PIV Measurement analysis on a pulsating jet flow

Nahale Sotoudeh[1], Henrik Lycksam[1], Robin Andersson[1], Mehrdad Raisee[2], Michel Cervantes[1]
[1] Department of Engineering and Mathematics, Luleå University of Technology, Luleå, Sweden.
[2] Hydraulic Machinery Research Institute, School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran.

Abstract. This study focuses on the investigation of pulsed jet flows using Particle Image Velocimetry (PIV). Non-pulsating jet flows are characterized by minimal mixing, while pulsating flows enhance turbulence and entrainment. The research aims to optimize these systems by analysing flow characteristics and comparing pulsating and non-pulsating jets at the same Reynolds number. The sinusoidal variation in flow rate, manipulated by the mean flow, is characterized by amplitude and frequency. Proper Orthogonal Decomposition (POD) analysis is employed to identify vortices with the highest energy, enabling a comprehensive comparison of uncertainties in mean velocity calculations. The study contributes to understanding and optimizing the behaviour of pulsed jet flows.

1. Introduction

Pulsed jet flows, with sinusoidal variations in mean flow discharge, have significant engineering applications, particularly for enhancing mixing processes in combustion and heat transfer systems. To understand and control mixing, entrainment, and flow stability, robust measurement techniques are crucial. Particle Image Velocimetry (PIV) provides high-resolution spatial and temporal data, enabling detailed analysis of flow characteristics and turbulence structures. This paper focuses on using 2D planar PIV measurements to investigate pulsed jet flows, aiming to optimize these systems by understanding mixing and entrainment. 2D PIV is well-suited for measuring the predominantly axial and radially axisymmetric flow of pulsating jet, as it provides comprehensive flow visualization without the need for extensive measurements in the tangential direction.

Non-pulsating jet flows exhibit steady and axisymmetric motion with a well-defined potential core and minimal mixing [1]. The potential core extends a distance from the nozzle, which varies with the Reynolds number (Re). At Re = 1800, considering D as the nozzle diameter, the potential core extends up to x/D < 15, while at Re = 15000, it extends up to x/D < 4 [2]. This core region maintains its shape and exhibits minimal spreading and mixing. The shear layer between the jet core and ambient flow generates periodic vortex rings, resulting in rolled-up fluid structures [3]. As the flow evolves, vortex rings break down, producing quasi-streamwise vortices in the inner and outer layers. Triple-helical and single-helical structured vortices are observed, with a higher number of streamwise-oriented triple-helical structures, although they contribute less to mean velocity diffusion compared to single helices [3]. The fully developed flow, typically observed around x/D > 30, becomes more complex and turbulent, featuring self-similar regions and dominant low-frequency off-axis helical structures [4].

Pulsating jet flows exhibit intricate dynamics governed by key parameters such as the Reynolds number (Re(t)), Strouhal number (St_p), and excitation amplitude. The Reynolds number equation for pulsating flow, $Re(t) = Re_m - Re_{osc}(2\pi f_p t)$, captures the periodic fluctuations introduced into the flow, with Re_m representing the mean Reynolds number and Re_{osc} denoting the amplitude of the pulses. Understanding the behaviour of pulsating flows requires considering the Strouhal number (St_p), defined as $St_p = f_p D/U_0$ where U_0 represents the velocity at the nozzle outlet. Different methods of applying pulses in the flow, such as reciprocating motion driven by a stepper motor piston, can generate vortex rings. The compactness of vortex rings positively correlates with St_p, leading to stronger entrainment and enhanced turbulence [5]. However, it is important to note that the St_p value must fall within the typical range of 0.3 to 0.5 for the formation of Kelvin-Helmholtz vortices in circular jet flows [6]. Below