Back

BREAKDOWN OF A STREAK VIA DEVELOPMENT OF VARICOSE SECONDARY MODE ON THE STRAIGHT WING WITH PRESSURE GRADIENT

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1. Introduction

The latest stages of the laminar flow breakdown on a wing are associated with a formation of longitudinal structures of low- and high-speed fluid streaks, which later on make the flow susceptible to secondary instabilities. In natural case such disturbances can be initiated by some surface irregularities such as uniform surface roughness or humps. On a swept wing, secondary instability of the cross flow plays an important role in the formation of streaks as it was shown in our previous studies in the frame of this project [1]. At that work it was found that the swept wing flow with the longitudinal vortices or streaks became secondary unstable to periodical disturbances. In the present investigation it is also shown that similar processes lead to the final flow breakdown at very late stages of transition. Additionally, for the first time it is demonstrated that the external pressure gradient have very strong influence on the development of secondary instabilities on the straight wing and hence the applicability of pressure gradient variation for the control purposes is proven in this case.

2. Experimental set-up and procedure

The experiments were performed in a wind tunnel at Thermo and Fluid Dynamics, Chalmers University of Technology in Göteborg, Sweden. The facility is closed circuit, has a test section 3m long, 1.8m wide and 1.2m high and a maximum free-stream velocity U_0 of 60m/s. The free-stream turbulence level in the test section is well below 0.1% of U_0 in the velocity range U_0 = 5–15m/s at frequencies between 0.1–10000Hz. The wing model used is made of wood and has a C-16 aerofoil. Its length C is 500mm, span 1500mm and the maximum thickness to chord ratio is 0.16 at about 0.3 chord. The top side of the wing after the 0.4 chord represents a flat surface, thus, making it possible to study the flow without wall-curvature effects. The wing is mounted horizontally in the middle of the test section (Figures 1, 2). To create the streaks, injection through the small hole on the surface of the wing was used in the same way as employed in the DNS work [2]. Also in the same fashion the varicose instability mode was artificially superimposed, thus allowing direct comparison of the experiment with the numerical simulation.

A method, which gains the advantage of flow visualization and gives quantitative description of the flow phenomena has been developed and employed in Chalmers for investigation of the three-dimensional features of flow breakdown. Comparing to traditional visualization methods which are limited in application and give little or no quantitative data for advanced analysis, a combination of accurate hot-wire anemometry techniques and modern data acquisition has been used to develop a new quantitative spatial "visualization" during a series of

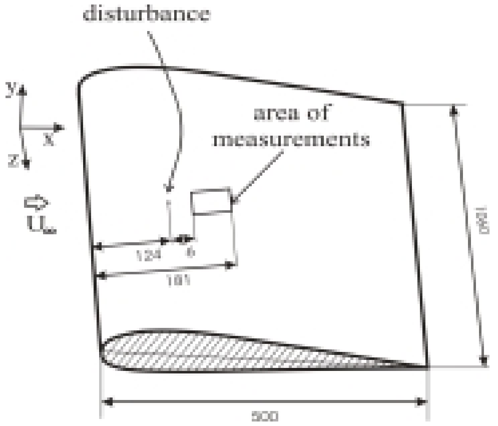


Figure 1: Sketch of experimental setup for cases *a*, *b*.

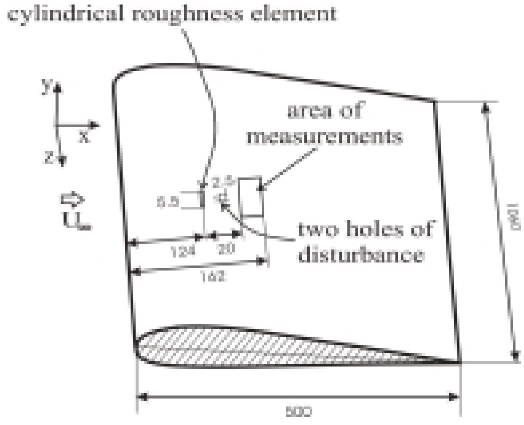
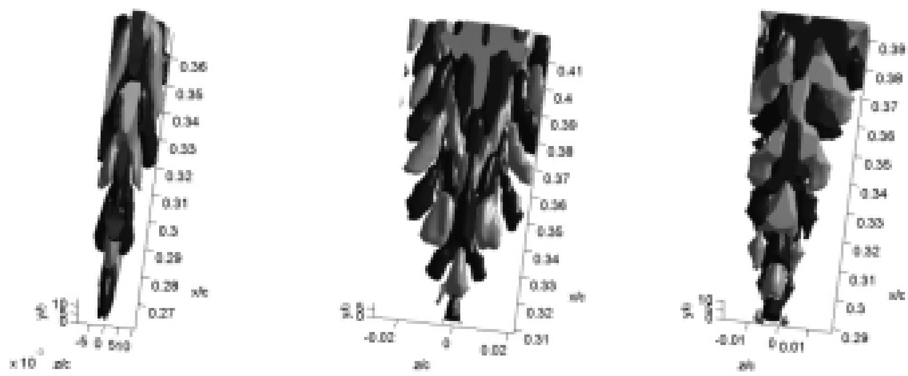


Figure 2: Sketch of experimental setup for case *c*.

experiments conducted. A comprehensive system for automated traversing and data acquisition has been designed and developed for this task. The developed hot-wire visualization technique is proved to be highly successful and great deal of experimental investigations was performed using this technique at this time.

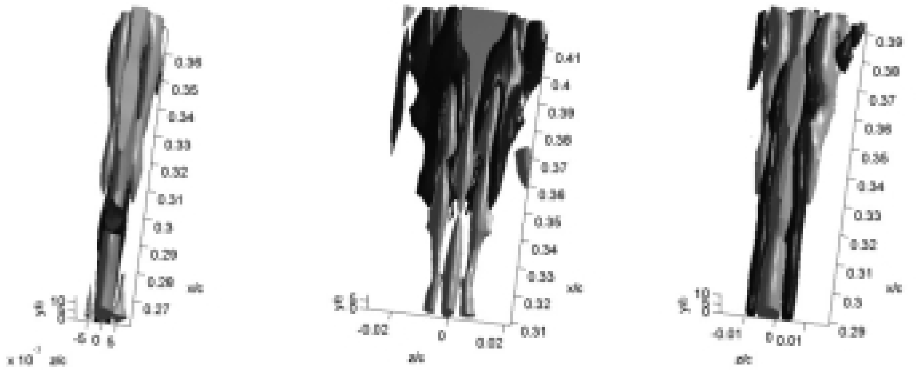
3 Experimental results

The data were obtained in three experiments regimes, Figure 3, with nearly zero streamwise pressure gradient (*a*) and the adverse one (*b*, *c*); in case c the boundary layer was perturbed by a cylindrical roughness element. The solid vertical lines in the figure show the areas where measurements were performed. In Figures 4 – 6 the spatial hot-wire visualization of the timeperiodic part of the disturbance, its time-periodic part together with the total velocity distortion, and the total velocity distortion is shown which is much similar to the breakdown process from DNS of Figure 7. Qualitatively, the comparison is very good, thus, the experimental and computational results demonstrate similar process of the streak breakdown.



(*a*) (*b*) (*c*)

Figure 3: Hot-wire visualization of the time-periodic part of the disturbance. *a* – ($dP/dx \approx 0$), *b* – ($dP/dx > 0$), *c* – ($dP/dx > 0$, with roughness element).

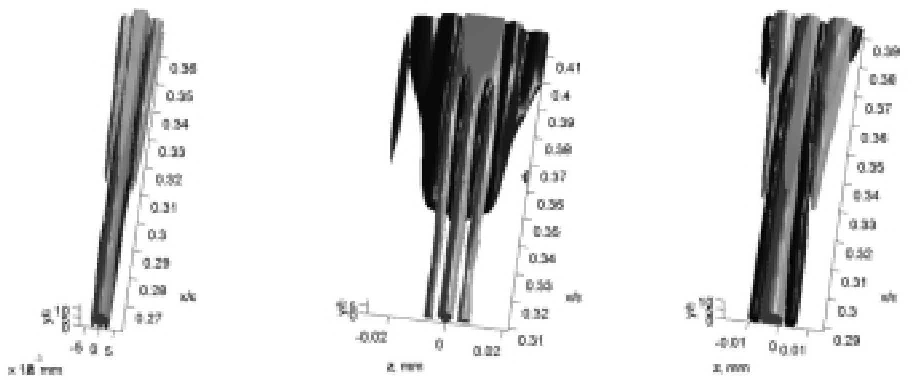


(*a*) (*b*) (*c*)

Figure 4: Hot-wire visualization of the time-periodic part of the disturbance together with the total velocity distortion.

a – (*dP/dx* ≈ 0), *b* – (*dP/dx* > 0), *c* – (*dP/dx* > 0, with roughness element).

Also, the figures demonstrate the effect of pressure gradient on the streaks evolution which is observed here for the first time. It is clearly visible that the development of streaks is affected by the character of flow motion, and in the area of decelerated flow the spread rate of the streaks and the secondary disturbances is increased, and their growth is promoted. The reason of this is not absolutely clear at the moment so that a continuation of these studies is required with a support by theoretical investigations. In conclusion, it should be noticed that the present data on the streak breakdown support the results on turbulence generation in the wall region of a turbulent boundary layer obtained in [2] through direct numerical simulations.Future work could include investigation of other instability modes and the influence of favorable pressure gradient on the streaks.



(a) (b) (c)

Figure 5: Hot-wire visualization of the total velocity distortion.

a – (*dP/dxP* ≈ 0), *b* – (*dP/dx* > 0), *c* – (*dP/dx* > 0, with roughness element).

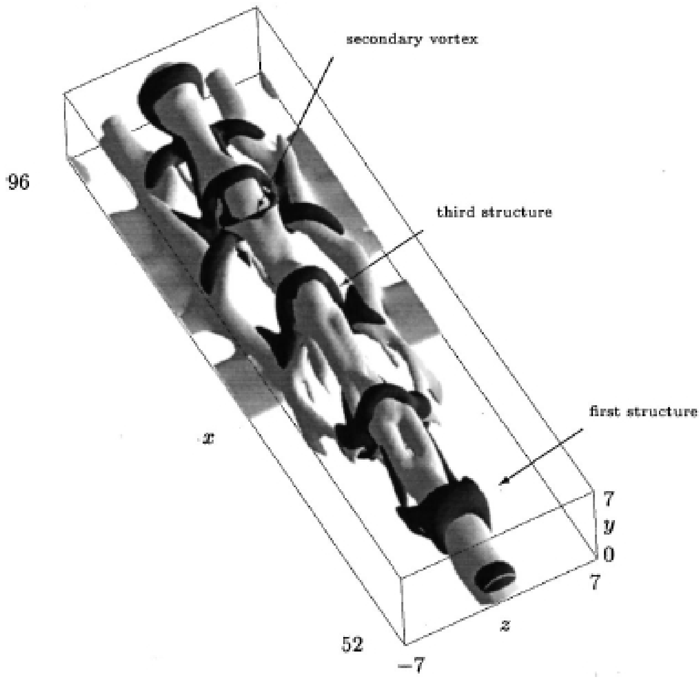


Figure 6: Breakdown of a streak via development of a varicose secondary mode.
From DNS results by Skote, Haritonidis, and Henningson [2].

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