EFFECTS OF FREESTREAM TURBULENCE ON CROSSFLOW INSTABILTIY

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Abstract The effects of freestream turbulence on the generation of crossflow disturbances in swept-wing boundary-layers are investigated through direct numerical simulations (DNS). The geometry and flow conditions correspond to those of experiments by [3] and [1]. In present study, we generate the isotropic homogenous freestream turbulence through DNS trying to match the characteristics of that measured in the experiments. The generated freestream fields are then applied as the inflow boundary condition for DNS of flow over the wing. Further, as in the experiments, a row of distributed roughness elements are placed near the leading edge to generate stationary crossflow disturbances. The effects of the generated freestream turbulence on the initial amplitudes of the boundary layer perturbations are then studied. Additionally their influences on the transition location are examined.

BACKGROUND

Drag reduction for aircraft has been the major driving force of many studies on mechanisms behind transition of flows from laminar to turbulent over the last decades. Four different types of instabilities are of importance for flow over swept wings, namely, attachment line, Görlter, Tollmien-Schlichting, and crossflow instabilities. The latter has been the focus of this study. Crossflow instabilities arise due to an inflection in the velocity profile, which is an inherent characteristic of three-dimensional boundary layers. Such instabilities of inviscid type take the form of counter-rotating vortices and are prone to occur on concave surfaces with negative pressure gradient.

It has been a common understanding that at low freestream turbulence level the transition scenario is dominated by stationary crossflow vortices. However, recent experimental studies indicate that even low freestream turbulence level can have significant effects on growth of these stationary vortices. In some cases, an increase of freestream turbulence delayed the transition [3]. The present studies try through direct numerical simulations find the physical explanations of the observed behaviour.

CASE STUDY

The set up of studies performed here follows that of experiments by [1] and [3]. In these experiments the authors use ASU(67)-0315 wing geometry which promotes growth of crossflow disturbances. Distributed roughness elements are locally placed near the leading edge with a given span-wise wavenumber optimising the excitation of crossflow vortices. The response of boundary layer to both roughness elements and freestream turbulence is measured. These studies include variations of roughness height and their spanwise distribution as well as Reynolds number and freestream turbulence characteristics. The results of the latter indicate an inverse proportionality between the level of freestream turbulence and amplitude of stationary crossflow vortices. It must be noted that the experiments were conducted at a very low level of freestream turbulence. Our main goal is to understand the observed behaviour. Here, we generate the isotropic homogenous freestream turbulence through DNS trying to match the characteristics of that measured in the experiments. The generated freestream fields are then applied as the inflow boundary condition for DNS of flow over the wing.

SIMULATIONS

In order to numerically generate stationary crossflow vortices, roughness elements are meshed and placed near the leading edge similar to the experiments. The initial amplitudes of the generated cross flow vortices are in good agreement to those measured in experiments. In absence of unsteady perturbations, the crossflow vortices grow all along the domain without breaking down to turbulence due to very low background noise caused by the high accuracy of the simulation code NEK5000 [2]. Figure 1 shows the velocity components of the stationary crossflow vortices generated by the meshed roughness elements.

The turbulence characteristics of the freestream flow is documented to a great detail in [1]. Direct temporal numerical simulations of isotropic turbulence with periodic boundary conditions in all directions have been performed to generate turbulent fields with characteristics similar to those in the experiments. The perturbation fields are saved at certain time intervals and third order Lagrange interpolants are used to obtain the perturbation field at time instants between each these intervals. Figure 2 depicts a snapshot of the streamwise velocity perturbation near the leading edge. The effect of different freestream turbulence characteristics on stationary crossflow disturbances are henceforth studied along with their influence on transition location.

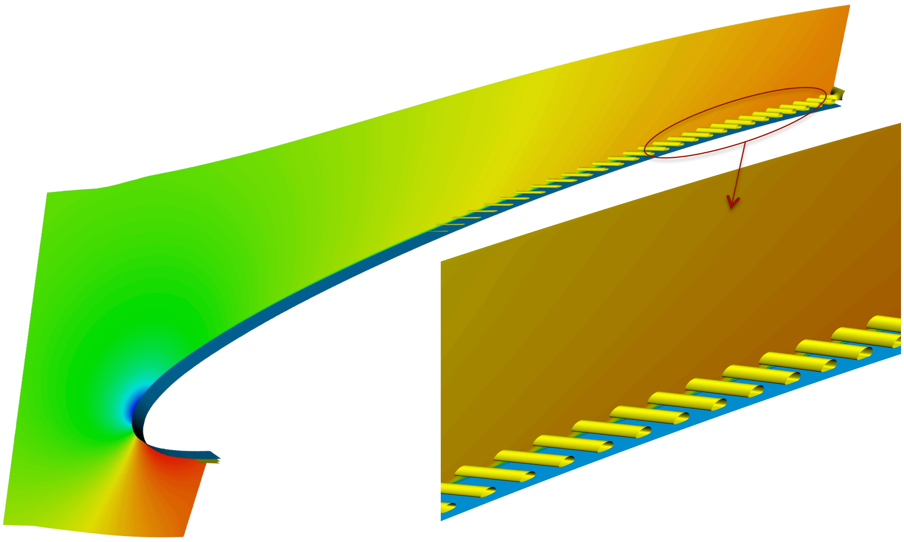

Figure 1. Visualisation of velocity components on the wing geometry, the pseudocolors depict the streamwise velocity and the isosurfaces represent the spanwise velocity component. The wing surface is illustrated in blue color.

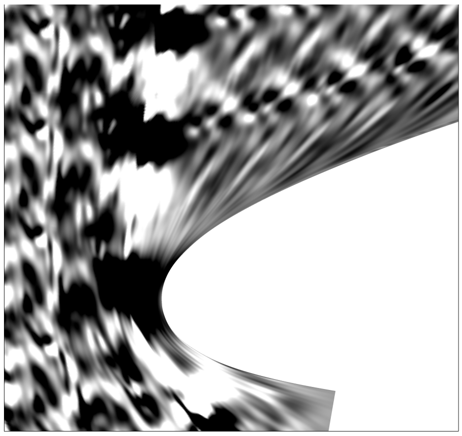

Figure 2. Streamwise velocity perturbation near the leading edge. The contour limits are set at $\pm 0.001 U_\infty$

References

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