SHEAR LAYER INSTABILITY AND FREQUENCY MODES INSIDE AN OPEN CAVITY

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Summary The dynamic behaviour of the vortex structures occurring in a cavity, in interaction with an upstream wall flow, drives the fluid confinement inside the cavity. This presentation concerns the coupling between the shear instability process and the mechanisms of frequency selection which depend on the size of the cavity. The analysis is based on an experimental exploration of the flow (LDV, PIV) and on direct numerical simulation.

INTRODUCTION

In case of moderate Reynolds number (Re<30000, based on the length of the cavity) the structure of the flow generated by a cavity in interaction with an upstream boundary layer, appears to be more complex (i.e. more unsteady and tri-dimensional) than observed at higher Reynolds number. With the aim to control the exchanges of mass or heat between the cavity and the main flow, it is first necessary to describe the main features of the vortex structures and their physical relationships. This communication concerns the coupling between the shear instability and the mechanisms of frequency selection depending on the size of the cavity. The analysis is based on an experimental investigation (Figure 1) of the flow (LDV, PIV-optical flow [1]) and on 2D and 3D direct numerical simulations (Figure 2).

Figure 1: flow inside cavity, light sheet in the plane of symmetry.

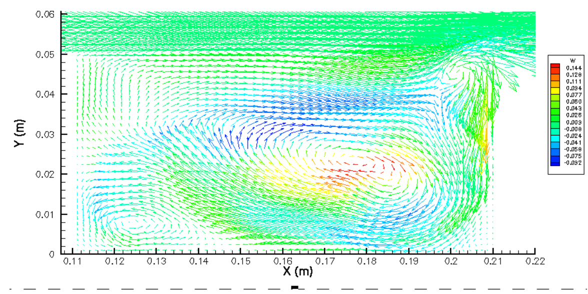

Figure 2: 3D DNS; velocity field in the plane of symmetry.

Following the development of the frequency modes with an increasing flow rate, four main modes appear (Figure 3). The latest one (mode 3) corresponds to oscillation in a turbulent regime flow. The modes 0, 1 and 2 allow a very good comparison between the numerical simulation and the experiment (Figure 4). The mode 2 has been identified with shear instability of the mixing layer above the cavity [2].

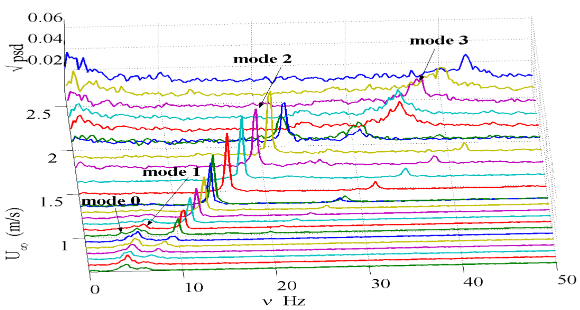

Figure 3: Power spectral density of energy from horizontal velocity component, measured by LDV vs. upstream flow rate

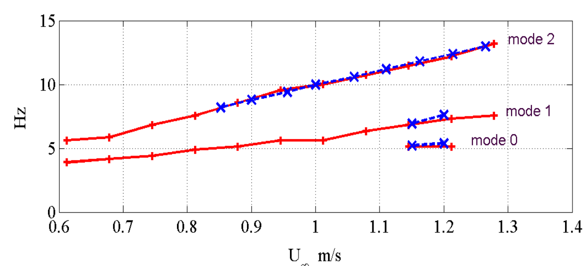

Figure 4: Comparison of numerical simulation (-x-) and experiment (-+-): Frequency modes vs. upstream flow rate.

RESULTS AND CONCLUSIONS

It is essential to stress that the increase of the cavity length *L* induces a frequency shift of the modes, even for mode 2 corresponding to the shear instability (Figure 5). That shows the existence of selection mechanism acting on the process of shear layer instabilities. This phenomenon is also described in a previous work concerning an open cavity, but at higher Reynolds number [3].

The linear relationship $f^k = f_0^k + \alpha^k U_{ref} = \alpha^k \left(U_{ref} - U_c^k\right)$ between the frequency f^k of each mode *k* and the flow rate velocity U_{ref} (see Figure 5), allows the construction of a Strouhal number based on the length *L*:

$$St_L^k = \frac{f^k L}{U_{ref}} = \alpha^k L + \frac{f_0^k L^2/\nu}{\mathrm{Re}_L} = \alpha^k L - \alpha^k U_c^k \frac{L^2/\nu}{\mathrm{Re}_L}$$

with U_c^k a critical flow rate and $\mathrm{Re}_L = U_{ref} L/\nu$. α^k and U_c^k are function of L.

Therefore the Strouhal number becomes asymptotically constant for increasing Reynolds numbers, as actually presented Figure 6. This representation reveals again the three modes and their continuation when the aspect ratio $R = L/h$ is changed. The range of validity of this result is limited one side to $R \geq 1$, value under which the vortex organization inside the cavity changes. On the other side, although we don't explore the aspect ratio bigger than 2, it is known that for high value of *R*, the flow develops as for a back facing step.

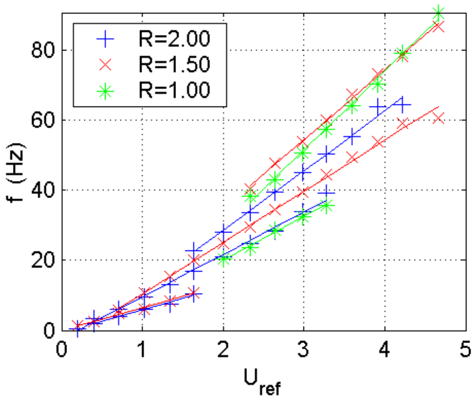

Figure 5:Frequency modes vs. flow rate for three values of the cavity length L; R=L/H the aspect ratio.

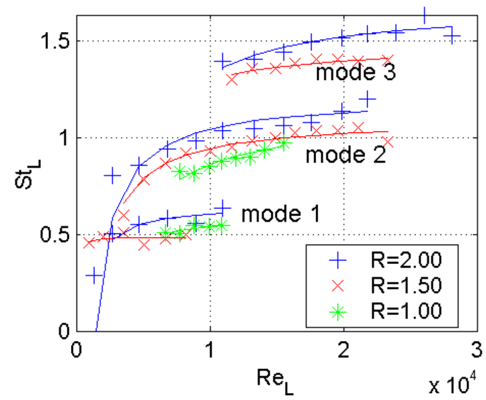

Figure 6: Data of the Figure 5, plotted as Strouhal number vs. Reynolds number (characteristic length L and velocity U_{ref}): 3 modes grouping effect.

The numerical simulation confirms the persistence and the frequency shift of mode 2, induced by the increase of length *L* (Figure 7 'circles'). Note that computation is done for a fine step increase of *L*, even if for a limited range of Reynolds number values.

The discrepancies of the modes grouping and the strong correlated behavior of the different modes have to be discussed.

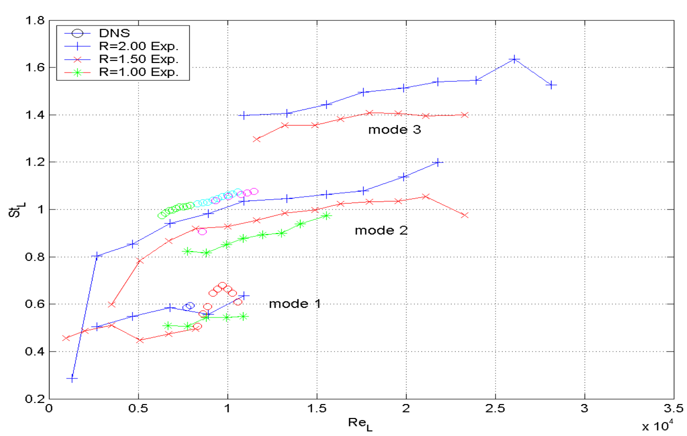

Figure 7: Comparison between the frequencies obtained from the numerical simulation for $1.5 < R \leq 2$ and those obtained from the experimental times series.

References

[1] G.M. Quénot, J. Pakleza, T.A. Kowalewski, "Particle image velocimetry with optical flow", *Exp. In Fluids 25, 1998* pp177-18

[2] Rambert A., Lusseyran F., Gougat P., Fraigneau Y., Elcafsi A., Quénot G., « Relationship between Fourier-modes and spatial-structures in a cavity - boundary layer interaction at moderate Reynolds numbers. » *11th Int. Symp. on Appl. of Laser Techniques to Fluid Mechanics*, Lisbonne (Juillet 2002).

[3] Rockwell D. and Naudasher E., Self-sustained oscillations of impinging free shear layers, *Ann. Rev Fluid Mech.*, **11** : 67-94, 1979.