FIFTH EDITION

INTRODUCTION TO FLUID MECHANICS

WILLIAM S. JANNA

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INTRODUCTION TO FLUID MECHANICS

To Him who ordered the Universe by a word,
whose love and glory are seen in the
beauty of natural science and in
the accomplishments of simple men,
and to my lovely wife, Marla, who daily reflects
this love and glory to me.

Preface

Introduction to Fluid Mechanics, Fifth Edition is intended for use at the undergraduate level in a mechanical or civil engineering or applied sciences curriculum. It is assumed that the students have knowledge of calculus and physics so that learning to use mathematics to model physical principles in fluid mechanics proceeds without much difficulty.

The book is arranged into 13 chapters and is written using SI units as well as British gravitational units. To exclude either of these unit systems from any fundamental area of study would be premature at this time, although efforts have been made for many years at a national level to convert entirely to SI units. A brief description of the engineering system, complete with a discussion of g_c, is also included (for illustrative purposes only).

A BRIEF DESCRIPTION OF THE CHAPTERS

Chapter 1, which introduces the text, presents definitions appropriate to the study of fluid mechanics. Chapter 2 deals with fluid statics, including pressure measurement, forces exerted by fluids at rest, buoyancy, and stability. In Chapter 3, the basic equations of fluid mechanics are derived from a general conservation equation. The control volume concept is explained, and the continuity, momentum, energy, and Bernoulli equations are presented. Chapter 4 deals mainly with dimensional analysis and modeling and introduces the Rayleigh method, the Buckingham pi method, and the inspection method. This chapter also discusses dimensional homogeneity, illustrates by example the use of dimensional analysis to correlate data, and shows mathematical techniques for modeling prototypes.

Chapter 5 provides an important application of the basic concepts. This application—incompressible flow in conduits—is of great significance to mechanical and civil engineers. Topics include laminar and turbulent flow, nominal pipe sizes, standard tubing sizes, friction factor and pipe roughness, minor losses, noncircular cross sections, and pump sizing for piping systems. Friction factor equations for the Moody diagram are given, as are correlations for coiled tubes and internally finned tubes. Chapter 6 continues with applications to fluid flows past objects and discusses lift and drag forces. It also presents analyses for flows past tractor–trailer trucks, automobiles, and bicycle–rider combinations. Chapter 7, on open-channel flow, is primarily of importance to civil engineers, and the first few sections follow a format similar to that found in classic hydraulics texts. Chapter 8 is an introduction to compressible flow, covering the basic concepts that lead to the solution of practical problems in the field.

In a one-semester course, completion of Chapter 8 could coincide with the end of the semester. The rest of the text is intended for use at an intermediate or second level of study in fluid mechanics. Chapter 9 provides a study of turbomachinery, including design criteria, a description of commercially available machines and installations, and the method used to select pumps and hydraulic turbines for various situations, as well as a section on windmill propellers. Chapter 10 surveys measurement techniques commonly employed in fluid mechanics, such as fluid properties, closed-conduit flows, and open-channel flows.

Some of the more mathematically oriented and classical topics of fluid mechanics then follow. Chapter 11 is an introduction to the equations of motion for isothermal systems (the Navier–Stokes equations) and includes applications to a number of laminar flow problems. Chapter 12 presents simple solutions to the equations of inviscid flow and illustrates the method of superposition to obtain equations for more complex flows. Chapter 13 discusses boundary-layer flows; boundary-layer equations are derived and applied to the problem of flow over a flat plate. The momentum integral equation is derived and applied to both laminar and turbulent flows over a flat plate.

Each chapter concludes with a Problems section. The problems are arranged so that the easier ones are presented first, which helps in building the students' confidence and skill in learning the principles involved. The more difficult problems then allow the students to analyze the topic in more detail. The problems are designed to systematically improve the students' ability to understand and apply the equations of fluid mechanics to various practical problems such as a flow from a draining coffee pot or drag force exerted by a bicycle–rider combination.

In addition, the end-of-chapter problems have been grouped together by topic. This feature makes it easier for the instructor to select and assign problems that pertain to the specific area under study. It will also be easier for the students to review specific portions of the text by solving pertinent problems.

In adding new material, I have tried to achieve a thorough and comprehensible presentation of fluid mechanics from a practical viewpoint, without producing an encyclopedic and therefore inaccessible book.

Learning is enhanced and strengthened when we use equations to mathematically model phenomena that we see and interact with every day. In all chapters, therefore, a strong emphasis is placed on solving practical problems. This approach makes learning a visual experience and provides the students with an introduction to the types of problems they are likely to encounter in practice.

The text has been used successfully in three different courses: a first course in fluid mechanics covering Chapters 1 through 6; an intermediate course in fluid mechanics covering Chapters 7, 8, 10, and 11; and a course in turbomachinery covering Chapter 9, supplemented with information from other sources.

Regardless of how many times a manuscript is checked, the occasional mistake does seem to slip past. The author invites readers to report any errors to the publisher so that misconceptions are not taught as truths. The author also invites readers' comments, which will be gratefully accepted as advice on how to improve the text.

Acknowledgments

I thank the many faculty members and students who wrote letters of encouragement, made suggestions on how to improve the text, and pinpointed portions of the text that required clarification. I am also greatly indebted and extend my gratitude to my manuscript reviewers.

I extend my thanks also to CRC Press staff members, Jonathan Plant, engineering editor, for his guidance, patience, sense of humor, and ability to suggest things politely, and Jill Jurgensen, senior project coordinator, and to the University of Memphis for various forms of help. Finally, I acknowledge the encouragement and support of my lovely wife, Marla, who made many sacrifices during the preparation of the various editions of this text.

Author

William S. Janna received his BSME, MSME, and PhD from the University of Toledo, Toledo, Ohio. He joined the mechanical engineering faculty of the University of New Orleans in 1976, where he became department chair and served in that position for four years. Subsequently, he joined the University of Memphis in 1987 as chair of the Department of Mechanical Engineering. He served as associate dean for graduate studies and research in the Herff College of Engineering. His research interests include boundary-layer methods of solution for various engineering problems, modeling the melting of ice objects of various shapes, and the study of sublimation from various geometries. He is the author of three textbooks and teaches short courses for the American Society of Mechanical Engineers (ASME). He teaches courses in heat transfer, fluid mechanics, and design of fluid/thermal systems. He has designed and constructed a number of experiments in fluid mechanics and heat transfer laboratories.

Introduction

Other Books by William S. Janna

Engineering Heat Transfer, 2nd edition, CRC Press, Boca Raton, FL, 2000

Most of the texts on heat transfer have focused on the mathematics of the subject, typically at an advanced level. Engineers need a reference that provides a strong, practical foundation in heat transfer that emphasizes real-world problems and helps develop problem-solving skills.

The second edition of *Engineering Heat Transfer* fulfills that need. This book emphasizes effective, accurate modeling of heat transfer problems. It contains several real-world examples to amplify theory and to show how to use derived equations to model physical problems. Confidence-building exercises begin with easy problems and progress to more difficult ones. Problem-solving skills are developed methodically and thoroughly.

The text is concise and user friendly. It covers the topics of conduction, convection, and radiation heat transfer in a manner that does not overwhelm the reader. It contains a multitude of drawings, graphs, and figures to clearly convey information that is critical to envisioning the modeling of problems in an abstract study like heat transfer.

The text is uniquely suited to the actual practice of engineering.

Design of Fluid Thermal Systems, 2nd edition, Cengage Learning, Boston, MA, 1998

This book is intended for a capstone course in energy systems or thermal sciences that corresponds to the machine design course in mechanical systems. The text is divided into two major sections. The first is on piping systems, blended with the economics of pipe size selection and the sizing of pumps for piping systems. The second is on heat exchangers, or, more generally, devices available for the exchange of heat between two process streams.

"Show and Tell" exercises are provided in this text; these require students to provide brief presentations on various topics (e.g., various types of valves that are commonly used, venturi meters, and pump impellers).

The text also contains numerous design project descriptions. A student group can select one of these design projects and devote an entire semester to finishing it.

Project management methods are described and students are taught how to complete task planning sheets to keep track of the progress made on the designs. Project report writing is also discussed, and a suggested format is provided.

When a student completes the course material, he or she will have mastered some practical design skills. For example, a student will acquire the ability to size a pipeline to meet least annual cost criteria, to select a pump and ensure that cavitation is avoided, and to select and size a heat exchanger to provide a required fluid outlet temperature or a heat transfer rate. The student will also gain the experience of working in a group and in observing the effective planning and management of project design activities.

The text is comprehensible and gives much practical information on design in the fluid thermal systems area. It relates industrial practice to fundamental engineering concepts in a capstone design experience.

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