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Experimental investigations of an air curtain device subjected to external perturbations

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Abstract

Although plane air jets are often used as dynamic barriers to separate two environments, only a few works have explored their sensitivity to perturbations. We investigated the influence of sharp changes of pressure on the flow field of a device designed to avoid air-borne contamination. Laser tomography and tracer gas experiments clearly indicate that the air curtain is strongly sensitive to perturbations such as draughts. The results highlight that the control of air curtains used in open protection devices should be further investigated.

Keywords: Plane air jet; Pressure variation; Contaminant control

1. Introduction

Plane air jets can be used as dynamic barriers to control contaminant spread in many situations (Rydock et al., 2000; Guyonnaud et al., 2000). They are usually associated with a laminar flow unit to fight the air-borne contamination in the electronic, pharmaceutical and food industries (Szatmary, 1997; Hu et al., 2002; Bridenne and Coffinier, 2002). Although open protection devices are subjected to perturbations like draughts, most of the extended literature concerns steady flows. Only Johnson states that air curtains are very sensitive to wind and pressure differentials (Johnson, 1998). In order to investigate the impact of sudden pressure perturbations on the behaviour of free jets used as dynamic barriers, a 1:4 scale test facility was created. It reproduces an air-borne contamination protection device placed in a room (Fig. 1). The working area is protected by a unidirectional airflow at a constant velocity ($U_0 = 0.47\ \mathrm{m\,s^{-1}}$). On one side, this clean area is separated from the external environment by a plane air jet whose velocity U can be fixed between 0 and 3 $\mathrm{m\,s^{-1}}$. The pressure in the test chamber is varied by way of a manual opening of a door. The resulting pressure difference is then recorded between static pressure taps P_1 and P_2 (SETRA Model 239). Previous experiments have shown that the pressure perturbations generated in the test bench correspond to draughts experienced in a typical room (Rouaud, 2002). Flow visualisations are carried out with a laser (110 mJ Nd:Yag, DANTEC) which generates a light sheet. Ethane, used to simulate the airborne contamination, is injected outside the area cleaned by the laminar flow unit and a flame ionisation detector (Fast FID-HFR400, CAMBUSTION) measures the contamination at stations A and B inside the working area (Fig. 1).

2. Results and discussion

Fig. 2 shows first a standard measure of the pressure difference ($P_1 - P_2$) due to the door opening. It clearly appears that this action induces a strong depression (ΔP_{max}) followed by a slower return to the atmospheric pressure. The resulting temporal evolutions of the jet for $U = 0.98$ and $U = 2.14\ \mathrm{m\,s^{-1}}$ are also presented at four instants. These visualisations of the shear layers confirm

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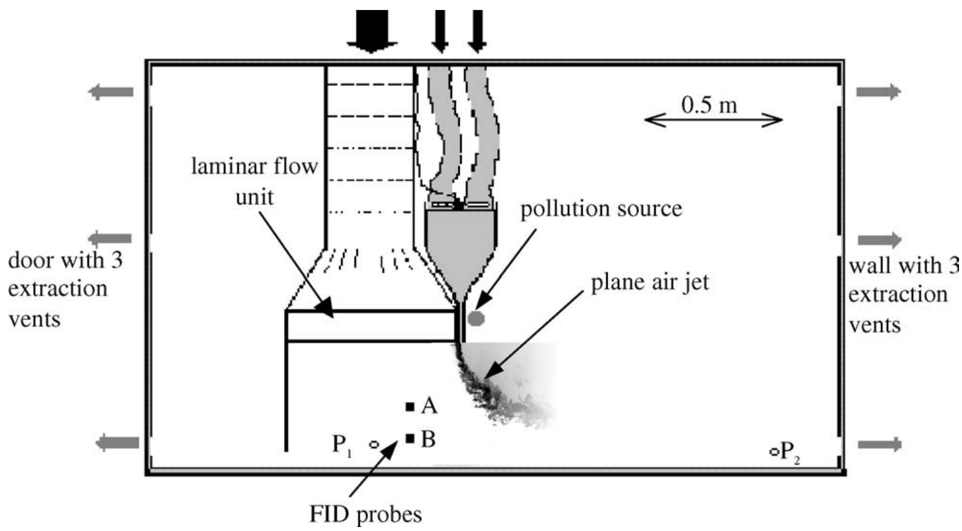

Fig. 1. Sketch of the experimental apparatus.

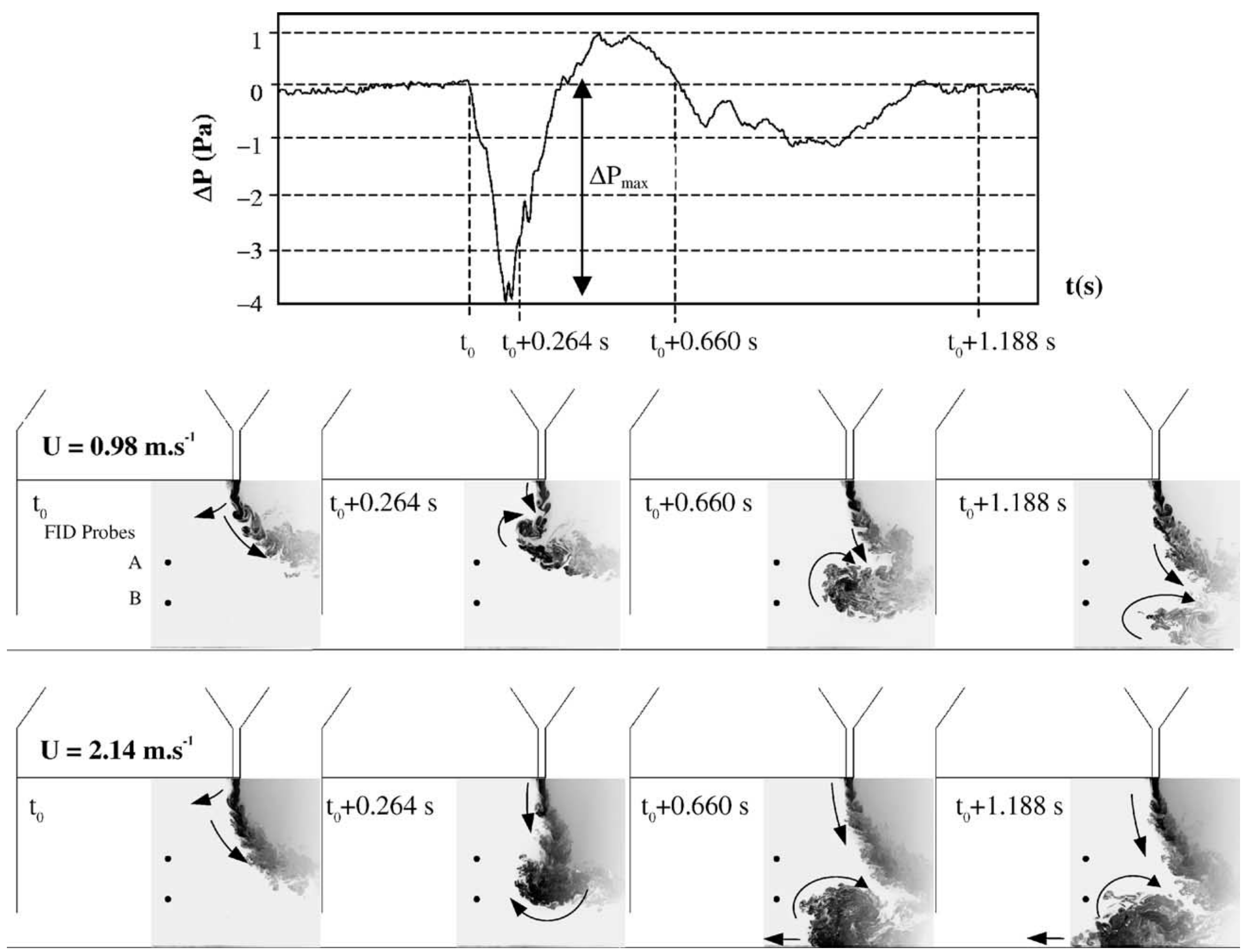

Fig. 2. Measurement of ΔP and visualisations of the unsteady behaviour of the jet for $U = 0.98$ and $U = 2.14$ m s^{-1}.

that the strong depression leads to an abrupt change of the flow direction. The jet curves towards the clean area at the beginning of the perturbation ($t = t_0$) and reverts to its original trajectory back only after maximum depression ($t = t_0 + 0.264$ s). The jet breaks up under the influence of this rapid reorientation and a large swirling

Table 1
Maximum transfer coefficient ($s\,m^{-3}$) at stations A and B according to the jet velocity for $\Delta P_{max} = 3.5$ Pa

U ($m\,s^{-1}$)	Station A	Station B
0.98	96.2	43.0
2.14	15.8	11.3
3.00	11.3	19.2

zone is thus created which is convected downstream ($t = t_0 + 0.660$ s). For $U = 0.98$ $m\,s^{-1}$, the swirl generated by the jet break-up retains a much more coherent structure. For $U = 2.14$ $m\,s^{-1}$, the coherent motion is still present but is less organised and impinges on the floor more quickly ($t = t_0 + 0.660$ s) before being evacuated. It thus appears that a strong recirculation zone carries away contaminants from the external environment. In order to focus on this mass transfer, we inject ethane at a constant rate ($q = 4.2410^{-5}$ $m^3\,s^{-1}$) on one side of the air jet and measure the concentration (C) on the other side at stations A and B. As the concentration changes with time, we calculate, in all cases, a transfer coefficient (C/q) for the greater value of ethane concentration (Table 1). These results can be correlated to the analysis of the jet structure. As the shear layer is unstable, vortices entrain ethane from the external ambience and the break-up in eddies lead to direct turbulent transfer of ethane to station A. For $U = 0.98$ $m\,s^{-1}$, this mechanism is important whereas it is of much less significance for larger inlet velocities where the break-up occurs further downstream. At station B, mass transfer result from the impingement of eddies. As they carry ethane, they contaminate the station B whatever the jet velocity.

3. Conclusion

Our experimental investigations clearly demonstrate that a plane air jet, used as a dynamic barrier, is strongly influenced by external perturbations such as sharp pressure changes. The resulting violent back-and-forth motion of the jet induces eddies responsible for entrainment of external pollution inside the working area. Two mechanisms explain these transfers: the direct passage through the jet due to its break-up and the impingement of eddies. From this preliminary work, it seems that additional studies will have to be carried out in order to find an optimal jet velocity and a strategy of control of the plane air jet in order to limit the mass exchange rate.

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