European Journal of Mechanics B/Fluids 48 (2014) 231–235

Contents lists available at ScienceDirect

European Journal of Mechanics B/Fluids

journal homepage: www.elsevier.com/locate/ejmflu

The vortex dynamics and the self sustained tones in a plane jet impinging on a slotted plate

Hassan H. Assoum [a,*], Mouhammad El Hassan [b], Kamel Abed-Meraim [c], Anas Sakout [c]

[a] Beirut Arab University (BAU), Tripoli Branch, Lebanon

[b] Department of Mechanical Engineering, Schulich School of Engineering - Calgary, Alberta, Canada

[c] Laboratoire des Sciences de l'Ingénieur pour l'Environnement (LaSIE), University of La Rochelle, Avenue Michel Crépeau, Pôle Sciences et Technologies, 17000 La Rochelle, France

ARTICLE INFO

Article history:
Received 24 February 2014
Received in revised form
4 June 2014
Accepted 30 June 2014
Available online 9 July 2014

Keywords:
Impinging jet
Aero-acoustic
Fluid dynamics
Vortex
PIV

ABSTRACT

Self-sustained tonal sounds are related to aero-acoustic coupling and occurs in impinging jets when a feedback loop is present between the jet exit and the impinged plate. The relation between the acoustic signal and the vortex dynamics should be understood in order to control the aero-acoustic coupling between the shear layer oscillation and the acoustic modes (self-sustained tones). In this study, a plane jet issuing from a rectangular nozzle and impinging a slotted plate is considered for different Reynolds numbers. Simultaneous measurements of the velocity and the acoustic fields were performed using respectively the time-resolved particle image velocimetry (PIV) and a microphone. The trajectories of the vortices are simultaneously investigated with the acoustic level. One single path was found for the vortices when the acoustic level was low. However, in the case of a peak in the acoustic level, two paths of the vortices can exist. A detailed illustration "step by step" of the convected vortices is presented simultaneously with the acoustic signal.

1. Introduction

Impinging jets on a surface with an edge geometry (slot, grid, etc.) are widely used in ventilation systems of commercial and residential rooms to improve the mixing and diffusion of air flow and ensure the necessary air quality and comfort. These jets may, under certain conditions, be a source of noise due to self-sustaining tones which lead to discomfort and thus should be reduced or suppressed. Since the source of these tonal noises are strongly related to the vortex dynamics in the jet, it is important to understand the vortex dynamics involved in the production of these tones [1–9,6,10].

When a sheared subsonic flow impinges on a slotted plate, self-sustained tones characterized by an acoustic energy distributed over a few discrete frequency peaks can be produced. The establishment of such self-sustained oscillations implies an energy exchange between the aerodynamic and the acoustic fluctuations. The self-sustained tones mechanism was described by [11,12] as follows: the downstream-convected coherent structures impinge on a downstream geometrical singularity and generate an acoustic fluctuation. Upstream-propagating pressure waves and coherent structures impinging the plate are phase locked at the nozzle exit. The acoustic waves excite the instabilities of the jet near the nozzle lip what creates periodic coherent structures. The oscillation period is determined by the nozzle-to-plate distance and the convection velocity of the flow. Thus, an aero-acoustic source results from the interaction between the jet and the impinged plate. The zone of interaction between the vortices and the wall was described by [13,14] and [15] and the pressure fluctuations produced by the coherent structures in an impinging jet are essentially produced in this zone [16]. The conditions favoring energy transfer from the aerodynamic fluctuation mode to the acoustic fluctuation mode could be studied using the vortex sound theory, developed by [17] and [18]. This approach is based on vorticity as a source of sound and can be used to express the acoustic power P generated in a volume V over one acoustical period T by using the vortical part ω of the velocity field. The acoustic velocity u' is required for this approach. Many works were developed to obtain the acoustic velocity u' from PIV measurements as in [19] where 4D-PIV is employed to evaluate the flow field pressure.

* Corresponding author.
E-mail address: hassan.assoum@gmail.com (H.H. Assoum).

http://dx.doi.org/10.1016/j.euromechflu.2014.06.008
0997-7546/

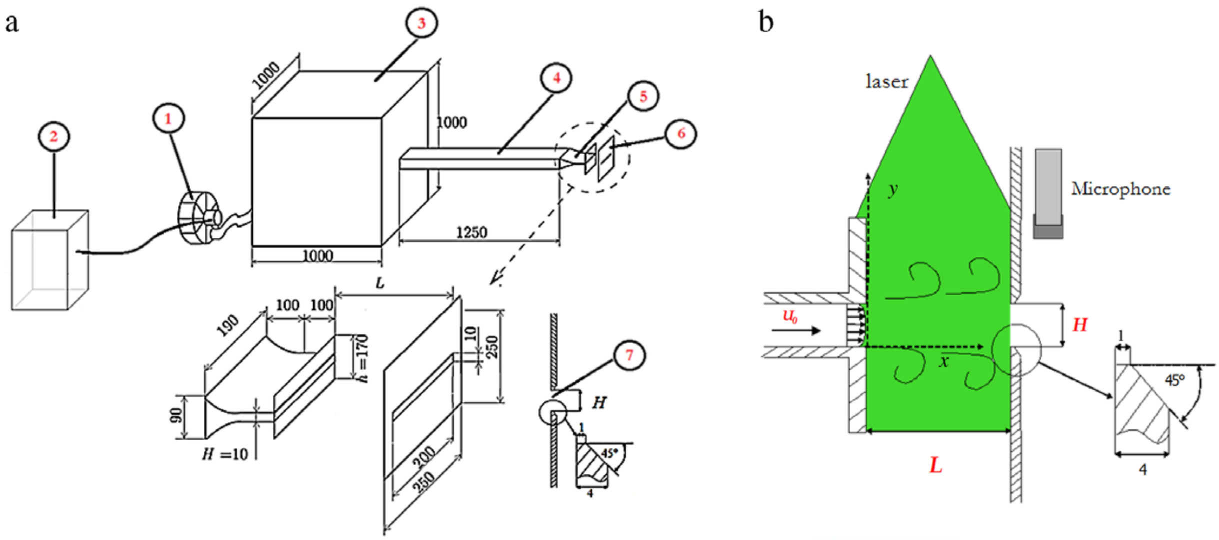

Fig. 1. Schematic of the experimental set-up (dimensions in mm). a: The flow leaves the convergent section after entering a rectangular cross-section from a large settling chamber. b: The impinged plate.

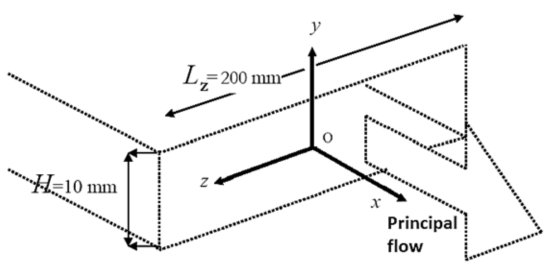

Fig. 2. Axis system.

In this study we consider a planar jet impinging on a slotted plate. We aim to investigate the vortices trajectories for different Reynolds numbers presenting low and high acoustic levels using 2D-PIV measurements.

2. Experimental apparatus and procedures

2.1. Jet flow facility

A schematic view of the experimental set-up is presented in Fig. 1. A compressor (1) creates an air flow in the installation. This compressor is isolated from the experimental room and is commanded by a controller (2) to regulate the velocity of the flow. The air flow is generated through a settling chamber (3) of $1m^3$ and a tube (4) of 1250 mm in length with a rectangular section (90×200 mm^2) extended by a rectangular convergent (5), which provides a free jet of height $H = 10$ mm and width $L_z = 200$ mm. A 4 mm thick aluminum plate (6) (250×250 mm^2) is fitted with a beveled slot (7) of the same dimension as the convergent outlet and is carefully aligned with the convergent using a gauge and a displacement system.

The distance from the impinged surface to the exit of the convergent section is denoted as L. In this paper, the nozzle-to-plate distance is equal to 40 mm ($L/H = 4$). The axis system is shown in Fig. 2. The origin is taken at the jet exit.

The Reynolds number is based on the dimension of the nozzle $Re = U_0.H/\nu$ (where U_0 is the average stream-wise velocity at the exit of the convergent and ν is the kinematic viscosity of air). The Strouhal number is based on the plate-to-nozzle distance $St_L = F_0.L/U_0$ (where F_0 is the frequency of the self sustained tones).

2.2. Pressure and time-resolved particle image velocimetry (PIV) measurements

Simultaneous measurements of the acoustic pressure and the velocity field were performed. A microphone was placed behind the plate ($X = 10$ cm, $Y = 10$ cm, $Z = 8$ cm) away from the aerodynamic disturbances to measure the radiated sound pressure. The microphone was a B&K Free-Field 1/2 Type 4189, which has a band width from 7 Hz to 20 kHz. The acoustic measurements are sampled at $F_s = 5$ kHz and therefore the spectral domain of this study is limited to frequencies that are smaller than 2.5 kHz.

The PIV system used for this study is composed of one Phantom V9 camera of 1200×1632 pixels^2 mounted normally to the direction of the light sheet plane generated from a Nd:YLF NewWave Pegasus laser of 10 mJ energy per pulse and 527 nm wavelength, the laser sheet obtained by a system of lenses has a minimal thickness of 0.5 mm in the measurement section. The acquisition frequency of the PIV system is 1500 Hz. The air jet flow was seeded with small olive oil droplets (particles are injected in the settling chamber), 1 to 2 μm in diameter, provided by a liquid seeding generator. The synchronization between the laser and the camera is controlled by a LaVision high-speed controller and the data acquisition is performed with DaVis 8.0 software, a CCD image acquisition and processing algorithm developed by LaVision. The average size of the particle-image is 2.5×2.5 pixels which is adequately resolved according to [20] with the absence of the peak locking phenomenon [21]. The accumulation of the error ratio and the bias error ratio gives the total error which is about 2%. The theoretical analysis of [21] is used to estimate the error on the particle-image displacement. The maximal displacement error is equal to 1.7% and 3% for the longitudinal and the vertical directions. The RMS PIV velocity error is about 0.11 m/s [22].

3. Results

3.1. Self-sustained tonal sounds

The self-sustained tones are accompanied by acoustic levels which can reach very high values. The sound pressure level is defined as $L_P = 20 \log_{10}(p_{rms}/p_{ref})$ where p_{rms} is the root mean square (rms) sound pressure being measured and p_{ref} the standard