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# INVESTIGATION OF FLOW BEHAVIOR PASSING OVER A CURVETURE STEP WITH AID OF PIV SYSTEM

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## ABSTRACT

Present paper investigate the effect of varying flow velocity and direction on flow separation, recirculation, flow patterns, adverse pressure gradient and other flow phenomena. Particle Image velocimetry (PIV) has become a more useful techniques for studying application used in fluid flows. Unfortunately very high price and safety concerns of using Class IV lasers prevent this technology being used most of projects and researches. Recently, however, a relatively inexpensive and safe "educational Particle Image Velocimetry (ePIV)" system with web based interactive software was developed. This novel technology is an instrument that can be used in diverse educational settings because of its effectiveness as an education tool, high-tech appeal, compact size, low cost and safety and it was used in the present paper. It was found that for the first velocity value, the flow upstream of step model starts to sense the first gradual reduction in flow passage by increasing of velocity magnitude in both directions x and y components in addition to a small deviation in vector direction towards the open area in flow passage also it is revealed that for almost half of the gradual step height, the velocity possess a lower values of velocity similar to that of the upstream one with a some shift in direction from the main flow direction. It was concluded that PIV technique is very important method for measurement of flow field and can be utilized by any researcher easily. Also, the ePIV system allows incorporating experiment with theory which stimulates creativity. In addition, the gradual step model tends to create a vortex area results from the stagnation of the flow near the curvature surface which leads to accelerate the flow towards the narrow passage at a closer regimes to the step model.

**Keywords:** gradual step model, separation, flow patterns, ePIV.

## INTRODUCTION

Present work investigate the effect of varying flow velocity and direction on flow separation, recirculation, flow patterns, adverse pressure gradient and other flow phenomena. The negative pressure gradient became more significant as the static pressure increases with the direction of the flow velocity. Fluid pressure increasing was related to the increasing of the potential energy inside fluid, which accordingly leading to a lower rate of kinetic energy that accordingly lead the flow to decelerate. Once the static pressure increases to a certain high level then the flow may slow down to a velocity almost equal to zero or even reverse their direction. The flow is said to be separated when the fluid pressure at the surface completely overcome the upstream pressure. Flow-separation and re-attachment are very important in civil, mechanical, aeronautical, and chemical engineering applications, because their repeated appearance may affect basic flow characteristics and result in a affordable change in the performance of fluid machinery and heat transfer devices. An originally laminar flow is affected by the existing of the walls however, in the layer near the wall, flow velocity start to decrease to a value of zero and the flow far from walls surfaces will be considered as inviscid, and can be also considered as potential flow. The shear forces near the wall are of the reason behind forming of boundary layer. The region over which the shear forces affect flow is namely called boundary layer thickness. The boundary layer thickness decreases as (Re) increases.

The results of the present work have focused on investigation for experimental data and results obtained from ePIV system which is produced and manufactured by interactive flow study. One prototype within many different models was selected to fulfill the presentation of flow patterns study after passing a certain restriction shape. Four range of field volumetric flow rate were used for the purpose of comparison between results of one prototype namely called 'Curvature Step Model '.

## LITERATURE SURVEY

The processes of physical flow was reached a certain understanding through studying of flow around building inside and outside the wake region.. But, according to Peterka *et al.* [1], even though there have been many studies in this area, there is still a high misunderstanding level on how the winds actually flow over and around buildings, They believe that these misleading are probably related to " extensions of two-dimensional flow". Author revealed the separation zone for a two-dimensional object covered by streamlines so that the cavities are closed. For a three-dimensional object, these separation lines are no longer valid. In addition, the flow approaching the obstacle has separated at some distance upstream, at a point that is actually depend on building height to width ratio, building height to boundary layer height ratio and finally on upstream surface roughness. The flow of air in separation region strikes the building, flows downward of it and rolls up into a vortex. It then wraps around the building and form what is called horseshoe shape that was discussed before. This horseshoe vortex can be the w ind that impinges on the front of the building forms a stagnation region somewhere near the top (about 2/3 the way up) depending on building height-to-width ratio. From this region, flow moves out toward all front edges of the object. The flow near the edges, will separates and may or may not reattach before the backedge was reached. This depends on many factors that will lead to reattachment of flow such as building length to width ratio, height to length ratio and upstream roughness (which also determine the turbulence intensity in the approaching wind).

H.P. Ranti, Tony W. H. Sheu [2] has been carried out a flow simulation in a backward facing step channel having an expansion-ratio of (2.02) and a span wise aspect- ratio of (8) in order to fulfill the physical conditions in sight in to the longitudinal and span wise flow motions. The range of Reynolds numbers was taken to be between (1000) and (2000), which means the flow is laying in the region of transitional flow. The simulated results were also validated in accordance with experimental and numerical data and the comparison results were found to be satisfactory. The simulated results reveal that the flow becomes unsteady and behave as a three-dimensional nature like, longitudinal vortices. The simulated data were analyzed to give certain knowledge of the flow interactions between the floor and roof vortex eddies, and the spiraling flow motion. T. LEE, [3] carried out a study for the results of experimental and numerical estimation of air flowing over a backward -facing step in the region where the flow possesses a condition of separation and then makes the reattachment on both walls. A certain technique using hot film sensor arrays for a range of Reynolds number of (3000) and expansion ration varies between (1.17 to 2). Experimental results were found in good agreement with the numerical predictions. Experimental output was mentioned by author to provide a study of unsteady flow in comparison with the flow separation.

## LITERATURE SURVEY

### Intended use of the ePIV

The ePIV Instrument is intended to be used in a laboratory. A pump circulates water through tubes and flow model. A diode laser is used to illuminate particles in the flow. The illuminated particles are observed with a digital camera. Analysis of the digital images is performed on the PC using FLOWEX™ software. The results show flow field and velocities of the flow.

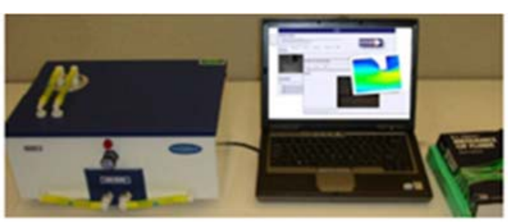

**Figure-1.** ePIV general setup.

### Caution and technical specifications

The Interactive Experiment should be placed on a flat horizontal surface such as a table and make sure that there is an access to the Flow Model and connections on the Interactive Experiment. Also, the Interactive Experiment should not operate with the top lid open or with no water in the reservoir more than 1 minute also the flow Insert have a dimensions of (30mm long x 25mm wide x 5mm) and flow channel entrance cross section of (5mm high x 25 mm wide high). Flow regime used in the present experimental setup includes a number of technical specifications and can be listed as follow:

- Laminar flow only.
- Complete flow field velocity measurement using PIV analysis.
- Instantaneous flow direction change with valve.

### Data acquisition and reduction

### Data acquisition setup

The insert is placed into the Flow Model. Then, the Flow model is inserted into the ePIV and connected. PIV seed solution is mixed well with tap water in the Reservoir, and the Reservoir is reconnected. By turning on the power for the ePIV, the laser would come on and the pump would be turned on. The flow valve is set to a desired position. Finally, the camera focus is controlled remotely with the provided cam-era control program. Once the system reaches a stable condition, a series of PIV images is captured through FLOWEX software.

Data acquisition procedures

Parameters such as video size, frames, gain, exposure, and brightness are controlled until satisfactory by monitoring previews of the video. Brightness, exposure, and gain parameters are specified in percentages between 0 and 100. Brightness controls the overall brightness of the image. Factory recommended values are medium-high for visualization and medium-low value for PIV. Exposure controls the length of time camera sensors are exposed per frame. With lower values sensors are ex-posed more. Factory recommended this value to be high for PIV. Gain factor controls how sensitive will be the device sensors for each unit time. A balance between exposure and gain is suggested as increasing gain it also amplifies noise. The Frames controls the number of frames that will be captured. Video size controls the scaling factor for the purpose of generating the video. For PIV analysis, camera parameters are typically set in a way to have seed particles as bright spot points in the image, while the background is as dark as possible. For the present tests parameters are fixed at 35, 100, 100, and 10 for exposure, brightness, frames, and gain, respectively, for all cases.

### Data reduction procedures

Two consecutive frames are cross correlated to calculate the particle displacement. This displacement and the knowledge of the time between the two frames provide the velocity of the particles. Parameters such as shift size, window size, and PIV pairs are selected. Window size sets the size of the interrogation area. The bigger the window size, the more stable the computed vector is, but it will average over more pixels, hence risk losing information on

ARPN Journal of Engineering and Applied Sciences



local flow. On the other hand a small window size gives more information on local variations but it has more noise. Factory suggested value is 80. Shift size controls pixels to move in each direction to initiate another interrogation. The smaller the size, one can have the more interrogation windows. Factory suggested values are 80 or 40, but 20 for denser vectors. PIV pairs controls how many image pairs to be processed. For multiple pairs all measurements are averaged over the number of pairs. For the present test two window sizes 80 and 60 and four shift sizes 15, 20, 30, 40 are used, and the number of pairs is fixed at 9. Finally, measured flow is visualized by displaying velocity vectors obtained through PIV. Velocities are available in pixel per second and millimeter per seconds.

**RESULTS AND DISCUSSIONS**

The results of the present work have focused on investigation for experimental data and results obtained from ePIV system which is produced and manufactured by interactive flow study. One prototype within many different models was selected to fulfill the presentation of flow patterns study after passing a certain restriction shape. Four range of field volumetric flow rate were used for the purpose of comparison between results of one prototype namely called 'Curvature Step Model'.

The experimental results obtained in this project will make use of data collected from zone of interest to scan the region lies in front and across the gradual step with a mesh moving particles with a certain spatial velocity that will controlled through a multi frame pictures.

Figures (2a and 2b) illustrate velocity vector and zoning according to the magnitude and or direction of flow velocities which were captured for the present case study (i.e. curvature step model) for two different velocities varied within the range (14, and 24 mm\s), also velocity can be represented by pixels per second but the better way to understand and discuss the present results is to adopt the SI values. The mathematical method used for flow visualization is known as the streamline pattern. These patterns, which represent several streamlines form, results in a very good description of the flow. In steady flow streamlines and streak lines are identical. Traditionally, a streak line can be results from experimental work by the continuous emission of marked particles such as bubble, smoke or dye. In the present ePIV streak lines are visualized using these solid particles which shall be illuminated through using of laser by increasing the exposure of the camera.

It can be noticed that for the first velocity value, the flow upstream starts to sense the first gradual reduction in flow passage by increasing of velocity magnitude in both directions x and y components in addition to a small deviation in vector direction towards the open area in flow passage. Also it is revealed that for almost half of the gradual step height, the velocity possess a lower values of velocity similar to that of the upstream one with a some shift in direction from the main flow direction. Once the flow reach the verge of gradual step a region of return flow direction or what is so called a vortex is formed while the upper part of the main flow start to build up higher velocity.

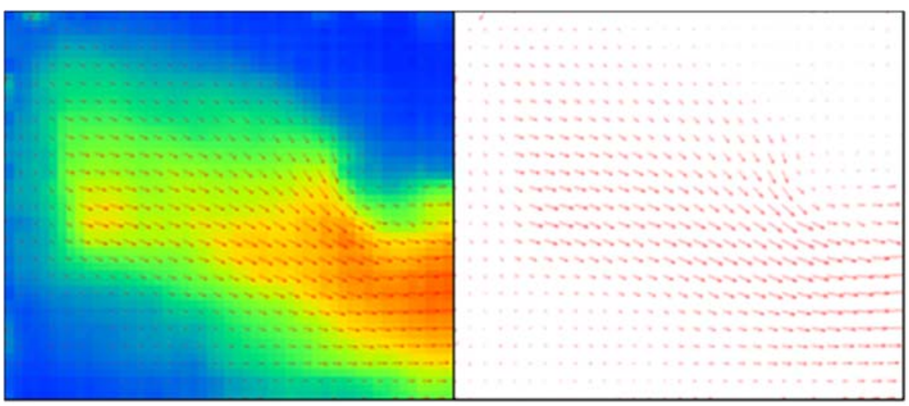

**Figure-2.** Velocity distribution in the shaded color and vector profiles.

In order to understand the roll of PIV technique in visualization and understanding the data and result, (24-frames) of pictures were captured in order to introduce a (12-pair) of dual frames in which these images can be monitored. PIV analysis requires two consecutive frames (i.e. one pair) so that the displaced particles can be cross correlated. First and second frames can be seen in figure (3a & 3b). The second frame is similar to the first frame but with displaced particles. This displacement and the knowledge of the time between the two frames provide the velocity of the particles. In the present work, the parameter of the system such as window and shift size were. The bigger the window size, the more stable the computed vector is, but it will average over more pixels, hence risk losing information on local flow. On the other hand a small window size gives more information on local variations but it has more noise.

Figure (3a & 3b) represent a random pair of frames selected for the purpose of study. It can be observed through focusing on seeding particles that there is a noticeable shift in particles position between the two captured frames for the same location also it is shown that

ARPN Journal of Engineering and Applied Sciences



there is a difference in the density of distributed particles near the end edge of the curvature surface. these figures is essential to let the student or researcher understand the procedure of using PIV techniques in fluid theory instead of the traditional one.

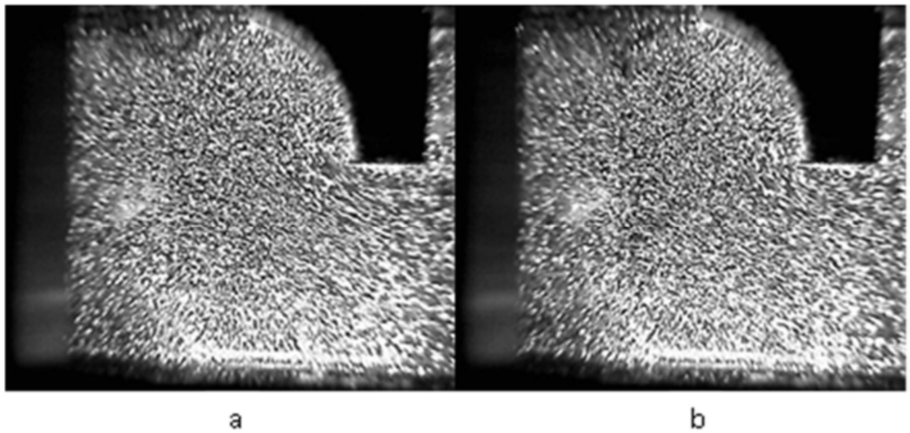

**Figure-3.** Typical PIV captured frames 1 and 2.

Figure-4 also represent the one of the captured frame of the curvature step model with the velocity vector profile is overlaid the frame and indicate the magnitude and direction for most of the particles shown in this figure. The reason behind not including all the particles is related to the selected mesh profile which works on average bases for almost four perimeter points that will be correlated with a single velocity vector refer to the previous mentioned perimeter. Researcher, will have the choice to select between different mesh criteria according to the requirements of experiments, insert models, and or zone of interest within the study therefore any one can make use of PIV technique to specialized it for the case study and can also the well to compare results from other measurement techniques with present utilized PIV technique for more validation

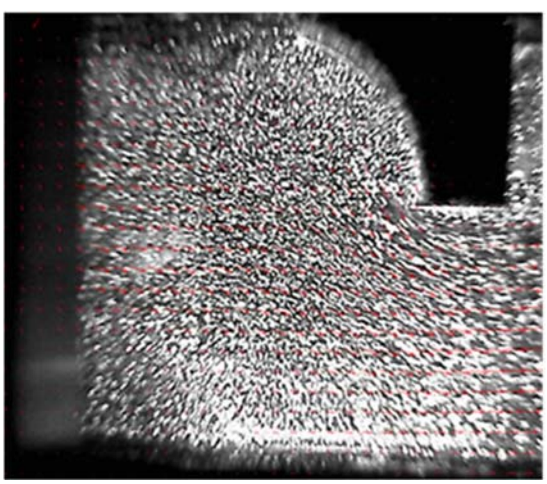

**Figure-4.** Typical PIV for the distribution of velocity vector on the captured frame.

As well as a comprehensive overview for the flow field shading the gradual step model was utilized, it is essential now to move with discussion into another level of velocity which is the second range and equal to (24 mm/s). Same representation criteria is repeated here and illustrated in Figures (5a & 5b), (6a & 6b), and (7). First and in order to compare the results with figures of the first range of velocity, it is important to start with pseudo color and or vector figures for the second rang of velocity. It was shown that with the increasing of velocity, kinetic energy, and momentum exchange between fluid layers, part of flow regimes that possess a lower velocity values and denoted by blue and green zones color which is located a little far from the gradual step model start to dominate and propagate forward in comparison to other velocity.

It was also noticed that the high zone of large momentum is now located at the entrance region of the narrow section above the gradual step model with a margin layers having lower values of velocity and as mentioned before. The results clearly show that the flow accelerated as the width of the channel decreases. This is a demonstration of continuity. The incompressible continuity law states that:

$$Q = \int u \, dA = \text{Constant} \tag{1}$$

Where Q is the flow rate, A is the cross sectional area and u is the velocity. The vector field can also be plotted as can be seen in figure (5a & 5b) which illustrate same behavior mentioned in the shaded format but here the vectors will represent both the direction and magnitude for velocity field.

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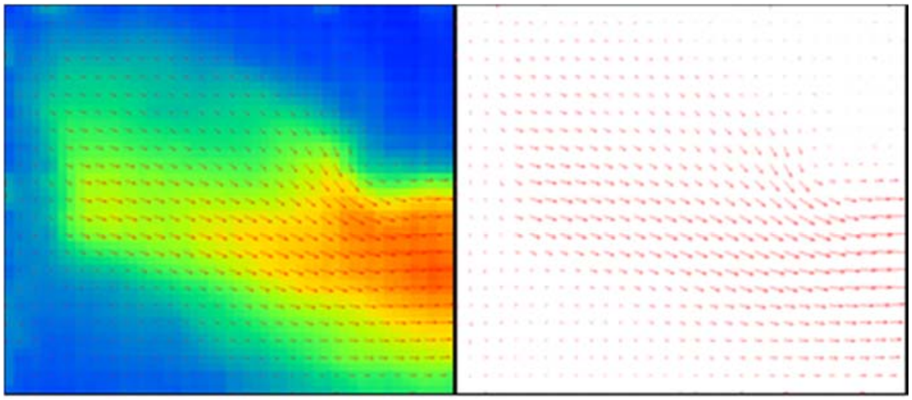

a b

**Figure-5.** Velocity distribution in the shaded color and vector profiles.

Streamline pattern technique is considered one of the most common mathematical methods used by researchers utilizing flow visualization in their work. The pattern, which several streamlines form, gives a very good description of the flow. In steady flow stream-lines and streak lines are identical. Traditionally, a streak line can be results from experimental work by the continuous emission of marked particles such as bubble, smoke or dye. In the present ePIV streak lines are visualized using solid particles which are illuminated by a laser through increasing the exposure of the camera. This can be deducted from Figures (6a & 6b) which was clearly show the two frames captured for the second velocity range and again the differences in particles position can be noticed if any compare between the two frames.

Finally the distribution of vector velocity on the real picture view captured is shown in Figure-7. This method of presentation is useful only for the purpose of understanding the relation between moving particles and their velocity values and direction and this allow the student to imagine and cross correlate between the physical and theoretical nature of any flow fields. Previous results with a presentation similar to that of particles and vectors figure can note be cross correlated as it is not logical to compare between particles that is based on a spatial differences note a numerical differences nor zoning regimes.

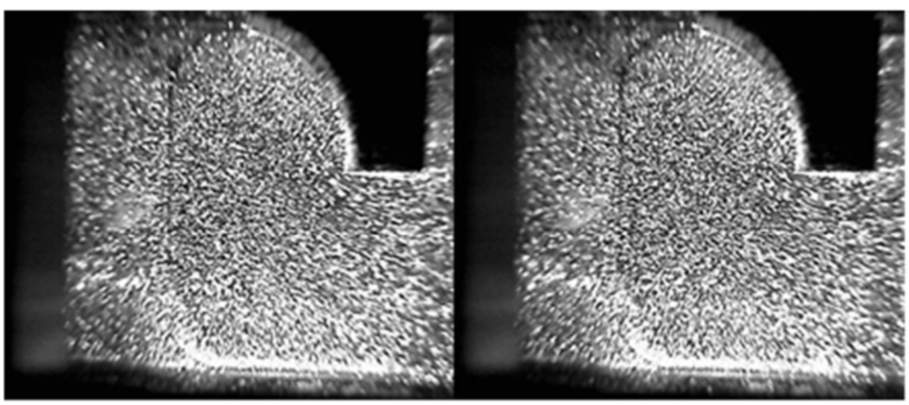

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**Figure-6.** Typical PIV captured frames 1 and 2.

ARPN Journal of Engineering and Applied Sciences



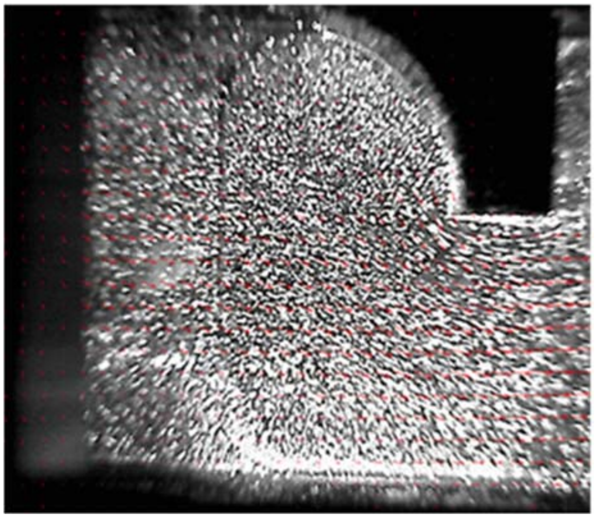

**Figure-7.** Typical PIV for the distribution of velocity vector on the captured frame.

## CONCLUSIONS AND RECOMMENDATIONS

It was concluded that ePIV technique is very important method for measurement of flow field and can be utilized by any researcher easily and this system allows incorporating experiment with theory which stimulates creativity. Creativity is a fundamental component in generating scientific and technological breakthrough. In addition, researcher can develop an understanding of fluid flow by an interactive experiment through a computer terminal in any place useful for submitting lectures. It was found also that there is a certain harmonization between the values of velocity distributed on the mesh created by FLOWEX software with physical nature of the experimental and the gradual step model tends to create a vortex area results from the stagnation of the flow near the curvature surface which leads to accelerate the flow towards the narrow passage at a closer regimes to the step model.

It is recommended to upgrading ePIV system software in order to accommodate the higher rate of velocity values and adopting a new strategy to compare results with a CFD code by exporting a rich text file into a boundary conditions for simulation programs. Finally, adopting a new strategy to compare results with another step model to enhance the effect of geometrical factor on flow field.

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