Control of cavity flow by means of a spanwise cylinder

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Introduction

Low frequencies induced by a shear layer cavity resonance are characterized by large dynamic pressure loads and represent an important problem in many aeronautical applications. Recent experiments [1] have shown that efficient amplitude reduction of these oscillations can be produced by a cylindrical rod parallel to the leading edge of the cavity. This passive control method has been applied to the case of the deep cavity flow described in [2]. Schlieren films and pressure signals have been performed for different cylinder diameters and positions in the flow and different Mach numbers. The efficiency of the system is confirmed and the underlying mechanisms are discussed.

Experimentals conditions

The experiments are conducted in a rectangular high-subsonic speed wind-tunnel at Mach numbers M = 0.7 and M = 0.78 . The cavity length is $L = 50\text{mm}$ and its depth, $D = 120\text{mm}$, the aspect ratio being $L/D = 0.42$. The boundary layer at the leading edge of the cavity is turbulent ($Re_{\theta 0} = 10780$ for M = 0.78). One considers spanwise cylinders, with different diameters, parallel to the leading edge of the cavity. The Reynolds number Re_d based on the cylinder's diameter d is subcritical (between 43 000 and 129 000). Two different longitudinal positions of this cylinder, with respect to the leading edge of the cavity, have been also tested. The height of the cylinder above the wall, *z*, has also been varied. So, the effect of the cylinder on the flow is actually a function of the following parameters : Re_d , M , x/L , z/L and d/L . As shown by previous investigations, the effect of the boundary layer thickness on the flow regime is negligible [6].

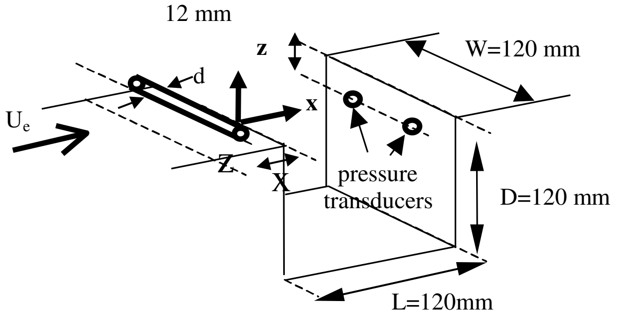

Figure 1 – sketch of the experimental set-up

Results

For z/d<0.7, see Figure 2, the cavity modes are identical to those found without the cylinder device. For z/d ≈ 0.7, a transition occurs from the cavity oscillations to a Von-Karman street regime. Low frequency cavity modes are suppressed and are replaced by oscillations at the cylinder's frequency. This new regimes holds for all values of d/L tested (between 0,05 and 0.15) and it is independent of both Re_d and M . As shown by figure 4, the maximum SPL value decreases from 170 dB to 140 dB and is shifted from 2 000Hz to 20 000Hz. The Strouhal number $St=fd/U_\infty$ of the new mode is 0.21, in accordance with the presence of a Von-Karman street. The same non-dimensional value is found for others diameters.

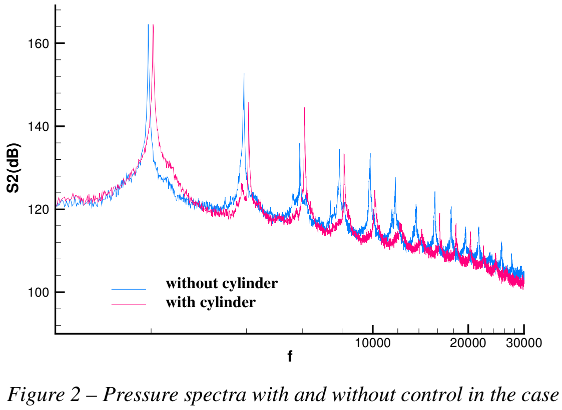

Figure 2 – Pressure spectra with and without control in the case z/d = .2, x/L = -0.1 at M = 0.78

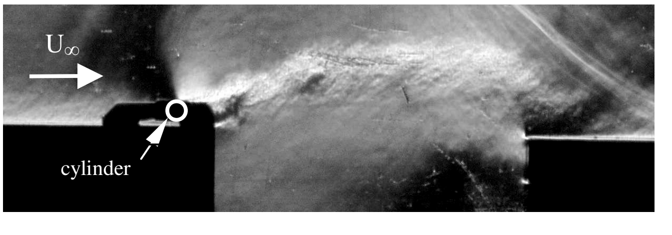

Figure 3 – Schlieren picture (horizontal knife) in the case of Figure 2

In all cases, the separation between the cylinder and the pressure transducers (see figure 1) is such that $L/d \leq 20$. This is a much smaller value compared to $L/d \geq 100$ prescribed in [5] for a change in the cylinder wake dominant frequency. Our results show that the cavity flow is entirely controled by the cylinder for $0.7 \leq z/d \leq 1.6$. Above $z/d \approx 1{,}6$, the cavity tones reappear. Tests have shown that translation of the cylinder upstream increases a little the threshold of z/d where the control becomes effective.

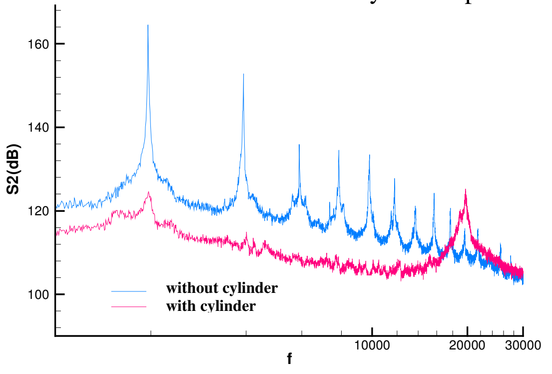

Figure 4 – Pressure spectra with and without cylinder in the case z/d = 1.2, x/L = -0.1 at M = 0.78

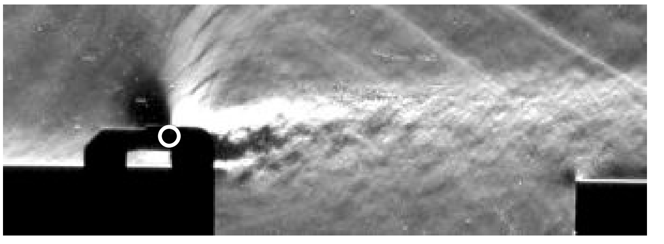

Figure 5 - Schlieren picture (horizontal knife) in the case of Figure 4

Discussion

In ref. [1], it is suggested that the effect of the cylinder could be due to turbulence mechanisms, i.e. to an increase of the rate of energy transfer (or dissipation) within the inertial range of turbulence scales separating the cavity modes ("large scales") from dissipation scales. This interpretation seems not appropriate because a resonant cavity flow does not behave as a standard developed turbulent shear flow. In particular, the Rossiter's modes cannot be considered as large scale turbulent structures. The present results suggest that the perturbations induced by the cylinder break the cavity flow oscillation loop, probably through the cancellation of the vortex formation process which takes place in the very vicinity of the cavity leading edge, as described in [2]. In the presence of the cylinder, two different flow physics are put together. On the one hand, the cylinder flow is driven by a global instability mode, see [4], which is very robust and almost insensitive to external perturbations and which does not feels the acoustics emanating from the cavity. One the other hand, the mixing layer behaves as an amplifier at the dominant forcing frequency. As shown by spectra, the cylinder imposes, by a way or another, its own dynamics when it is immersed in the region of the cavity leading edge. However, following [8] the shear layer could be stabilised due to the change in the mean axial shear layer velocity profiles in presence of the cylinder. This was suggested by LES simulations, see [7]. The modification of the velocity profile could be due to an increase in the diffusion of momentum in the mixing layer forced by the cylinder modes. Further experimental investigations of the mean shear layer profile in presence of the cylinder are in progress to test such proposals. The results will be presented during the symposium.

References

[1] Stanek, M.J., Raman,G., Kibens, V., Ross, J.A., Odreda, J., Peto, J.W., *Control of cavity resonance through very high frequency forcing,* AIAA paper 00-1905 (2000)

[2] Forestier, N.,Geffroy, P. & Jacquin, L., *The mixing layer over a deep cavity at high-subsonic speed,* J. Fluid Mech., Vol. 475, 101-145 (2003)

[3] Glezer A. & Wiltse J.M., *Direct high-frequency excitation of turbulence in free shear flows,* AIAA paper, juanuary 15-18 (1996)

[4] Hammond, D.A. & Redekopp, L.G., *Global dynamics of symmetric and asymmetric wakes,* J. Fluid Mech., Vol. 331,pp 231-260 (1997)

[5] Cimbala J.M., Nagib H.M. & Roshko A., *Large structure in the far wakes of two-dimensional bluff bodies,* J. Fluid Mech., Vol. 190, 265-298 (1988)

[6] Illy, H. , Geffroy, P. & Jacquin, L., *Influence de l'état de la couche limite sur les écoulements de cavité*, RT ONERA (2003)

[7] Arunajatesan, S., Shipman, J.D. & Sinha, N., *Hybrid RANS-LES simulation of cavity flow fields with control*, AIAA-2002-1130

[8] Stanek, M.J., Ross, J.A., Odreda, J. & Peto, J., *High frequency acoustic suppression*, AIAA 2003-0007