INTERACTION OF TWO PARALLEL RECTANGULAR JETS

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Abstract

In the present study, incompressible twin jet flow, emanating from identical rectangular slots is investigated experimentally. Interaction of parallel jets with small spacing ratio has been examined by using hot wire anemometer. The effect of convex surface between jet exits on the merging process and spreading characteristics of twin jet flow is studied.

1 Introduction

Two parallel jets, issuing from nearby nozzles, into still surrounding is called, in the literature, "twin jets" or "dual jets "[1].

The entrainment of surrounding fluid from the jet boundaries causes a subatmospheric region between jets. Because of the depressurized region, jet trajectories deflect towards each other. Finally two jets converge and merge together to form a single jet (Figure 1).

Twin jet flow field is characterized by three distinct regions. These regions are converging region, merging region and combined region. The schematic of the flow field is given by Figure 2.10. Two converging jets, deflected by the subatmospheric region between them, approach the plane of symmetry with increasing distance x from the nozzle exit. At the end of the converging region, jets merge at X_{mp}. The merging point is determined by the stagnation point where the mean velocity is zero in the symmetry axis x. The axial mean velocities have positive direction downstream of the merging point and negative direction upstream of the merging point. The velocity on the symmetry axis increases from zero at the merging point until it reaches a maximum value, just upstream of the point where two jets join to form a single jet. After this point (X_{cp}), jet behaves like a single jet.

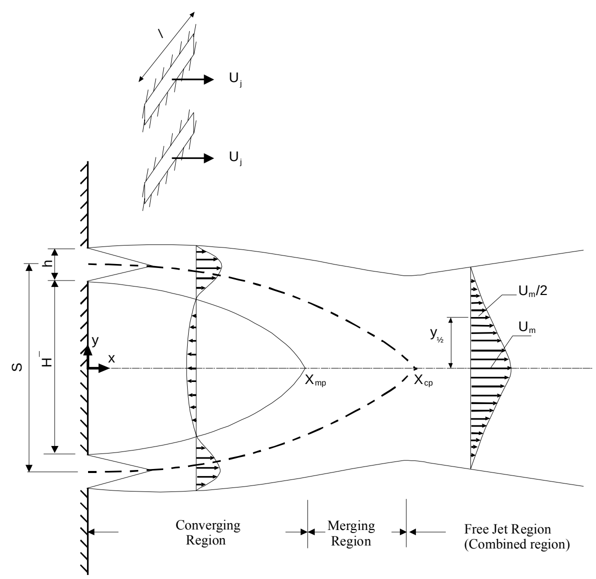

Fig. 1. Schematic of twin jet flow structure

Parallel turbulent jets, having various technological applications have been investigated by many researchers [1-13]. The turbulent mixing of jets can be applied in a variety of fluid as in burners, in trust augmenting ejectors of VTOL and STOL aircrafts, fluidics, and injection systems.

In multi-jet studies, the mutual influence of the neighboring jets on each other requires clear understanding and hence twin jet studies become important.

Studies on parallel turbulent jets have been concentrated on two dimensional flow fields. Although the practical applications are mostly three dimensional, there is a lack of documentation on the interaction of rectangular twin jets. The present study aims to investigate experimentally the flow structure of incompressible unventilated rectangular twin jets.

Lin and Sheu [4,5], studied with various nozzle spacing and found that the normalized values of merging and combining point by nozzle spacing S (X_{mp}/S and X_{cp}/S), are constant at various nozzle spacing (S/h were varied from 30 to 40). Tanaka [2,3], studied the effect of the distance between two nozzles on the interference region of dual jets. Marsters [11] and Elbanna et al. [9,10,12], investigated unventilated twin jet flows.

Previous studies were mainly focused on large nozzle spacing ratios (S/h). There is a lack of documentation on the whole flow field of parallel jets with small nozzle spacing ratio. The unique study with small spacing ratio belongs to Nasr and Lai [8]. Other studies mentioned above are focused on large spacing ratios.

2 Experimental Setup

Experiments are carried out in a blowing down open type wind tunnel which provides a jet flow from a rectangular nozzle. The wind tunnel comprises a fan which draws air from the atmosphere and delivers it along a pipe to a settling chamber which is located above the nozzle. A valve in the pipe is used to regulate the discharge from the fan. Air jet velocity provided by the jet facility can be varied between 3 m/s and 32 m/s. A separating body is inserted in to the nozzle as sketched in Figure 2 so that the jet facility produces two parallel rectangular (5 mm x100 mm) jets.

Characteristics of twin jet flow have been examined by using hot wire anemometer (HWA). Jet flow exit velocity is maintained at 30 m/s during the experiments. Turbulence intensity at the jet exit is approximately 0.8 %.

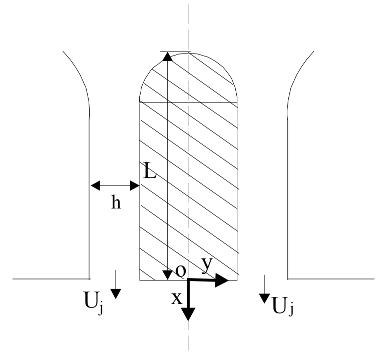

Fig. 2. Schematic diagram of the nozzle exit arrangement for twin jet flow

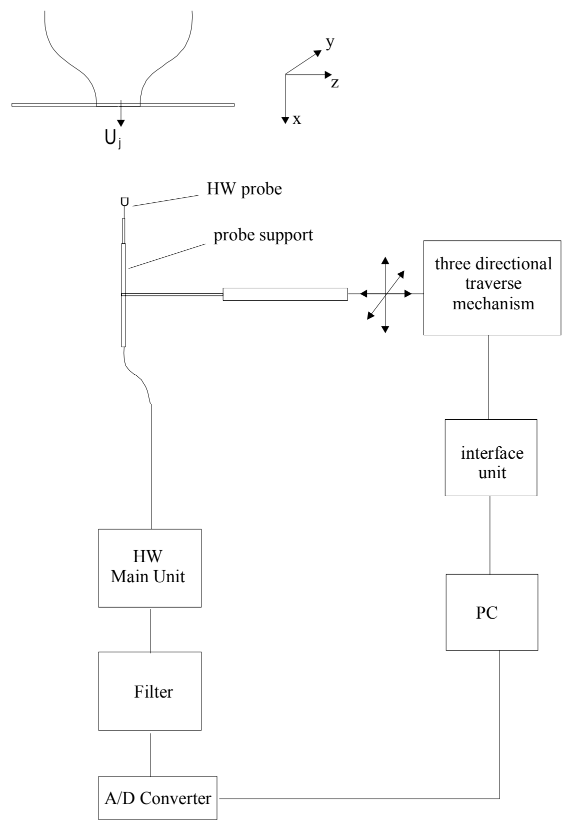

Fig. 3. Schematic diagram of the experimental rig.

All velocity and turbulence data were obtained using a DISA 55D01 type CTA main unit. Voltage output of main unit is filtered by DISA 55D35 filter. 55P01 and 55P15 type single wire sensors with a diameter of 5µm and an active length of 1.25 mm were used. The hot wire signal was digitized using a DAS 20 A/D 12 bit converter. Sampling rate was set at 0.5 KHz and sampling time was about ~8s for each measurement point. During the experiments, probe location was controlled by a DANTEC three directional (linear motion along three axis x, y, z and rotation around z axis) traverse mechanism. The accuracy of linear motion was ± 0.016 mm. Both probe traversing and data acquisition processes were controlled by a PC. A software application written for CTA systems was used for probe calibration, data acquisition and processing, and instrument control. Schematic diagram of the experimental rig is given in Figure 3.

In the second part of twin jet experiments a cylindrical solid body is placed between jets as sketched in Figure 4. The effect of convex surface on the flow field is investigated.

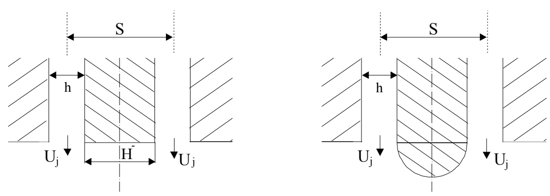

Fig. 4. Schematic diagram of the nozzle exit

3 Experimental Results

3.1 Initial Conditions

Mean velocity distribution at the exit plane of the nozzle is given in Figure 5. The exit velocity profiles of jets are almost uniform along the y axis. The turbulence intensity distribution at the nozzle exit section is also uniform and has a constant value of 0.8% along the uniform velocity region. Mean exit velocity is retained constant, Uj=30m/s (Re_h~10000), during the experiments.

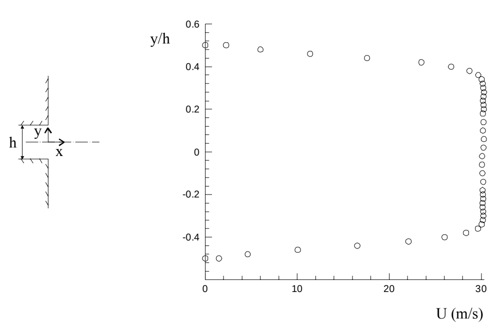

Figure 5 Velocity profiles at the exit plane

Figure 6 shows inner and outer boundary layer velocity profiles at exit plane for different jet configurations. Initial boundary layers are plotted in non-dimensional form and agreed well with the Blasius laminar profile.

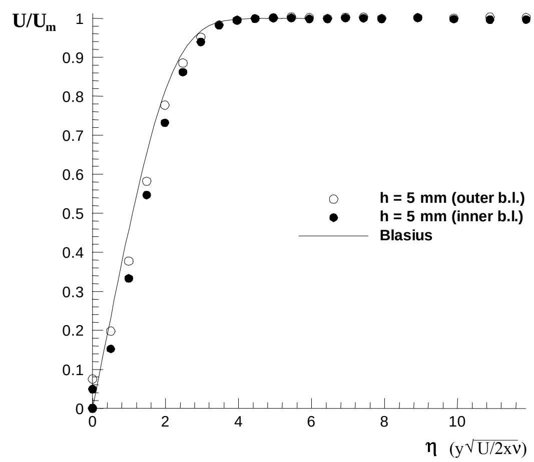

Figure 6 Initial boundary layer profiles

Boundary layer thickness δ, displacement thickness δ^* and momentum thickness θ are calculated and listed in Table 1. The values of shape factor H (=2.58) is approximately equal to that of Blasius profile.

δ mm	δ^* mm	θ mm
1.05	0.2715	0.1052

Table 1 Initial boundary layer characteristics

Even though the initial boundary layer is laminar, the flow in the mixing layer is highly unstable and quickly becomes turbulent.

3.2 Mean Velocity and Turbulence Intensity Distributions

Normalized velocity and turbulence intensity distribution in x-y plane are presented in Figure 7. The velocity is normalized with respect to maximum velocity U_m and y coordinate is normalized with respect to nozzle spacing S. Downstream distance x is normalized with nozzle height h. Jet trajectories deflect towards each other because of the depressurized region. It is possible to observe converging and merging processes by following the maximum and zero velocity lines. The recirculation region terminates at the merging point $X_{mp}/h = 15.2$ and two individual jets continue to merge until the combined point $X_{cp}/h = 44.6$ where the velocity on the axis of symmetry is maximum.

The length of the recirculation region which is surrounded by two jets is important in practice. The extension point of recirculation region where the mean velocity is zero on the symmetry axis gives the merging point of two jet. Downstream from the merging point non-dimensional centerline velocity U_c/U_j increases up to a maximum value at the combined point.

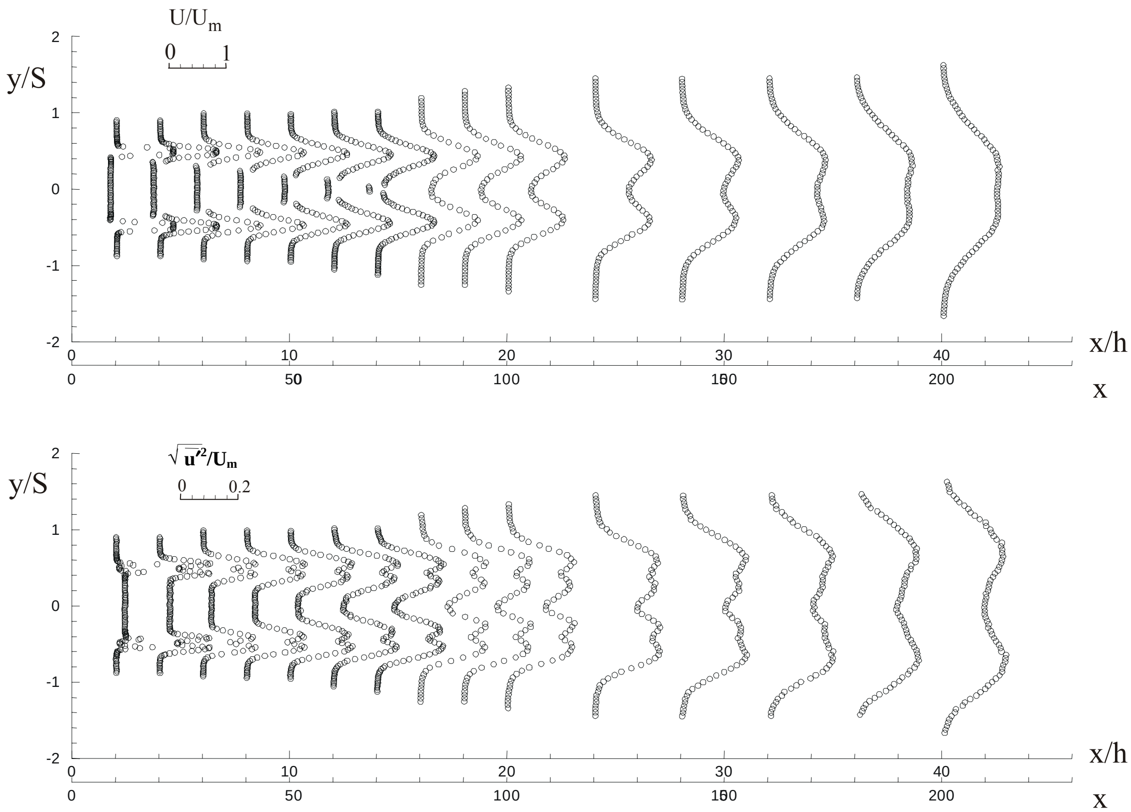

Figure 7 Spatial distribution of velocity and turbulence intensity profiles of twin jet

After the combined point, flow resembles to a single free jet and it reaches self-similarity. Self-similar velocity profiles are presented in Figure 8. Non-dimensional velocity profiles agree with the theoretical curve of Gortler. This result indicates that the flow in combined region is approached to a fully developed single jet flow.

Figure 9 shows the decays of square of the non-dimensional maximum velocity with downstream distance. Maximum velocity decay retains its rectangular jet characteristics and the flow field may be classified as potential core, characteristic region and axisymmetric region.

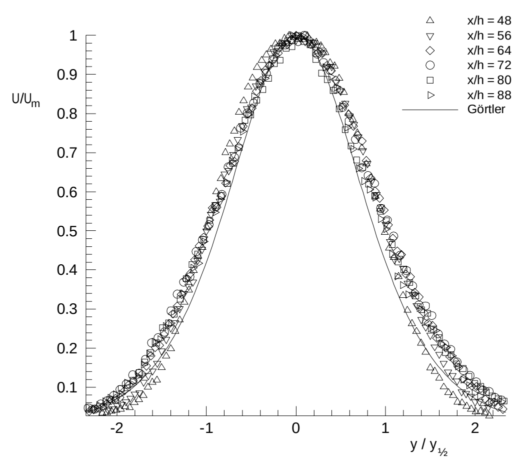

Figure 8 Self-similarity profiles

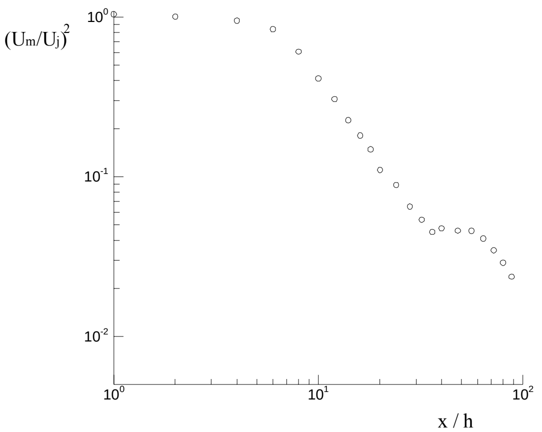

Figure 9 Decay of maximum velocity with downstream distances

3.3 Convex Surface Effect on the Flow Structure

In the second part of the study a cylindrical surface is placed between two jet exits. Velocity and turbulence intensity profiles are compared with the previous twin jet measurements in order to examine the convex surface effects. The convex surface effects can easily be observed from the Figure 10. The jets issued tangentially to the cylindrical surface, do not collide to the surface as a wall jet, but approach to it by the Coanda effect. At a certain distance from the nozzle exit they interact with each other and coalesce in to a single free jet. Figure 10 presents the profiles in downstream positions from the solid surface. It is obvious that the existence of the convex surface make the recirculation region shorter. Thus merging point moves to upstream positions ($X_{mp}/h = 9.8$, $X_{cp}/h = 22.1$). Merging process of jets results in the coalescence of two jets at upstream positions from the combined point of twin jets (without convex surface).

Comparison of the turbulence intensity profiles indicates higher values for twin jet with convex surface configuration. The appearance of saddle back shaped turbulence profiles indicating the single free jet flow, is clearly observed near the combined point, located about x/h~22.

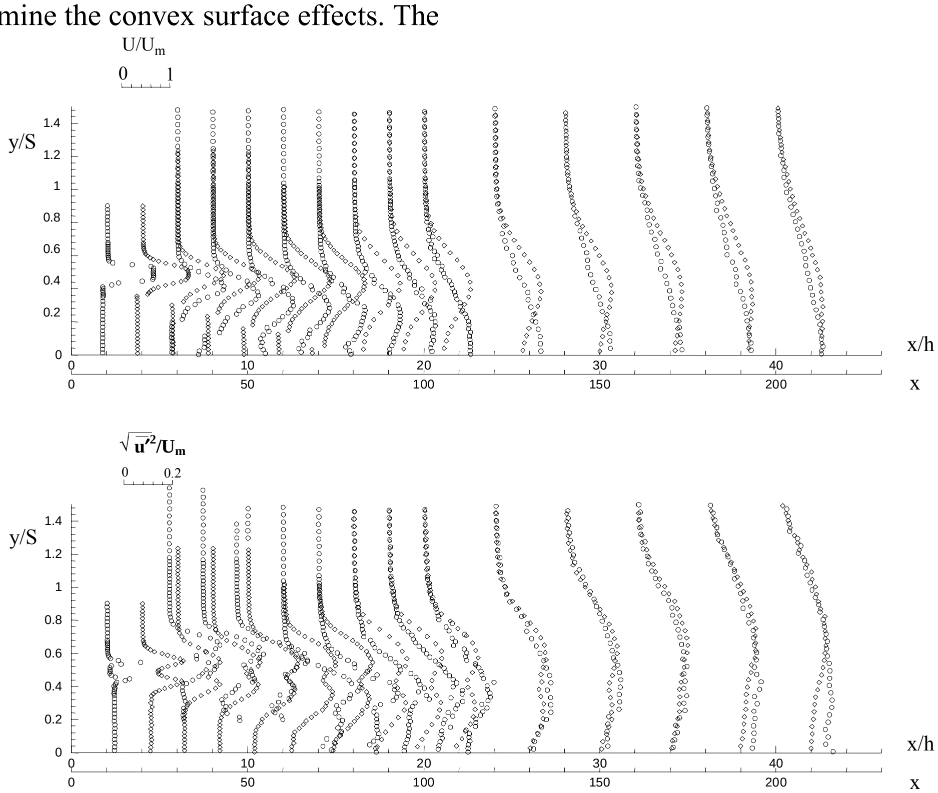

Figure 10 Spatial distribution of velocity and turbulence intensity profiles of twin jet with (◇), and without surface curvature (○)

To investigate the influence of the surface curvature on jet growth rates, jet half widths versus downstream positions are plotted in Figure 11. Even though the jet half width values decreases in near field of the twin jet with surface curvature, after the combined point, in the single free jet region it grows faster. As a consequence, the flow reaches higher half width values at far downstream positions.

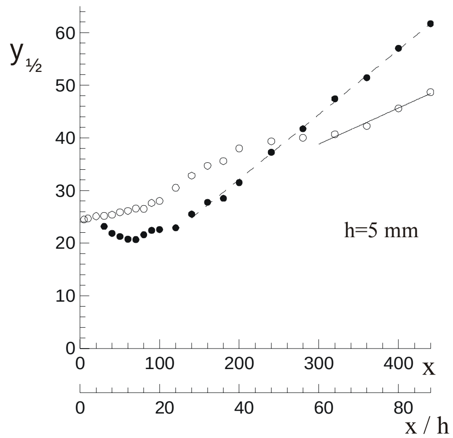

Figure 11 Spreading rates of twin jets with (●) and without (○) convex surface

The variation of centerline velocities are represented in Figure 12. The influence of the convex surface on the length of recirculation region can easily be noticed from the figure. Centerline velocity curves are shifted upstream by the convex surface effect. After the combined point centerline velocity decreases rapidly due to high spreading rates of the "twin jet with surface curvature" flow.

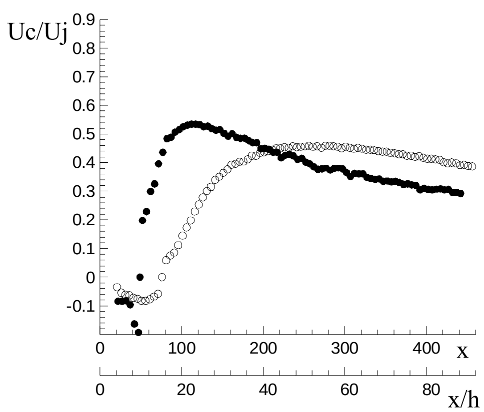

Figure 12 Variation of centerline velocity of twin jets with (●) and without (○) convex surface

Turbulence intensity variations along the x axis are presented in Figure 4.43. Higher values obtained just after the merging point of twin jet with surface curvature flow, may be attributed to the strong interaction between the jets.

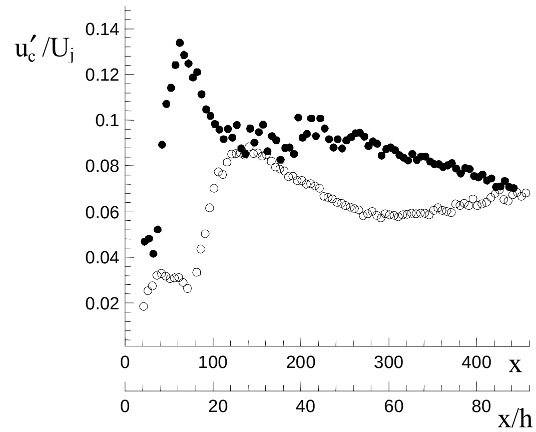

Figure 13 Turbulence intensities along the jet centerline of twin jets with (●) and without (○) convex surface

4 Conclusions

Subsonic, incompressible twin jet flow, emanating from identical 5mm x 100mm rectangular slots is investigated experimentally. Flow characteristics as spreading rate, maximum velocity decay, variation of centerline velocity and velocity / turbulence profiles are examined.

The effect of surface curvature is investigated by placing a cylindrical convex body between two jets. Velocity and turbulence intensity profiles are compared with the previous twin jet measurements. It is observed that a convex surface deflects the jets towards the symmetry axis more strongly and accelerates the flow development procedure.

Spreading rates of jets are affected by the convex surface. In the single free jet region of the twin jet with surface curvature flow, jet grows faster than that of the twin jet flow.

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