Transition Delay of a Boundary Layer by Smooth Steps

Hui Xu, Jean-Eloi W Lombard, Spencer Sherwin

1. Motivation

A long-standing goal of laminar flow control (LFC) is the development of drag-reduction mechanisms for delaying transition. In a low-level disturbance environment such as the flight condition at cruise altitude, the process of laminar-turbulent transition is dominated by the growth of Tollmien-Schlichting (TS) waves. The growth of the T-S waves is reduced or completely suppressed and providing no other instability mechanism comes into play, natural transition could be postponed or even eliminated. Generally, an ideal strategy to stabilise a boundary layer should not give rise to any other vital phenomena or factors on transition promotion by using typical devices. For a flat plate boundary layer, any sharp local changes on the flat plate could induce a vital problem such as receptivity and separated flow regions. Traditionally, research on stabilising/destabising the TS waves focused on addressing effects of some typical localised roughness elements (such as humps, indentations). The recent investigations show that both humps and indentations have the same destabilisation effect on the TS waves. Whilst, the recent linear analysis on the boundary layers on a single smooth step and two-isolated smooth steps shows that the TS waves can be stabilised.

2. Research

The linear analysis is implemented to study the stabilisation effect of smooth steps on the TS waves. The results of the linear analysis shows that in the presence of a single smooth step, there exist several free parameters which can be adjusted to gain a significant performance in attenuating the TS waves. The single-step height plays a key role in stabilising the TS waves. The investigation on two isolated smooth steps indicates that a much more significant reduction of TS waves' amplitude can be obtained compared with a single smooth step when the same step parameters except for locations are used for individual steps. In order to validate transition delay, the effect of smooth steps on transition is studied by direct numerical simulation (DNS) for K- and H-type transition scenarios.

3. Application

By linear analysis and non-linear calculations, the key findings on the stabilisation effect of smooth steps are outlined as follows:

- A single smooth step has a stabilisation effect on the TS waves;
- Two-isolated smooth steps generate further reduction of TS waves' amplitude;
- Smooth steps can delay K- and H-type transitions;
- Higher steps gives rise to more reduction of TS waves' amplitude assuming width scale of steps is fixed.

These findings lead us to believe smooth steps might be used to delay transition on wings in industrial application.