Separated Boundary Layer Transition (SBLT)

Laminar-turbulent transition of a boundary layer (BL) subjected to adverse pressure gradient (APG) and subsequent separation and re-attachment downstream is studied. The flow over the suction surface of a highly loaded axial compressor blade typically undergoes SBLT under wake impingement. Understanding and controlling the transition process is important to reduce the blade-row losses and to improve the performance range of the compressor stage. In the present work, two different types of disturbances in the form of a loud speaker puff (LSP) and a bar wake (BW) are introduced into the upstream laminar part of an experimentally simulated compressor blade. The nature of the propagation of the two disturbances are then studied with a view to better understand the transition process.

How do we simulate SBLT experimentally?

The SBLT over a highly loaded compressor blade (Stator 67B, [1]) has been experimentally simulated using a flat plate placed in a wind tunnel test section with contoured top and bottom walls that impose the required pressure field. The LSP is introduced through a surface pressure tapping located at 11% axial chord (Cₐ) downstream of the plate leading edge (LE). In the case of BW, the wake disturbance is produced from a 12 mm diameter moving bar located 0.6Cₐ upstream of the LE. The bar size and location are chosen so as to produce a wake that is representative of an upstream rotor blade. The strength of the LSP was intended to be such that at the point of introduction its amplitude and temporal range matches that of the wake when it is at the same location. Measurements were conducted along the plate mid-span using pressure tappings, hotwire traversing and PIV data capture at selected chord-wise locations. The plate chord based Reynolds number is 2.1 x 10⁶ and the inlet turbulence intensity is 0.75%.

What did we find?

The non-dimensional pressure distribution realised under no-disturbance (ND) condition over the top surface of the flat plate (solid line) against the Stator 67B target (symbols) is shown in Fig. 2. The dotted lines annotated S and R represent the approximate location of separation (0.49Cₐ) and re-attachment (0.69Cₐ) as due to the bubble. The flow diffusion level is correctly modelled by the flat plate arrangement. Fig. 3 shows how the disturbances (at selected axial chord positions) when introduced into the undisturbed case as shown in Fig. 3 and Fig. 4. The resulting ensemble averaged time traces are shown in Fig. 6. Although the LSP disturbance at the source is intended to be of the same amplitude as the wake it is clear from the traces below that it is much weaker to the wake prior to the separation point. In both cases, there is evidence of the appearance of a low frequency hump as reported by [2] although this effect seems to be much more pronounced for the wake traces. Note that the upstream LSP traces are scaled up for clarity whereas no such scaling was applied for the BW traces. For the LSP traces, as reported by [2] there is clear evidence of three separate growth regions; (I) low-dispersion, mild growth rate region up until the separation point, (II) a region of exponential growth with increased oscillations followed by (III) a region of non-linear growth close to the re-attachment point. The same can be said about the BW traces except that there was no evidence of multiple oscillations amplified within the wake region. The wake itself is dispersed however, followed by a longer calmed/humped region where any fluctuations are seen suppressed even after flow re-attachment.

In order to compare the propagation characteristics of the two types of disturbances, their amplitude growth in terms of u’_rms intensity is presented in semi-log form in Fig. 7 for three disturbance scenarios; ND, LSP and BW. The values plotted are those measured along the maximum u’_rms intensity line for the undisturbed case. The ND and LSP follow a similar growth pattern with a linear instability region (red lines in Fig. 7) that extends well into the bubble followed by a region of nonlinear growth in the rear part and the re-attachment region. For BW, the linear instability part at the front of the bubble is much shorter and appears 7% Cₐ earlier than that for the LPS. The higher u’_rms intensity of the BW in the flow upstream is thought to be due to the velocity deficit associated with the wake.

References


Fig. 1 Experimental setup

Fig. 2 Non-dimensional pressure distribution: ND

Fig. 3 Boundary Layer Velocity profiles:

Fig. 4 Contours of normalised RMS intensity (u’_rms/μp): ND

Fig. 5 Ensemble averaged PIV images at 0.48Cₐ (left) and 0.63Cₐ (right) U velocity contours

Fig. 6 Time traces of the two disturbances as they propagate in the chord-wise direction

Fig. 7 Semi-log plot of amplitude growth of the two disturbance compared with the no disturbance case

Fig. 8 Propagation of LSP

Fig. 9 Propagation of BW