On the implementation of simultaneous unsteady surface pressure, far-field noise and PIV flow measurements in an anechoic wind tunnel

Chaoyang Jiang[1], **Charitha de Silva**[1], **Con Doolan**[1] **and Danielle Moreau**[1]

[1]School of Mechanical and Manufacturing Engineering, The University of New South Wales,
*chaoyang.jiang@unsw.edu.au

1 Introduction

Aeroacoustic noise arises from the unsteady surface pressures caused by the interaction between an object and the surrounding fluid flow. Identifying flow structures contributing to noise generation is crucial for under-standing these mechanisms and developing effective control strategies. This talk will detail an approach to ob-taining noise-related Spectral Proper Orthogonal Decomposition (SPOD) flow modes from non-time-resolved PIV data, assisted by synchronised, time-resolved acoustic/unsteady surface pressure signals. Experiments are conducted on two test cases to verify this approach and demonstrate its capability in flow structure identification and reconstruction. This abstract provides a brief overview of the methods and sample results.

2 Methods and Sample Results

To obtain SPOD (Towne *et al.*, 2018) flow modes from non-time-resolved Particle Imaging Velocimetry (PIV) data, the velocity field data must be linked to a correlated time-resolved signal. Simultaneous measure-ment of the velocity field, unsteady surface pressure, and far-field noise offers time-resolved pressure signals that are strongly correlated with the fluctuating velocity field and can be synchronised with it. A pressure-weighted fluctuating velocity quantity v'^* can be obtained by $v'^*(\tau) = E[v'(t_n) \cdot p'(t_n+\tau)]/p'_{rms}$, where v' and p' are the instantaneous fluctuating velocity and pressure, t_n is the time instance of the n^{th} PIV snapshot, τ is a time delay applied to the time-resolved pressure signal, and E denotes the expected value. This constructed variable v'^* is a function of τ and can have a sampling rate as high as the fluctuating pressure signal. Frequency-based analysis can be performed on v'^* to identify flow modes responsible for the noise or surface pressure fluctua-tions, providing valuable insights into understanding the mechanisms of noise and surface pressure fluctuation generation.

Experiments are performed in the UNSW Anechoic Wind Tunnel (UAT), which is an open-jet wind tunnel with a 0.455×0.455 m test section surrounded by a $3\times4.7\times2.15$ m anechoic chamber with a cut-off frequency of 300 Hz (Moreau *et al.*, 2022). Figure 1 depicts the experimental setup of two test cases: (a) the flow surrounding tandem cylinders measured using High-Speed PIV (HS-PIV); and (b) the wake of a square Finite Wall-Mounted Cylinder (FWMC) measured using Low-Speed PIV (LS-PIV).

Test case (a) serves as a control case to demonstrate the effectiveness of the proposed approach in capturing SPOD modes. A tandem cylinder configuration with a cylinder diameter D = 20 mm and a gap of 3.7D is tested at a freestream velocity U_∞ = 15 m/s (Re_D = 20000). A VEO 640L camera is placed on the side of the test section to take HS-PIV measurements in the stream plane (x-y plane) at the mid-span of the cylinder (1 kHz sampling rate with a resolution of 2560×1192 pixels). Far-field acoustic data are acquired using a microphone

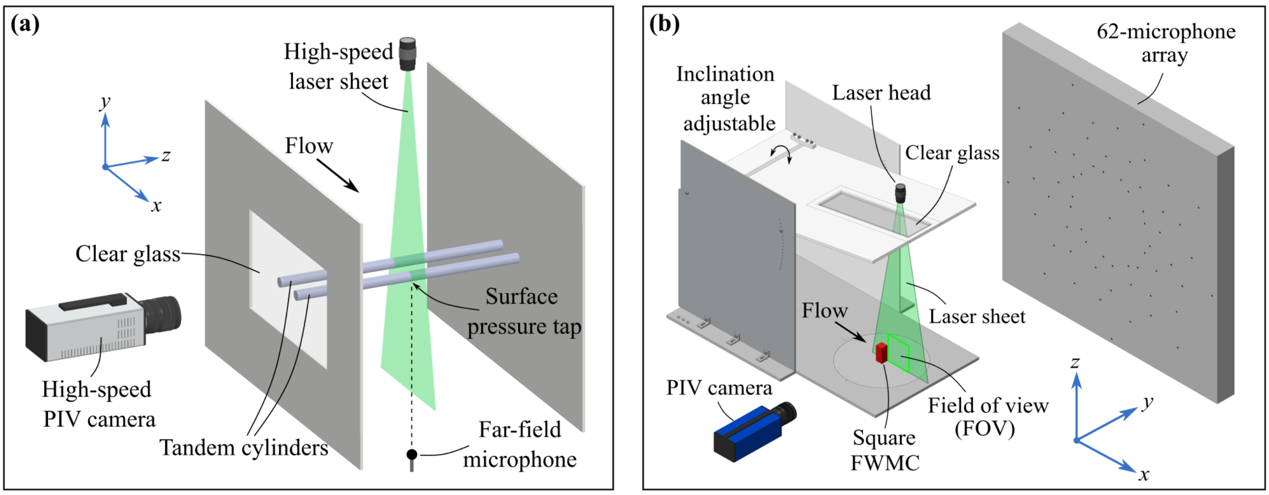

Figure 1. Experimental setup of (a) HS-PIV test case (tandem cylinders), and (b) LS-PIV test case (finite wall-mounted cylinder).

placed 0.95 m (47.5D) underneath the midspan of the downstream cylinder. Unsteady surface pressure data are measured using a remote microphone technique (Awasthi, 2015) from a surface pressure tap (0.9 mm diameter) located at the midspan of the downstream cylinder, facing the far-field microphone.

For test case (b), a square FWMC model with a width $D = 25$ mm and a height $H = 60$ mm is tested in the open-jet pressure gradient test rig (Jiang *et al.*, 2024) at $U_\infty = 30$ m/s ($Re_D = 48000$). Inside the test model, 19 cylindrical channels (0.9 mm diameter) are created from the surface pressure taps to the cylinder bottom surface for unsteady surface pressure measurements using the same technique as for test case (a). Details of the pressure tap locations can be found in (Jiang *et al.*, 2023). A LaVision Imager Pro X 4M CCD camera is placed perpendicularly to the cylinder sidewall to take LS-PIV measurements on multiple streamwise ($x - z$) planes at $y/D = 0$, 0.25, 0.5, 0.75, 1 and 1.25 in the wake (5 Hz sampling rate with a resolution of 2048×2048 pixels). A 62-channel microphone array is placed 1.31 m away from the cylinder streamwise centre plane ($y/D = 0$) on the other side of the test section to measure the far-field noise. GRAS type 40 PH 1/4 inch microphones are used for both test cases, with all microphone signals being recorded using a National Instruments PXI platform simultaneously with the PIV measurements. The microphone sampling frequency is 40,000 Hz for test case (a) and 65,536 Hz for test case (b). Data acquisition and synchronization between the laser and camera are controlled using a LaVision Programmable Timing Unit (PTU X). The synchronisation of the PIV data and pressure signals is achieved using the camera trigger signal measured from the PTU X.

Sample results of the test case (a) are shown in figure 2. The presence of bi-stable vortex-shedding regimes at Stouhal numbers (based on cylinder diameter) of $St_{p1} = 0.132$ and $St_{p2} = 0.173$ is evident from the far-field noise spectrum and the spatially averaged velocity spectrum. Figures 2(b) and 2(c) present the two leading SPOD modes obtained from the time-resolved HS-PIV data and the proposed pressure-weighted fluctuating velocity data, respectively, where the latter are obtained without using the temporal information of the flow data. Both approaches identify comparable flow patterns in the two leading SPOD modes, demonstrating the effectiveness of the proposed pressure-weighting approach. This also indicates that both of these leading SPOD modes are responsible for far-field noise generation. More details of the methods and 3D flow modes reconstruction results of the LS-PIV test case (b) will be presented at the conference.

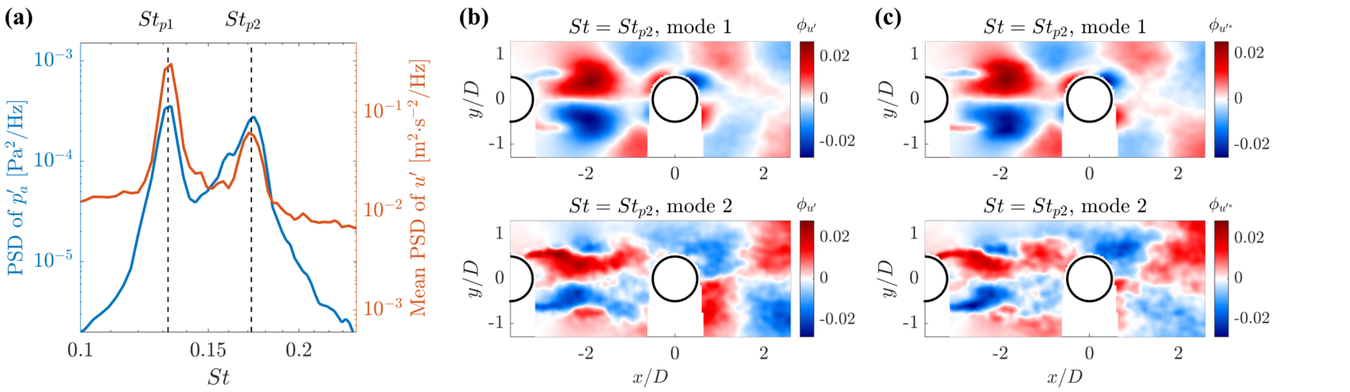

Figure 2. (a) Power Spectral Density (PSD) of the far-field sound pressure p'_a and the mean PSD of the fluctuating streamwise velocity u' of the entire flow field; (b) two leading SPOD modes of u' at Strouhal number St_{p2}, directly calculated using the HS-PIV data; (c) two leading SPOD modes of the fluctuating streamwise velocity weighted by p'_a at Strouhal number St_{p2}.

Acknowledgments

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