POD analysis of turbulent flow and its physical meaning

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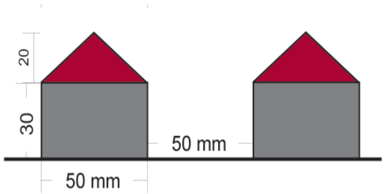
Introduction

This contribution describes the character of turbulent flow generated above series of street canyons in wind-channel. Main concern is to clarify how intermittent dynamics of the flow determines the ventilation process inside the canyon using POD.

Experimental set-up

The roughness on the floor of the channel represents long series of identical and parallel street canyons (Figure 1). Aspect ratio between the width and the height of street equals to one. Channel itself has a dimension of 0.25 m x 0.25 m in cross-section and about 3 m in longitudinal direction. Reference velocity at the mouth of the channel is 5 m/s.



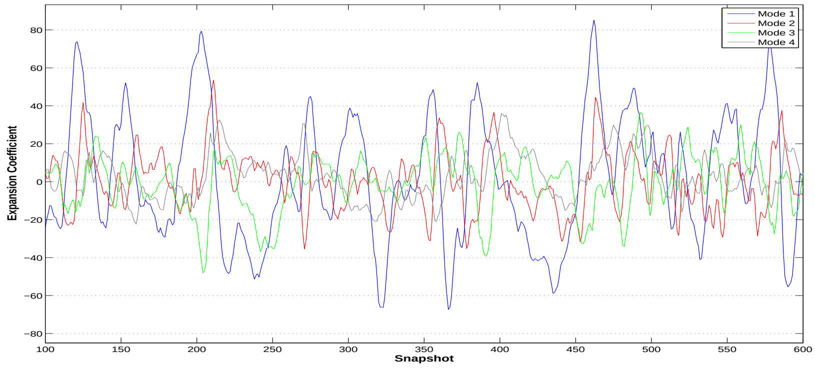
Obrázek 1: Side-view of the street canyon inside the wind-channel.

Time-resolved PIV (500 Hz) is used to record 2-D velocity vectors in vertical plane X-Z, where X-direction is horizontal axes parallel to the approaching flow and Z-direction is vertical axes. Camera has resolution of 1280 x 1024 pixels. The illuminated area is 0.1 m x 0.1 m large and involves more than 4800 vectors, since we use overlapping of 50% in postprocessing. Spatial resolution of PIV results in 1.2 mm. Data were recorded over time of 3.2 s in each run. By this, we got more than 1600 snapshots in one run.

Results

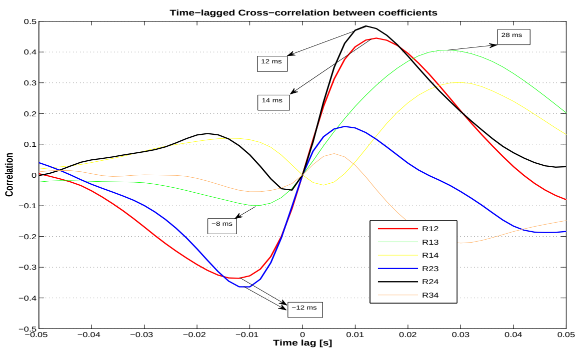
Velocity information (U- and W-component) in snapshots is decomposed by Proper orthogonal decomposition (POD). The most dominant modes from the TKE point of view are achieved. The most important phenomena reveal to be a formation of vortices behind the roof (Mode 1), an intensification of the vortex inside the street (Mode 2), sweep and ejection events in the main flow (Mode 3) or formation of low vortex at the bottom of the street (Mode 4). Every mode has its own expansion coefficient that is a function of time. When an extreme appears in this time-evolution of coefficient, the particular mode plays a significant role for a moment.

The expansion coefficients exhibit some repetitive patterns. For example, the local maximum of the first coefficient is often followed by local maximum of the second coefficient (see Figure 2). With certain level of simplification, we can draft a scenario of flow dynamics. These scenarios are visible in Figure 2 around snapshots number 200, 470 and 580, where large peaks in Mode 1 take place.



Obrázek 2: Example of temporal evolution of expansion coefficients for four POD modes. Each colour corresponds to one POD mode.

We derived mutual correlation amongst all expansion coefficients of the first four modes (see Figure 3). Between the first and the second mode, the correlation reaches up to 0.45 for temporal lag of 14 ms. It means that once the vortex behind roof is established, the strong downdraft on its upper boundary penetrates into canyon and speeds up the rotation between the wall after 14 ms. Likewise, there is marked negative peak at time lag of -12 ms, what suggests that the decelerated rotation of vortex between walls precedes the formation of vortex behind the roof by 12 ms. Generally, the strongest correlation (0.48) is amid second and fourth modes,



Obrázek 3: Time-lagged cross-correlation between particular expansion coefficients (e.g. R12=correlation between expansion coefficients of Mode 1 and Mode 2). Thick line labels the correlations with significant maximum.

since they both represent the vortices at slightly different position. At first, the vortex between walls is formed (getting energy from penetration of the flow associated with Mode 1) and in 12 ms later, the lower vortex receives sufficient level of energy to spin up. There is also connection (0.4) between roof vortex and final ejection event at time lag of 28 ms. It implies that dynamics starting with vortex behind roof and going through all the before-mentioned stages ends up by ejection event.

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