The investigation of friction velocity determination techniques for turbulent boundary layers influenced by miniature vortex generators

Jiahao Kong[*], Luke G. Bennetts[†], Bagus Nugroho[‡], C. I. Chan[*] and R. C. Chin[*]

The influence of miniature vortex generators (MVGs) on zero pressure gradient turbulent boundary layers (TBLs) over a flat plate remains unclear. There are few studies investigating the MVG effects over TBL by the direct numerical simulation (DNS) study of Chan and Chin (2022)[1]. However, the understanding of MVG-TBLs at higher Reynolds numbers remains to be enhanced by experimental methodology due to the lack of friction velocity U_τ determination techniques. This study conducted one MVG-TBL experiment and utilized the DNS database[1] to investigate the performance of five wall-similarity methods in friction velocity U_τ estimation. The defect profile method is based on the outer-layer similarity hypothesis, which shows failure for most upstream profiles $x^*/h \leq 200$ with the outer layer region $y/\delta = 0.6$–1, where x^* is the streamwise distance from the trailing edge of MVGs, h is the height of MVGs, y is the wall normal distance and δ is the boundary layer thickness. The outer layer region is too short to reflect the actual friction velocity. Modified Clauser chart and log-law slope methods also show failure in U_τ estimation at the most upstream location $x^*/h = 5$ due to the distortion of the linear log region for the experimental and DNS results with uncertainty levels of $\geq 16\%$. The inner1 and inner2 methods, utilizing the inner-layer similarity and the Musker function in describing the viscous, buffer and log-law regions, provide a good estimation of U_τ. In the analysis of the DNS profile without the near-wall data points $y^+ < 12$, the inner2 method provides more robust performance with the uncertainty level maintained at less than 3% for all streamwise profiles $x^*/h \geq 5$ because this method is improved by the hump function [2], compared with the inner1 method. Also, the application of the inner2 method for the experimental data shows the result is reasonable. Thus, the inner2 method is recommended for the U_τ estimation from the streamwise velocity profile in MVG TBLs.

[*]School of Mechanical Engineering, University of Adelaide, South Australia 5005, Australia
[†]School of Mathematical Sciences, University of Adelaide, Adelaide, 5005 South Australia, Australia
[‡]Department of Mechanical Engineering, University of Melbourne, Melbourne, 3010 Victoria, Australia

[1]C. Chan and R. Chin, *J. Fluid Mech.*, **932**, A29 (2022).
[2]P. A. Monkewitz et al., *Phys. Fluids.*, **19**, 115101 (2007).