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**The minimal seed of turbulent transition in the boundary layer.** (English) Zbl 1241.76246  
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Summary: This paper describes a scenario of transition from laminar to turbulent flow in a spatially developing boundary layer over a flat plate. The base flow is the Blasius non-parallel flow solution; it is perturbed by optimal disturbances yielding the largest energy growth over a short time interval. Such perturbations are computed by a nonlinear global optimization approach based on a Lagrange multiplier technique. The results show that nonlinear optimal perturbations are characterized by a localized basic building block, called the minimal seed, defined as the smallest flow structure which maximizes the energy growth over short times. It is formed by vortices inclined in the streamwise direction surrounding a region of intense streamwise disturbance velocity. Such a basic structure appears to be a robust feature of the base flow since it is practically invariant with respect to the initial energy of the perturbation, the target time, the Reynolds number and the dimensions of the computational domain. The minimal seed grows very rapidly in time while spreading, and it triggers nonlinear effects which bring the flow to turbulence in a very efficient manner, through the formation of a turbulence spot. This evolution of the initial optimal disturbance has been studied in detail by direct numerical simulations. Using a perturbative formulation of the Navier-Stokes equations, each linear and nonlinear convective term of the equations has been analysed. The results show the fundamental role of the streamwise inclination of the vortices in the process. The nonlinear coupling of the finite amplitude disturbances is crucial to sustain such streamwise inclination, as well as to generate dislocations within the flow structures, and local inflectional velocity distributions. The analysis provides a picture of the transition process characterized by a sequence of structures appearing successively in the flow, namely,  $\Lambda$  vortices, hairpin vortices and streamwise streaks. Finally, a disturbance regeneration cycle is conceived, initiated by the fast nonlinear amplification of the minimal seed, providing a possible scenario for the continuous regeneration of the same fundamental flow structures at smaller space and time scales.

**MSC:**

[76F06](#) Transition to turbulence

[76D10](#) Boundary-layer theory, separation and reattachment, higher-order effects

Cited in **1** Review  
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**Keywords:**

[boundary layer stability](#); [nonlinear instability](#); [transition to turbulence](#)

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