SECONDARY INSTABILITY OF STATIONARY VORTEX PACKETS IN A SWEPT WING BOUNDARY LAYER

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Summary The fact is that stationary vortex packets are most likely to be generated under natural flight conditions on the wing and these disturbances lead to breakdown the fastest. A detailed experimental study on the formation of crossflow vortex mode packets and their secondary instability in a swept wing boundary layer was carried out.

INTRODUCTION

There is a number of indications that three-dimensional velocity perturbations such as streamwise vortices and streaks are involved in transition to turbulence in wall bounded shear layers. Creating local flow distortions, they induce velocity gradients in spanwise and wall-normal directions, which in turn lead to the growth of secondary high-frequency disturbances with further laminar flow breakdown. This transitional phenomenon seems to be general for different flow configurations. The three-dimensional boundary layer of a swept wing is focused on in the current paper.

There are just a few experiments on the secondary instability of swept wing boundary layers. To our knowledge, there are as yet no experimental investigations available which reveal the spatial structure of the secondary instability modes and details of disturbance evolution across the transition region, even though such experiments are of great necessity. Under natural conditions of wing flow, transition packets of stationary crossflow vortex modes, rather than single-mode vortices, develop in the boundary layer. It emerged recently that secondary instabilities develop in a different way on the vortex packets than on the single-mode vortices. Both calculations [3] and experiments [1] show higher instability of packets of stationary crossflow modes as compared to single crossflow vortex modes, hence, a lower limit for secondary instability can be obtained through a consideration of the stability of such packets. Moreover, there are some indications that for crossflow vortices it is not absolutely required to reach a saturation state for a secondary instability to start to grow and this is additionally investigated.

The present experiments were designed with an idea of modelling the phenomenon under fully controlled conditions. In this work, which is mostly based on findings of work [1] utilizing very similar experimental set-up, secondary instability of various packets of stationary crossflow vortex modes is investigated. In our case, to resolve the secondary disturbances as much as possible, a method of point-by-point hot-wire visualization is employed.

PROCEDURE OF THE INVESTIGATION AND SELECTED RESULTS

The study is performed at Thermo and Fluid Dynamics, Chalmers University of Technology. All the experimental runs discussed in what follows were performed at the oncoming flow velocity of 8.2 m s^{-1}, making the chord-based Reynolds number about 390000. All data were acquired from hot-wire measurements. The wing model has a C-16 aerofoil profile and was positioned at the sweep angle, Λ, of 45°, see figure 1. Different roughness elements or localized continuous suction were applied at 0.3 of the wing chord to generate stationary crossflow vortices in the boundary layer. High-frequency travelling disturbances evolving along the streaks were excited naturally or in a controlled manner using periodic blowing-suction.

A unique hot-wire traversing mechanism was developed, which is computer controlled and can be completely automated for long experimental runs through definition of a geometrical mesh of measurement points. The software used to control the sampling and saving of data files is linked into a program for automated, triggered flow measurements using the traverse system and a pre-defined mesh of sampling points. Using this high-precision equipment and fully automated experimental procedure it was possible to obtain detailed experimental data.

At first, secondary instabilities which occur naturally were studied and then, to allow phase-locked measurements, these disturbances were modelled and introduced artificially.

In figure 2 the oscillations developing behind the surface roughness element are shown. Two different modes of secondary disturbances are developing on the sides of the roughness element because of the specific symmetry properties of the flow. Different stationary vortex packets (of various symmetry and of different rotation) are to be triggered under 'natural' conditions as well.

In brief, it was observed that the secondary disturbances are located either inside the area of the streamwise velocity deceleration or near the position of highest spanwise gradient of this velocity component. The conditions which favour one or the other instability mode were investigated. As our analysis revealed, the preferred secondary instability modes of the vortex packets are dependant upon their direction of rotation, since different velocity gradients are induced. The presence of a strong positive $\partial U/\partial z$ gradient (of the same sign as the base crossflow) favours so-called 'z' mode of secondary instability. As this gradient is weak and the low-speed streak is wide, different instability mode (of 'y' type) is established within the low-speed streak, which among other properties has a significantly different amplification rate.

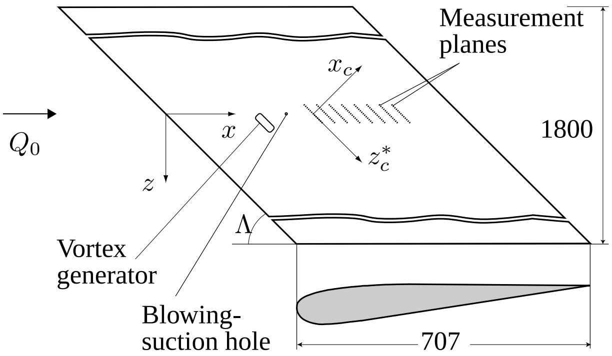

Figure 1. The swept wing model. Dimensions are in mm.

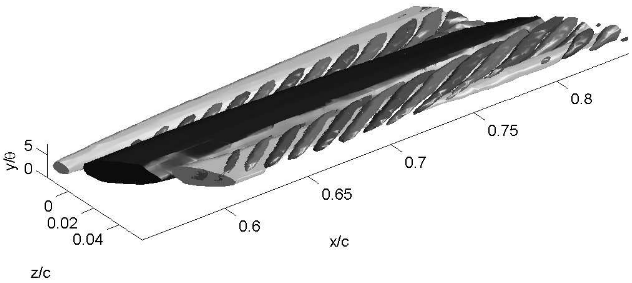

Figure 2. Forced periodical disturbances together with the stationary vortices are shown.

Beyond this, the width-to-height ratio of the primary vortex is also a parameter defining the secondary instability. The vortex packets are found to be more unstable as compared to single-mode disturbances.

CONCLUSIONS

As a result of the current study, experimental data on secondary instability in a swept wing boundary layer including characteristics of the base flow, primary streamwise vortices and secondary perturbations were obtained. Detailed measurements were performed with both stationary vortices and secondary instabilities excited in a controlled manner. The characteristics of secondary instability obtained include phase information, growth rates and the development of nonlinear harmonics.

References

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