EFFECTS OF FREESTREAM TURBULENCE ON CROSSFLOW INSTABILTIY

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Abstract Direct numerical simulations (DNS) have been performed in order to investigate the interaction of freestream turbulence and crossflow generated instability on a swept wing. The experiments by [3] and [1] are selected as the reference cases. In those experiments the authors explore the interaction between different freestream turbulence characteristics and different roughness element characteristics. In the current study, isotropic homogenous freestream turbulence are generated following experimental parameters and then fed as the inflow boundary condition for DNS of flow over the wing. A spanwise array of roughness elements corresponding to the most unstable stationary modes are used to generate the crossflow vortices. The effects of the freestream turbulence on the crossflow instability and transition to turbulence are later studied.

BACKGROUND

Crossflow instability is a major contributing factor to the flow transition from laminar to turbulent on swept wings. Reduction of the higher drag attributed to turbulent flow is a driving force in investigation of crossflow dominated transition. Crossflow instabilities are due to an inflection in the velocity profile, which is an inherent characteristic of three-dimensional boundary layers on swept wings. Such instabilities of inviscid type take the form of counter-rotating vortices and occur on surfaces with negative pressure gradient. Stationary crossflow transition are associated with low freestream turbulence level. However, recent experimental studies indicate that even low freestream turbulence levels can have significant effects on growth of these stationary vortices. In some cases, an increase of freestream turbulence delayed the transition [3]. The current study explores such behaviors through direct numerical simulations.

SIMULATIONS

The numerical set up follows that of the experiments by [1] and [3]. In those experiments the authors use ASU(67)-0315 wing geometry . Distributed roughness elements are locally placed near the leading edge with a given span-wise wavenumber optimising the excitation of crossflow vortices. In those studies, roughness height, their spanwise distribution as well as the Reynolds number and freestream turbulence characteristics have been varied. The experiments were done at a very low level of freestream turbulence. 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 fed as the inflow boundary condition for DNS of flow over the wing. 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. Two different sets of freestream turbulence characteristics are selected with their respective length and time scales, and intensities, namely, Tu04 (turbulent intensity = 0.04%) and Tu40 (turbulent intensity = 0.4%).

Roughness elements are meshed and placed near the leading edge following the experiments. The direct numerical simulations are done by the incompressible NEK5000 code developed by [2]. The velocity distribution for the DNS is extracted from a RANS solution. Figure 1 shows the flow configuration and the spectral element mesh.

Figure 2 depicts the instantaneous streamwise velocity field between for two different turbulent intensities. It could be seen that increasing the turbulent intensity by one order shifts the transition location by around 10% chord. It also emphasized that fact that low level freestream turbulence level could play a significant role in crossflow instabilities.

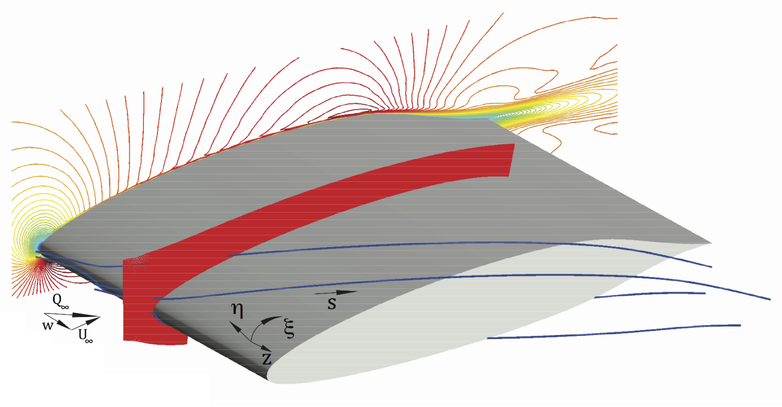

Figure 1. Swept ASU(67)-0315 wing, with the incoming velocity Q_∞. The wing is at an angle of attack of $-2.9°$. (ξ, η, z) and (x, y, z) represent fitted curvilinear and cartesian coordinate systems respectively. (u_ξ, v_η, w) and (u, v, w) are the corresponding velocities. The spectral element mesh is depicted in red. The normalized streamwise velocity contour lines from the RANS solution are shown ranging from 0.0 to 1.54 with a spacing of 0.024, which their values are used for the DNS baseflow. The blue lines represent the streamlines of the baseflow.

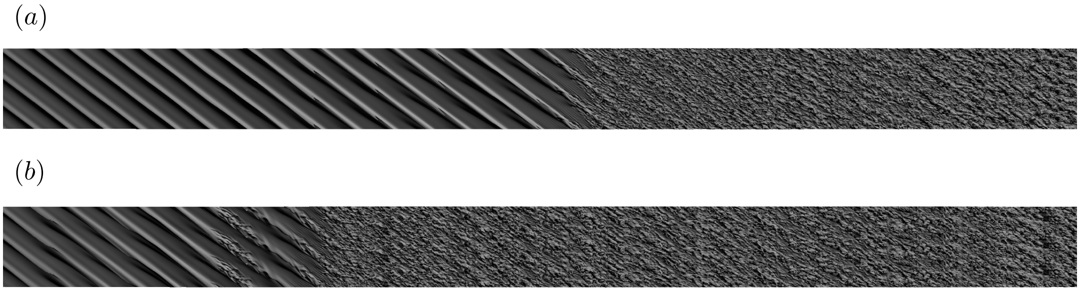

Figure 2. Visualization of stationary crossflow vortices. The isosurfaces represent the streamwise velocity u. Three spanwise periods are shown for visualization purposes for (a) Tu04 and (b) Tu40

References

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