DEVELOPMENT OF A FEEDBACK MODEL FOR THE SELF-EXCITED IMPINGING PLANAR JET

**David Arthurs & Samir Ziada*
McMaster University
Hamilton, ON, Canada, L8S 4L7
**** Corresponding Author***
***ph:** 1 (905) 393-1709, **em:** davidgarthurs@gmail.com*

Abstract

High-speed impinging planar jets are used in a myriad of important industrial uses such as thermal processing in both heating and cooling applications, drying and blow-off, as well as coating control processes, such the in the production of galvanized sheet steel. These flows are also known to be liable to the production of very intense narrow-band acoustic tones and strong self-excited flows which may limit the usefulness of these geometries in many applications due to high levels of noise, and the tendency to excite vibrations in nearby systems. These phenomena are produced by a feedback mechanism between instabilities in the free shear layers of the jet, which roll up to form large-scale vortical flow structures, and pressure fluctuations produced by the impingement of these structures at the downstream surface. Previous measurements of the planar impinging jet have shown that the self-excited response of the system is quite different from other related geometries such as the impinging axisymmetric jet, with the planar system being self-excited over a much larger range of impingement ratio, and beginning at low flow velocities (Arthurs & Ziada, 2012). These distinctions result in significant differences in both the structure of the flow, as well as the form of the jet oscillation modes producing the acoustic tones compared to related systems, and as a result, the application of existing feedback models results in relatively poor predictions of the oscillation frequency.

This paper uses phase-locked PIV measurements to experimentally investigate flow evolution of a high-speed planar gas jet impinging on a plate at some distance downstream, and to quantify the behavior of coherent flow structures responsible for sustaining the feedback mechanism. An example of these PIV measurements are given in Figure 1, which shows a series of four phase-averaged velocity fields at phase angles of $\phi=0°$, 90°, 180° and 270° with respect to the periodic pressure signal measured at the impingement surface. The black contours shown in the figure represent the distribution of the velocity discriminant parameter (d_2), which has been used to identify coherent vortical structures within the flow, and has been displayed at a single contour level of $d_2=0$. The flow fields clearly show the form of the flow oscillation, which in this case takes the form of a pronounced flapping motion of the jet column, along with an anti-symmetric distribution of flow structures on either side of the jet centerline. As the flow oscillation progresses, the coherent flow structures, which form in the initial shear layer of the jet, convect downstream with the flapping oscillation of the jet column, eventually impinging on the surface of the plate.

The behavior of these coherent structures within the flow is a key parameter in modeling the self-excited response of the impinging planar jet. The present investigation uses phase-locked PIV technique and a new structure tracking method to directly measure and quantify the characteristics of these structures within the flow. These characteristics include the convection speed, an example of which is given in Figure 2, the convection path, and the nature of fluid-structure interaction at the impingement surface. The results of these measurements are then used to develop a new feedback model capable of producing accurate predictions of the oscillation

frequency of the impinging planar jet as a function of Mach number, jet thickness (h), and impingement ratio (x_o/h).

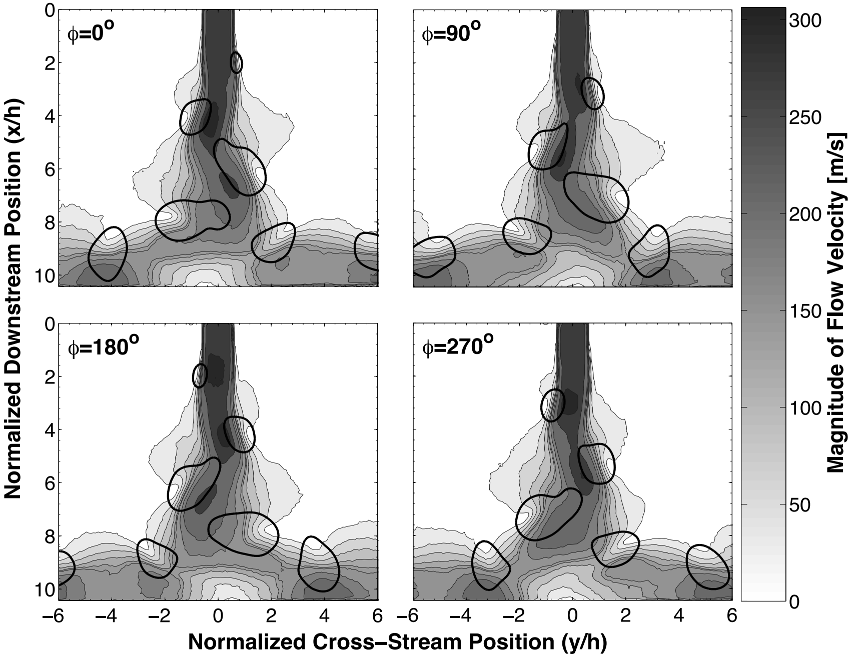

Figure 1: Phase-averaged velocity fields showing one cycle of the flow oscillation with phase increments of 90 °for the n=3 anti-symmetric hydrodynamic mode. Black lines show the velocity discriminant parameter (d_2=0) to identify coherent structure in the flow. x_o/h=10.5, M=0.9, f=10.2kHz.

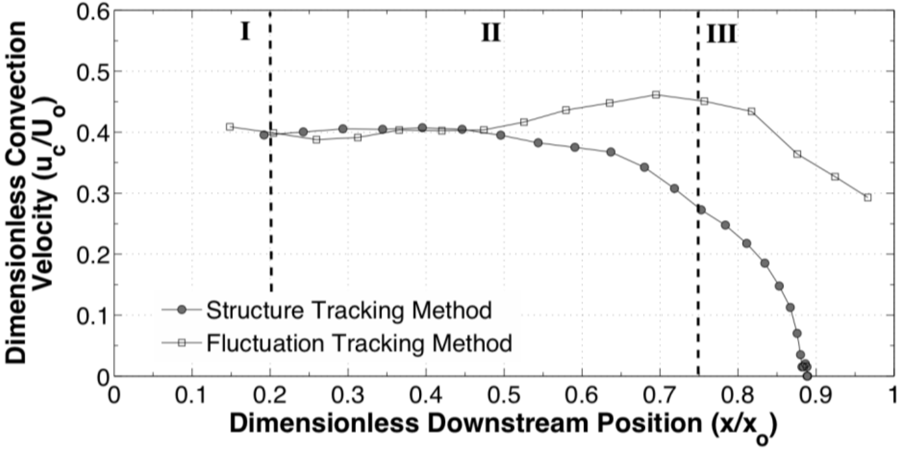

Figure 2: A comparison of the dimensionless convection velocities obtained by the two structure tracking methods for a Mach number of M=0.9 for the n=3 anti-symmetric jet mode.

References

Arthurs, D., Ziada, S., 2012. Self-excited oscillation of a high-speed impinging planar jet, Journal of Fluids and Structures, 34, 236-258.

Keywords

Jet impingement; Impinging planar jet; Jet Noise; Feedback model; Flow-acoustic interaction; Acoustic tone;