Reynolds-number effects on the outer region of adverse-pressure-gradient turbulent boundary layers

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Adverse-pressure-gradient (APG) turbulent boundary layers (TBL) typically have a pronounced 'outer' region as compared to their zero-pressure-gradient (ZPG) counterparts, which is in part owing to the increase in wall-normal convection of turbulence by the PG[1]. Both large[2]- and small-scale[3] motions are known to be energised in this region. This understanding, however, is based on studies limited to low Reynolds numbers ($\mathrm{Re}_\tau \leq 2000$) and has been hypothesized to differ at larger Re_τ[1].

To this end, the present study investigates APG TBLs over a decade of Re_τ. Data for $500 \leq \mathrm{Re}_\tau \leq 2000$ were taken from high-fidelity simulations[3], with $\beta \sim 1.4$, while new data at $\mathrm{Re}_\tau \sim 7000$ and similar β are obtained via hotwire anemometry in the Melbourne wind tunnel. Figure 1 details the set-up established for these experiments.

Spectral analysis of this database, at nearly-constant β, reveals that small-scale contributions decrease in the outer region with increasing Re_τ. This is also confirmed by investigating the velocity variance for various computational grids and hotwire spatial resolutions, where the spatial-filtering error is found to decrease with increasing Re_τ. The study, hence, suggests negligible spatial filtering when measuring in the outer region of low-to-moderate APG TBLs at high Re_τ (≥ 3000), thereby setting the stage for future high-Re_τ experiments aimed at establishing accurate scalings.

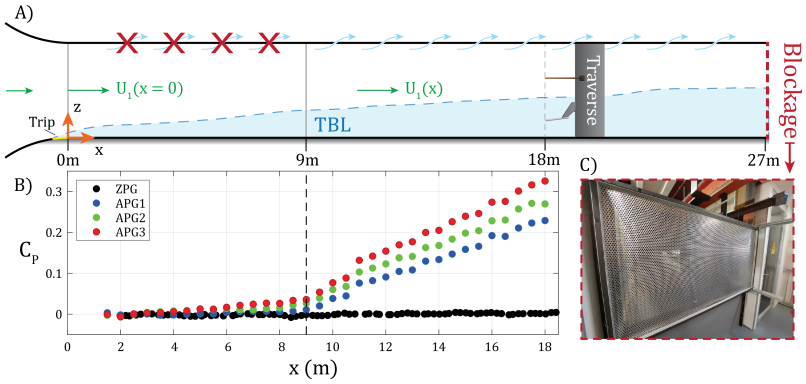

Figure 1: (A) Schematic of the wind tunnel (not to scale). The test-section outlet is choked by multiple mesh screens (porosity ∼51%). Air bleeds on the ceiling are also choked for the first $8m$ to maintain a ZPG, after which a constant PG is allowed to form. (B) The pressure coefficient C_P (and β) is varied by changing the number of screens (C) to 0, 1, 2 and 3 (ZPG, APG1, APG2 and APG3, respectively).

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[1]Vinuesa et al., *Int. J. Heat Fluid Flow* **72**, 86 (2018)
[2]Harun et al., *J. Fluid Mech.* **715**, 477 (2013)
[3]Pozuelo et al., *J. Fluid Mech.* **939**, A34 (2022)