Journal of Fluids and Structures 50 (2014) 528–546

Contents lists available at ScienceDirect

Journal of Fluids and Structures

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

Numerical investigation of steady and periodically unsteady flow for various separation distances between a wall jet and an offset jet

Tanmoy Mondal, Manab Kumar Das*, Abhijit Guha

Department of Mechanical Engineering, Indian Institute of Technology Kharagpur, West Bengal 721302, India

ARTICLE INFO

Article history:
Received 16 May 2013
Accepted 12 July 2014
Available online 20 August 2014

Keywords:
Wall jet
Offset jet
Unsteady RANS
Periodic vortex shedding
Strouhal number

ABSTRACT

The effects of separation distance between two jets in the near field region of turbulent dual jet flow consisting of a wall jet flow and an offset jet flow have been investigated using two-dimensional unsteady RANS equations. The unsteady fluid mechanics of two interacting jets have been illustrated by means of time series analysis of the instantaneous flow field. For a comprehensive understanding of the fluid mechanics, computation has been carried out at a large number of values of the ratio of separation distance (d) and jet width (w) for finely resolving the relevant range of d/w. Results show that when d/w lies in the range $0.7 \le d/w \le 2.1$, the near field of the flow domain is characterized by a periodic large scale von Kármán-like vortex shedding phenomenon similar to what would be expected in the wake of a bluff body. On the contrary, for $d/w \le 0.6$ and $d/w \ge 2.2$, no periodic vortex shedding is detected; rather, a pair of steady counter rotating stable vortices are formed in between the two jets close to the nozzle plate. Fast Fourier transform of the velocity signals provides vortex shedding frequency corresponding to the Strouhal number that decreases with the increase in separation distance between the two jets.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Turbulent jets have attracted considerable research attention due to their intriguing physics as well as many engineering applications. The theory of turbulent jets has been thoroughly discussed by Abramovich (1963). Rajaratnam (1976) has provided comprehensive experimental and theoretical treatments of the characteristics of various types of turbulent jets.

The present study involves a wall jet and an offset jet. A wall jet is generated when a fluid is discharged from a nozzle tangentially along a solid wall. Therefore, the wall jet is bounded by a solid wall on one side and the quiescent fluid on the other. Forthmann (1936) has presented the first authoritative analysis of turbulent wall jet. Since then many studies have been carried out on various aspects of turbulent wall jet flow and the subject continues to be an active area of research up to the present time; see, for example, the works of Glauert (1956), Myers et al. (1963), Chandrasekhara Swamy and Bandyopadhyay

* Corresponding author. Tel.: +91 3222 282924; fax: +91 3222 282728.
E-mail address: manab@mech.iitkgp.ernet.in (M.K. Das).

http://dx.doi.org/10.1016/j.jfluidstructs.2014.07.009
0889-9746/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

Roman symbols

$c_{1\epsilon}$, $c_{2\epsilon}$	constants in the model equation for ϵ
c_μ	turbulent viscosity constant of the $k-\epsilon$ model
d	separation distance between two jets (dimensional)
f	frequency (dimensional)
G	production of turbulent kinetic energy (non-dimensional)
I	turbulence intensity
k	turbulent kinetic energy (dimensional)
N	number of grids
P	non-dimensional pressure
p	dimensional pressure
Re	Reynolds number ($u_0 w/\nu$)
St	Strouhal number (fw/u_0)
T	time period (non-dimensional)
t	time (dimensional)
U_i	non-dimensional Cartesian mean velocity components (U, V)
u_i	dimensional Cartesian mean velocity components (u, v)
u_τ	friction velocity (dimensional)
w	nozzle width (dimensional)
X_i	non-dimensional Cartesian coordinates (X, Y)
x_i	dimensional Cartesian coordinates (x, y)

Greek symbols

Δ	non-dimensional wall boundary layer thickness
$\Delta\tau$	time step size (non-dimensional)
δ	dimensional wall boundary layer thickness
ϵ	rate of dissipation of turbulent kinetic energy (dimensional)
ν	laminar kinematic viscosity (dimensional)
ρ	fluid density (dimensional)
$\sigma_k, \sigma_\epsilon$	turbulent Prandtl numbers for kinetic energy and dissipation, respectively
τ	time (non-dimensional)
ω	vorticity (non-dimensional)

Subscripts

0	inlet, ambient
0.5	half of maximum
cp	combined point
i,j	indices
m	maximum quantity
mp	merging point
n	non-dimensional quantity
t	turbulent
x	x-direction
y	y-direction

Overbar

$\overline{()}$	time averaged quantity

(1975), Launder and Rodi (1981), Abrahamsson et al. (1994), Gogineni and Shih (1997), Eriksson et al. (1998), George et al. (2000), Dejoan and Leschziner (2005) and Agelin-Chaab and Tachie (2011b).

An offset jet refers to a jet whose axis, at the inlet of the flow domain, is offset by a distance from the solid wall, similar to the flow over a backward facing step or that in a sudden expansion. A low pressure region where the pressure is lower than the ambient forms (near the equivalent of the backward facing step) underneath the offset jet; as a result, the jet deflects towards the solid wall and eventually attaches to the surface. In the literature (Nasr and Lai, 1997), this point is usually referred to as the reattachment point. The flow has a strong interaction with the solid wall in the reattachment region which occurs downstream of the reattachment point. Further downstream, in the wall jet region, the flow continues to develop and displays the characteristics of the classical wall jet flow described in the previous paragraph. The details of the mean flow and turbulence characteristics of an offset jet flow have been studied by several authors, e.g., Bourque and Newman (1960), Sawyer (1960, 1963), Rajaratnam and Subramanya (1968), Hoch and Jiji (1981), Pelfrey and Liburdy (1986b,1986a), Koo and Park (1992), Gu (1996), Gao and Ewing (2007) and Agelin-Chaab and Tachie (2011a).

While several studies have been conducted on either a wall jet or an offset jet separately, only a modest number of literature are available on the interaction of two jets. The most common topic in the latter category is the study of two parallel jets. In this flow configuration, two turbulent jets are issued parallel to each other from two nozzles which are set on a common end wall. As a result of mutual entrainment, the two jets deflect to each other and merge together at the merging point (mp); the region between the nozzle exit and the merging point is known as the converging region. This is followed by the merging region which extends up to the combined point (cp). In this region, vigorous interaction of the two jets takes place. The two jets combine at the combined point, develop as a single jet in the combined region, and eventually display the characteristics of the free jet at a far downstream position. Miller and Comings (1960), Tanaka (1970, 1974), Lin and Sheu (1990, 1991), Nasr and Lai (1997), Anderson and Spall (2001), Anderson et al. (2003), Spall et al. (2004) and Bunderson and Smith (2005) have studied the flow and turbulence characteristics of two parallel jets. Only two studies (Anderson et al., 2003; Bunderson and Smith, 2005) out of the cited references report the unsteady behavior of two parallel jets, although the nature of the unsteadiness is entirely different in both the cases. Anderson et al. (2003) have found that the near field region is characterized by a periodic vortex shedding phenomenon similar to what would be

Download English Version:

https://daneshyari.com/en/article/7176090

Download Persian Version:

https://daneshyari.com/article/7176090

Daneshyari.com