Can Kang · Haixia Liu · Yongchao Zhang
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Preface

Fluids engineering covers a wide spectrum of topics from the miniature blood pump to the large-scale pump station. As a matter of fact, many problems encountered in fluids engineering cannot be explained with existing knowledge. For instance, regarding fluid machinery, an important constituent of the flow system, new problems arose constantly in recent years with the extension of its application. Some problems are challenging. This prompts researchers to seek advanced research techniques to recognize and explain the influential factors underlying the problems. Moreover, a bridge between academic achievements and engineering applications is sorely needed.

This book is intended to provide insight into problems encountered in fluids engineering. The emphasis is on the application of experimental and numerical techniques. For experimental techniques, nonintrusive optical measurement and flow visualization are emphasized. The numerical techniques are not limited to computational fluid dynamics (CFD), the application of the finite element method is discussed as well. The cases which the authors selected involve various flows such as rotating flows and multiphase flows; they are related not just to a single machine but also to a whole system. The readers might expand their vision or plan a further exploration based on some cases presented here.

Chapter 1 contains an overview of the complex problems encountered in fluids engineering, particularly, in recent years. Meanwhile, generally used methods for addressing these problems are briefly introduced. In Chap. 2, experimental techniques used in treating complex flows are introduced. Optical measurement and flow visualization techniques are emphasized. Numerical methods, which are sometimes equivalently important as experimental ones, are introduced as well. In Chap. 3, the waterjet with distinct features is investigated. High-pressure waterjet is issued from a small nozzle and flows near the tiny jet stream deserve a full consideration from every aspect. Cavitation might occur as the waterjet is injected into stationary water; therefore, both flow characteristics and cavitation phenomenon are analyzed in this chapter. Chapter 4 deals with the motions of the bubble in stationary water and in flowing water. Tracing transient bubble characteristics and bubble image processing are two aspects focused in this chapter. Ventilation serves as an effective measure for increasing the gas or oxygen content in liquid. In Chap. 5, an attempt is made to inject air into water through a cylinder. Gas bubbles trapped in such a unique wake flow are studied. Chapter 6 records a drag-type hydraulic rotor. Such a rotor can be traced back to the conventional Savonius rotor. In this chapter, the rotation of this rotor is driven by flowing water. Flow patterns near the rotor are observed. The impeller pump is used commonly in fluids engineering. Flows in the impeller pump remain a focus in relevant studies. In Chap. 7, flows in the impeller pump are investigated. It is anticipated to relate the flow patterns with the geometry of the pump hydraulic components. Meanwhile, the effects of operation conditions are taken into account. In Chap. 8, cavitation in the pump is discussed. Chapter 9 treats the interaction between flows and solid structures; specifically, the flow–structure interaction in the impeller pump is explained. In this book, the mechanism of complex flows is particularly emphasized. After all, the understanding of flow mechanisms is the base of the optimal design of relevant machinery and system.

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Brief Introduction

This book presents a comprehensive introduction to flow-related problems encountered in fluids engineering. Methods and strategies used for treating these problems are emphasized. The importance of experimental and numerical tools is substantiated through several cases. Although fluids engineering encompasses a wide range of subjects, the cases exhibited in this book are representative in today's view. Meanwhile, this book can be used as a material for an introductory graduate course on complex flow problems in fluids engineering.

Chapter 1
Introduction to Complex Problems in Fluids Engineering

Abstract Fluids engineering is a huge subject and involves not just fluid machinery but also the entire flow system. The major foundations of fluids engineering are fluid mechanics and mechanical principles. A tendency in recent years is new flow phenomena are constantly revealed. Meanwhile, the complexity of these flow phenomena is apparently high. A broad range of challenges in fluids engineering are being faced by both engineers and researchers. Fluid itself is inherently complex; meanwhile, operation environment nurtures many unknowns. In this chapter, a brief overview of the problems encountered in fluids engineering is presented. Fundamental flow characteristics and typical flow system are covered.

1.1 Background Knowledge

The American Engineers' Council for Professional Development (ECPD) has defined engineering as: The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property. Such a definition applies to all kinds of engineering and engineering activities. In many countries, fluids engineering is not an independent engineering branch, it is generally attached to mechanical engineering or chemical engineering.

Engineering applications exert significant restrictive conditions on flows. For instance, in the flow passages of the impeller pump, flows are subjected to various effects such as the flow rate, the blade geometry, the interaction between the impeller and the diffuser. In many occasions, the cavitation phenomenon has to be considered. These factors are sometimes inter-connected. The flow structure and its scale are two factors that are emphasized in fluids engineering. For the former, a general viewpoint argues that it depends on the restriction of the fluid-wetted wall. This is a macroscopic viewpoint. In fact, we do not know exactly what kind of solid

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wall would result in what kind of flow structure. Furthermore, a vast majority of academic papers would rather link the flow structure with various losses in the flow. In these works, qualitative description instead of quantitative relationship is overwhelming. The scale of the flow structure is another important subject discussed in fluids engineering. The scale is also an important factor considered in selecting the research tool. Here, the microscopic scale is beyond the scope of this book. We are just concerned with the scales that are meaningful to engineering applications.

Apart from the external environment, the fluid itself is complex as well. In practice, completely pure liquid or gas has rarely been found. Instead, the mixture of two or three phases is ubiquitous. In some occasions, even the same phase has constituents of different dynamics properties. For example, as the flow of pure water carries sand particles of 50 μm and 1 mm in diameter, the motion characteristics of these two kinds of solid particles are considerably different. Meanwhile, the influence of solid particles on water varies with the particle size.

The research in fluids engineering can be classified into three categories, namely basic research, applied research and product development. In this context, there is no definite demarcation between basic and applied research. The contents of this book fall into the category of applied research. Research methods and practical cases are two major aspects that the authors are intended to elucidate. The purpose is to replenish the knowledge of complex flows witnessed in engineering. In particularly, for some flows that the existing theoretical and experimental support is not sturdy. As the flows are fully understood, the improvement in the design of relevant machinery or system is facilitated.

1.2 Strategies for Treating Complex Flows

1.2.1 Fundamental Flow Features

A fluid is defined as a material that deforms continuously under the influence of shear stress. There are numerous ways of classification of fluid flows. In a very general way, fluid flows are divided into laminar and turbulent flows. The majority of flows found in engineering applications are turbulent flows. Although possessing such a high popularity, turbulence has no formalized definition until today. Here, three classical definitions of turbulence or turbulent flow are cited, they are:

(1) Turbulence is an irregular motion which in general makes its appearance in fluids, gaseous or liquid, when they flow past solid surfaces or even when neighbouring streams of the same fluid flow past or over one another (This definition is given by von Karman in 1937, he quoted this from a lecture made by G.I. Taylor in 1927 [1]).
(2) Turbulent fluid motion is an irregular condition of flow in which the various quantities show a random variation with time and space coordinates, so that statistically distinct average values can be discerned (Hinze [2]).

(3) Turbulence is a three-dimensional time-dependent motion in which vortex stretching causes velocity fluctuations to spread to all wavelengths between a minimum determined by viscous forces and a maximum determined by the boundary conditions of the flow. It is the usual state of fluid motion except at low Reynolds numbers (Bradshaw [3]).

Although a thorough understanding of turbulence has not been achieved to date, general features of turbulence can be described. Since this book is not a book devoted to the mechanism of turbulence, the readers are advised to search detailed explanations of turbulence in published literature.

Flows can be divided into internal and external flows. For the former, the walls bounding the flow are critical for determining the flow pattern. For the latter, flows passing a body are of special interest. Regarding some simple flows such as flows in a straight pipe, available theoretical foundation is sufficient and clear; therefore, the accordance between experiment results and theoretical results is conceivable. Nevertheless, with respect to rather complex internal flows in rotating machinery such as pumps and hydraulic turbines, both theoretical and experimental achievements are limited. In this case, the validation of assumptions is undoubtedly important.

1.2.2 Common Methods for Treating Flow Issues

The first step in solving a complex problem in fluids engineering is to analyze the environment of the case. Often, it is necessitated to trace the origin of the problem and establish a complete and specific description of the problem. Then seeking theoretical support or proof seems to be the most important but intricate step, particularly as the existing knowledge is inaccessible. After theoretical preparations are finished, a plan for addressing the problem will take shape, hopefully, as soon as possible. Then it is time to find tools to implement the plan. In this context, experimental and numerical tools are always expected. As a matter of fact, a huge amount of literature published recently in fluids engineering recorded experimental or numerical studies.

The analytical solution of flow-governing equations should be granted high priority. Since that most flows encountered in fluids engineering are in the turbulent regime, obtaining analytical solutions of the governing equations is not easy. A general strategy is simplification. The non-linear governing equations are simplified according to the characteristics of the problem. In this connection, some flow features might be intentionally weakened or even eliminated with the simplification. Therefore, to adopt such an approach, the physical essence of the flow problems considered should be sufficiently comprehended.

Regarding experimental techniques, expensive ones are not always advantageous. If you just want to know the averaged velocity of wind, then you do not need to use a laser Doppler velocimeter (LDV). In this context, a prudent consideration of what you are focusing on and what you should obtain with the research tools is crucial. Nevertheless, in fluids engineering, high-level measurement accuracy and resolution are helpful in most cases. As we measure the flow field inside the pump, the first instrument coming into mind is often particle image velocimetry (PIV). Traditional tools such as three-hole velocity probes cannot meet the requirements in today's view.

Computational fluid dynamics (CFD) has developed rapidly in recent 20 years. Certainly, this is related to the advancement of computer hardware. It should be noted that the contributions of numerical algorithms, turbulence models and multiphase models should never be omitted. There have been so many textbooks iterating the fundamental knowledge of CFD; therefore, the details of CFD are not presented here. Commercial CFD software is popular among researchers, particularly the graduate students. We should not criticize them for just simply inputting predefined parameters and setting boundary conditions and then waiting for the numerical results. Instead, we should encourage them to dig into the code and to find the reason why numerical results are dependent on the algorithms, turbulence models and the convergence criteria. Apart from CFD, the finite element method (FEM) has attracted lots of attention in fluids engineering. The most prominent advantage of FEM is it targets the solid components and extracts detailed information of the solid components such as stress and strain. Provided that the loads of fluid are properly exerted on the solid components, the FEM results are more valuable than CFD results for innovating the product or evaluating the operation stability of the fluid machine or the whole system.

In practical engineering, what we see are various machines and pipes rather than flows. Therefore, for the designer and maintainer, they are not concerned with distributions of velocity or turbulent kinetic energy. Instead, they are eager to know more about the machine itself or the operation performance of the machine. How does the flow affect the operation of the machine? How to build a connection between the flow and solid components of the machine? How to optimize the design of real products based on the flow parameter distributions? These questions are sometimes daunting for both researchers and engineers.

Problems encountered in fluids engineering provide a thrust to the technical advancement. In general, practical cases in fluids engineering involve a wide range of knowledge; thus, the treatment of these cases necessitates a systematic strategy. During the process of investigating the cases, the viewpoints will be expanded, various methods attempted and wisdom is concentrated. In this context, we cannot hide ourselves behind the fluid exclusively and we must strive to assimilate the knowledge of other disciplines. For instance, noise is emitted from an operating fan. To suppress the noise, one has to find the source of the noise and then to seek the route of noise emission. During this process, the knowledge of acoustics must be mastered. This is a case that justifies the importance of inter-discipline communication.

One cannot expect the benefits of research are acknowledged immediately after the conclusions are obtained. Some research results or conclusions can be used in the optimization of real product. However, a considerable amount of research achievement might be sealed for many years or just reflected in academic papers.

1.3 Characteristics of Flow Problems

1.3.1 Flow Quantities

Flow quantities are the premise of describing flow characteristics. Commonly, the flow quantity can be decomposed into averaged and fluctuation parts. A common viewpoint in engineering states that averaged flow quantities are much more important than fluctuation quantities. This is in most occasions acceptable since that a high percentage of total energy loss is associated with averaged flow quantities. Nevertheless, in some cases, the importance of fluctuations exceeds that of the averaged flow quantity. For instance, transient shock due to pressure fluctuations can lead to the damage to instruments mounted in the pipe flow system.

Vorticity, the divergence of velocity, is the flow quantity used extensively in fluids engineering. Vorticity distributions have been frequently used to express flow structures. For the optimal design of mechanical components wetted by fluid, the suppression of vorticity has often been taken as an objective. It is noteworthy that two-dimensional flows often serve as a simplification with respect to the original three-dimensional flows. Meanwhile, cross sections are frequently sliced from a three-dimensional flow field. In these two cases, the vorticity components should be used instead of the whole vector.

Turbulent fluctuations are important for describing the inherent feature of flow phenomena. To capture turbulent fluctuations, the temporal and spatial resolutions of the tool used must be very high. Alternatively, small temporal and spatial scales should be reached. The most popular turbulent quantities used today is the turbulent kinetic energy and the turbulent kinetic energy dissipation rate. In published reports, the two turbulence quantities have been used widely. Essentially, velocity distributions are the base of calculating vorticity or vorticity components; fluctuations of velocity are constituents of the turbulent kinetic energy. In this context, the proper orthogonal decomposition (POD) method has been adopted to extract the flow patterns that assume different percentages of total flow energy [4].

1.3.2 Unsteadiness

Flows can be divided into steady and unsteady flows. For steady flows, flow quantities at fixed position do not vary with time. Therefore, the time-related terms in the governing equations can be neglected. Meanwhile, for experimental treatment, in terms of both the instrument selection and experiment rig construction, convenience is appreciable. In contrast, unsteady flows are much more intricate. To obtain physically true flow information, the data-acquisition instrument should possess adequately high temporal resolution or alternatively, the response to the transient variation of flow quantities is quick enough. A typical case is the unsteady flows in the pump. Researchers attempted to measure pressure fluctuations in the pump with high-frequency pressure transducers. Then the data acquired were processed using the method of fast Fourier transformation (FFT).

1.3.3 Symmetry

Some flows are characterized by symmetry. For instance, as flow passes around a cylinder with a rather low Reynolds number, apparent symmetry is witnessed. In addition, the flow confined in a circular pipe is generally deemed as symmetrical relative to the axis of the pipe. This kind of flows are relatively easy to address. Nevertheless, the majority of flows in fluids engineering are non-symmetrical. In this case, corresponding theoretical support is not sound and even suffers from controversy.

1.3.4 Stability

For researchers, stability is an issue that considerably enhances the research difficulty. A very pertinent example is jet. As jet progresses, the surrounding fluid penetrates the jet stream consistently. During this process, the stability of the jet is undermined. Eventually, the jet cannot keep its original integrity. Thus far, the problem of flow stability is intricate. The reason of the stability loss is intricate; and the measures for capturing the initialization of instability are difficult to devise.

Solid boundary is extremely meaningful for large-scale flow structures. Meanwhile, loss of flow stability often stems from near-wall flows. From an academic view, near the wall, non-linear flow essence might be revealed and the linear relationship between the flow velocity and the distance from the wall seems ideal. In the flow passages inside the impeller pump, flows are affected significantly by the curved blade and passages. Meanwhile, the rotating blades impose another influence on flows inside the passage.

1.3.5 Symmetry, Intermittency and Periodicity

Some flows are characterized by symmetry, which is exemplified with the flow passing around a cylinder at a rather low Reynolds number. For these flows, the governing equations can be simplified. Meanwhile, for numerical simulation, the computation domain can be simplified as well. Nevertheless, in some cases, the seemingly symmetry is in fact not true. For instance, as a waterjet issued from a circular nozzle into ambient air. General viewpoint is that the jet flow is symmetrical with respect to the axis of the jet stream. Nevertheless, the disturbance from ambient air and the mixing of water and air at the jet edge might ruin the symmetry. Therefore, in an averaged manner, we may obtain symmetry flows; but for instantaneous flow parameter distributions, symmetry does not hold.

Intermittent flow phenomena are frequently witnessed in fluids engineering. We still use waterjet as an example. As waterjet is issued form a nozzle, the possibility of an intermittent jet is high. Some reports argue that the frequencies of the driven pump are the most influential factor underlying the intermittency. Some believe that the geometry of the flow passage in the nozzle plays a critical role. To treat this kind of flow phenomena, the concept of frequency is often introduced. Furthermore, not just an assessment of the intermittency, but also the relationship between the intermittency and flow parameters and the characteristic scale are anticipated to be explained.

As pump blades pass the volute tongue periodically, complex impeller-tongue interaction will be imposed on the flowing medium between the impeller and the volute tongue. This is just one simple case of periodic flows in fluids engineering. At present, the combination of rotating and stationary components in fluid machinery is diverse; therefore, the complexity of flow patterns in the narrow space between the neighbouring components is perceivable. In practice, for flows with periodic behavior, of interest are the flow structures and their excitations. This is also a topic of significance from both academic and engineering aspects. Most importantly, the excitation or periodic flows results in vibration and noise, sometimes, even the fatigue failure of mechanical components can be ascribed to the excitation.

1.3.6 Phase Change

When a substance transforms from one phase such as solid, liquid or gas to another phase, phase-change phenomenon occurs. In fluids engineering, phase change occurs occasionally. In this context, we will not go further in the chemical aspect of phase change. Meanwhile, in this book, the gas flow is not included and we will deal with phase-change phenomena in liquid flows.

Specific environment nurtures specific flow phenomenon. Cavitation is a phase-change phenomenon occurring in liquid. Cavitation is the formation of vapor cavities in a liquid as the static pressure is reduced to some threshold value in the liquid. When subjected to higher pressure, the cavities implode and might generate an intense shock wave, which can damage the adjacent objects. Cavitation can be detrimental to the performance of the hydraulic turbines and impeller pumps. Cavitation can undermine the thrust produced by a propeller. In some occasions, cavitation can severely damage a mechanical component and the operation of the whole unit must be halted. However, cavitation sometimes is helpful in disinfection and industrial cleaning. A pertinent example is the underwater cleaning using cavitating waterjet. Overall, the goal of studying cavitation is to control cavitation. In this book, cavitation will be analyzed in detail in different cases.

1.3.7 Flows in an Integrated System

Studies on flows can be limited to a single valve or pump, but practical engineering does not permit the isolation of flows from other components of the system. For instance, the flow system shown in Fig. 1.1 contains not just a single pump but also the valves, pipes and other auxiliary components. For such a system, only paying attention to flows in the pump will lead to non-physical results. Essentially, the operation of the pump is subjected to the resistance characteristics of the system. More specifically, the flow rate of the pump is not determined by the pump itself but by the whole system. Moreover, flow conditions at the inlet and outlet of the pump are affected by the system as well. Therefore, for numerical simulation, the assumption of uniform inflow and constant pressure at the pump outlet deviates from reality to some extent. To describe the flow characteristics of this system, the whole system should be modeled and analyzed.

Another example demonstrating the flow integrity is the prefabricated pump station (PPS), which is popular today because of its flexibility in installation and maintenance. The tank is a major component of PPS. In the tank, one, two or even three impeller pumps are mounted. Adjacent to the tank, inflow pipe and outflow pipe are equipped. Certainly, valves and filters are necessary for such a system.

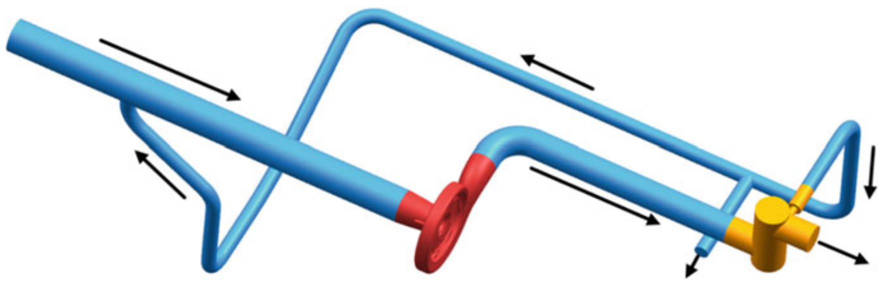

Fig. 1.1 The pipe flow system

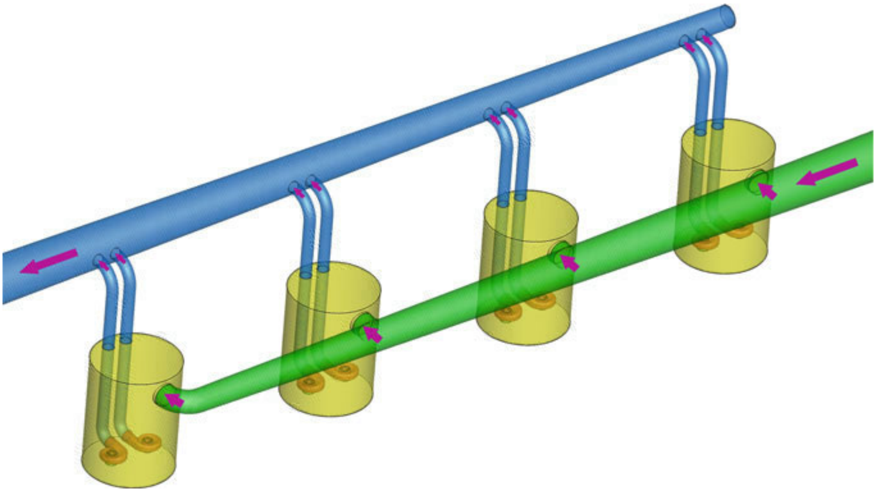

Fig. 1.2 Geometric model of a prefabricated pump station

Sometimes, to adapt to the transportation of medium of large flow rate, more than one tank is deployed. In Fig. 1.2, a schematic view of a prefabricated pump station with four tanks is shown. In each tank, there are two delivery pumps. For such a complex flow system, a comprehensive consideration of all pumps and tanks as well as the pipes is required. Actually, flow rate allocation among the four tanks influences significantly the operation of the pumps. Meanwhile, in each tank, the flow rates of the two pumps are possibly not equal. In addition, in each tank, the interaction between the inflows of the pumps and flows in the tank is related to both the pumps and the wall of the tank. These should be synthetically considered.

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Chapter 2
A Brief Overview of Research Methods

Abstract Theoretical, experimental and numerical methods are three primary methods that are commonly used in fluids engineering. For the theoretical method, it requires a sound base of mathematical and mechanical knowledge. Meanwhile, the gap between theoretical results and applications is often remarkable. In contrast, the latter two methods can be easily exercised and the results can be transplanted into practical design. In this chapter, a brief overview of the two methods is presented. For each method, we do not intend to trace its origin or to explain its fundamental principles; these have been documented in detail. Only those contents that are much related to fluids engineering are presented here. In the following chapters, different cases will be introduced and the function of these methods will be substantiated then.

2.1 Introduction of Experiment

2.1.1 Definition of Experiment

Generally speaking, measurement is a process of gathering information from a physical world and comparing this information with agreed standards. Measurements are essential activities for observing and testing scientific and technological investigations.

Measurements are carried out using instruments, which are designed and manufactured to fulfill specific tasks. In this context, for the flow measurement, a focused subject in this book, conventional and advanced measurement techniques and instruments coexist. Pressure, velocity and temperature are three quantities of significance in incompressible flows. In this book, temperature is not the major concern; instead, pressure and velocity are emphasized. For velocity measurement, non-intrusive measurement techniques have exhibited distinct advantages relative to other techniques. Regarding pressure measurement, various dynamics sensor are used as the primary tools to respond to pressure fluctuations. Overall, the advance and development in measurements, instrumentation, and sensors have facilitated the deep

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understanding of complex flows in recent years. Moreover, the instruments can be connected together using wired, optical, or wireless networks. The development of the control software behind these networks plays an important role as well.

The task of the experiment in fluids engineering generally includes three aspects: monitoring flow quantities or flow patterns, control of flow data acquisition or image capturing, analysis of obtained results. For the first aspect, it refers to situations where the measurement apparatus is used to keep track of flow quantities or images. As we measure the wind speed using a small handheld anemometer, or we measure the water velocity in an open channel using a Pitot tube, the exercise falls into this category. The control of data acquisition or image capturing requires a systematic consideration of the setting of the experimental parameters. This is based on the specific cases considered. As for the analysis of the obtained results, both researchers and engineers need to be proficient in conducting this job. This stage is very important for solving an engineering problem or designing a more favorable product or system.

2.1.2 Experimental Instruments

It is perceivable that the measurement apparatus is crucial for the experimental work. In this book, the applications of measurement apparatuses are presented in a rather straightforward manner. The authors do not intend to reiterate fundamental principles underlying the apparatuses. Meanwhile, some advanced techniques such as magnetic resonance imaging (MRI) have been used in flow visualization, but these techniques have not been widely acknowledged; they will not appear in this book. Instead, commonly used instruments such as particle image velocimeter are used in this book to address flow issues and to disclose flow details.

Optical velocity measurement techniques are relatively advanced compared to the Pitot tube or other velocity probes. Currently, the laser Doppler anemometry (LDA) and particle image velocimetry (PIV) are two popular non-intrusive measurement techniques used in flow research. In some occasions, to identify small-scale flow structures, micro-PIV is put into use. As flow structures are fully three-dimensional, tomo-PIV can satisfy the requirement of flow structure construction. As the flow velocity is high, time-resolved PIV can yield results of sufficiently high temporal resolutions. With time-resolved PIV, the shooting frequency of the camera can be as high as 10,000 Hz. In contrast, ordinary PIV captures consecutive images at the frequencies from tens to more than 100 Hz.

The preparation of non-intrusive flow measurement or flow visualization experiments is not an easy task. First, the experiment model should be made transparent, or at least the incident light can penetrate the flow field and the reflected light can be received concurrently. In general, the experiment model can be made of plexiglass. Nevertheless, as the experiment model involves curved walls, the manufacturing methods and cost should be considered carefully. Sometimes the strength of the transparent model cannot meet the requirements of the flow load. In this case, the adoption of the transparent model is impractical. Additionally, as the incident light enters the flow field via curved transparent wall, the difference of the refractive index on the two sides of the curved wall will induce optical distortion. This is why we see the scenario where a circular transparent pipe is enclosed by a transparent rectangular pipe. Water is filled in the circular pipe as well as in the space between the two pipes. The purpose is to measure the flow velocity in the circular pipe.

As for turbulent fluctuation measurement, laser Doppler velocimetry is an unparalleled measurement tool. LDA uses Eulerian approach and sets a measurement volume in the flow field. Tracing particles passing through the measurement volume are recorded. As the velocity acquisition in one measurement volume is finished, the optical focus is shifted to another position in the flow field. Between PIV and LDA, similarity and difference are distinct. If you are intended to obtain the flow pattern or flow parameter distributions at the same moment, PIV is undoubtedly a better choice.

Processing and analyzing experimental results are an important step in experimental studies. We still take PIV as an example. Based on the consecutive images displaying the luminous tracing particles, an examination of the parameter setting should be performed to ensure that enough velocity vectors are covered in each inquiry window. Hence, averaged flow quantities should be calculated based on a sufficiently large group of transiently recorded images. Flow characteristics cannot be described without a comprehensive analysis of distributions of averaged and instantaneous flow quantities. In some cases, the dimensions of the monitored window of PIV are limited; therefore, an entire view of the flow cannot be obtained simultaneously. In this context, several images corresponding to different monitored windows might be stitched together to provide a full view of the flow.

For multiphase flows, the application of existing experimental techniques encounters many barriers. Multiphase flows encompass a diversity of flows such as the bubbly flow, the solid-liquid flow and the gas-liquid flow. For instance, the difficulty in dealing with the bubble flow is appreciable. For the observation of the flow patterns of the bubbly flow, high-speed photography is probably the most feasible approach that has ever been invented. The instantaneous pictures captured with short time intervals facilitate the seeking of unsteady flow mechanisms that otherwise cannot be illustrated. Often, many researchers are daunted by the huge number of the images recorded. In this context, effective image processing requires a powerful tool. The majority of the software packages affiliated to the high-speed camera cannot meet the requirements of image processing. In this context, the development of a specific code is necessitated. Such a code not just can extract statistical information from the images but also can identify distinct elements in the image. For bubble images, even the profiles of individual bubbles can be recognized using the developed code.

Apart from flow velocity measurement, static pressure is also a flow quantity of significance. Nevertheless, available optical instruments cannot measure pressure distribution in the flow field. Instead, pressure probes and transducers are used overwhelmingly at present to realize pressure measurement. Since the disturbance