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Experimental cross-correlation of turbulent boundary-layer velocity and wall-pressure fluctuations

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1 Introduction

The wall-pressure fluctuations underneath a turbulent boundary-layer flow heavily depend on the velocity fluctuation within the boundary layer. This allows the wall-pressure spectra to be modelled based on certain flow parameters of the boundary layer, such as its mean velocity gradient and fluctuating velocity correlation. However, there is still no widely accepted model for the velocity correlation in the wavenumber domain, primarily due to the anisotropic nature of boundary layer flows (Grasso et al., 2019). The study presented here focused on better understanding the relationship between the wall-pressure and the velocity fluctuations associated with a turbulent boundary-layer flow, by looking into the cross-correlations between these two variables.

2 Methodology and Results

The test section in the UNSW Anechoic Wind Tunnel (UAT) was fitted with a variable-angle roof wall allowing the wall-pressure gradient along the test sections to be adjusted (Jiang et al., 2022). Two cases, the zero (ZPG) and adverse (APG) pressure gradients were tested, where the roof angle was set at 0° and 8°, respectively. The tunnel was operated such that the freestream speed is $U_\infty = 30\,\text{m/s}$ for both cases. To allow for high-frequency sampling and smaller pressure tap spacing, the wall-pressure fluctuations were measured using the remote microphone technique (Awasthi et al., 2018), where GRAS 40PH free-field microphones were used. The velocity measurement was done using a Dantec P14 hotwire probe connected to a Dantec 90C10 constant temperature anemometry (CTA) module, with an overheat ratio of 0.8. Both the microphone and hotwire probe readings were sampled time-synchronously at a rate of 65,536 Hz for 32 seconds using NI-4499 data acquisition modules. The time synchronisation between the hotwire and wall-pressure data sampling was done using an NI PXIe-1085 chassis.

Select boundary layer parameters for the ZPG and APG cases are listed in Table 1. Here, δ_{99} is the boundary-layer height defined by the wall distance where the hotwire-measured velocity, U, reaches 99%

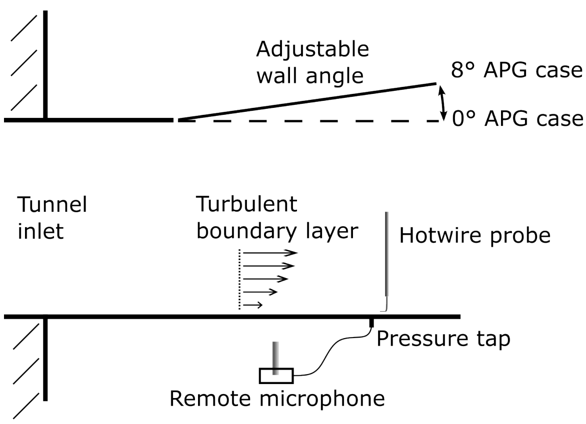


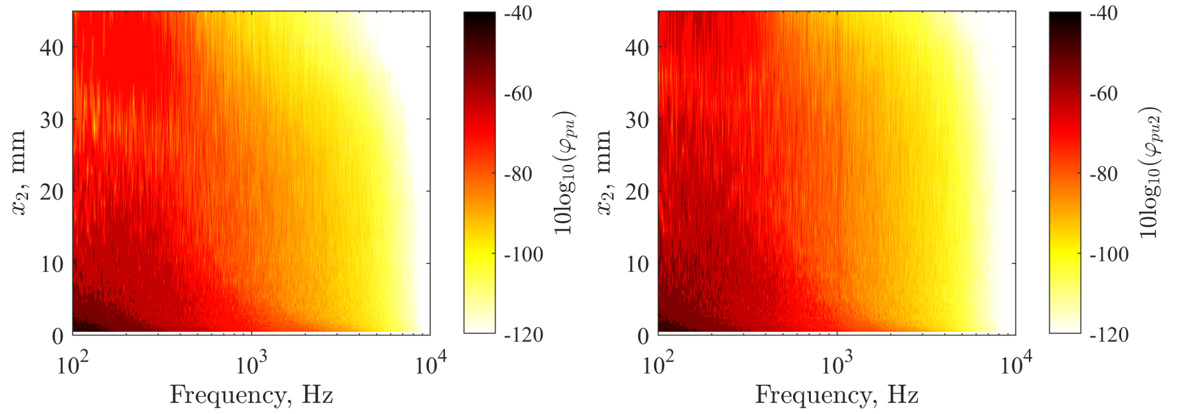
Figure 1. Schematic diagram of the experiment setup.

of U_∞ and the friction velocity, u_τ, was estimated by fitting the mean velocity profile to the logarithmic region of the Law of the Wall. Introducing adverse pressure gradient increases the thickness of and the velocity fluctuations within the boundary layer.

Case	Roof angle	δ_{99}, mm	u_τ, m/s	Re_τ
ZPG	0°	28.2	1.19	2140
APG	8°	35.2	1.02	2290

Table 1. Boundary layer parameters for the ZPG and APG cases.

Figure 2 shows the normalised cross-spectra between the wall-pressure and the velocity fluctuations at a range of wall distance, x_2, above it, for the ZPG and APG cases. The cross-correlations were normalised against their respective root-mean-square values. For both cases, the strongest correlation is at low-frequency near the wall. However, the correlation for the APG case is relatively higher and stays high even at positions further away from the wall. There is no observable difference at the high frequency region. There is also a slight drop in correlation around the wall distance at the boundary layer thickness for both cases.



(a) **(b)**

Figure 2. Cross-correlation spectra of the wall-pressure and velocity fluctuations for the: (a) ZPG and (b) APG cases.

3 Conclusions

Time-synchronous measurements of the velocity fluctuations within a turbulent boundary layer and the wall-pressure fluctuations underneath it were taken in order to improve the accuracy of the wall-pressure spectra model. Two cases of wall-pressure gradient were tested, zero and adverse pressure gradients. The cross-correlation is stronger for the adverse pressure gradient case, especially in the low-frequency region. Further analysis will be conducted to quantify the effects of wall-pressure gradient on the wall-pressure spectra and how it relates to the cross-correlation presented here.

References

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