INVESTIGATION OF FLOW FIELD OVER POST FLOW MODEL WITH THE AID OF ePIV SYSTEM

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ABSTRACT

Post flow model was used in the present study as an insert model for the interactive flow study innovative device namely called ePIV. The separation of the flow and its subsequent reattachment to a solid surface occurs in many systems, and is of practical as well as of theoretical interest. Three different values for the upstream velocity were selected in the present work within the range (14, 24, and 32 mm\s) and two set of figures were observed for every value of upstream velocity. First set for velocity vector plots and shaded color plot while the second is for picture frames captured for the purpose of ePIV system software. It was found that ePIV system can be used in diverse educational settings because of its effectiveness as an educational tool, high-tech appeal, compact size, low cost and safety. Also, It was concluded that the sudden appearance for the post height result in a vortex spot that lead to an adverse pressure gradient concentrate the majority of high bulk velocity magnitude at the upper half of the post flow model height.

KEYWORDS : Post model, Separation and reattachment, flow patterns, ePIV.

التحقق من حقل الجريان المار فوق نموذج لعمود جريان باستخدام نظام تصوير سرعة الجسيمات التعليمي

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الخلاصة

تم استخدام نموذج عمود الجريان في الدراسة الحالية كإضافة لجهاز الجريان التفاعلي المبتكر والمسمى بنظام تصوير سرعة الجسيمات التعليمي. تم في الدراسة الاهتمام بظهور الانفصال للجريان وأعاده الاتصال بسطح الجسم الصلب من الناحية العملية والنظرية كما وتم اختيار ثلاثة قيم لسرع الجريان في الدراسة الحالية ضمن الحدود (14، 24 و 32 ملم / ثا) وتم إنشاء مجموعتين من الرسومات لكل قيمة من السرع حيث تمثل المجموعة الأولى رسومات لمتجهات السرع والرسوم بالألوان المظللة بينما تمثل المجموعة الثانية صورة هيكلية مأخوذة بنظام تصوير سرعة الجسيمات التعليمي .

تم التوصل في الدراسة الحالية بفاعلية جهاز تصوير سرعة الجسيمات كأحد الأدوات التعليمية المضغوطة عالية التقنية والأمنية ومنخفضة الكلفة أيضاً. كما تم الإستنتاج بأن الظهور المفاجي لأرتفاع عمود الجريان يؤدي الى ظهور دوامات مركزة تؤدي الى تركز الضغط السلبي التدريجي والذي يكون على النصف العلوي لنموذج عمود الجريان .

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Nomenclature:

LP Low Pressure turbine.
PIV Particle Image Velocimetry.
ePIV Educational Particle Image Velocimetry.
LDA laser Doppler anemometry.
VMG Velocity magnitude graph.

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. An adverse pressure gradient occurs when the static pressure increases in the direction of the flow. This is important for boundary layers, since increasing the fluid pressure is similar to increasing the potential energy of the fluid, leading to a reduced kinetic energy and a deceleration of the fluid. For a large enough pressure increase, this fluid may slow to zero velocity or even become reversed. When flow reversal occurs, the flow is said to be separated from the surface. Flow separation and reattachment are of great importance in such fields as aeronautical, mechanical, civil, and chemical engineering, and in the environment, because their frequent occurrence may affect fundamental flow characteristics and result in a drastic change in the performance of fluid machinery and heat transfer devices. Particle Image Velocimetry is a state of the art flow measurement technique. Small tracer particles carried out by the flow are illuminated twice by very short pulses of a laser light sheet defining the measurement plane. Digital optical sensors capture the light scattered by the particles then employing image analysis techniques instantaneous velocity vector fields are obtained. Particle Image velocimetry (PIV) has become a very powerful technique for studying fluid mechanics. Unfortunately very high price and safety concerns of using Class IV lasers prevent this technology being used in undergraduate and graduate project and research. Recently, however, a relatively inexpensive and safe "educational Particle Image Velocimetry (ePIV)" system with web based interactive software was developed. This technology is an instrument that can be used in diverse educational settings because of its effectiveness as an education tool, high-tech representation, compact size, low cost and safety. Therefore present work aims to investigate the effect of adverse pressure gradient on the flow structure, introducing new techniques for measuring velocity regimes, and introducing new techniques for measuring velocity vectors. Rory Douglas Stieger (1992) conducted an experimental investigation into wake-induced transition in separating boundary layers. Measurements were made on a flat plate with an imposed pressure distribution and on a 2D cascade of LP turbine blades. The unsteady effects of wakes were simulated in both facilities by wake generators consisting of cylindrical bars traversed across the inlet flow. Single component LDA measurements were made on the flat plate with a technique developed to measure the ensemble averaged Reynolds stresses by making measurements at multiple probe orientations. The convection of a turbulent wake through a LP turbine cascade was measured by author through using of 2D LDA. The resolution of these measurements is unprecedented and the measurements will provide a database for future CFD validation.

The Influences of the secondary flow have been investigated by Gregory- Smith and Lashminarayana (1988) in details. They have referred to the consequences of secondary flow in axial turbo machines and summarized them as the secondary flow introduces cross-flow velocity components, which result in three-dimensionality in the flow field and the secondary flow tends to form a vortex, which will eventually initiate a separation region near the suction surface of the wall. Their effect on the overall performance is thus substantial. P. Van Ransbeeck and M. Vermeulen (2009), reported that particle image velocimetry (PIV) is integrated in engineering education for teaching fluid dynamics in laboratory assignments and the application in project work. A unique and relatively inexpensive "Educational Particle Image Velocimetry" or ePIV system (Interactive Flow Studies LLC, Rochester, Minnesota) is used in a classroom environment. Through project work, PIV experiments are integrated in the product development cycle for the engineering of a tidal stream generator. Using CAD and Rapid Prototyping Machining (RPM) technology, an ePIV compatible model was developed and constructed for the rotor blades. Through the interactive flow visualization experiments the students developed an understanding of the fluid flow that they correlated with Computational Fluid Dynamics (CFD) results. Justin B. Grant [2010] mentioned that design optimization is a common practice in industry. Mechanical Engineering (ME) students and, ultimately, their employers will benefit from learning the design optimization process early in their careers. In fluid mechanics engineering, product development cycles begin with a design. This initial design is then optimized using both Computational Fluid Dynamics (CFD) and prototype testing. CFD minimizes the number of tests required during the design validation process; thereby reducing costs associated with development. Once the CFD analysis is performed, the potential design is prototype tested. If the results do not agree with the CFD analysis, the design process is repeated until an optimized working design is developed. Available technology allows an undergraduate ME Design Team to inexpensively conduct a CFD analysis, manufacture a prototype and conduct a subscale test using Particle Image Velocimetry (PIV) in a real-world fluid engineering project. Herman S. Cousin [2015], conducted a research project in order to design and analyze fluid flow models "micro valves." Micro valves allow the user to control fluid flow in a microchannel by varying a given macroscopic parameter. The Computational Fluid Dynamics (CFD) and the Particle Image Velocimetry (PIV) are integral methods of our investigation. PIV is an experimental technique which provides a measurement of the various fluid variables including velocity field, vorticity, and visualizations, etc. Author refers that the proposed study are currently more interested in how to use these experimental methods and computational techniques in order to better analyze and design micro valves for flow regulation. The project was started, first, by studying existing flow models on the ePIV (Educational Particle Image Velocimetry) with its embedded software FLOWEX and later be verified by COMSOL. Varieties of flow models for micro valves will be later tested with ePIV and then will be verified by FLOWEX and COMSOL for fine-tuned final design. The practice of CFD and the PIV lead to a better understanding of the fluid phenomenon in designing a fluid system. On becoming proficient with these instruments and software, Author mentioned that they will be designing (using Solid Works and COMSOL Geometry platform) a fluid flow model of micro valve that can be tested with ePIV. This model was studied and analyzed on the ePIV and CFD. Ricardo Medina [2011], mentioned that visualization experiments can be used to enhance the learning experience and improve understanding on the following concepts: (i) streamlines, path lines, timelines and streak lines; (ii) laminar and turbulent flow regimes on a flat plate; (iii) boundary layer development and its associated shear stresses, vorticity and the velocity field; (iv) separation of flows past an object; (v) laminar flow over slender bodies, airfoils, or cylinders; and (vi) the development of vortices behind a moving object, among others. Results present some outcomes of visualization experiments and their corresponding computational fluid dynamics (CFD) simulations, which may be used as a basis for the development of innovative teaching modules.

EXPERIMENTAL SETUP

ePIV System Setup and Description

All the reading and outcomes of this work was conducted by using of ePIV system setup shown in figure (1) which was used to study the fluid flow's velocity of curvature flow model. The velocity obtained can then be used for a wide range of proposed calculations, including velocity magnitude and their direction, in addition to velocity gradient, and viscous shear, stream function, vorticity. From the scope of present work, we focused on the velocity magnitude graph (VMG). The VMG offers a visual representation of how the fluid flow changes velocity at different positions. The curvature post processing calculations gathered from ePIV system are calculated by the FLOWEX software, provided with the ePIV which is actually embedded inside it. The quality of the obtained VMG post processing calculations depends on two major things: first the cleanliness of the ePIV (i.e. no air bubbles and/or debris), and second is the seeding selection. For this work the seeding selection depended on how small the seed should be to follow fluid motion and should not alter fluid or flow properties. Interactive Flow Studies provided device with a polyamide seed, which has a diameter of 50μm, a specific gravity of 1.03g/cm3, and a refractive index of 1.5 that is one of the recommended seeds for water flow applications. Note that a pump will circulates water through tubes and over curvature flow model that 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). A diode laser is used to illuminate particles in the flow and the illuminated particles are observed with a digital camera. Analysis of the digital images is performed on the PC using FLOWEX™ software as mentioned before.

Data acquisition and reduction

Data acquisition setup

The curvature 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 brightness, exposure, gain, frames, and video size 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 controls how sensitive the sensors are per 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 brightness, exposure, gain, and frames, 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 window size, shift 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 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 DISCUSSION

The experimental results obtained in this paper will make use of data collected from zone of interest to scan the region lies in front and across the post flow model with a mesh moving particles having a certain spatial velocity that will controlled through a multi frame pictures. Figures (2a, 2b, 2c) and figures (3a, 3b, 3c) 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. post flow model) for three different velocities varied within the range (14, 24, and 32 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 most common mathematical method for flow visualization is the streamline pattern. The pattern, which several streamlines form, gives a very good description of the flow. In steady flow streamlines and streak lines are identical. Traditionally, a streak line can be produced experimentally by the continuous release of marked particles such as dye, smoke or bubble. In the present ePIV streak lines are visualized using solid particles which are illuminated by a 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 post flow model 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 post flow model 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.

All what was mentioned for the case of velocity vector plot, start to be explained with zoning color which is shown clearly in figures (2a, 2b, 2c). Each color represent a certain velocity value and again with a units of (mm/s). It was shown that the regimes located far from the post flow model possess same range of velocities pertaining to upstream values. These range of velocities value repeated again in the stagnation zone which lies near the area of post height. In order to explain the behavior located within this area it is important to mentioned that the stagnation in flow field can now related to the regions having zero and negative velocities which works as a region of adverse pressure gradient against the incoming flow. Basically, beyond this region, the mean flow run against the flow turned from the curvature surface exits and tends to reduce the core of maximum flow rate passing over the post flow model. This is obviously shown with green zones located in the narrow passage surrounded the maximum velocity regimes marked with red and orange color.

The above result survey which uses PIV technique is essential for the prediction of aerodynamic and mechanical performance in dames, bridges, and any hydraulic channels or submarine applications. The final figure related to velocity vector is (3a, 3b, 3c) which reflect same behavior for that of the zoning and or vector profile alone, therefore it depends on the purpose of study either to select which form is more convenient for the purpose of discussion or analyzing the outcome data with theoretical results if there is a real need for comparison between them.

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 figures (4b,4c). 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 is selected with different trails until a best results were obtained. 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. These figures 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 there is a difference in the density of distributed particles near the end edge of the post flow model. 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 (4a) also represent the one of the captured frame of the post step model with the velocity vector profile is overlaid the captured 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.

As well as a comprehensive overview for the flow field shading the post flow 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 (2b, 2c) and (3b,3c). 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 post flow 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 post flow model with a margin layers having lower values of velocity and as mentioned before.

The results clearly shows 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 (3b) which illustrate same behaviour mentioned in the shaded format but here the vectors will represent both the direction and magnitude for velocity field. The most common mathematical method for flow visualization is the streamline pattern. The pattern, which several streamlines form, gives a very good description of the flow. In steady flow streamlines and streak lines are identical. Traditionally, a streak line can be produced experimentally by the continuous release of marked particles such as dye, smoke or bubbles. 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 (5b, 5c) 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 (5a). 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.

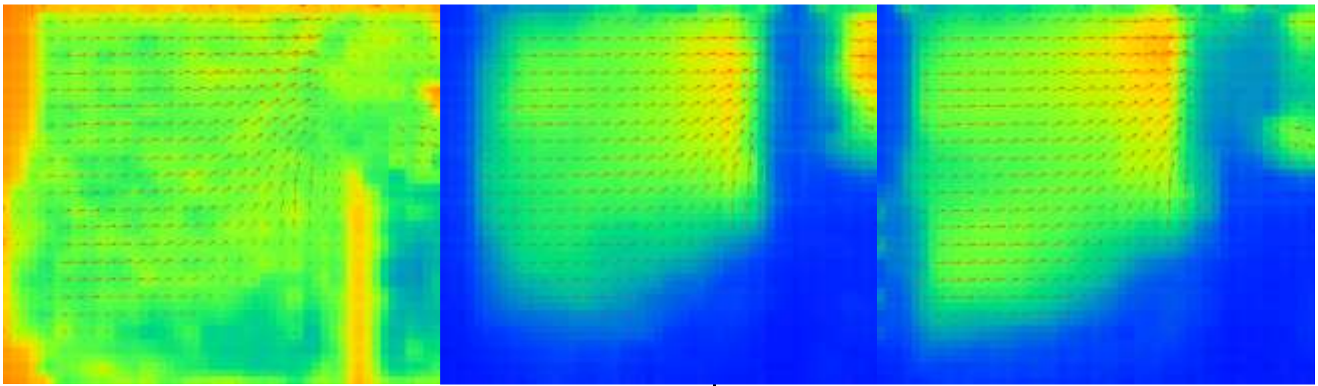
Now, for the third range of velocity value which equals to (32 mm/s), figures (2c, 3c) illustrate the variation of velocity regimes by using of shaded zones and or velocity vector, and (6a,6b,6c) which represent the pair of captured frames and the distribution of velocity vectors over another chosen frame. The figures of the third value of velocity as compare with other results were found to have the same general trend in terms of behavior of flow structure but with higher range of kinetic energy range and can be shown in the set of figures for this range of velocity.

CONCLUSIONS

It was concluded that the sudden appearance for the post height result in a vortex spot that lead to an adverse pressure gradient concentrate the majority of high bulk velocity magnitude at the upper half of the post flow model height. Also, almost half of post flow model height maintains a lower value of velocity distribution for all three range of upstream velocity due to the adverse back pressure generated by the height of post-flow model. Finally, It was found that ePIV system can be used in diverse educational settings because of its effectiveness as an educational tool, high-tech appeal, compact size, low cost and safety.

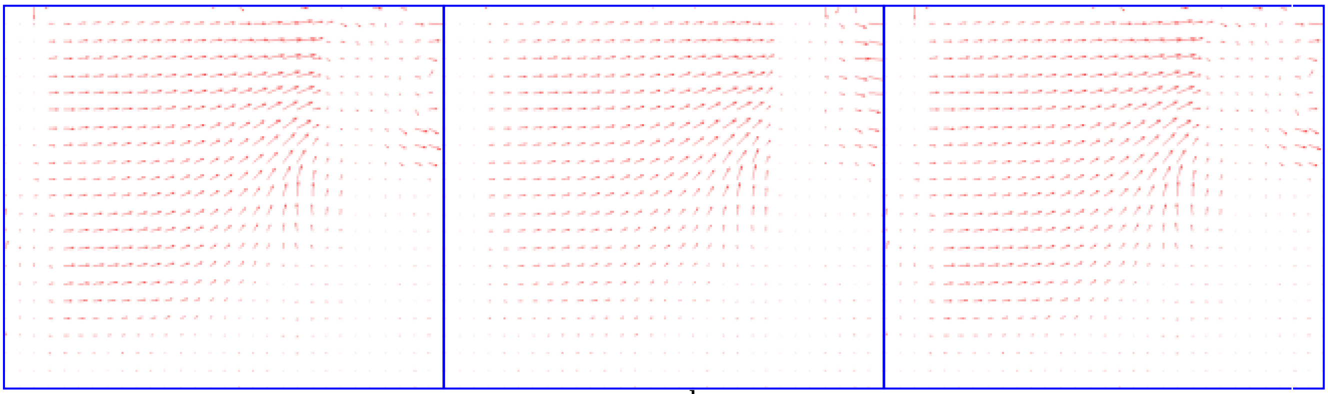
It was recommended that Flowex ePIV software should be upgraded so that future result should be accommodate for measurement of higher magnitudes of velocity values. Also, correlation between CFD and ePIV results in order let students understand the differences between them which may be related to many reasons such as seeding density for the ePIV, the choice of the grid and solver in CFD, the resolution of the PIV analysis, the boundary conditions, and so on.

Figure 1 ePIV general setup



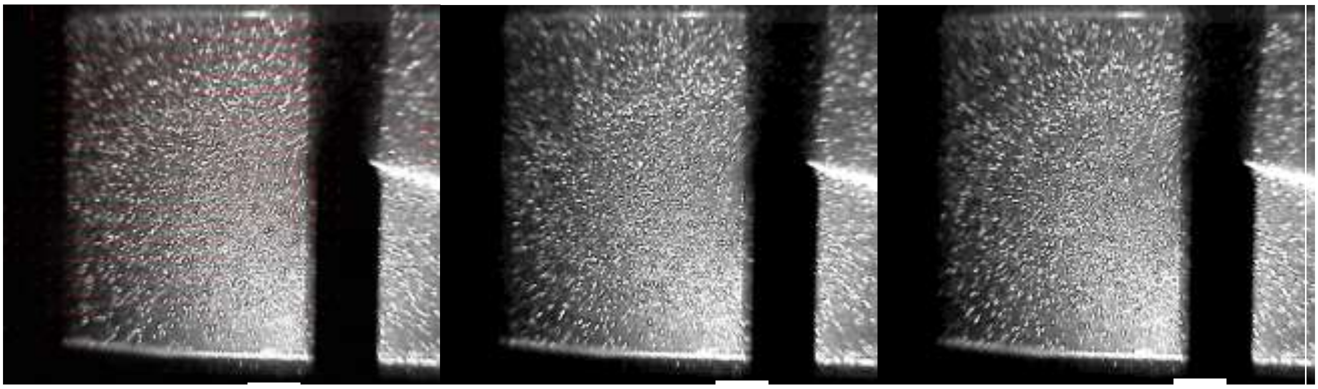
a b c

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



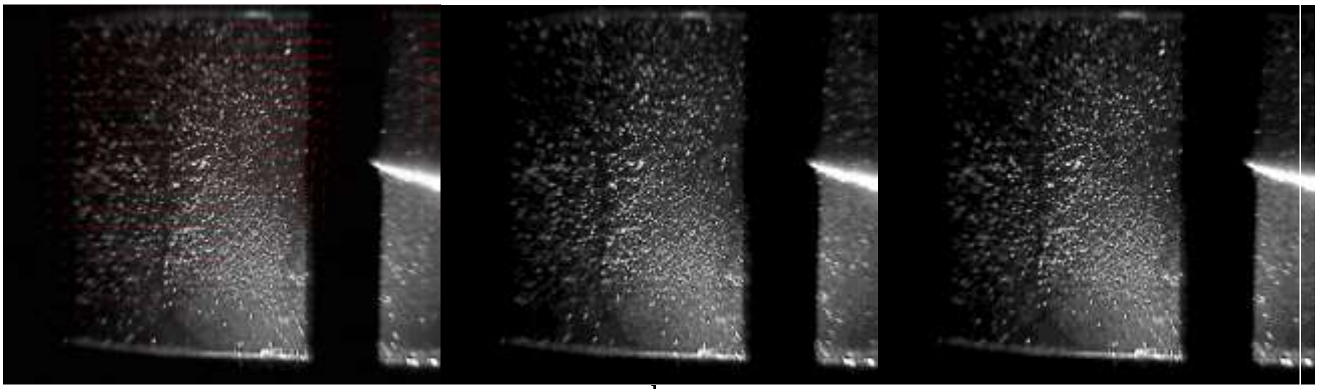
a b c

Figure 3 Velocity distribution in vector profiles.



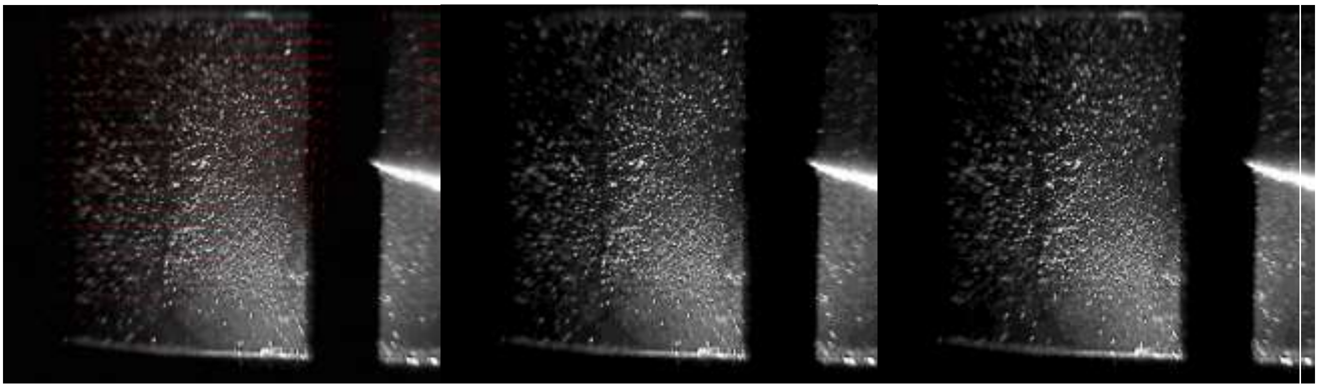
a b c

Figure 4 Typical PIV frame and velocity vector on the captured frame.



a b c

Figure 5 Typical PIV frame and velocity vector on the captured frame.



a b c

Figure 6 Typical PIV frame and velocity vector on the captured frame

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