Physics of transitional shear flows

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Abstract
A summary of recently published book on hydrodynamic stability and transition phenomena in incompressible shear layers with the same title as that of the present contribution to the EUCASS proceedings is given. The objective is to emphasize the milestones of the edition which is aimed, most of all, at university and postgraduate students starting with the problem and may be of interest for the experienced "transition" community, as well.

1. Motivation

The origin of turbulence in shear flows is a fundamental problem of fluid mechanics being the focus of long-term studies. Most specialists are familiar with the classical "Boundary layer theory" by Hermann Schlichting available in several editions, e.g., [1] with a lot of experimental material included making an attractive description of the transition phenomena. Also a bunch of full-weight monographs were issued in the second half of the 20th century considered in their time as reference and text books devoted to the subject, [2–4] seem most well known. Last decade is marked by appearance of several new titles, e.g., [5–7]. Most of them, in contrast to the Schlichting's approach, concentrate the reader's attention on theoretical foundations; however, there are a lot of experimental evidences which are quite diverse and up to now were not rigorously supported by theoretical and numerical results.

The present book of 2012 is aimed to close the gaps. In essence, it is a textbook with a balanced proportion of the theoretical and the experimental material on hydrodynamic instability and transition phenomena in incompressible shear layers which is scattered among other monographs, conference proceedings and journal papers.

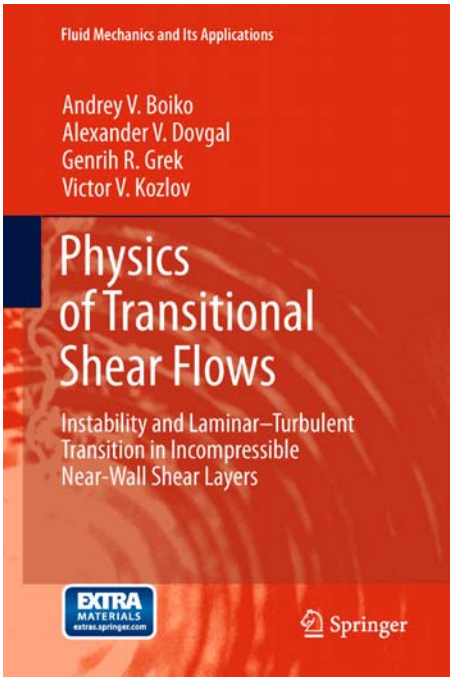

Figure 1: Book cover

2. Main body

The starting point is the concept of hydrodynamic stability. First of all, basic formulations and fundamentals of the classical linear stability theory reducing small-amplitude shear-layer disturbances to elementary waves are outlined. The following consideration focuses the results, both theoretical and experimental, on linear perturbations of parallel shear layers (plane Couette and Poiseuille flows) which are the most simple in the present context. Effects of streamlines non-parallelity on stability characteristics become pronounced in a flat-plate boundary layer as a canonical near-wall flow which was subjected to extensive studies for many years. The problem is further complicated with different modifiers of the linear instability including pressure gradients, surface curvature, fluid suction, heat transfer, boundary layer separation, etc., providing a general view of key aspects of the stability analysis.

Indeed, the transition to turbulence initiated by amplification of a solitary instability wave is an exception to be found in specific conditions, only. Most of all, the initial stage of the laminar flow breakdown in quiet environment is dominated by small-amplitude disturbances localized in space (time). This makes reasonable to consider evolution of linear wave packets of the shear-layer oscillations as a separate subject of the transition problem. Then, at increase of the flow perturbations, e.g., surface roughness and external turbulence, there is one more instability phenomenon to be emphasized. It appears as transient non-modal growth of the shear-layer disturbances which is beyond the classical stability approach. The associated stationary and quasi-stationary deformations of the laminar shear flow known as “streaky structures” are much different from the wavy perturbations and also the focus of the present book.

The next point is the generation of shear-layer disturbances contributing to the transition. In convectively unstable configurations they are due to flow response to external forcing including free-stream turbulence, acoustic oscillations, surface vibrations, etc. Thus, a special topic is examination of different paths of the excitation of amplifying shear-layer perturbations. This makes the so-called “receptivity” problem which is discussed in detail, as well.

Proceeding step-by-step with the transition process, one comes to its nonlinear stage where the originally small-amplitude disturbances grow beyond a certain amplitude threshold initiating secondary instabilities whose initial behavior is predicted by solutions to the linear equations of motion. Further downstream, the flow perturbations become fully nonlinear with a variety of their interactions inherent to basic scenarios of the shear-layer transition. A description of the final onset of turbulence, mostly phenomenological, is presented in the final sections of the book.

3. Some other features

Following new trends, multimedia files rich with movie clips and color pictures supplement the book providing illustrations of the instability phenomena in shear layers. Some graphic examples of the transition events are presented below, for the whole exposition of the supplementing material see `http://extras.springer.com`.

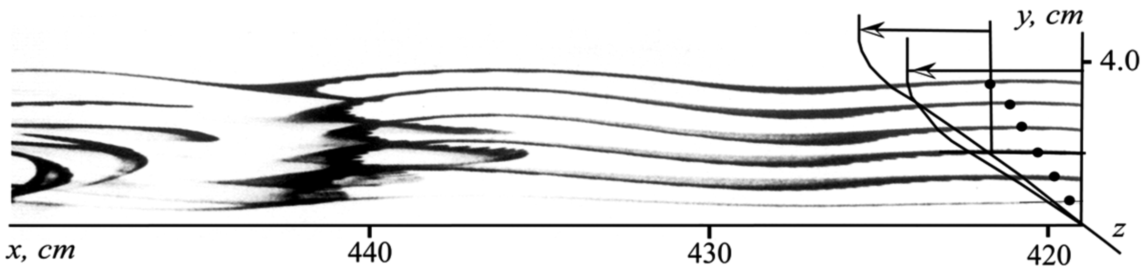

Figure 2: Visualization of laminar flow disturbances in a boundary layer obtained by F.X.Wortmann, side view. At the right part of the figure, two-dimensional waves are observed amplifying downstream; flow is from right to left

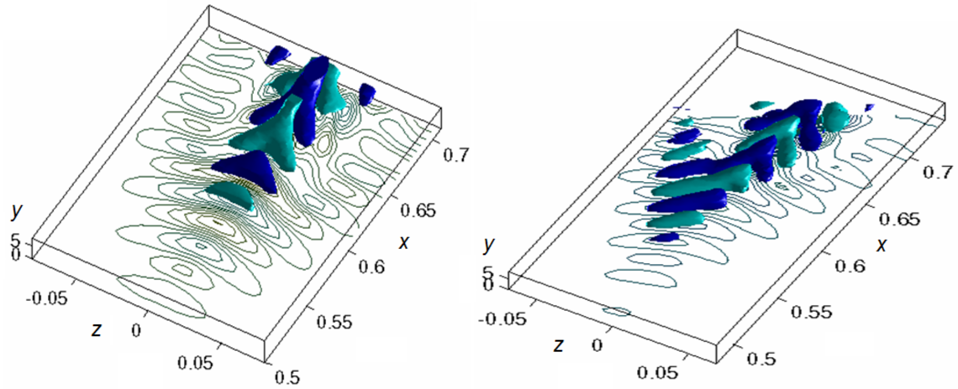

Figure 3: Wave packets of time-periodic disturbances generated locally on a wing in 2D flow (*left*) and at a 30-degree sweep (*right*). A pronounced effect of the cross flow on the oscillations is well seen

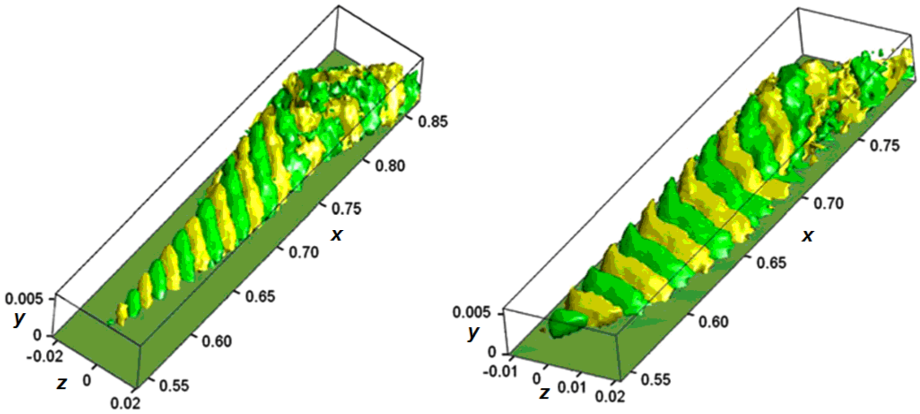

Figure 4: Secondary oscillations of stationary streamwise vortices in a swept-wing boundary layer, instantaneous isosurfaces of positive and negative velocity perturbation shown in *green* and *yellow*. Spatio-temporal distributions of the disturbances are somewhat different (*left* vs *right*) due to particular conditions of the vortices generation

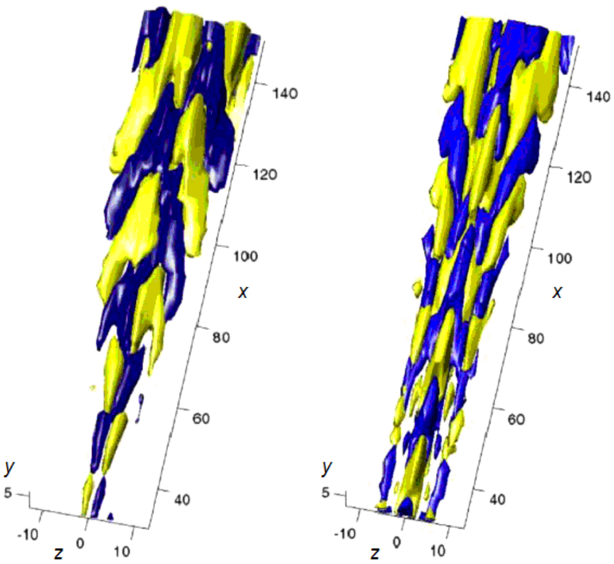

Figure 5: Sinusoidal (*left*) and varicose (*right*) instabilities of the streaky structure in a flat-plate boundary layer, instantaneous isosurfaces of positive and negative velocity perturbation shown in *blue* and *yellow*

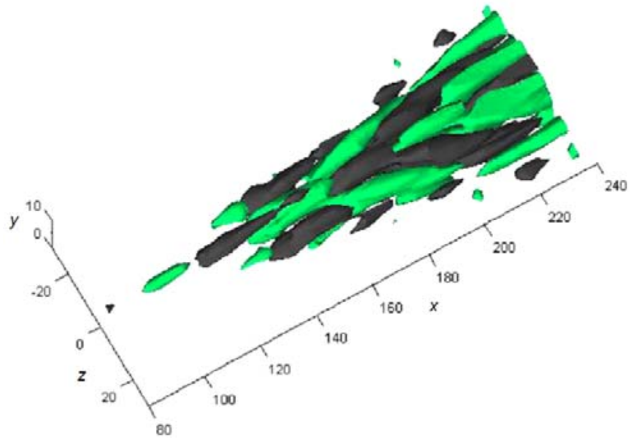

Figure 6: Varicose instability of the streaky structure in an adverse-pressure-gradient boundary layer, instantaneous isosurfaces of positive and negative velocity perturbation shown in *dark* and *green*. As is seen, the secondary perturbations spread much faster in the transverse direction (*z*), as compared to Fig. 5

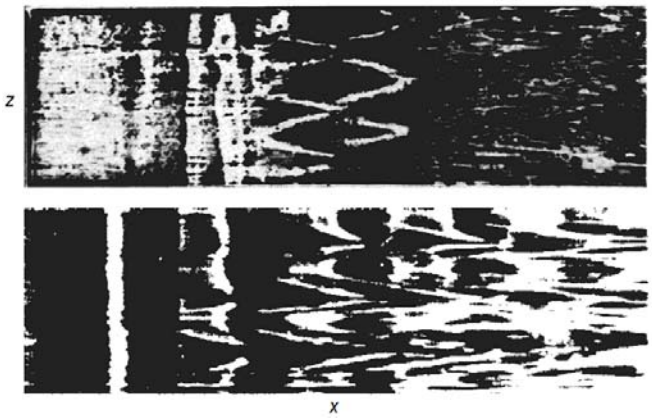

Figure 7: Laminar flow disturbances in a plane channel. The transition starts from amplification of two-dimensional linear instability waves which transform to nonlinear three-dimensional perturbations at their spatial arrangement depending on the initial conditions, compare *top* to *bottom*; flow is from left to right

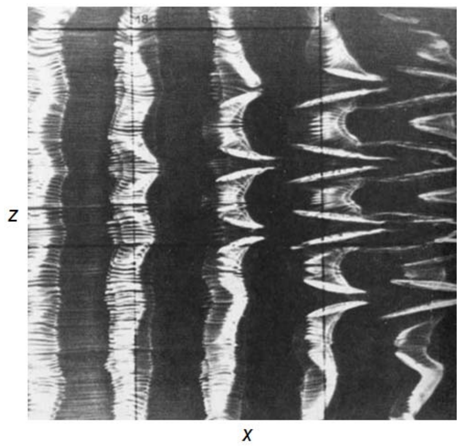

Figure 8: Laminar flow disturbances in a flat-plate boundary layer. Similarly to Fig. 7, nonlinear breakdown of the originally two-dimensional linear perturbation is clearly seen; flow is from left to right

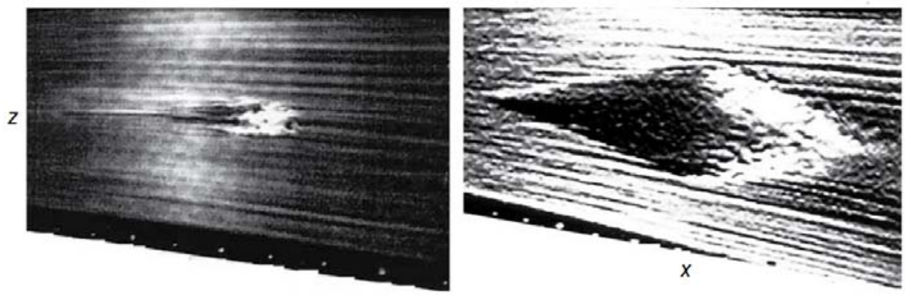

Figure 9: Turbulent spot in flat-plate boundary layer (*right*) originating from an incipient one (*left*); flow is from left to right

For those who like to feel the nature through numbers, the book is supplemented by a set of sample codes and ‘toy’ MATLAB functions, which allow a reader to understand ‘how it works.’ The core routines cited in the book are accompanied by interface programs. To simplify the process and to give some guidelines, many chapters contain exercises, which can be fulfilled with the help of the functions as a starting point.

References

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