Poincaré section analysis of an experimental frequency intermittency in an open cavity flow

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POINCARÉ SECTION ANALYSIS OF AN EXPERIMENTAL FREQUENCY INTERMITTENCY IN AN OPEN CAVITY FLOW

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Summary Open flows over a cavity present, even at medium Reynolds number, sustained oscillations resulting from a complex feedback process [1]. Previous works have reveals a mode-switching phenomenon which remains to characterize from a dynamical point of view. In the configuration here investigated, the intermittency between the two dominant modes is characterized using a symbolic dynamics based approach. The first step of the procedure is to reconstruct the phase space from the time series measured by the Laser Doppler Velocimetry (LDV) technique, using the principal components. We show that the quite high dimensionality of the reconstructed space ($d < 10$), can be overcome by using a Poincaré section of the 2D projection of the phase portrait. The key step consists of a partition of the Poincaré section (the set of intersections of the trajectory in the reconstructed phase space with a transverse plane). The two modes are thus label led 0 and 1, respectively. The partition is based on an angular map, itself based on a first-return map to the Poincaré section. This partition allows, without any arbitrary thresholding (as spectral based modes separation method needs), a very precise quantification of all oscillating events.

FLOW DESCRIPTION AND EXPERIMENTAL CONTEXT

The system under study consists in a cavity of length $L = 10$ cm. The height of the cavity is such as the aspect ratio $R = \frac{L}{H}$ is equal to 2. The width of the cavity 30 cm (Fig. 1). The air flow is produced by a centrifugal fan located at the inlet of the settling chamber. The incoming boundary layer is laminar and stationary. The reference velocity is the external velocity $U_e = 2.09$ m.s^{-1}, corresponding to Reynolds number $Re_L = \frac{U_e L}{v} \approx 14\,000$. The whole analysis is performed using a velocity time series recorded, at the cavity downstream, by a Laser Doppler Velocimeter ($N = 840\,000$ points at the mean sampling rate $f_s = 1530 Hz$. The two dominant frequency modes ($f_0 = 23.2$ Hz and $f_1 = 31.0$ Hz) present an intermittency visible on the spectrogram(Fig. 2).

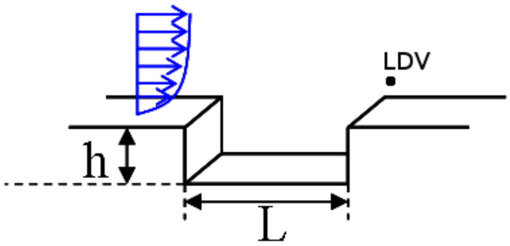

Figure 1. Flow past the open cavity

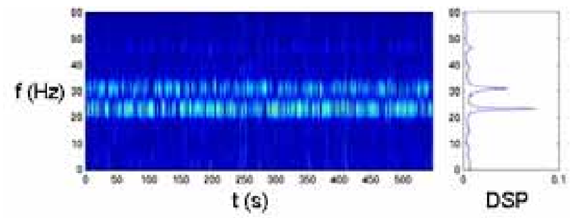

Figure 2. Spectogram and normalized amplitude spectral density

METHODOLOGY OF SYMBOLIC SEQUENCE STATISTICAL ANALYSIS

Hereafter we investigate the intermittency between this dominant modes using an approach based on the symbolic non-linear dynamics. So doing we strive towards a double goal:

- the separation in the signal of the time events associated with one or the other frequency. We have explored, in previous works [2], spectral based modes separation method (Hilbert and wavelet transforms, spectrogram,...). All this spectral methods are limited at least by the $\Delta f.\Delta t$ uncertainty, which makes difficult to catch the short events closed to one period.
- the physical understanding of the non-linear modes coupling.

Three steps of signal transformations lead to the exact location of each events, inside the time series, corresponding to either the frequencies f_0 and f_1 or to the events associated with the transitions between the two modes. This spotting of index in the time series allows a lot of statistical analysis (Fig. 6) and even of orbits characterizations. The first step of the procedure consists in a reconstruction of the phase space from the time series measured, using the principal components (Fig. 3). We show that the quite high dimensionality of the reconstructed space ($d < 10$), can be overcome by using a Poincaré section of the 2D projection of the phase portrait (Fig. 4). The second step consists of a partition of the Poincaré

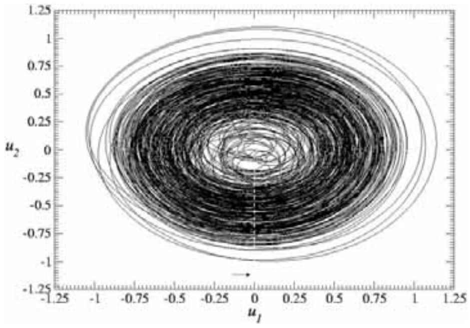

Figure 3. Phase portrait spanned by the first two principal components reconstructed from the measurements of the vertical component of the velocity.

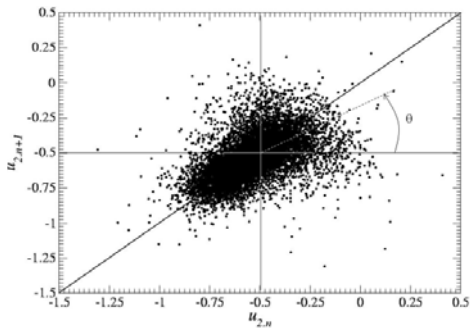

Figure 4. First-return map to a Poincaré section of the phase portrait. The Poincaré section is defined by $u_1 = 0$ and $\dot{u}_1 > 0$.

section (the set of intersections of the trajectory in the reconstructed phase space with a transverse plane). The two modes are thus labelled 0 and 1, respectively. The partition is based on an angular map (Fig. 5), itself based on a first-return map of the Poincaré section [3]. Then for the third step, all the existent linking sequence of mode 0 and 1, are coded using 'words' of 8 digits. As example, $\Sigma_{65} = 0011\ 1111$ codes the event: 2 periods of mode 0 followed by 6 periods of mode 1.

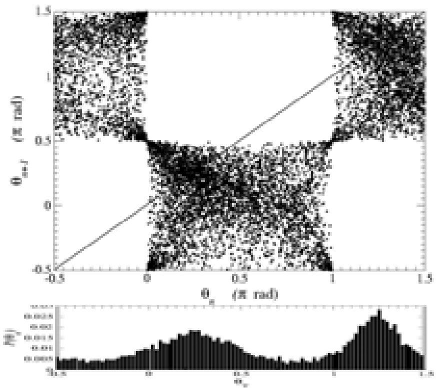

Figure 5. Angular map built on the first-return map.

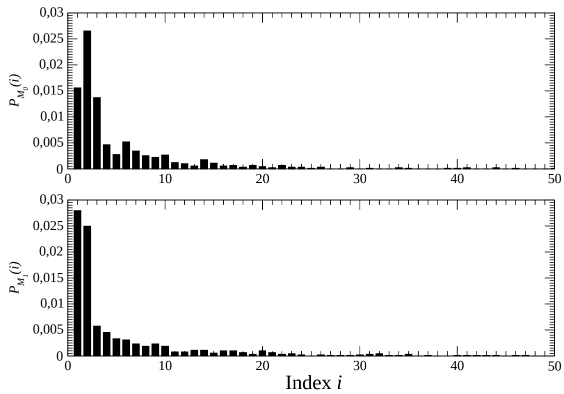

Figure 6. Probabilities of realization of mode 0 (top) and mode 1 (bottom), vs. the life length of the mode

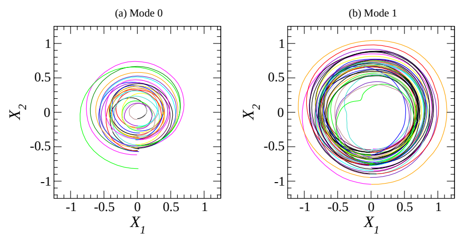

Figure 7. Plane projection of typical trajectories associated with the two different modes.

CONCLUSIONS

We have shown that the short one-mode standing events are more numerous than the long one, but long lengths still significantly contributes to the dynamics. This very fast switching between modes is hidden to the spectral analysis. The statistics on the symbolic sequences indicates that the underlying dynamics is not a white noise, neither a deterministic system characterized by a complete symbolic dynamics. It is rather a dynamics resulting from the superposition of a deterministic components and a stochastic process. A remarkable fact is that each dynamical orbit generating the resulting signal can be separately observed and studied (Fig. 7).

References

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