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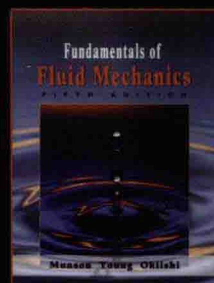
（第五版）（英文改编版）



Fundamentals of Fluid Mechanics

Fifth Edition

Bruce R. Munson
[美] Donald F. Young 著 邵卫云 改编
Theodore H. Okiishi

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工程流体力学（第五版）（英文改编版）

Fundamentals of Fluid Mechanics Fifth Edition

本书是根据美国著名出版商John Wiley & Sons出版的精品教材改编而成的工程流体力学英文教材，其内容包括绪论、流体静力学、流体运动基本原理、控制体法流动分析（恒定总流）、微分法流动分析、量纲分析与流动相似、内流和外流、有压管流、孔口和管嘴出流、明渠流、堰流、渗流和可压缩气体一元流动。改编者根据多年双语教学的成功经验，将原版教材的特色与国内教学的需求融为一体，既注重内容上实际问题的解决，又强调教学上先进理念的体现，并鼓励采用现代化教学方式和手段，可为教师免费提供习题解答、PPT、图形库以及视频等教学资源。

本书可作为高等院校土建、市政、给排水、水利等专业的流体力学（水力学）的双语教学用书，亦可作为专业技术人员和全国注册土木工程师考试的参考书。

邵卫云 浙江大学建筑工程学院副教授，工学博士。长期从事流体力学的课堂教学和教学改革，主持国家级教改项目“流体力学双语课程建设”，是国家级精品课程“工程流体力学”、教育部项目“新世纪网络课程工程流体力学”和浙江大学国家工科基础课程力学教学基地建设的主要骨干。2002年被评为全国力学教学优秀教师；2003年赴英国曼彻斯特理工大学进修；2005年“工程流体力学课程建设及成果辐射”项目获国家优秀教学成果二等奖。现从事水动力学、城市防洪排涝减灾、城市水文水环境等方面的研究。

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内 容 简 介

本书是根据美国著名出版商John Wiley & Sons出版的精品教材改编而成的工程流体力学英文教材。为了保持原版教材的特色，同时满足中国高校教学的要求，本书主要依据最新的高等学校土建类专业的《流体力学课程教学基本要求》进行改编，尤其注重理论基础及实际问题的解决，其主要内容有：绪论、流体静力学、流体运动基本原理、控制体法流动分析（恒定总流）、微分法流动分析、量纲分析与流动相似、内流和外流、有压管流、孔口和管嘴出流、明渠流、堰流、渗流和可压缩气体一元流动。

本书可作为高等院校土建、市政、给排水、水利等专业的流体力学（水力学）的双语教学用书，亦可作为专业技术人员和全国注册土木工程师考试的参考书。

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导　读

流体力学是一门古老的学科，它的发展历程是生产发展对其促进的过程。其中，实验流体力学与理论流体力学交错前进或齐头并进，结果是当代流体力学中不仅有着众多复杂的基于物理起因和数学理论的方程，而且还包含众多的经验公式、经验值（图表）等，并且许多术语、基本原理与方程直接由创立它们的学者姓名命名，如Bernoulli's equation，Navier-Stokes（N-S）equation，Eulerian description of motion，Poiseuille flow, Reynolds number 等。因此，采用双语传授流体力学，不仅仅是通过有关知识内容的传授，促使学生及早地接受国外前沿科研成果，提高他们参与国际竞争的能力和后期的学术与就业竞争力，更是促使学生对流体力学发展历史的了解，从而更深入地了解知识点的内涵，以及由此引申出的相关技术。

工程流体力学是土建类、水利类的一门专业技术基础课。2003年，在浙江大学的支持和力学基地的支撑下，我开始试点开设流体力学课程双语教学。通过三年多的实践，我发现仅仅依靠双语版的电子教案和讲义还很不够，双语教学的正常开展还必须依托原版教材，才能让学生接触到正宗的英文表述、流体力学的发展历史及相关背景、知识和发展方向，等等。因此，2005年，在浙江大学国家工科基础力学教学基地的依托下，在流体力学国家级精品课程的基础上，由我主持申请了国家级教改项目——“流体力学双语教学课程建设”，其重点在于双语教学教材的建设。

Fundamentals of Fluid Mechanics, Fifth Edition 是一本非常适合于教学的教材，已经在美国Iowa大学、Colorado大学、加拿大Alberta大学等著名大学使用。改编教材在保留原版教材主要特点的基础上，具有如下特点：(1) 流体力学的理论叙述非常详尽，实践性强，利用大量例题作为理论内容的延伸和讨论，并且通过“Fluids in the News”来说明时刻充实在自然界以及我们日常生活中的流体力学现象。(2) 习题类型丰富多变，且与每章小结相对应。本教材每章的习题不仅包括标准习题（这在国内教材中占绝大多数），而且还包括大量计算性（基于spreadsheet或计算机）、讨论性习题，基于“Fluids in the News”及各种视频材料的习题。在一章学习结束并完成有关习题后，每章的小结对学生提出了应该掌握的概念和要点，以及通过本章学习应该能够解决的问题。(3) 教材将全书的制式基本上统一为SI单位制，满足了国内教学的需求。(4) 教材的编排别具特色。简图、主要概念及要点、例题与正文紧密结合、互动，“Fluids in the News”与视频紧随各相关知识点。(5) 教辅材料翔实丰富。在John Wiley & Sons公司的网站上，有大量的视频材料、学生学习用的辅导材料和教师教学用的辅助材料，既丰富了教学资源，又缩减了教材的容量。

但是，由于国内外文化传统、教学体系的差异，原版教材与我国教学体系和教学习惯有着较大的差异，部分内容已超出国内的教学要求。由此，为了保持原版教材的特色，同时满足中国高校教学的要求，本教材的改编主要依据最新的高等学校土建类专业的《流体力学课程教学基本要求》，同时亦适用于水利类专业课《工程水力学》的先学课程。

在本教材的改编过程中，对原版教材的结构体系做了一定的调整，主要体现为：原第3章和第4章部分内容合并成为流体运动基本原理；第4章部分内容和第5章内容合并为控制体法流动分析；第8章和第9章合并成为内流和外流，并缩减了第9章中大部分有关边界层和升力、阻力的理论计算内容；第11章保留一元气流的基本理论，删除了其余内容；直接删除了第12章涡轮机械。另外，根据国内教学大纲的要求，主要增补了以下内容：压力体，孔口出流和管嘴出流，明渠均匀流的特性、渐变流的水面曲线及其定性分析，实用堰、堰流的基本理论与流量系数经验公式，渗流的基本理论。根据结构体系的调整，相应地增减了部分习题、例题，删除了部分“Fluids in the News”。改编后教材的内容体系依次为：绪论，流体静力学，流体运动基本原理，控制体法流动分析（恒定总流），微分法流动分析，量纲分析与流动相似，内流和外流，有压管流、孔口和管嘴出流，明渠流，堰流，渗流和可压缩气体一元流动。至于原版教材的习题解答、PPT、图形库以及视频等资源，教师可填写改编教材后的“教学支持说明”，然后通过电子工业出版社向John Wiley & Sons公司申请，便可在网上免费下载。

本改编教材沿袭了原版教材的编排特点和主要的内容结构体系，增补内容主要依据2006年年底将由高等教育出版社出版的国家“十一五”规划教材《应用流体力学》（毛根海、邵卫云、张燕编）。但是，由于删/缩减了原版教材的部分内容并对部分内容结构体系进行了调整，因此，在遵循原版教材使用方式的使用过程中，尚需注意以下几点：(1) 有些内容由于删/缩减可能不能构成完整的独立体系，如外流等，请参考原版教材；(2) 在大多数中文教材中，连续性方程、动量方程和能量方程一般分别由质量守恒定律、动量定律和元流伯努利方程推导而来，但在本教材中，它们分别由质量守恒定律、牛顿第二定律、热力学第一定律结合雷诺传输定理推导而出；(3) 本教材中没有包括有压管道中的非恒定流（水击）理论、明渠渐变流水面曲线的数值计算理论，若需要，请参考各有关文献；(4) 在堰流一章中，虽然在改编时我对堰流流量公式进行了统一，但仍保留了原版教材中不同的堰流经验公式，其中各系数均为经验系数，与国内使用的有一定差异，要注意；(5) 本教材中的公式大多保留了其一般形式，即微分形式，在工程应用时则应根据具体情况选用特定的简化公式计算；(6) 本教材中的BG单位制，除了第1章为了对不同的单位制进行说明保留了部分BG制外，其余基本上已经统一转换为SI单位制，在使用时请注意。

本教材在改编的过程中，得到了毛根海教授的大力支持，朱嵩博士帮助整理了渗流的内容，胡卫红女士提供了增补内容中的原图，在此表示衷心的感谢。同时，电子工业出版社的谭海平先生和余义先生，在对原版教材的调研、编辑加工等方面做了大量的工作，为改编工作提供了很好的支持，在此一并感谢。最后，要感谢我的先生和女儿，在改编的过程中，给了我很多的支持和鼓励。

最后，我希望本改编教材能够为国内流体力学的双语教学尽到一份微薄之力，也恳请各位专家、同行和读者能够提出宝贵的建议，促使本教材在重印或再版时能够更加完美。

邵卫云
于浙江大学求是园
2006年8月30日

About the Authors

Bruce R. Munson, Professor Emeritus of Engineering Mechanics at Iowa State University, received his B.S. and M.S. degrees from Purdue University and his Ph.D. degree from the Aerospace Engineering and Mechanics Department of the University of Minnesota in 1970.

Prior to joining the Iowa State University faculty in 1974, Dr. Munson was on the mechanical engineering faculty of Duke University from 1970 to 1974. From 1964 to 1966, he worked as an engineer in the jet engine fuel control department of Bendix Aerospace Corporation, South Bend, Indiana.

Dr. Munson's main professional activity has been in the area of fluid mechanics education and research. He has been responsible for the development of many fluid mechanics courses for studies in civil engineering, mechanical engineering, engineering science, and agricultural engineering and is the recipient of an Iowa State University Superior Engineering Teacher Award and the Iowa State University Alumni Association Faculty Citation.

He has authored and coauthored many theoretical and experimental technical papers on hydrodynamic stability, low Reynolds number flow, secondary flow, and the applications of viscous incompressible flow. He is a member of The American Society of Mechanical Engineers and The American Physical Society.

Donald F. Young, Anson Marston Distinguished Professor Emeritus in Engineering, received his B.S. degree in mechanical engineering, his M.S. and Ph.D. degrees in theoretical and applied mechanics from Iowa State Uiversity, and has taught both undergraduate and graduate courses in fluid mechanics at Iowa State for many years. In addition to being named a Distinguished Professor in the College of Engineering, Dr. Young has also received the Standard Oil Foundation Outstanding Teacher Award and the Iowa State University Alumni Association Faculty Citation. He has been engaged in fluid mechanics research for more than 35 years, with special interests in similitude and modeling and the interdisciplinary field of biomedical fluid mechanics. Dr. Young has contributed to many technical publications and is the author or coauthor of two textbooks on applied mechanics. He is a Fellow of The American Society of Mechanical Engineers.

Ted H. Okiishi, Associate Dean of Engineering and past Chair of Mechanical Engineering at Iowa State University, has taught fluid mechanics courses there since 1967. He received his undergraduate and graduate degrees at Iowa State.

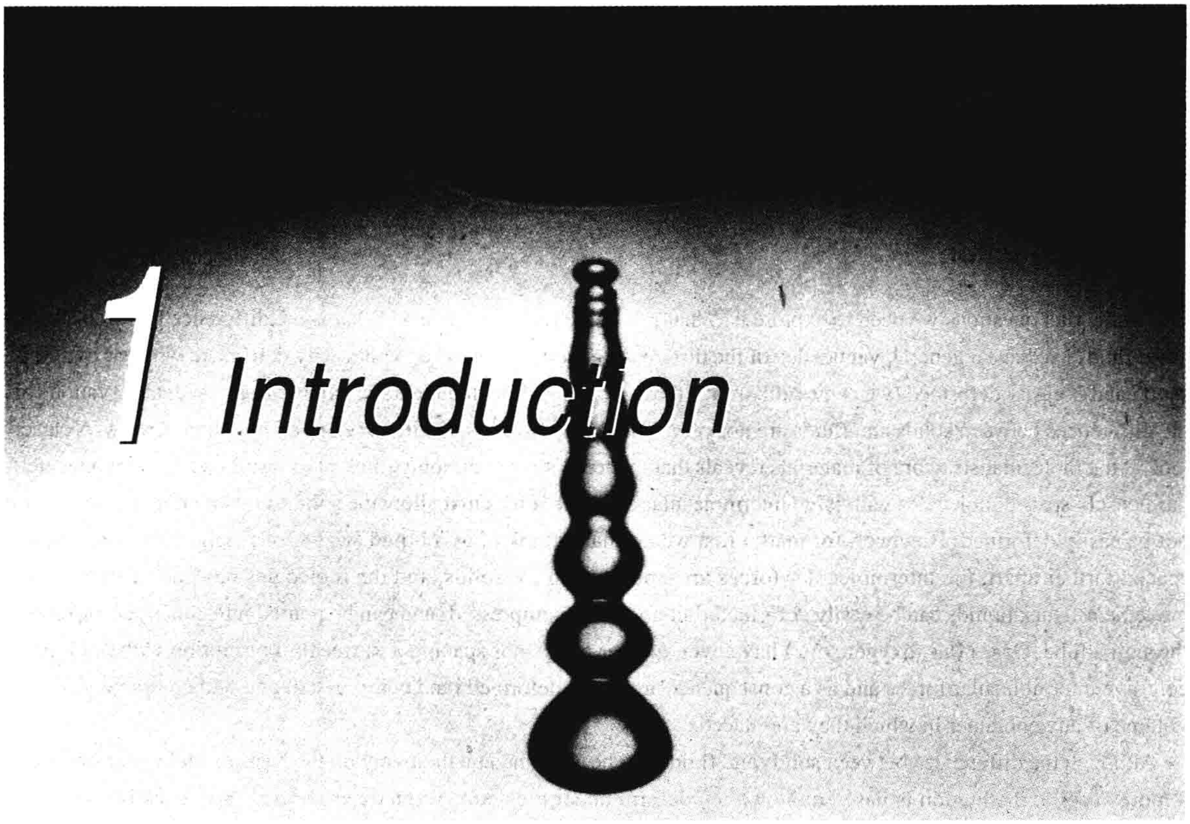
From 1965 to 1967, Dr. Okiishi served as a U.S. Army officer with duty assignments at the National Aeronautics and Space Administration Lewis Research Center, Cleveland, Ohio, where he participated in rocket nozzle heat transfer research, and at the Combined Intelligence Center, Saigon, Republic of South Vietnam, where he studied seasonal river flooding problems.

Professor Okiishi is active in research on turbomachinery fluid dynamics. He and his graduate students and other colleagues have written a number of journal articles based on their studies. Some of these projects have involved significant collaboration with government and industrial laboratory researchers with two technical papers winning the ASME Melville Medal.

Dr. Okiishi has received several awards for teaching. He has developed undergraduate and graduate courses in classical fluid dynamics as well as the fluid dynamics of turbomachines.

He is a licensed professional engineer. His professional society activities include having been chair of the board of directors of The American Society of Mechanical Engineers (ASME) International Gas Turbine Institute and chair of the Engineering Research Council of the American Society for Engineering Education. He is a Fellow of The American Society of Mechanical Engineers and the past editor of the *Journal of Turbomachinery*.

Contents



1 Introduction

CHAPTER OPENING PHOTO: The breakup of a fluid jet into drops is a function of fluid properties such as density, viscosity, and surface tension. [Reprinted with permission from American Institute of Physics (Ref. 6) and the American Association for the Advancement of Science (Ref. 7).]

Fluid mechanics is that discipline within the broad field of applied mechanics concerned with the behavior of liquids and gases at rest or in motion. This field of mechanics obviously encompasses a vast array of problems that may vary from the study of blood flow in the capillaries (which are only a few microns in diameter) to the flow of crude oil across Alaska through an 1287-km-long, 1.22-m-diameter pipe. Fluid mechanics principles are needed to explain why airplanes are made streamlined with smooth surfaces for the most efficient flight, whereas golf balls are made with rough surfaces (dimpled) to increase their efficiency. Numerous interesting questions can be answered by using relatively simple fluid mechanics ideas. For example:

- How can a rocket generate thrust without having any air to push against in outer space?
- Why can't you hear a supersonic airplane until it has gone past you?
- How can a river flow downstream with a significant velocity even though the slope of the surface is so small that it could not be detected with an ordinary level?
- How can information obtained from model airplanes be used to design the real thing?
- Why does a stream of water from a faucet sometimes appear to have a smooth surface, but sometimes a rough surface?
- How much greater gas mileage can be obtained by improved aerodynamic design of cars and trucks?

The list of applications and questions goes on and on—but you get the point; fluid mechanics is a very important, practical subject. It is very likely that during your career as an engineer you will be involved in the analysis and design of systems that require a good understanding of fluid mechanics. It is hoped that this introductory text will provide a sound foundation of the fundamental aspects of fluid mechanics.

Fluid mechanics is concerned with the behavior of liquids and gases at rest and in motion.

1.1 Introduction

One of the first questions we need to explore is, What is a fluid? Or we might ask, What is the difference between a solid and a fluid? We have a general, vague idea of the difference. A solid is "hard" and not easily deformed, whereas a fluid is "soft" and is easily deformed (we can readily move through air). Although quite descriptive, these casual observations of the differences between solids and fluids are not very satisfactory from a scientific or engineering point of view. A closer look at the molecular structure of materials reveals that matter that we commonly think of as a solid (steel, concrete, etc.) has densely spaced molecules with large intermolecular cohesive forces that allow the solid to maintain its shape, and to not be easily deformed. However, for matter that we normally think of as a liquid (water, oil, etc.), the molecules are spaced farther apart, the intermolecular forces are smaller than for solids, and the molecules have more freedom of movement. Thus, liquids can be easily deformed (but not easily compressed) and can be poured into containers or forced through a tube. Gases (air, oxygen, etc.) have even greater molecular spacing and freedom of motion with negligible cohesive intermolecular forces and as a consequence are easily deformed (and compressed) and will completely fill the volume of any container in which they are placed.

Although the differences between solids and fluids can be explained qualitatively on the basis of molecular structure, a more specific distinction is based on how they deform under the action of an external load. Specifically, *a **fluid** is defined as a substance that deforms continuously when acted on by a shearing stress of any magnitude.* A shearing stress (force per unit area) is created whenever a tangential force acts on a surface. When common solids such as steel or other metals are acted on by a shearing stress, they will initially deform (usually a very small deformation), but they will not continuously deform (flow). However, common fluids such as water, oil, and air satisfy the definition of a fluid—that is, they will flow when acted on by a shearing stress. Some materials, such as slurries, tar, putty, toothpaste, and so on, are not easily classified since they will behave as a solid if the applied shearing stress is small, but if the stress exceeds some critical value, the substance will flow. The study of such materials is called *rheology* and does not fall within the province of classical fluid mechanics. Thus, all the fluids we will be concerned with in this text will conform to the definition of a fluid given previously.

A fluid, such as water or air, deforms continuously when acted on by shearing stresses of any magnitude.

Although the molecular structure of fluids is important in distinguishing one fluid from another, it is not possible to study the behavior of individual molecules when trying to describe the behavior of fluids at rest or in motion. Rather, we characterize the behavior by considering the average, or macroscopic, value of the quantity of interest, where the average is evaluated over a small volume containing a large number of molecules. Thus, when we say that the velocity at a certain point in a fluid is so much, we are really indicating the average velocity of the molecules in a small volume surrounding the point. The volume is small compared with the physical dimensions of the system of interest, but large compared with the average distance between molecules. Is this a reasonable way to describe the behavior of a fluid? The answer is