EFFECT OF A 3D SURFACE INDENTATION ON BOUNDARY LAYER STABILITY

Hui Xu*[1], Shahid Mughal[1], and Spencer J. Sherwin[2]

[1]*Department of Mathematics, Imperial College London, 180 Queens gate, London, SW7 2AZ, UK*

[2]*Department of Aeronautics, Imperial College London, 180 Queens gate, London, SW7 2AZ, UK*

Summary Effect of a three-dimensional (3D) surface indentation on boundary layer stability is studied in a high Reynolds number (Re) regime. Once the Tollmien-Schlichting (TS) wave undergoes a base flow (with/without a separation flow bubble) distorted by a 3D surface indentation, the growth rate of the TS wave can be changed downstream and some interesting properties from the 3D indentation distortion are observed. It is also found that under suitable indentation geometry parameters, it is observed that a global instability can be triggered, which has a strong impact on boundary layer transition. In this paper, these instabilities are investigated and effect of a 3D surface indentation is elucidated.

In a boundary layer, the primary unstable mode is a Tollmien-Schlichting (TS) wave which is a viscous instability. The TS wave is receptive to surface roughness interacting with free stream disturbances and/or surface vibrations. Once the excited TS wave propagates downstream and experiences a base flow distortion which is generated by a surface indentation, the growth properties (energizing or weakening) of the TS wave can be changed. These properties are significantly influenced by 3D effect of a base flow distortion. When a 3D separation flow bubble appears, 3D effect of the separation flow bubble on the TS wave varies with respect to indentation geometry parameters, which is remarkably different from that of a 2D separation flow bubble. This difference has a strong impact on the growth properties of the TS wave. Generally, the boundary layer transition onset is prompted. Meanwhile, under suitable indentation geometry parameters, it is observed that a global instability can be triggered, which also has a strong impact on boundary layer stability. In this paper, these instabilities are conducted and effect of a 3D surface indentation is elucidated. The linear analyses of the TS wave growth properties are investigated by the parabolic stability equations (PSE) and the triglobal stability is done by the time-stepper-based Arnoldi algorithm. Finally, a DNS calculation is implemented to simulate the boundary layer transition.

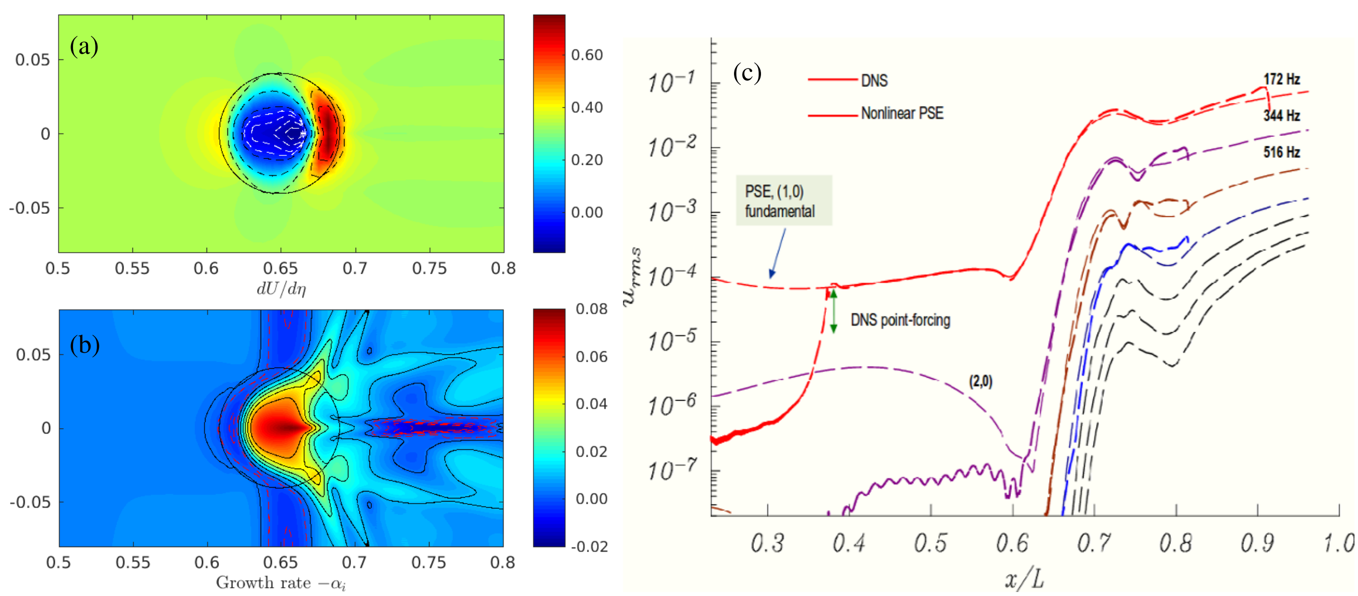

Figure 1: Wall shear (a), the growth rate (b) of the TollmienSchlichting wave and harmonics calculated by nonlinear PSE (c).

References

[1] Herbert T.: Parabolized stability equations. Annu. Rev. Fluid Mech. 29: 245-283, 1997.
[2] Theofilis V.: Global linear instability. Annu. Rev. Fluid Mech. 43: 319-52, 2011.
[3] Xu H., Sherwin. S. J., Hall P., Wu X.: The behaviour of Tollmien-Schlichting waves undergoing small-scale localised distortions, J. Fluid Mech., to appear, 2016.
[4] Wu X. S., Hogg Linda W.: Acoustic radiation of Tollmien-Schlichting waves as they undergo rapid distortion. J. Fluid Mech. 550: 307347, 2006.
[5] Newman D. J., Karniadakis G.: A direct numerical simulation study of flow past a freely vibrating cable. J. Fluid Mech. 344: 95-136, 1997.
[6] Darekar R., Sherwin S. J.: Flow past a square-section cylinder with a wavy stagnation face. J. Fluid. Mech. 426: 263-295, 2001.
[7] Gao B., Park D. H., Park S. O.: Stability analysis of a boundary layer over a hump using parabolized stability equations. Fluid Dyn. Res. 43: 055503, 2011.

*Corresponding author. Email: hui.xu@imperial.ac.uk