CAVITY FLOWS: CHANGE OF REGIME IN THE RATIO BETWEEN THE PRESSURE AND KINETIC ENERGY FLOWS ACROSS THE CAVITY MOUTH.

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Abstract The incompressible flow in a rectangular cavity located along one of the wall of a plane channel is studied. The focus is put on the flow in the cavity and on the energy dynamics, in particular on the pressure and kinetic energy exchange across the interface surface between the cavity and the channel. Moreover, using the incompressible formulation of fluid equations, we look for observable properties that can be associated to acoustic emission which is normally observed in this kind of flow beyond a critical value of Reynolds number.

FLOW SYSTEM

Fundamental properties of the fluid motion in a rectangular cavity located along one of the wall of a two-dimensional channel flow are considered, see Figure 1. In the present work the cavity mouth is seen as the exchange surface between the cavity and the channel. The focus is put on the flows into the cavity and on the energy exchange across the cavity mouth, in particular on the accumulation of energy in the cavity which takes place in the form of pressure and kinetic energy. The flow is studied by means of a sequence of direct numerical simulations in Reynolds number Re range $25 - 2900$ (referred to the U bulk velocity in the channel flow and on the half height of the channel). This allows to span across the steady laminar regime up to a first coarse turbulent regime.

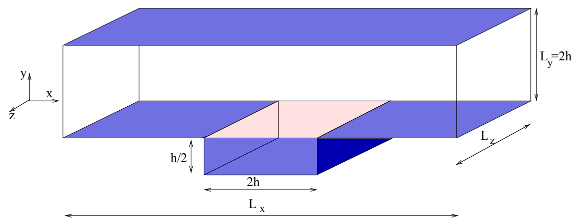

Figure 1. Fig.1 Scheme of the channel-cavity domain. Dimensions are defined with reference to the half channel height, h. The cavity is located at the centre of the lower wall. The size of the computational domain is $L_x/h = 4\pi h$ and $L_z/h = \pi$.

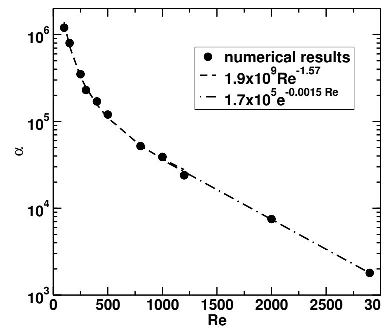

Figure 2. The ratio $\alpha = \frac{<pv>}{<Ev>}$ between pressure and kinetic energy flow across the cavity mouth, versus Re. The value of α initially falls down with $Re^{-1.57}$, then above $Re \simeq 1000$, α sets to an exponential asymptote.

OBATAINED RESULTS

We observed that the pressure flow grows with the Reynolds number and peaks at a Reynolds close to 1000. At Reynolds values as low as 25-50, the kinetic energy flow is about six orders of magnitude lower than the pressure flow. But, on the contrary to the pressure flow, the kinetic energy flow monotonically grows . As a consequence, beyond $Re \simeq 1000$, we observe a change of regime in the ratio between the pressure and kinetic energy flow. This ratio in fact reaches an asymptotic state, see Figure 2, where the decay becomes exponential (trend proportional to $exp(-0.0015Re)$).

Beyond a certain threshold, when the convective forcing is increased, by increasing the Reynolds number, the kinetic energy inside the cavity grows but the pressure cannot. Why this happens? We think that the reason relies in the difficulty met in such a closed kind of domain by the energy to diffuse and dissipate in a sufficient way to get the steady state. In

fact, the vertical cavity walls block the energy diffusion also in the stream-wise direction. The dissipation is then also limited because the wall presence circumvents the generation of small unsteady/turbulent scales. To get the steady state, an energy release is needed. This is in the form of pressure waves, that is, an acoustic emission.
Moreover, visualizing the averaged pressure field inside the cavity in the turbulent case, we observed for the first time the trace of a sheet stretched along the span-wise direction where a kind pressure oscillation in space appears. See Figure 3, where a zoomed particular of the pressure field close to the downward cavity step is shown. Since the image shows data averaged in time and in space along the span-wise direction, this sheet can be interpreted as a kind of standing wave that departs from the high pressure spot visible on the surface of the downward cavity step. The sheet is backward inclined of about 26 degrees with respect to main flow in the channel. The wavelength of the wave is of the order of 1/8 of the cavity depth (1/32 of the cavity width). In this condition, the measure of the maximum pressure difference inside the cavity shows a value of the order of 10^{-1}Pa. This value in a sound wave could be roughly equivalent to a sound pressure level of 50-60 dB. We interpret the presence of this standing wave as the fingerprint of the noise emission which exists in flow configurations similar to this one and that cannot be observed in this study since we are not dealing with the full compressible model. The interesting point here is, however, the fact that the incompressible formulation seems capable to yield a signature of the acoustic production.
The results obtained in the present work agree with laboratory findings (Gharib and Roshko, (1987) [1]) related to a turbulent cavity flow with a different geometry and a Reynolds number about 10 times larger, a thing which highlight a good level of generality for our results, see Figure 4.
We hope to open the discussion on the physics of this flow and to promote the wish to carry out laboratory and numerical experiments at very low Mach numbers in the fluid dynamic community active in such a field. To promote the laboratory experiments we have presented our results for a system which can easily reproduced in a normal fluid dynamics laboratory (the cavity is $20cm$ long and $5cm$ deep). By means of the new class of massive parallel and low energy consuming machines, the idea to carry out compressible simulations at Mach numbers as low as 10^{-3} can now be accepted.

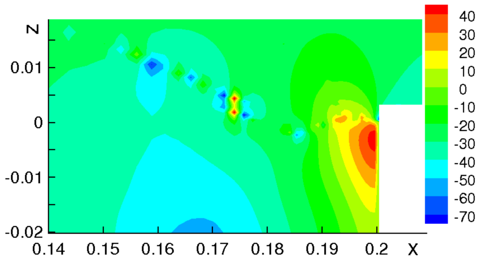

Figure 3. Particular of the pressure field in the downstream edge region at $Re = 2900$. A sequence of high and low pressure spots departs from the edge. The Mach number is of the order of 10^{-3}. The line joining the spot centres is backward inclined of about 26°, which is close to the inclination of the acoustic wave observed in the compressible simulations or laboratory observations with Mach numbers in the range $0.1 - 0.7$ [5]. The pressure field is averaged in time over 16 flow time scales and in space over the whole spanwise length of the computational domain.

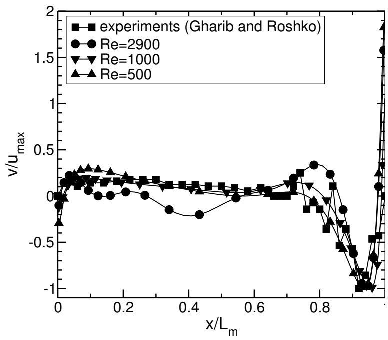

Figure 4. The v velocity in the y direction, divided by the maximum of the streamwise velocity component, versus the distance from the edge of the cavity. The velocity profiles obtained for different Reynolds number are compared with the laboratory results by Gharib and Roshko (1987) [1], obtained for a cavity placed along a boundary layer in cylindrical symmetry (Reynolds number equal to 24000).

References

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