ARTICLE IN PRESS

CRAS2B:3619

C. R. Mecanique ••• (••••) •••–•••

Contents lists available at ScienceDirect

Comptes Rendus Mecanique

www.sciencedirect.com

Jet noise modelling and control/Modélisation et contrôle du bruit de jet

Acceleration and wall pressure fluctuations generated by an incompressible jet in installed configuration

Matteo Mancinelli [a,*], Roberto Camussi [b]

[a] *Institut Pprime – CNRS, Université de Poitiers, ENSMA – Département Fluides, Thermique et Combustion, 11, boulevard Marie-et-Pierre-Curie, 86962 Chasseneuil-du-Poitou, Poitiers, France*
[b] *Università degli Studi Roma Tre, Dipartimento di Ingegneria, Via della Vasca Navale 79, 00146 Rome, Italy*

A R T I C L E I N F O

Article history:
Received 24 May 2017
Accepted 1 February 2018
Available online xxxx

Keywords:
Fluid mechanics
Jets
Aeroacoustics

A B S T R A C T

In this work, the cross-statistics of acceleration and wall pressure fluctuations generated by an incompressible jet interacting with a tangential flat-plate are presented. The results are derived from an experimental test campaign on a laboratory-scale model involving simultaneous velocity and wall pressure measurements. The pressure footprint of the jet on the surface was measured through a cavity-mounted microphone array, whereas pointwise velocity measurements were carried out by a hot wire anemometer. The time derivative of the velocity signal has been taken as an estimation of the local acceleration of the jet. The multivariate statistics between acceleration and wall pressure are achieved through cross-correlations and cross-spectra, highlighting that the causality relation is more significant in the potential core where the Kelvin–Helmholtz instability is dominant. The application of a conditional sampling procedure based on wavelet transform allowed us to educe the acceleration flow structures related to the energetic wall-pressure events. The analysis revealed that, unlike the velocity, the acceleration signatures were detected only for positions where the jet had not yet impinged on the plate, their shape being related to a convected wavepacket structure.

1. Introduction

The increasing size of aircraft engines is bringing about strong concerns for their conventional under-wing installation due to the interaction between the exhausting jet and the airframe components. As pointed out by Huber et al. [1,2], the increase of the radiated acoustic emissions due to the jet–wing interaction can jeopardize the noise breakdown achieved by the jet velocity reduction consequent to the increase of the By-Pass Ratio (BPR) in the new engine models. On the other hand, the pressure fluctuations generated by the jet impinging on the fuselage play a fundamental role in terms of panels structural strength and generation of interior noise. Indeed, the jet impact on the fuselage induces panel stress and vibrations, these vibrations being partially re-emitted in the aeroacoustic field and partially transmitted to the aircraft cockpit, causing passengers' annoyance. Hence, manufacturers are investing in research to develop appropriate technologies to mitigate the installation effects in the future aircraft configurations. As a consequence, a deeper insight on the complex mechanism underlying the jet–surface interaction is needed.

* Corresponding author.
E-mail addresses: matteo.mancinelli@univ-poitiers.fr (M. Mancinelli), roberto.camussi@uniroma3.it (R. Camussi).

https://doi.org/10.1016/j.crme.2018.07.008

Many studies in the literature were devoted to the investigation of the effect of a surface on the emitted far-field noise (see, e.g., Papamoschou & Mayoral [3] and Podboy [4]). The shielding/scattering effect of a flat-plate tangential to the nozzle axis of a compressible jet was studied by Cavalieri et al. [5], where the acoustic emissions of the jet were computed through a wavepacket source model. More recently, Piantanida et al. [6] highlighted that a strong deformation of the aerodynamic field is expected when the mutual distance between the jet and the surface becomes of the order of the nozzle diameter, the jet–surface interaction being consequently stronger. Hence, the investigation of the incident pressure field in addition to the scattered one can provide a better understanding of the interaction phenomena between the jet and the surface [7]. Indeed, as pointed out by Di Marco et al. [8], the characterization of the spectral content of the wall pressure fluctuations is essential to develop appropriate tools for noise prediction and verification of the structural strength of the panels.

The discussion above motivated the authors to carry out a series of experimental tests on a laboratory-scale model to characterise the installation effects of a flat plate tangential to an incompressible jet [9]. The jet–surface interaction was mainly studied in terms of statistical and spectral features of the wall-pressure field, laying the foundations for the modelling of the wall-pressure fluctuations. The jet flow conditions as well as the geometry were significantly simplified with respect to the real industrial problem. Nevertheless, the novelty of the approach offered the basis for an improved physical understanding of the jet–plate interaction phenomena. Furthermore, as reported by Di Marco et al. [8], the weak dependence of the wall pressure features on Mach and Reynolds numbers of the flow suggested that the outcome obtained in incompressible conditions could be likely extended to jet–surface configurations with higher velocities. Such aspect encouraged the authors to extend the previous work in Mancinelli et al. [10,11], where simultaneous velocity and wall pressure measurements were carried out on the same configuration. The aerodynamic field was characterised through pointwise single-component hot-wire (HW) anemometer measurements, whereas the streamwise evolution of the wall-pressure fluctuation field was measured by a cavity-mounted microphone array. The plate effect on the velocity field was addressed as well as the multi-variate statistics between velocity and wall-pressure fields were provided. The conditioned statistics were also achieved through the application of a wavelet-based conditional sampling procedure that revealed the velocity and wall-pressure signatures underlying the interaction phenomena between the jet and the flat-plate.

In the present work, the investigation on the same installed configuration is further extended, performing a cross-statistical and conditional sampling analysis between the wall-pressure and the acceleration fields. A preliminary analysis of the acceleration field in free-jet conditions is also provided. To the best of the authors' knowledge, this represents the first attempt to characterise experimentally the acceleration field of a jet. The main motivation of such an approach lies in the Euler's equation, where the pressure gradient, i.e. a term related to vorticity and entropy fields as well as strictly associated with noise emissions ([12] and [13]), is a function of the acceleration. According to Camussi & Grizzi [14], the time derivative of the velocity signal has been taken as an estimation of the local acceleration of the jet, the computation of the convective term related to the spatial velocity gradient through parallel double-component HW or PIV measurements being a task for future applications. The cross-statistics between acceleration and wall pressure fluctuations are provided in both the time and frequency domains. A wavelet-based cross-conditioning technique permitted to educe the coherent acceleration structures associated with the energetic wall pressure events. The outcome was compared with the results obtained in Mancinelli et al. [10,11] using the velocity instead of the acceleration.

The paper is organised as follows. In §2, the experimental set-up is briefly described, and details about the initial state of the jet flow are given, whereas in §3 the conditional sampling procedure based on wavelet transform is summarised. §4 is devoted to the presentation of the main results concerning the characterisation of the acceleration field, the multi-variate and the conditioned statistics between acceleration and wall pressure. Final remarks are addressed in §5.

2. Experimental set-up

The experiments were performed in the Aerodynamic and Thermo-fluid dynamic Laboratory of the Department of Engineering of University Roma Tre. The facility reproduces the one presented in [15] and is briefly described in the following. The flow is generated by a centrifugal blower and is guided into a wide-angle diffuser, then it issues in a plenum chamber where honeycomb panel and turbulence grids are installed. The fluid finally flows into a quiescent ambient through a convergent nozzle with a diameter $D = 52\,\text{mm}$. A sketch of the facility is represented in Fig. 1.

The experiments were carried out at a nominal jet velocity $U_\text{j} = 42\,\text{m·s}^{-1}$, to which correspond Mach and nozzle diameter-based Reynolds numbers of 0.12 and $1.5 \cdot 10^5$, respectively, which classify the jet as a moderate Reynolds number jet [16]. The mean velocity and turbulence intensity profiles close to the nozzle exhaust at the streamwise position $x/D = 1$ are shown in Fig. 2. As outlined by Zaman [17], the laminar Blasius-like shape of the mean velocity profile is associated with a high turbulence intensity peak of the order of 10%. Such feature implies that the jet was in a transitional highly disturbed initial state, or nominally turbulent according to Bogey et al. [16,18]. For a more detailed description of the facility and for the characterization of the jet flow, the reader can refer to Di Marco et al. [9].

Simultaneous velocity and wall pressure measurements were carried out in an installed configuration. A flat plate was placed tangentially to the jet at different radial distances H from the nozzle axis, spanning a range from $1\,D$ to $2.5\,D$ with a step of $0.5\,D$. The area of interest was divided into five measurement stations, each station being constituted by five measurement locations along the streamwise direction, in order to cover the range $x/D = [1, 25]$. The streamwise evolution of the wall pressure fluctuation field was provided by cavity-mounted 5-microphone array measurements, while the velocity field was characterised by hot-wire anemometer measurements, the HW being moved along the z-direction orthogonal to