Improvement of the Jet-Vectoring through the Suppression of a Global Instability

Vincent G. Chapin*, Nicolas Boulanger* & Patrick Chassaing**

* Fluid Mechanics department, ENSICA, 1 place E. Blouin, 31056 Toulouse, FRANCE, E-mail:Vincent.chapin@ensica.fr
** Institut National Polytechnique de Toulouse (INPT), 31029 Toulouse Cedex 4, FRANCE

Abstract. : The behaviour of the near-field region of a vertical rectangular jet of aspect ratio 4:1 controlled by a rotating cylinder placed on the jet major-axis is investigated experimentally using a new design facility. The objective is to investigate flow control strategies of a rectangular jet based on instability manipulation. It is found experimentally that the controlled jet exhibits similar behaviour to the one described theoretically and numerically by Hammond & Redekopp (1997a, b) on bluff-body wakes with higher control efficiency when the global instability mode is suppressed.

Keywords: Flow-vectoring, thrust vectoring, flow control, global instability, rectangular jet, rotating cylinder

1 Introduction

We present experimental results about jet-vectoring using a rotating cylinder placed on the jet major-axis near the exit plane (z/h=1.3, y/h=0) as shown in Figure 1. An interpretation of these results is proposed, within the theoretical framework of Hammond & Redekopp (1997a, b) concerning the relationship between the control efficiency and the presence of global instability modes. Finally, it is concluded that a highly efficient rectangular-jet vectoring can be obtained when the global instability mode present in the controlled flow is suppressed by using a supercritical rotating speed.

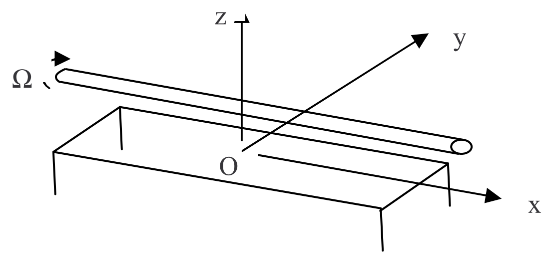

Fig. 1. : Jet flow configuration

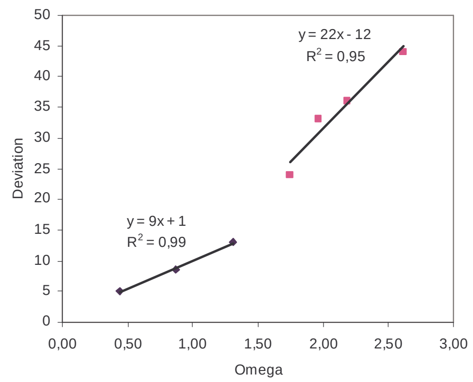

Fig. 2. : Mean deviation angle of the jet versus rotating speed of the cylinder Ω^*. Linear regression equations and correlation coefficient are given below and above the critical speed Ω^*_c.

2 Results

The control methodology proposed by Hammond & Redekopp (1997b) will be tested here. Briefly speaking, they show that when a global instability mode is present in the flow, it is necessary to suppress it to be able to develop an efficient control.

In our experiment, the rectangular jet is known to be convectively instable, according to the theoretical concepts reviewed by Huerre & Monkewitz (1990). By introducing a cylinder on the jet centreline, an absolute instability region of critical size develops behind the cylinder, which results in the von Karman vortex shedding (a well known global mode). Also, following the theoretical scenario, it should be necessary to suppress this global mode to enhance the flow control effectiveness.

Numerical simulations of a rotating cylinder in a uniform flow, by Mittal & Kumar (2003), have shown that the von Karman street disappears for supercritical rotating speed ($\Omega^*=\Omega.d/2.U_\infty > 2$). Since, in the present situation, the cylinder is located in a jet of centreline velocity U_j, various rotating speed have been applied to investigate the existence of a threshold Ω^*_c specific to our flow.

The response of the controlled jet to the rotating speed $\Omega^*=\Omega.d/2.U_j$ is given in Figure 2, in terms of the mean deviation angle. A critical rotating speed may be identified around $\Omega^*_c = 1.5$ where the slope of the curve changes by more than a factor of two. This slope, which represents the jet-vectoring efficiency, is more than two times higher for supercritical values of Ω^*.

Given this result, we have investigated the flow in greater detail to see whether this critical behaviour could be associated with the disappearance of the von Karman global mode behind the cylinder when its rotating speed is increased. Flow visualizations given in Figure 3, obtained with a high speed CCD camera by illuminating an oil droplets seeded flow with a thin laser sheet, clearly illustrate this point. In the left view, the von Karman anti-symmetric vortex shedding is clearly seen. In the right view, it has disappeared being replaced by a chaotic flow.

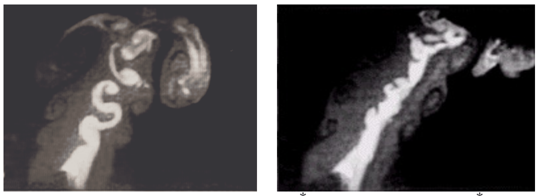

Fig. 3. : Visualizations of the flow at Ω^*= 1.4 (left) and Ω^*= 1.64 (right).

Spectral analyses of the hot-wire measurements of the longitudinal component of the instantaneous velocity in the jet flow behind the cylinder, located along the jet centreline at z/h=0.33, are given in Figure 4. Below the critical speed, a unique sharp peak dominates the spectrum, a typical feature of a self-exited oscillator (Monkewitz & Bechert 1988). Above the critical speed, the spectrum is typical of a noise amplifier with broadband and lower peaks at a dominant frequency close to the one found in the free jet shear layers and identified as a jet cavity resonance.

The conjunction of theses observations about flow deviation angle, flow visualization and velocity spectra indicates that the suppression of the global instability results in a more efficient jet vectoring for supercritical values of Ω^*.

3 Conclusion

In a rectangular jet of aspect ratio 4:1 controlled by a rotating cylinder, it is shown experimentally that the suppression of the global instability mode is correlated to an increase of the jet-vectoring efficiency. This first experimental evidence supports the theoretical scenario proposed by Hammond & Redekopp (1997) on wakes and Lim & Redekopp (2002) on jets.

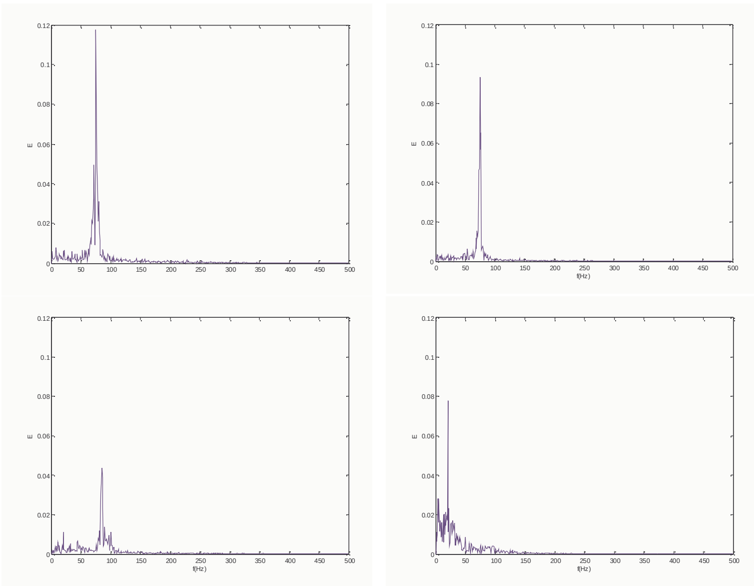

Fig. 3. : Velocity Spectra (a) $\Omega^* = 0$, (b) $\Omega^* = 0.14$, (c) $\Omega^* = 0.8$, (d) $\Omega^* = 3.1$

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