24th Australasian Fluid Mechanics Conference – AFMC2024
Canberra, Australia
1-5 December 2024

Paper No: AFMC2024-234

High Spatial Resolution PIV Measurement of a Self-similar Adverse Pressure Gradient Turbulent Boundary Layer

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1. Introduction

Adverse pressure gradient (APG) turbulent boundary layer (TBL) flow, common in diffusers, turbine blades, aircraft wings, and marine vessels, can cause flow separation, leading to loss of lift and increased pressure drag. Understanding APG-TBL flow is crucial for designing efficient aerodynamic surfaces and controlling flow separation. This study uses high-spatial-resolution (HSR) 2C-2D particle image velocimetry (PIV) to measure a self-similar APG-TBL. Establishing a self-similar APG-TBL (SS-APG-TBL) isolates the effects of pressure gradients from upstream conditions. In a SS-APG-TBL flow, the statistical profiles of the flow collapse if the velocity is normalised by frictional velocity and the length are normalised by viscous length which allows the flow profiles have the same shape in this region.

2. Approach

The experiment utilizes the LTRAC APG-TBL wind tunnel, which has a 4.5 m long test section, allowing the boundary layer to develop into a SS-APG-TBL. A trip device, consisting of 40-mm wide sandpaper, is installed at the entrance of the wind tunnel test section to initiate the development of TBL, as shown in Figure 1. The wind tunnel is equipped with a flexible roof to achieve the SS-APG-TBL in the region of interest (ROI), which is located 2.75 meters from the test section inlet.

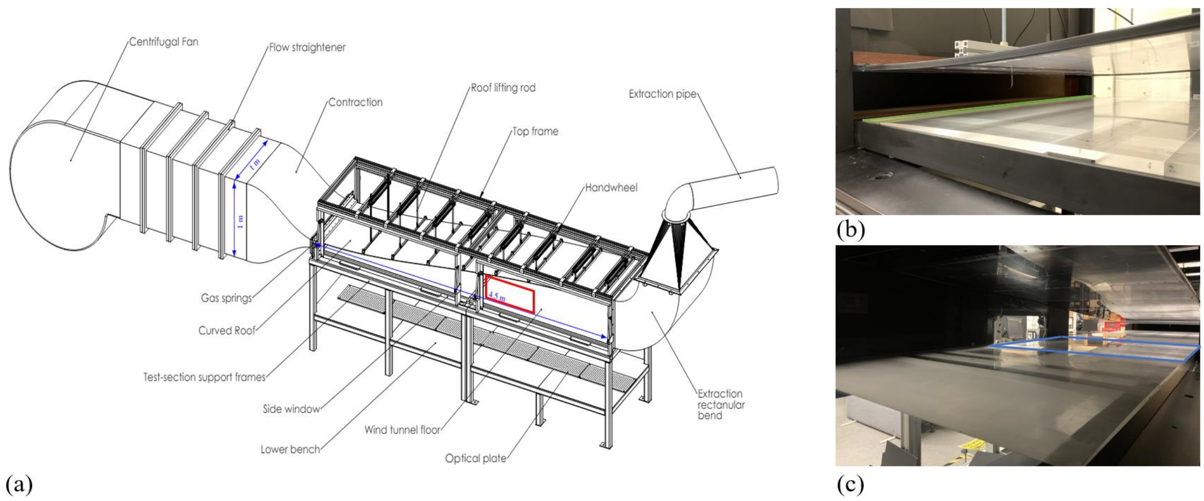

Figure 1. LTRAC APG-TBL wind tunnel: (a) 3D model and ROI (red), (b) Inlet with trip device(green) and the leading edge of acrylic surface, (c) rear edge and replaceable part(blue) of acrylic surface

A machined smooth acrylic surface, with a thickness of 12 mm, is placed on the wind tunnel floor. Both the leading and rear edges of the acrylic surface are designed to have a streamlined shape to avoid flow interference caused by sudden shape changes. The acrylic surface is designed with a replaceable part at the ROI, allowing different surfaces to be installed for further study of the development of self-similar APG-TBL on rough surfaces.

The flow is seeded by a smoke generator using a water-glycerol mixture, producing seeding particles with a mean diameter of 1 μm and an average aerosol output of 283 mg/sec. A dual 200-mJ Nd:YAG laser provides the laser sheet illumination.

A sCMOS camera with a resolution of 2160×2560 pixels and double exposure capability is used with a 200 mm focal length lens. This setup achieves a magnified pixel size of 23.809 μm/pixel and a combined field of view of 0.32δ×1.25δ, providing high-quality PIV measurements of the self-similar APG-TBL. The PIV parameters are given in Table 1 for the 5 PIV measurement heights used. The single-exposed PIV image pairs are further analysed using the multigrid/multipass cross-correlation digital PIV (MCCDPIV) (Soria 1996).

Height [% δ]	**Δt [μs]**	**IW size [pixels × pixels]**	**Multigrid Size [pixels × pixels]**
-11.15%	100	192 × 64	8 × 8
1.06%	50	128 × 64	16 × 16
26.22%	25	64 × 32	16 × 16
53.93%	25	64 × 32	16 × 16
75.80%	25	64 × 32	16 × 16

Table 1. The Δt and IW size selection in different height of ROI, δ is the boundary layer thickness of 160.64 mm measured in centre of ROI with inlet speed of 15.91 m/s

4. Results

The boundary layer thickness has been determined to be 161 mm with a free-stream velocity of 8.73 m/s, the mean skin friction coefficient is constant around 1.3×10^{-4}, frictional velocity is 0.071 m/s, wall-shear stress is 0.0061 Pa. This paper will present the 1st and second order velocity statistics of the SS-APG-TBL

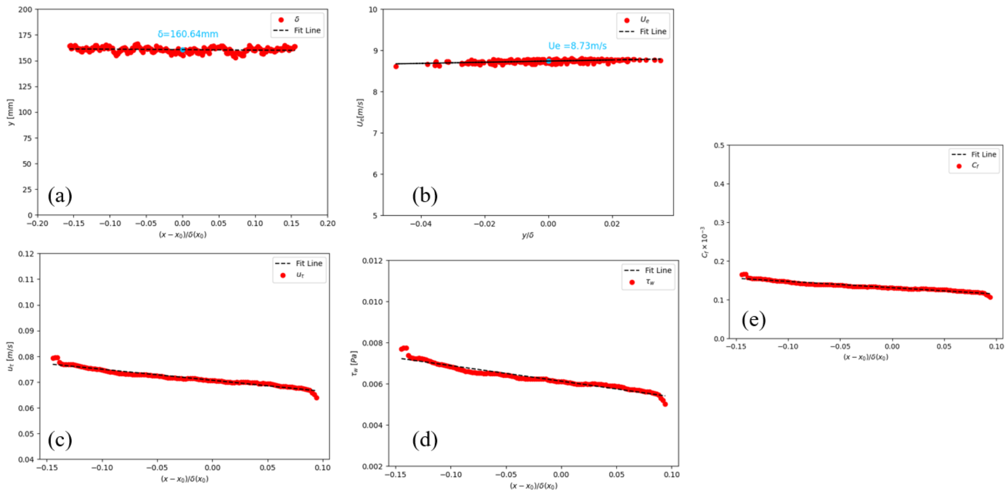

Figure 2. The streamwise variation of the length and velocity scales: (a) the boundary layer thickness δ, (b) the free-stream velocity U_e, (c) friction velocity u_τ, (d) the wall-shear stress τ_w and (e) the mean skin friction coefficient C_f

Acknowledgments

The authors gratefully acknowledge the support of the Australian Research Council via a Discovery grant.

References

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