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A Review on Applications of Particle Image Velocimetry

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Abstract. Fluid dynamic field is frequently classified and designated into two which are hydrodynamics and aerodynamics. Particle Image Velocimetry (PIV) has been exerted to many flow problems in a broad range. PIV application to the measurement of velocity distributions in fluid flow is represented by the Stokes number. PIV can be executed to practically for any sort of flow if the fluid is transparent to allow suspended particles image. The purpose of this paper is to present some examples of application of PIV in general cases. In the midst of numerous applications of PIV, turbulent flows are the most comprehensively demanding because of their three-dimensionality, naturally large ranges of length and unsteadiness. Sudden flow field measurements of PIV method can be applied for the demotion of turbulence quantities and mean velocities.

1. Introduction

Fluid dynamics is the study of the fluid flow which are hydrodynamic which is liquid and aerodynamic which is gas normally all over and in solid surfaces. Pattern of flows can be distinguished as laminar or turbulent [1]. All industrial man-made flows are mostly turbulent practically and naturally occurring flows in atmosphere and ocean on earth are turbulent normally. Thus, exact turbulent flows calculation and measurement has wide ranging significance and applications [2]. Generally, turbulent motion is in three dimensional (3D) and diffusive based of governing Navier-Stokes equation so it is hard to solve in most real applications [3]. Therefore, measuring the flow is essential. Turbulent k- ω model is one of Reynold Average Navier Stokes (RANS) which is making of the averaged Navier-Stokes equations while the closure equations are performed on the fundamental Boussinesq turbulent eddy viscosity principle [4].



Primitively turbulence study has been enhanced by experimental methods that included by the point and pressure technique of measurement using Hot Wire Anemometry (HWA) [5]. Then, technological innovations including Particle Image Velocimetry (PIV) broad range established. The study in specific difficulties by using these intrusive methods includes highly turbulence flows, vortices and reversing flows [6]. Moreover, intrusive probes are subject to non-linearity that needs calibration, sensitivity to variables effects such as humidity and temperature and also breakage among others problems [5, 6].

There are some numerical and analytical researches of flow field [7]. Performance enhancement of few cases like turbomachine needs deep theoretical comprehension of geometry influence on flow field characteristics structure. Systematic development attempts will require experimental procedures that come up with mathematical models along with true velocity data [8]. Long-established instrumentations like hot wires need particular signal transmission and mechanical balancing traversing when attached to the structure. The instrumentations may raise disturbance into flow field and it may be decalibrated in hostile environments. The problems make the instrumentations for velocity data acquisition in some of the cases less practical [8,9]. Therefore, application of PIV is more suggested compared to the other instrumentation in fluid flow field.

1.1 Particle Image Velocimetry

One of the least intrusive methods of measuring flow fields is Particle Image Velocimetry (PIV) [2,3]. It is also considered as non-intrusive measurement instruments that not affect the flow. The reason PIV is considered as non-intrusive measurement instruments is they are located outside of the flow. Thus, the phenomena to be analysed is unaffected [1]. Even though PIV is a relatively new measurement technique but the amount of PIV experiments is raising outstandingly from time to time. Development of non-intrusive flow measurement techniques for measuring scalar quantities and vector in flow is the most significance in latest times [4]. They have been primarily optically-based. Besides, other techniques are available when fluid opaqueness prohibits access [2].

This technique be made up of measuring the displacement of fluid (Δx) over a given time interval (Δt) based upon the definition of velocity. The definition is the first derivative of position with respect to time [6]. Besides it may be time complex, consuming and costly, it is able to deliver measurement of velocity across a range of volumetrically and geomorphological scales. It also determines higher order statistical analysis with efficient accurately [3,6]. It is able to reveal secular linkages in fluid motion on a scale from nanoseconds to minutes and micrometres to meters [1]. There are a few common applications of PIV that have been done for fluid flow studies.

1.2 Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) simulation can be an effective approach for investigations [3]. to Calculation of estimate solution can be used by numerical method. There is more detailed analysis of the flow fields by means of CFD was not reliable due to limitations on computer power and memory in the past [2]. However, mathematical models and computer technology advanced have enabled researchers to use smaller time-steps and computational grids. It also enables researcher to use more complex turbulence models [2]. CFD may not completely remove the requirement for experiments because it is possible to perform detailed numerical simulations of fluid flows in a virtual flow laboratory by using CFD [1, 2]. The benefit and modernity of PIV are that it provides high resolution velocity vector pf flow information of a whole plane in a time [3]. Other than that, it measures movement of vortices including whole velocity vector flow field outright. Therefore, PIV is more practical compared to other techniques [5, 14].

2. Applications of Particle Image Velocimetry

Applications of PIV techniques in various engineering researches of flow measurements were summarized in this section. As mentioned before, technique of measurement of PIV was developed to measure turbulent flows of wall bounded [4, 5]. One of the advantages of PIV is whole flow field can be measured with minimal disruption in instrumentation. The main difference between PIV and other techniques is other techniques measure velocity just at a point. Meanwhile, PIV can provide two-dimensional or three-dimensional vector fields [6]. Particle concentration is possible to identify single particles in an image during PIV is operated [6]. There are many studies on fluid measurements that require PIV technique to capture the flow velocity and vortex of stupendous flow fields outrightly.

2.1 Dam-Break Flows

Based on studies, flood disaster causes immense damages to the infrastructure and economic activities [2]. It also causes major human lives losses all over the world [2]. The study of dam-break waves (DBW) is very essential in giving information required for and management of river and coastal areas besides risk assessment [15]. Flow velocity is generally presumed to influence flood damage [1,19]. Reasonable and adequate readiness for the event is important to enable adverse impacts mitigation. It needs flood modelling besides flow velocity, timing of the flood arrival and potential flood depth accurate estimation [15]. By modelling a dam-break phenomenon, these studies determined the floodwater waves effects in a long wave tank on numerous wall slopes and surfaces [16]. The novel simple methods of Sensor Signal Capture (SSC) and Imaging System (IS) technique used for estimating wave front propagation velocity that adapted with commonly used PIV are reported. They show a good agreement with the dam break wave theory [16].

2.2 Biogenic or Biologically Important Flows

Since 1993, PIV has been implemented by using systems that either expanded for this purpose that tuned or adapted to the specific circumstances of biogenic or biologically particular flows [8]. PIV can be characterised as a best instrumentation for studying animal-generated flows because it by means non-natural behaviour to a minimum based on its non-intrusive character restricting disturbances [6]. Information on methods for flow studies of facilities of flow and on results are being exchanged in benthic zone [7]. These studies describing the basics and principles of PIV contributes to this exchange is being one of the more recently developed flow mapping methods. It also can be implemented in the study of flows in the benthic zone [7,9]. The applications are depending on tolerance to of densely present seeded particles in flow and laser illumination that is relatively high level and to that may prevent it from behaving naturally or disrupts the organism [6].

2.3 Motion of Blood Cells in a Micro-Channel

Red blood cells biophysical behaviors are important factors in the circulatory system due to high concentration in blood volume to describe blood flow [11]. It is characterized as solid-liquid phase flow and non-Newtonian that imply cell-free layers close to wall and red blood cells deformation [11]. Numerous technologies have been implemented for in vitro and in vivo velocity measurement profile and blood flow volume because blood flow in the vascular network is important [12]. Structure of qualitative flow can be determined from methods of conventional flow visualization [12]. The studies demonstrate blood flow confocal microscopy by using blood cells as the tracing particles [11]. In reflection mode, a video rate of confocal laser scanning microscope (CLSM) was applied to capture and observe the motion of the blood cells [10]. While micro-channel, blood cells sequential images using micro-PIV can be determined [11,12].

2.4 Aerodynamic Researches

PIV instrumentation and techniques are raising in the uses to determine outright unsteady velocity fields [14]. It provides information and data about unsteady flow fields which is hard to capture by other experimental techniques. In huge scale wind tunnels and test facilities, rapid data availability and short acquisition times obtained minimize operational cost and time [13,14]. Portable systems flexible is illuminated with providing a few recent PIV applications results [14]. Recently, actual photographic has been partially exchanged by high resolution electronic imaging which can give PIV data through nearly online by recording PIV image [15]. Other than that, in the study of helicopter rotor aerodynamics and airplane model measurements of wake vortex, a high-resolution dual-frame digital camera was implemented [15].

2.5 Transonic Flows

PIV has investigated transonic flow fields in a bluff cylinder. In order to measure instant velocity fields in a blow-down wind tunnel with particular measuring time, a few improvements of the PIV technique had to be determined [16]. Vorticity distribution and other parameters provide velocity distribution gradients in the flow field and insight of relative importance [17]. In the transonic flow field in a model, outright shocks embedded spatial structure is possible to be investigated by PIV. Velocity data give high accuracy that differential vector operators application such as rot and div to them is acceptable and provides information of flow field or it is not obtainable [17]. Difference between tracer particles velocity and fluid velocity results can be investigated in that kind of case [16, 17].

3. Methodology

Fluid dynamics principle can be used to determine an almost unimaginable phenomena apart from the more familiar cases [4]. PIV is an instrumentation and technique to determine outright turbulent velocity fields quantitative measurement as an extension of flow visualization qualitative. PIV could track particles seeded in the fluid to get whole given measurement area velocity field [16, 18]. PIV is a non-intrusive technique which enable the complete two-dimensional or three-dimensional flow field in a tank to be observed and captured immediately at a single time [3,19].

Typical PIV apparatus consists of camera, laser, lens, fibre optic cable that connect the laser to the lens setup [14,16]. Then, water is seeded in a tank with tiny neutrally particles and illuminated with a pulsed laser light on plane sheet. Photographic film is exposed multiple moving particles images using a camera operating with an exposure time exceeding the pulse period. The particle pairs displacement which determines velocity at specific points is determined by illustrating convenient point on the developed film with light from a low power laser are formed in the diffraction pattern that the orientation and separation are linked directly to particles [19]. The generalised PIV setup is shown in Figure 1.

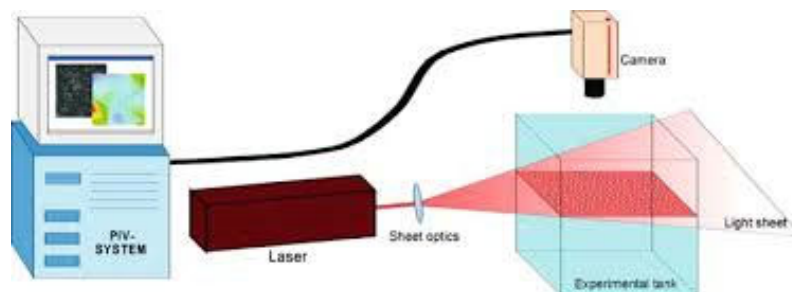


Figure 1. Generalised PIV setup [6]

4. Conclusion

Flow patterns in a fluid is depends on three factors which are solid surface shapes, fluid characteristics and flow speed. Three fluid characteristics that are compressibility, density and viscosity is important. To define the density at a point like the point supposed to be surrounded by a very tiny element that is smaller compared with length scales of interest in experiments, despite it contains a very large number of molecules. Then, the molecules total mass in the element divided by element volume [1]. All in all, pressure, velocity and other parameter as functions of position and time in space is constant with techniques of measurement using fixed instruments in moving fluids. Meanwhile, viscosity is the amount of resistance or internal friction to flow [1,3].

Among the applications of PIV, turbulent flows are the most comprehensively demanding [3]. Based on the common flow visualization methods, information and qualitative flow structure can be acquired. Besides that, large amounts of quantitative flow structure data are required considering spatial distribution information. Digital and optic image techniques of processing, velocity fields can be extracted outrightly using the implemented of PIV technique with the help of rapid advances in computers. Besides the present data set being of crucial importance to validate CFD predictions. All the data provided can be utilize to specify initial conditions in numerical model that solve complex problems of hydrodynamic type especially when dealing with free surface hydraulic phenomena.

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