levels of free-stream turbulence (>5%) as for instance present in gasturbines transition occurs rapidly, bypassing the natural transition mechanism. Morkovin[1] showed in his route map to turbulence the presence of two types of bypass mechanisms. The first indicated by mode D is the transient growth mechanism, secondly the 'direct' mechanism (mode E) exists.

The first disturbances present in a boundary layer during bypass transition are the elongated alternating low- and high-speed streaks. In the transient growth case breakdown to turbulence is initiated by a secondary instability on the streaks[2]. In the 'direct' mechanism breakdown is a result of free-stream disturbances which directly interact with the streaks[3].

Both natural (non-triggered) bypass instabilities have been studied using a water channel. Visualization results reveal the presence of a sinuous and varicose secondary instability mode[4] and a more compact 'direct' instability mode.

The experimental set-up consists of a water channel with a camera traversing system. In the measuring section of the channel a flat plate boundary layer is exposed to free-stream turbulence (Tu = 6.7 %) generated by a static turbulence. A velocity field and a visualization field are measured at the same moment in time and space in the boundary layer using a combined PIV-LIF technique mounted on the traversing system. By setting the translation speed of the traversing system approximately equal to group velocity of the natural secondary instability the developments in a 'contained' fluid area around a natural secondary are determined. The authors want to emphasise that the random appearance of the natural instability makes it experimentally difficult to measure a 'contained' fluid area in which an instability is initiated.

The main features in the development of the sinuous and varicose secondary instabilities are determined. The measurements show that in the sinuous secondary instability mode multiple low- and high-speed streaks, which interact with each other in spanwise direction, are involved. In the varicose case only two streaks are active, a streamwise interaction is present between a high speed streak which frontally runs into a low speed streak. In both instabilities discontinuities in the streak configuration are present. At these discontinuity locations a strong interaction between the local high and low speed streaks is present and with the development of the streaky base flow in streamwise direction vortices appear in the vicinity of these locations. These vortices result in the presence of the typical sinuous (staggered vortex configuration) or varicose motions (symmetrical vortex configuration) in the unstable boundary layer, see figure 1.

Besides these sinuous and varicose modes the existence of a direct breakdown mechanism was established. This type of breakdown appears to be connected to

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[1]Morkovin, *AIAA paper* **84**, 0009 (1994).

[2]Brandt et al., *J. Fluid Mech.* **517**, 167 (2004).

[3]Jacobs and Durbin, *J. Fluid Mech.* **428**, 185 (2004).

[4]Mans et al., *Exp. Fluids.* **39(6)**, 1071 (2005).

random branches occurring at the sides of the low speed streaks, figure 2. It seems that at the sides of the branche free-stream disturbances directly interact with the low-speed branche. As a result vortices appear at the sides of the branche. The vortices strongly interact with each other as the flow develops in streamwise direction resulting in a rapid breakdown into a turbulent spot.

The results indicate that both mode D (sinuous and varicose) and mode E (direct) breakdown occurs under the present experimental conditions.

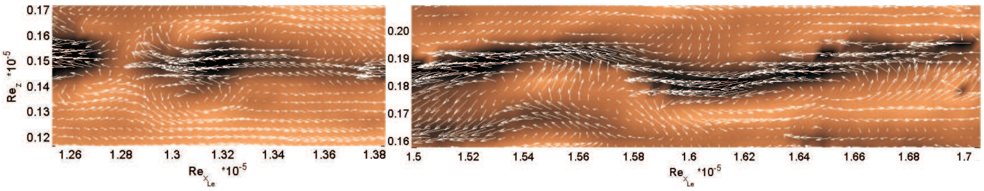


Figure 1: The varicose (left) and sinuous (right) velocity fields during breakdown.

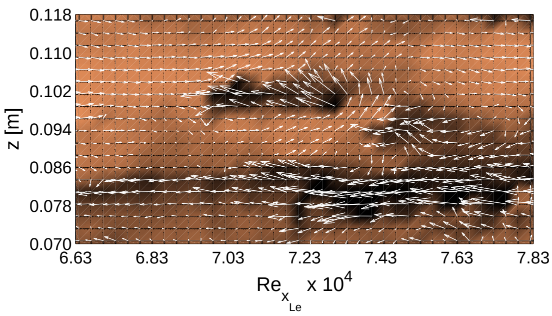


Figure 2: The 'direct' velocity fields during breakdown.