The persistence of trip-induced spanwise periodicity in developing turbulent boundary layers

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The present work investigates spanwise periodic modes introduced at the inception point (trip) of a developing turbulent boundary layer. Empirical evidence suggests that these modes can be persistent, and the idea here is to exploit this apparent persistence/amplification of weak lateral variations in turbulent boundary layers, to explore whether the downstream evolution can be substantially modified. The experiments are performed in the High Reynolds Number Boundary Layer Wind Tunnel, as illustrated in figure 1, at the University of Melbourne. Typically, the boundary layer in the facility is tripped using a strip of 40 grit sand paper (SP40) to produce a nominally two-dimensional boundary layer. However, for the present work, a series of micro vortex generators (MVGs) are positioned immediately downstream of the SP40 trip to introduce the spanwise-periodic modes. In total, three MVG configurations with a varying spanwise wavelength, Λ, are used in the current study as summarised in table 1.

To quantify the modification resulting from the three-dimensionality introduced by the MVGs, velocity profiles are measured at two spanwise locations relative to the MVG array. These represent the two lines of spanwise reflectional symmetry for the blade array (as shown in figure 1 inset), and we would expect to see flow away from the wall (▲, ▲, △) and flow towards the wall (▽, ▼, ▽) due to the vortices generated by the MVG array. Figure 2 show the evolution of the integrated difference in the mean velocity, $\mathcal{U}_d$, as functions of streamwise development length, x, for different Λ cases. Here, $\mathcal{U}_d = \left| \int_0^\infty (U - U_s)/U_\infty \, d\eta \right|$, where U_∞ is the freestream velocity, $U - U_s$ is the difference in the mean velocity between the modified and the canonical case (corresponding to the MVG and SP40 trips), while $\eta = z/\delta_s$ where δ_s corresponds to boundary layer thickness of the canonical case and z is the wall-normal location.

Preliminary results suggest that the spanwise wavelength of the trip seems to play a critical role in determining the downstream development and subsequent evolution of the turbulent boundary layer towards a canonical state. Furthermore, for a certain configuration the disturbances introduced at the trip appear to strengthen after some distance downstream of their introduction (this strengthening can occur almost 350 blade heights downstream of the trip, cf. figure 2 - case △), and hence may support the theoretical prediction by Townsend (1976) that the boundary layer selectively amplifies and sustains lateral variations that are in order of the local boundary layer thickness. Collectively, these findings suggest that three-dimensionality introduced at the trip may be a viable approach to perturb the evolution of developing turbulent boundary layers over a large streamwise development length.

REFERENCES

Townsend, A. A. 1976 *The structure of turbulent shear flow*, 2nd edn. Cambridge Univ Press.

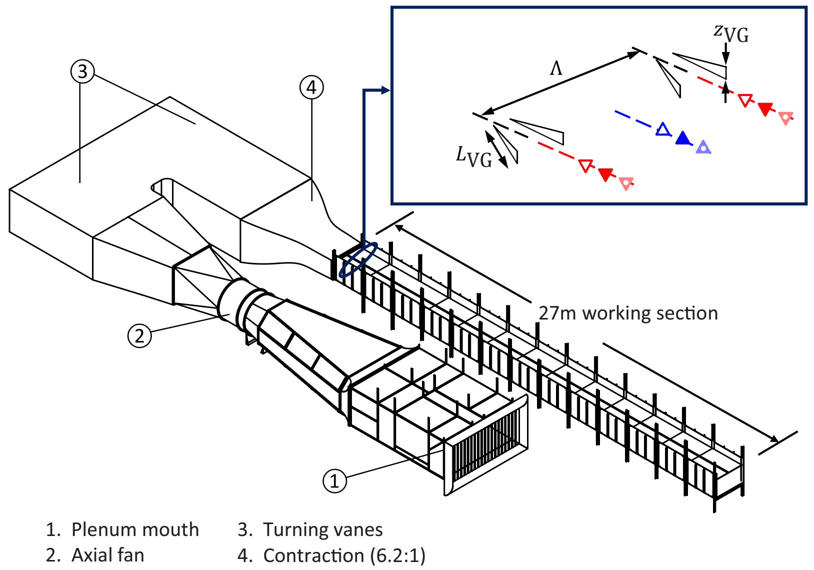

Figure 1: An overview of experimental campaign. The main figure shows a schematic of the wind tunnel facility, while the inset illustrates the micro vortex generators (MVG) used to introduce spanwise heterogeneous disturbances at the trip.

Cases	Λ (mm)	z_{VG} (mm)	L_{VG} (mm)
△, ▽	216	14	75
▲, ▼	144	14	75
▲, ▽	72	8	18

Table 1: Summary of MVG parameters.

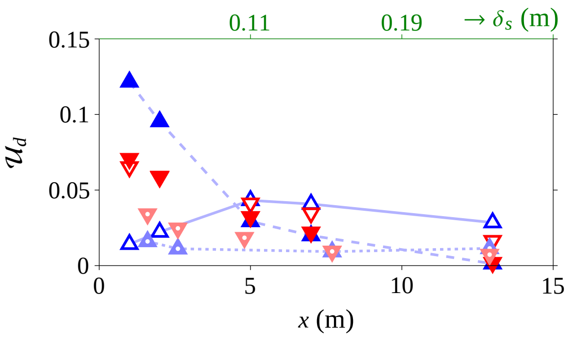

Figure 2: Evolution of an integrated difference in U ($\mathcal{U}_d$) between the modified and canonical boundary layers. The symbols correspond to velocity profiles in the common flow up (▲, ▲, △) and down (▽, ▼, ▽) regions (see table 1 for the details).