Determine pinhole size

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1 Introduction

In the measurement of wall pressure fluctuations in a turbulent boundary layer, we use a microphone cap with a pinhole (PH) to avoid spatial attenuation and aliasing effects. To reconstruct the measured pressure, we must calibrate the treated microphone setup and determine a transfer function (H) that maps PH $\mapsto$ NKD, where NKD is the known pressure measurement. If the PH is too small, the suppression of the signal is too much and H is ill-conditioned.

Past data has shown that an inner- and outer-scaled part of the premultiplied wall-pressure spectra exist, with the inner-scaled part being invariant to frictional Reynolds number ($\delta^+ \equiv \delta u_\tau/\nu$) (Massey *et al.*, 2025). Figure 1 shows that the peak of the inner-function sits at

$$T^+ \approx 20, \tag{1}$$

where the $\bullet^+$ superscript denotes normalisation by viscous units so that length scales $d^+ \equiv du_\tau/\nu$, time scales $t^+ \equiv tu_\tau^2/\nu$, and frequency scales $f^+ \equiv f\nu/u_\tau^2$. With this region of known behaviour, we can determine the size of the pinhole and correct accordingly.

2 Spatial approximation using Taylor's frozen turbulence hypothesis

Convection velocity can be used to convert temporal fluctuations into spatial structures such that

$$c_x^+ = \frac{\omega^+}{k_x^+} = (2\pi f^+)/(2\pi/\lambda_x^+) \implies c_x^+/\lambda_x^+ = f^+. \tag{2}$$

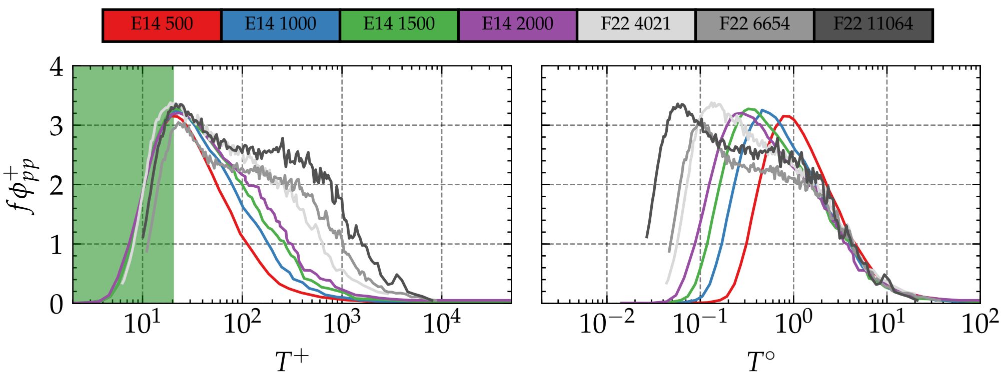

Figure 1: Inner-scaled, pre-multiplied wall-pressure spectra in inner-(**left**) and outer-scaled (**right**) coordinates for a range of Reynolds numbers. The region $T^+ \leq 20$ is highlighted in green. Data from Eitel-Amor *et al.* (2014); Fritsch *et al.* (2020, 2022)

Propagating the equality–acknowledging the relationship $T^+ \equiv 1/f^+$–established in (1) leads to

$$\frac{\lambda_x^+}{c_x^+} \lesssim 20, \tag{3}$$

where c_x^+ is the convection velocity and λ_x^+ is the wavelength of the structures. To minimise the attenuation of the smallest wavelengths, the pinhole diameter $d^+ = 0.5\lambda_{x\,\mathrm{min}}^+$ (Corcos, 1964). The convection velocity of the pressure fluctuations is not constant throughout the boundary-layer (Willmarth & Wooldridge, 1962), but a widely adopted approximation is $c_x^+ \approx 10$ leading to

$$\boxed{\frac{du_\tau}{\nu} < 100.} \tag{4}$$

3 Viscous scales in the Stanford wind tunnel

The plan is to deploy three pinholes, the largest is geared to the atmospheric conditions, the smallest to the highest δ^+, maximum pressure, and one in between, the approximations are summarised in table 3. For this study, the boundary-layer thickness is assumed fixed at $\delta = 0.035$ m and the free-stream velocity is fixed at $U_{\mathrm{CL}} = 14$ ms^{-1}.

$\sim \delta^+$	ν/u_τ [μm]	d_{max} [mm]
1500	23.33	2.33
5000	7.00	0.70
8200	4.27	0.43

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