Experimental investigation of the vibration of a slotted plate and the acoustic field in a plane impinging jet

H.H. Assoum[a], A. Sakout[a], M. El Hassan[b], J. Vetel[b], A. Alia[c] and K. Abed-Meraïm[a]

[a]Laboratoire d'Étude des Phénomènes de Transfert et de l'Instantanéité : Agro-industrie et Bâtiment, Bâtiment Fourier Avenue Michel Crépeau F-17042 La Rochelle Cedex 1
[b]Fluid Dynamics Laboratory, Ecole Polytechnique de Montréal, Montréal, Canada QC H3T 1J4
[c]Laboratoire de mécanique de Lille, Bâtiment M6 Bvd Paul Langevin 59655 Villeneuve d'Ascq Cedex
hassan.assoum@gmail.com

The impinging jet is a flow configuration in which a fluid issuing from a simple geometry hits a wall (perpendicular or with angle). Impinging jet exhibits rich phenomena in terms of vortex structures and fluid-structure interaction. These phenomena become more complicated if the obstacle (a plate in this study) has a slot and are accompanied in some cases by a high level of noise due to the installation of a loop of self-sustained tones. Several parameters influence these phenomena such as the Reynolds number and the plate to nozzle distance. Therefore, we consider a plane jet issuing from a rectangular nozzle and a slotted plate. The sound pressure and the plate vibration are respectively measured using a microphone and accelerometers mounted on the plate. The spectra of both sound and vibration signal and the corresponding coherences are presented. This study brings out the correlation between the plate vibration and the acoustic field in a plane impinging jet for two Reynolds numbers (Re = 12350 and Re= 18200).

1 Introduction

The dynamics of fluid flow can be a source of noise when a transfer of energy occurs between the aero-dynamic and the acoustic fields. The generated noise can have a large spectrum when it concerns the flow turbulence or a spectrum of high energy when the flow is organized as in the case of a jet impacting on a slotted plate.

Actually, in the case of an impacting jet on a slotted plate, the interaction between the flow and the obstacle near the slot, under certain conditions, generates a perturbation which travels the flow and controls its detachment at the out of the nozzle. The disturbance thus produced by this feedback loop optimizes the transfer of energy between the aero-dynamic field of the jet and the radiated acoustic field. The generated noise is known as the self-sustaining tones.

Self-sustaining tones were studied and their mechanism of production was described in several reviews [4, 7, 9, 10]. Understanding the dynamics of the vortex structures involved in the production of these tones, its synchronization with the sound field and the coupling between the sound source and the resonances of the blow pipe were studied and analyzed by Glesser [1].

The study presented here concerns the vibrations of a slotted plate impacted by a rectangular jet and the acoustic field associated [5, 6]. Thus, the objective of this work is to study the relationship between the acoustic field radiated by the flow and the vibration of the plate. Results are presented for two Reynolds numbers: Re = 12350 and Re = 18200. The spectra of the acoustic and the vibration of the plate signals are presented and compared with the numerical modes of the plate and the duct.

2 Experimental apparatus

Figure 1 is a diagram of the experimental device designed to allow the variation of the following geometrical and flow parameters: L, the distance between the plate and the nozzle outlet, and U_0, the average velocity of the flow at the nozzle. The duct has a rectangular cross-section of 9x19 cm made of 5mm thick aluminum and is followed by a 20 cm contraction nozzle. It creates a 1 cm high and 19 cm wide free jet. The jet height is denoted by H. A settling chamber is placed upstream of the duct to ensure acoustic isolation of the duct from the blower. A 5 mm thick aluminum 25x25 cm plate is fitted with a beveled slot of the same dimension as the nozzle outlet and is carefully aligned with the nozzle using a gauge and a displacement table. The dimensionless distance between the nozzle outlet and the slot, L/H, called ‘‘length parameter’’ is equal to 4 in this paper. L is defined with a precision of 0.1 mm.

Experiments were performed using a data acquisition card allowing 16 inputs: National Instruments. Of these, 8 were used as accelerometers to measure the acceleration of the plate on points chosen arbitrarily and one microphone placed behind the plate, away from the hydrodynamic disturbances) to measure the sound pressure.

The accelerometers used were DGB A/24/E piezotronics, 8 mm in diameter, weighing 2 g and with a sensitivity of 0 Hz to 10 kHz. The microphone was a B&K Free-Field 1/2” Type 4189, which has a sensitivity of 6.3 Hz to 20 kHz.

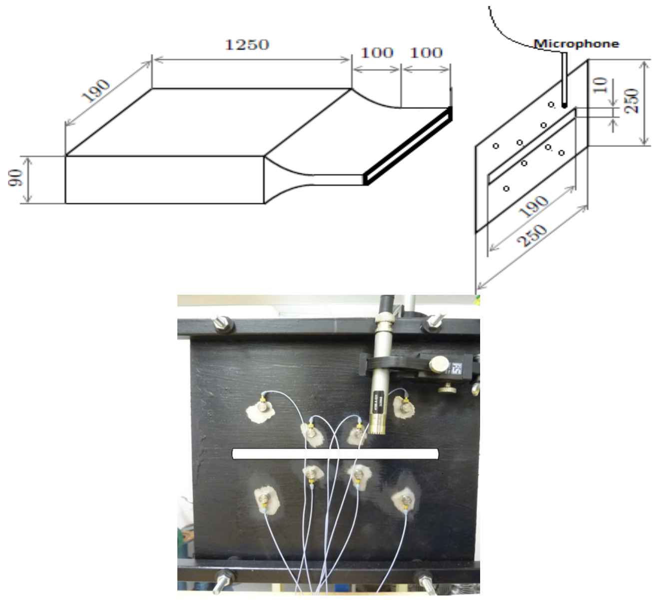


Figure 1: Experimental apparatus

3 Results

To obtain the eigenmodes of the plate, it was modeled numerically using the explicit (FEM). Thus, these modes were calculated for a plate embedded and isolated. The first twenty modes are presented in Table 1

Table 1: Numerical modes of the slotted plate

Mode Propre	1	2	3	4
Fréquence propre	130	268	296	338
Eigen Mode	5	6	7	8
Eigen Frequency	604	647	679	881

Eigen Mode	9	10	11	12
Eigen Frequency	921	1164	1237	1455
Eigen Mode	13	14	15	16
Eigen Frequency	1515	1771	1842	1857
Eigen Mode	17	18	19	20
Eigen Frequency	1967	2042	2403	2498

The vibration of the plate was measured using eight accelerometers glued on the plate.

Figures 2 (a) and 2 (b) show the spectra provided by one accelerometer for both studied Reynolds. The most representative signal was selected each time after verifying that all accelerometers have the same excited frequencies (but with different contributions depending on the position of each accelerometer).

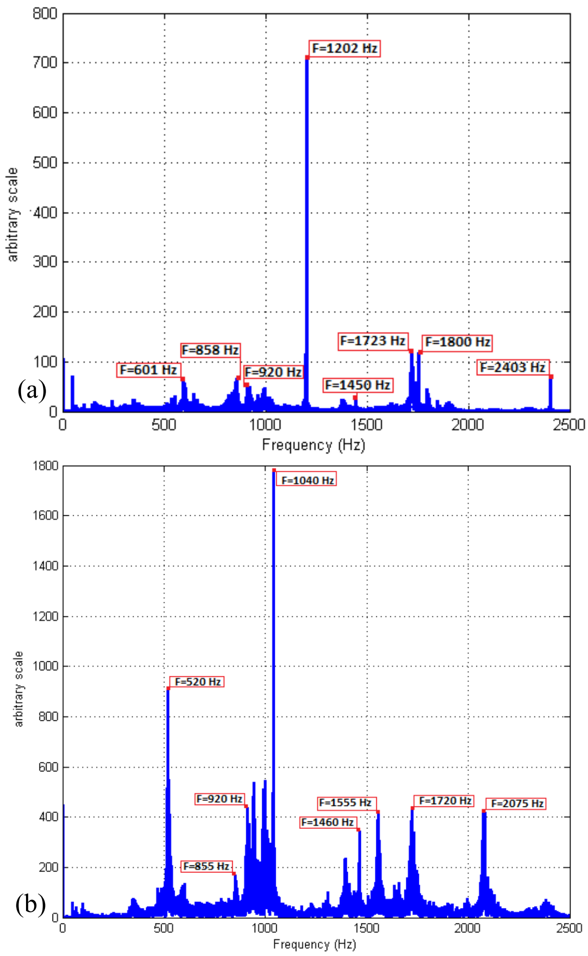


Figure 2: Spectrum of the plate vibration (a) Re=12350, (b) Re=18200.

In Figures 2 (a) and 2 (b), one can see that two excited frequencies are very similar to two modes of the plate, the 9th at f = 920 Hz for both Reynolds and the 12th at f = 1460 Hz and 1450 Hz for Re = 12 350 and Re = 18 200 respectively.

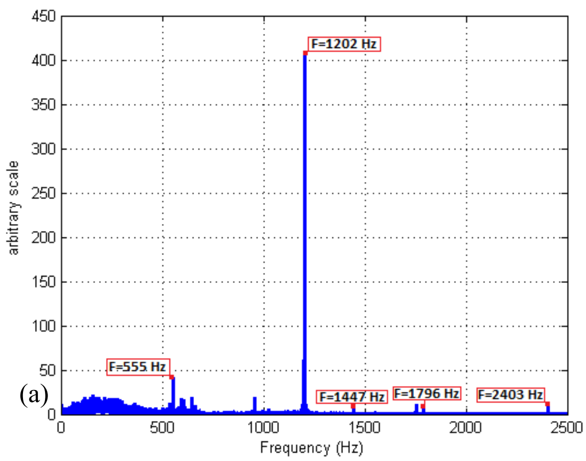
The excited frequencies, f = 858 Hz in Figure 2 (a) (Re = 12 350) and f = 855 Hz in Figure 2 (b) (Re = 18 200) are similar to the longitudinal resonance frequencies of the duct. Theirs harmonic 2f ~ 1720 Hz is also present in the spectrum. The longitudinal modes of the duct are calculated numerically [1] and are presented in Table 2

Table 2: Numerical modes of the duct

Mode Propre	1	2	3	4
Fréquence propre	85	207	336	467
Eigen Mode	5	6	7	8
Eigen Frequency	597	726	853	974
Eigen Mode	9	10	11	12
Eigen Frequency	1081	1179	1288	1407
Eigen Mode	13	14	15	16
Eigen Frequency	1529	1648	1765	1880

In Figures 3 (a) and 3 (b), the spectra of the pressure signals measured by the microphone are presented for two Reynolds. One can notice the existence of the 12th mode of the plate at 1455 Hz (f = 1447 Hz for Re = 12350 and f = 1462 Hz for Re = 18200). This excited mode of the plate has a very low energy. The 9th mode of the plate is not present in the spectrum of the acoustic signal in contrast to the spectrum of the vibration signal.

For both Reynolds, in Figure 2 which shows the spectra of the accelerometer signals of the plate and in Figure 3 which shows typical spectra of self-sustaining sounds [2], the frequencies f1 = 1039 Hz for Re = 12350 and f2 = 1202 Hz for Re = 18200 and theirs harmonics 2f are excited. A sub-harmonic f/2 and a harmonic 3f/2 (due to nonlinear interactions between the modes) are also present.



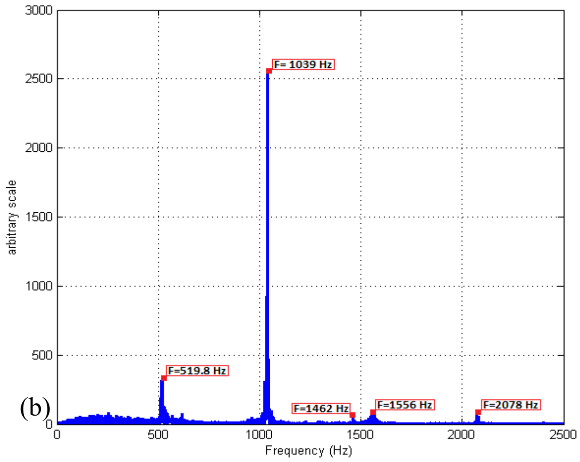


Figure 3: Spectrum of the pressure signal (a) Re=12350, (b) Re=18200.

We define the Strouhal number St:

$$St = \frac{f_0 L}{U_0} \tag{1}$$

where U_0 is the velocity in the center of the flow near the nozzle and L is the distance between the outlet of the jet and the plate.

For both Reynolds, we calculate the Strouhal number of the self-sustained tones (using the highest frequency found in the energy spectrum). We find $St \approx 2.5$ and $St \approx 1.43$ respectively for Re = 12350 and Re = 18200.

The evolution of the Strouhal number obtained through the most energetic frequencies found from the sound and the vibration spectra is consistent with the work of Billon [3] where it was shown that this evolution of the Strouhal number follows three steps according to the Reynolds number.

Figures 4 (a) and 4 (b) show the coherences between the measured pressure and the vibration of the plate for both Reynolds. The evolution of the coherences is shown during the acquisition time (five seconds). In both cases, for Re = 12350 and Re = 18200, we can notice that the coherences present continuous horizontal lines showing high coefficients of coherence between frequencies f1 and f2 of the acoustic and the vibration signals.

In Figure 4 (a), the coherence reaches a maximum of 0.98 at the frequency f1 = 1202 Hz and 0.86 at the frequency 2f1.

In Figure 4 (b) the coherence reaches a maximum of 0.78 at the frequency f2 = 1040 Hz, 0.62 at the subharmonic f2/2 and 0.54 at the harmonic 2f2. One may note that other modes have significant coefficients of coherence for example at f = 920 Hz, 1460 Hz and f = 3f / 2 = 1556 Hz.

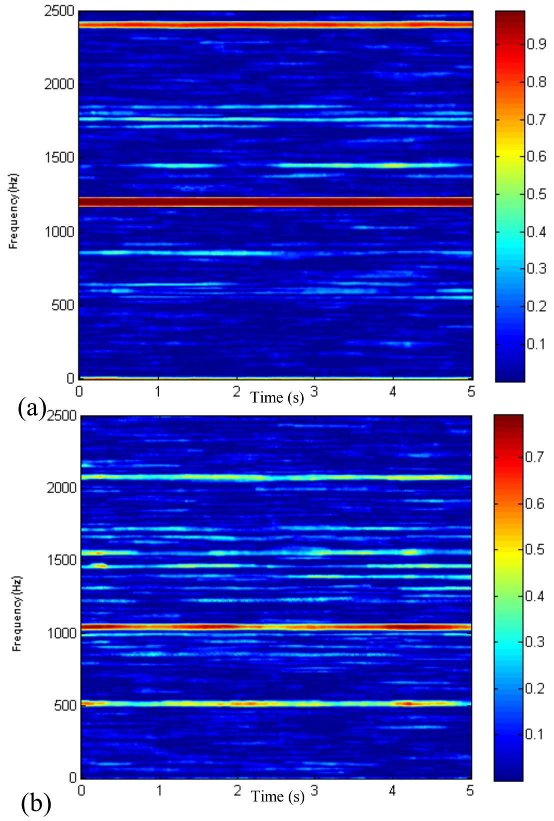


Figure 4: Coherence 'frequency- time' between the pressure and the vibration signals (a) Re=12350, (b) Re=18200.

5 Conclusion

In this study we investigated the coupling between the vibration of the plate exposed to the impact of a plane jet and the acoustic field radiated for two Reynolds number, Re = 12350 and Re = 18200.

The comparison between the numerical eigenmodes of the plate and the acoustic signal measured for both Reynolds shows that the eigenmodes of the plate does not control the fundamental mode of the self-sustaining tones, however, the 12th mode of the plate (f = 1460 Hz) has a low contribution in the spectra of acoustic signals.

The diagrams of coherence show a strong coefficient between the most energetic frequencies (the fundamentals f1 and f2) present in the acoustic and the vibration spectra as well as their harmonics 2f1 and 2f2.

Other frequencies have significant coefficients of coherence, particularly the sub-harmonics and harmonics (f1/2, 3f1/2, f2/2 and 3f2/2) and two other modes of the plate at f = 920 Hz and f = 1460 Hz.

References

[1] Martin Glesser. “Sons auto-entretenus produits par l’interaction d’un jet plan avec une plaque fendue : étude expérimentale et modélisation du couplage avec un résonateur’’, Doctorat, Université de La Rochelle, 2006.

[2] A. Billon, V. Valeau, A. Sakout, Two feedback paths for a jet-slot oscillator. Journal of Fluids and Structures 21 (2005) 121–132

[3] A. Billon. “Etude expérimentale des sons auto-entretenus produits par un jet issu d’un conduit et heurtant une plaque fendue’’, Doctorat, Université de La Rochelle, 2003.

[4] D. Rockwell, J.-C. Lin, P. Oshkai, M. Reiss and M. Pollack: Shallow cavity flow tone experiments: Onset of locked-on states. Journal of Fluids and Structures, 17(3):381–414, 2003.

[5] S. Ziada. Feedback control of globally unstable flows: Impinging shear flows. Journal of Fluids and Structures, 9(8):907{923, 1995.

[6] W.K. Blake and A. Powell: The development of ontemporary views of flow-tone generation. In Recent advances in aeroacoustics, pages 247–325. Springer Verlag, New-York, 1986.

[7] D. Rockwell and E. Naudascher: Self-sustained oscillations of impinging free shear layers. Annual Review of Fluid Mechanics, 11:67–94, 1979.

[8] D.K. Holger, T.A. Wilson and G.S. Beavers: Fluid mechanics of the edgetone. Journal of the Acoustical Society of America, 62(5):1116–1128, 1977.