Identification And Improvement Of Expanded Flow At Various Step Heights

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Abstract - When the fluid passes through the constant area geometry, it results in the reduction of pressure because of presence of friction between the material and wall. But if the geometry increases suddenly, it undergo loss of pressure and it produces strong re-circulating flow. This re-circulated flow is not at all desirable for sudden expansion flows. Present work aims at the re-circulated region and uses the control technique namely; suction to break the undesirable re-circulated zone. In the present study, flow over sudden expansion geometries with and without suction scenario is studied for different Lmax/Lmin models of 3, 4 and 5. For L_{max}/L_{min} = 5, it is found that the re-circulation and loss zones are more. Further, the configuration of L_{max}/L_{min} = 5 is subjected to suction. With suction, flow scenario is completely changed and attachment point is observed at the base of the model itself. Results, thus identify the improved flow structure that can be useful to different applications.

Index Terms - Sudden expansion geometries, flow structure, flow pattern, suction, re-circulated zone and vortex.

INTRODUCTION Fluid flow over obstacles like steps with increasing and decreasing dimension is an interesting problem with wide range of applications. As we can find them in many engineering applications like an automobile, the front side of the car is like decreasing cross sectional area, whereas, the rear side of the car is like increasing cross sectional area. The present study aims at understanding the flow structure for suddenly increasing cross sectional area, problems encountered, formation of loss zones with this sudden change in geometry and also discusses about control techniques to reduce the loss zones. The loss zones (vortex) are created because of presence of low pressure at the corners of the suddenly expanded geometries. These vortices are responsible for reducing the vehicle movement. The more is the size of vortex, more will be the reduction in the mileage of the vehicle. The size of the vortex depends on the step height of the geometry. Present work aim to understand the variation of vortex size with step height and control of vortex with suction. Vortices are formed because of low pressure at the corner, but, the theme of providing suction at the corner is to further reducing the pressure in the expansion region, which creates strong low pressure region at the corner. That enables to suck the fluid from the top; thereby it creates a flow free from vortices, and diminishes the primary re-circulating region. With the effect of suction, the fluid particles at the beginning of the sudden expansion itself, are sucked towards the corner of the geometry, because of strong low pressure region. There by, the fluid particles move as the geometry changes.

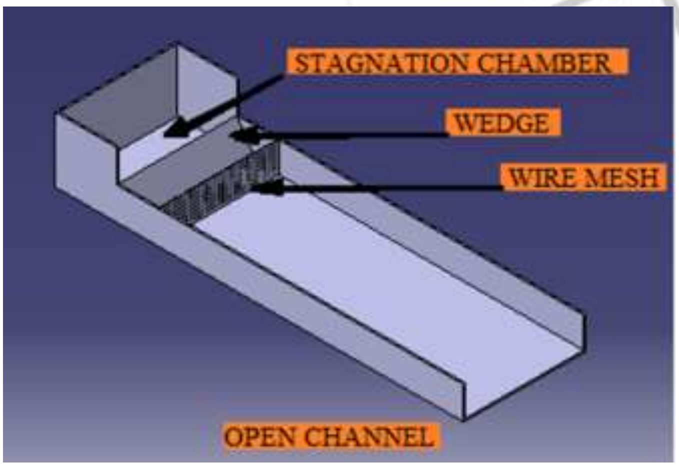

Figure 1. Experimental section.

EARLIER WORKS

Mistrangelo et al. [1] investigated the flows in sudden expansion of rectangular channels with walls of finite electric conductivity and found the formation of vortical recirculation behind the expansion for moderate magnetic fields . They were however suppressed for sufficiently high Hartmann numbers. Zhang et al. [2] conducted experiments for sudden expansion flows to study the inception of cavitation for various enlargement ratios in high speed flowsand identified more cavitation with increase of velocity and enlargement . This results in large vortex and recirculation region. Mak et al. [3] studied the swirl characteristics of flow of sudden expansion with expansion ratio of 2.5 and found swirl intensity increment with increase of Reynolds number. Uruba et al. [4] investigated on the control of narrow channel flow behind backward facing step by blowing and suction. Preliminary results indicated that both blowing and suction could reduce the length of separation zone to one third of its value without control. Hussan et al. [5] studied the symmetry of breaking flow bifurcation phenomenon and its control of flow through symmetric sudden expansion channel by applied magnetic field in the transverse direction. Zong Yuan Guo et al. [6] studied the symmetric sudden expansion flows with heating effect in the corner recirculation zone (CRZ). The heat addition to such flows will lead to the reduction of recirculation of CRZ length and it even disappears if the heating intensity is sufficiently large. Bender et al. [7,8] studied sudden expansion flows with and without solid particles moderately at high Reynolds numbers and found that flow with solid particles had less vortex compared to flow without solid particles. Tihon et al. [9] experimentally and numerically studied the backward facing step flow at moderate Reynolds numbers for different expansion ratios. As the channel expansion ratio is increased, the recirculation pattern becomes more complex in the laminar flow regime. According to Nejad et al. [10], improving swirl to the inlet flow resulted in a considerable reduction of corner recirculation length. Das et al. [11] studied pressure characteristics in the configuration of sudden expansion with central restriction and suction with 2% to 10% of inlet mass flow. Chakrabarti et al. [12] studied performance of vortex controlled diffuser at low Reynolds number regime and revealed that when the bleed is incorporated, the VCD behaves in a completely different manner from that of sudden expansion.

FLOW DEVELOPMENT OVER A MODEL OF STEP HEIGHT (H) = 20 MM LMAX/LMIN = 5 WITHOUT SUCTION

Figure 2 represents the flow visualization study of Lmax/Lmin = 5 at without suction. Flow is initially detached from the wall as shown in the fig. This is called detachment point, this occur where the crosss section of the object abruptly changed. This flow is attached to wall far away from the vertical wall with spiraling effect known as vortex. This is called attachment point, which occurs at a distance of 3 (ration of attachment point to step height) from the vertical wall. After the flow gets attached to the wall, comes back towards the vertical wall because of the presence of low pressure at the corner. This creates the pockets of eddies, results in recirculating region. This region is called primary recirculation zone. If the length of the Lmax is large enough, then the free stream flow, which crosses the primary recirculation region gets dettached from the wall. Again, attaches afterwards, which is called re-attachment point. In between the detachment and re-attachment points, flow circulates and this is called secondary recirculation region. But, the present study aims only at understanding and control of primary recirculation region.

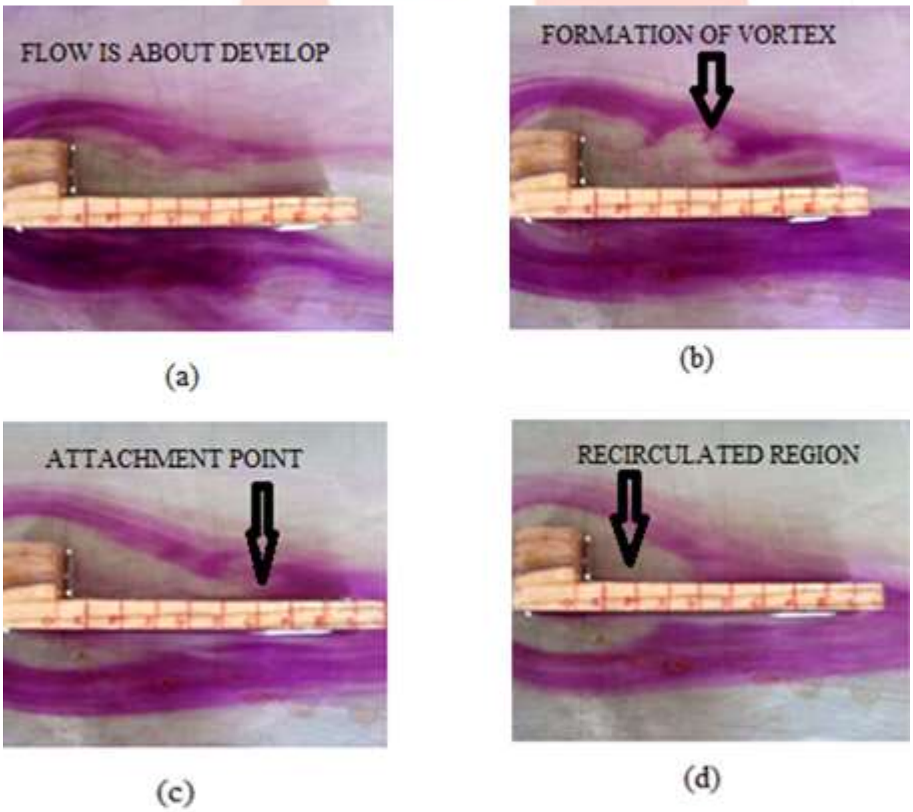

FIGURE.2. FLOW DEVELOPMENT OVER A MODEL OF LMAX/LMIN = 5 AT WITHOUT SUCTION

LMAX/LMIN = 5 WITH SUCTION

When the flow finds the sudden expansion in its direction, it does not follow the geometry change, but it folows a typical strucure as shown in the Fig.2. In that case, the loss zones are more and are responsible for reduction of mileage of automobiles. In order to avoid or to minimize these zones, suction is introduced. The effect of suction is to create further strong low pressure rigion at the corner of the model. This strong low pressure region at the corner enables to hold the particles, which are at the beginning of the expansion region so that these traveldirectly to the corner of the model, which will minimize the recirculation flow and vortex as shown in Fig.3. Initially, the flow attaches the wall at a distance of 1 (ration of attachment point to step height) from the vertical wall. As the time passes the attachment point shifts towards the vertical wall resulting in diminished recirculated region. With suction, it follows the physical structure of the model. Then the flow doen not find detachment point. Hence, the flow through sudden expansion geometry with suction is like potential flow through sudden expansion.

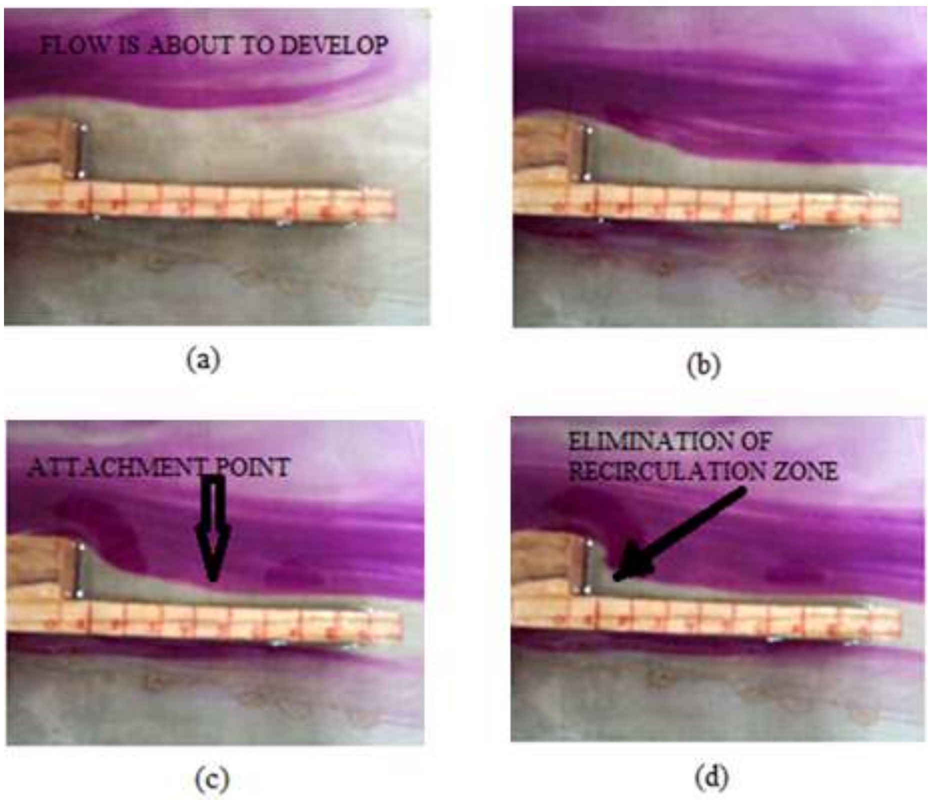

Figure3.Flow Development Over A Model Of Lmax/Lmin = 5 With Suction.

FLOW DEVELOPMENT OVER A MODEL OF STEP HEIGHT (H) = 30 MM

LMAX/LMIN = 3 AT WITHOUT SUCTION

Figure 4 represents the flow visualization study of L_{max}/L_{min} = 3 without suction at a step height of 30 mm. As the step height increases, the flow pattern changes a lot as shown. Flow does not directly separate from the vertical wall as in the case with step height 20 mm, but it follows the vertical wall in the vericaly down ward direction then separates from the wall at a distance 3 mm from top (where the actual separation would occur). After that, this detached flow moves gradually over L_{max} and gets attached at a distance of 1.83 from the vertical wall. Then turns back and forms the typical recirculated flow.

Compared with step height 20 mm, the results with step height 30 mm show large vortex with high intensity of recirculation region. Attachment point with step height 30 mm might occur at lesser distance than with step height 20 mm. This happens because, for step height 30 mm, flow after encountering the sudden expansion, comes down towards corner and then gets detached from the vertical wall. At this condition, the fluid particles have already travelled in the downward direction along the vertical wall. After detachment, fluid particles with downward velocity get attachment point very near to the vertical wall comparatively. But, in this case, the flow experiences large vortex in the vertical direction as shown.

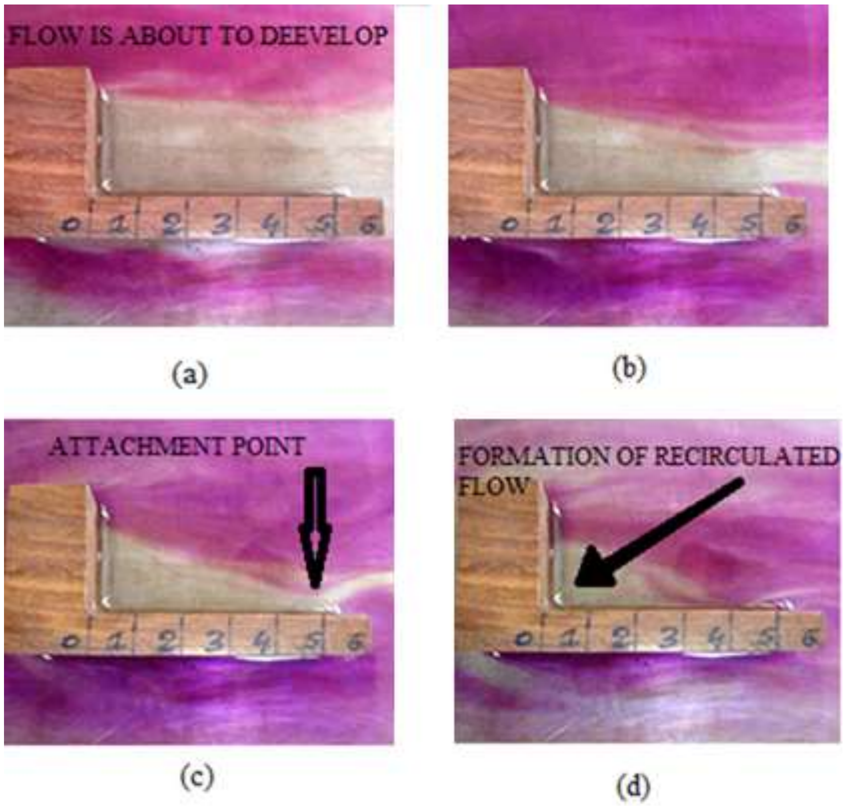

FIGURE4.**F**LOW DEVELOPMENT OVER A MODEL OF LMAX/LMIN = 3 WITHOUT SUCTION

FIGURE 4 REPRESENTS FLOW VISUALIZATION STUDY OF L_{MAX}/L_{MIN} = 3 WITH SUCTION. WITH THE EFFCET OF SUCTION, THE ATTACHMENT POINT IS SHIFTED TO 0.67 FROM THE VERTICAL WALL, CAUSING THE REDUCTION IN RECIRCULATION ZONE. AFTER ATTAINING EQUILIBRIUM, FLOW ATTACHES TO THE VERTICAL WALL, WHICH RESULTS IN ELIMINATION OF RECIRCULATION ZONE. FIGURE 5 CLEARLY REPRESENTS THE EFFECT OF SUCTION.THE FLUID PARTICLES AFTER SUDDEN EXPANNSION, ARE SUCKED TOWARDS THE CORNER BECAUSE OF PRESENCE OF STRONG LOW PRESSURE. WHEN THESE PARICLES ARE SUCKED TOWARDS CORNER, THE FLOW COMES DOWN DIRECTLY OVER THE VERTICAL THE WALL, WITHOUT SEPARATION. HENCE, FLOW THROUGH SUDDEN EXPANSION WITH SUCTION EVEN WITH INCREASING STEP HEIGHT IS LIKE POTENTIAL FLOW THROUGH SUDDEN EXPANSION.

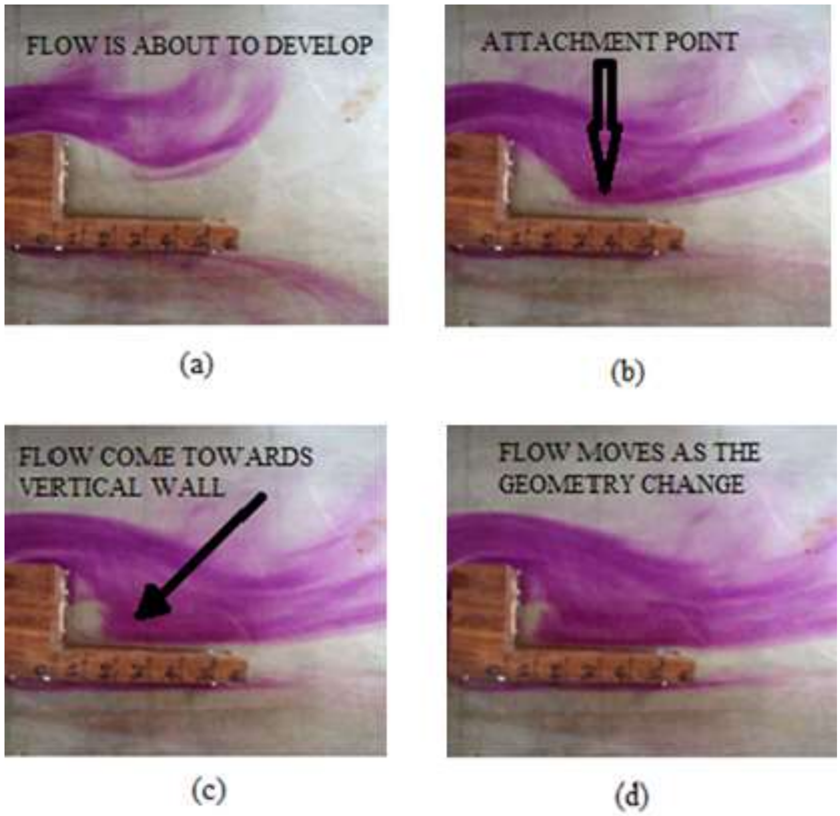

FIGURE5.FLOW DEVELOPMENT OVER A MODEL OF LMAX/LMIN = 3 WITH SUCTION

CONCLUSIONS

FLOW STRUCTURE OVER SUDDEN EXPANSION GEOMETRY IS EXPERIMENTALLY STUDIED FOR DIFFERENT CONFIGURATIONS INVOLVING VARIED L_{MAX}/L_{MIN} VALUES. THE VORTEX SIZE AND RE-CIRCULATION ZONES INCREASE AS THE STEP HEIGHT INCREASED. FOR STEP HEIGHT OF 20 MM, THE ATTACHMENT POINT OCCURS FAR AWAY FROM THE VERTICAL WALL THAN WITH A STEP HEIGHT OF 30 MM. BUT, FOR STEP HEIGHT OF 30 MM, THE VORTEX SIZE IS MORE IN VERTICAL DIRECTION. WITH SUCTION, THESE ISSUES ARE SOLVED AND REDUCE THE VORTEX AND RECIRCULATION REGIONS, WHICH ARE VERY MUCH DESIRABLE FOR SUDDEN EXPANDED FLOWS. HENCE, IT IS CLEAR THAT THE FLOW THROUGH SUDDEN EXPANSION WITH SUCTION APPROACHES POTENTIAL FLOW. SUCH IMPROVED FLOW STRUCTURE WILL BE HELPFUL FOR MANY ENGINEERING APPLICATIONS.

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