Computers & Fluids 114 (2015) 48–65

Contents lists available at ScienceDirect

Computers & Fluids

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

Mean flow characteristics of a turbulent dual jet consisting of a plane wall jet and a parallel offset jet

Amitesh Kumar *

Department of Mechanical Engineering, National Institute of Technology, Rourkela 769008, India

A R T I C L E I N F O

Article history:
Received 11 July 2014
Received in revised form 23 September 2014
Accepted 25 February 2015
Available online 5 March 2015

Keywords:
Turbulent jet
Wall jet
Offset jet
Twin parallel jet
Dual jet
Numerical simulation

A B S T R A C T

An exhaustive study is carried out to highlight the flow features arising due to a dual jet consisting of a plane wall turbulent jet and a parallel turbulent offset jet (hereafter this combination is termed as a dual jet). The standard high Reynolds number two equation k–ε model is used to solve the two-dimensional, incompressible, turbulent flow. A detailed analysis is carried out to compare the flow characteristics of the offset jet and the dual jet for an offset ratio between 3 and 15 at an interval of 2. It is noticed that the presence of wall jet in addition to the parallel offset jet has a tremendous effect on the flow characteristics. In the present study, the location of reattachment point and vortex centre of an offset jet and merge point, combined point, and the vortex centres of a dual jet are identified and expressed by correlations which depend on the offset ratio. It is interesting to observe that the cross-stream movement of vortex centre is linear with the change in offset ratio for both kind of jets either an offset jet or a dual jet. However, the streamwise movement of vortex centre follows a parabolic trend with respect to the offset ratio with an exception of combined point which is weakly dependent on the cubic power of offset ratio. The jet half width of a dual jet is compared for different offset ratios by a unique scaling method for which the correlation is also proposed; it is observed that the variation is parabolic with respect to the axial location. The total momentum flux of a dual jet is found to decrease with the increase in the offset ratio as opposed to almost insignificant change in the value for an offset jet. And, the value of integral constant is on the lower side as compared to the corresponding case of either an offset jet or a parallel jet.

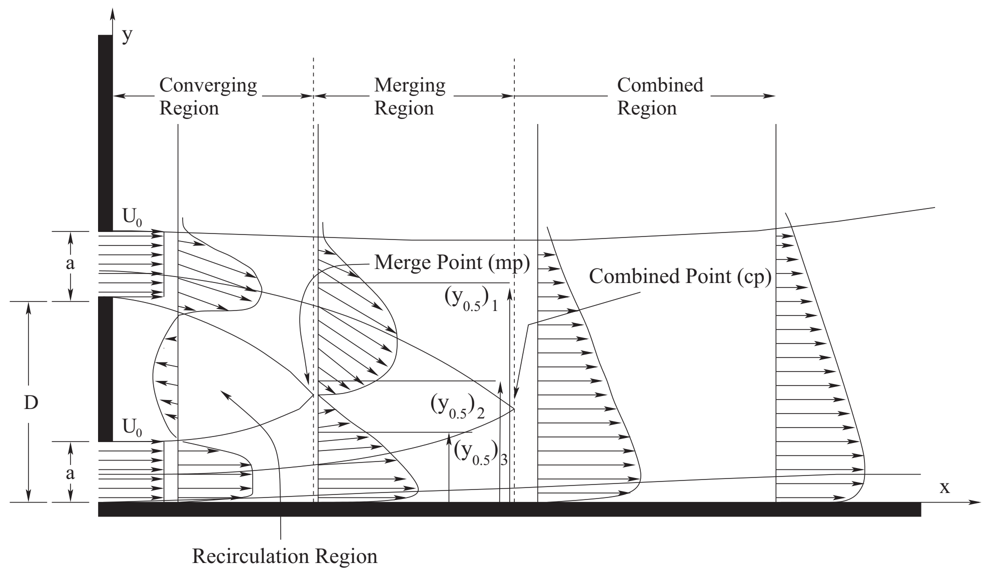
1. Introduction

Studying the flow characteristics of a turbulent jet is an important topic amongst researchers across the world because of its various applications in industries. Some of the common examples include: cooling of a combustion chamber wall in a gas turbine, the use of an air deflector as a circulation controller, an automobile demister, film cooling, evaporation enhancement, entrainment and mixing process in gas turbine and boiler combustion chambers, heat exchangers, carburetor systems, environmental dischargers, burners, thrust-augmenting ejector for V/STOL aircrafts, heating, ventilation, and air-conditioning [2,6,12,14,16,24,30]. Turbulent jet can be broadly classified into following categories: free jet, wall jet, wall attaching offset jet, two parallel jets, and dual jet consisting of a wall jet and a parallel offset jet. These classifications are done based on the position and presence of the horizontal impingement wall in the domain. The discussion on various types of jet can be found in Rajaratnam [28].

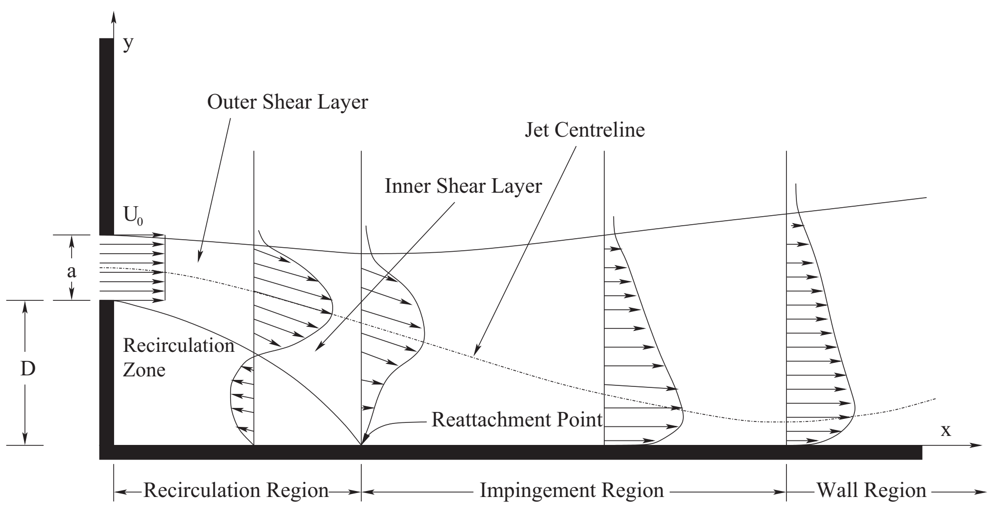
Free jet is characterised by a flow which is unbounded from all the sides but one. A wall jet is a jet flow which is bounded by a wall from one side and the flow is directed along this wall. As a result, a boundary layer develops over the wall where the variation of streamwise velocity takes place and above which there exists a free region. The wall jet flow has been extensively studied by many researchers [7–10,13,17]. When the jet is placed at an offset of some distance from the wall, it is termed as an offset jet. Such a jet is shown in Fig. 1(b), where D is the jet offset and a is the jet width at the exit. The offset ratio (OR) is defined as jet offset D to the jet width a, i.e. $\mathrm{OR} = D/a$. This definition of offset ratio is different than the definition which is usually found in the literature; the reason will be discussed in the next section. When the offset jet is issued from the nozzle, the jet at some downstream location attaches to the impingement wall because of the Coanda effect [36]. This effect takes place when there is an imbalance between the entrained masses from above and below of the issuing jet. The jet after impinging onto the wall changes its direction and further downstream behaves like a wall jet. There have been many studies on a planar offset jet [3,11,22,24–27,31,32,37]. Various experimental techniques have been utilised to study this

* Tel.: +91 661 2462532; fax: +91 661 2462549.
E-mail address: kumaramitesh@nitrkl.ac.in

http://dx.doi.org/10.1016/j.compfluid.2015.02.017
0045-7930/



(a) a dual jet



(b) an offset jet

Fig. 1. Schematic diagram of turbulent jets.

phenomenon which includes pressure tap [3,11], single hot wire [11], Prandtl type pitot static tube [29], one component Laser Doppler Anemometer (LDA) system [26,27], and two-component LDA system [24]. The effect of Reynolds number and offset ratio on the reattachment length and wall static pressure in the converging region is studied by Bourque and Newmann [3]. Pelfrey and Liburdy [27] studied the mean flow characteristics of a turbulent offset jet for a Reynolds number of 15,000 and an offset ratio of 7. They defined the offset ratio as the jet centre line height to the jet (nozzle) width. They noted that the jet decay and spread rates are similar to those of a plane jet if appropriate curved coordinates are used. They also mentioned that the magnitude of curvature strain rate, due to jet deflection, is significant, whose effect has been studied in Pelfrey and Liburdy [26]. Nasr and Lai [25] studied the turbulent flow characteristics of an offset jet for a small offset ratio of 2.125 using two-component LDA system. Their definition of offset ratio is similar to the one defined by Pelfrey and Liburdy [26]. For this small offset ratio, they noted a high turbulence in a region close to the nozzle plate between the jet and the offset plate. The flow field was also studied numerically using three turbulence models: standard k–ε, RNG, and Reynolds stress. The numerical results were compared to the experimental results and the conclusion withdrawn is that the standard k–ε turbulence model best agreed with the experimentally determined values. Chaab and Tachie [6,7] have studied the characteristics of three-dimensional wall jet and offset jet using Particle Image Velocimetry (PIV). They considered three Reynolds numbers equal to 5000, 10,000, and 20,000 and four offset heights of 0.5, 1.0, 2.0, and 4.0. They also noted that the location of reattachment point is independent of the Reynolds number. The decay and spread rates were found to be independent of Reynolds number at certain downstream distance for small offset ratios (<2). The comparison of two low Reynolds number turbulence models has recently been done by Rathore and Das [30] for studying the flow characteristics of an offset jet with an offset ratio of 3, 5, 7, 9, and 11. They compared the different turbulence models for a Reynolds number of 15,000; their geometry is similar to the geometry of Pelfrey and Liburdy [27]. The Moffatt vortices (secondary recirculation region) were identified near the corner of the wall with low Reynolds number turbulence modelling. Their study reveals that apart from near wall region, standard k–ε model can give reliable result with less computing time.