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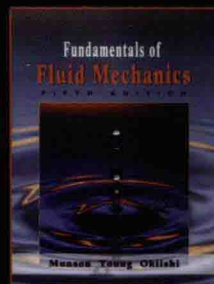


工程流体力学

(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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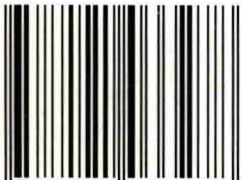
Fundamentals of Fluid Mechanics Fifth Edition

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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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[美] Donald F. Young 著

Theodore H. Okiishi

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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,主要体现在: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 University, 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

Chapter 1	Introduction	1
1.1	Introduction	2
1.2	Dimensions, Dimensional Homogeneity, and Units	3
1.2.1	Systems of Units	5
1.3	Analysis of Fluid Behavior	8
1.4	Measures of Fluid Mass and Weight	8
1.4.1	Density	8
1.4.2	Specific Weight	9
1.4.3	Specific Gravity	9
1.5	Ideal Gas Law	10
1.6	Viscosity	12
1.7	Compressibility of Fluids	17
1.7.1	Bulk Modulus	17
1.7.2	Coefficient of Volume Compressibility	19
1.8	Vapor Pressure	19
1.9	Surface Tension	20
1.10	Forces Descriptions	23
1.11	A Brief Look Back in History	23
1.12	Chapter Summary and Study Guide	26
	References	26
	Review Problems	27
	Problems	27
Chapter 2	Fluid Statics	36
2.1	Pressure at a Point	36
2.2	Basic Equation for Pressure Field	38
2.2.1	Basic Equation for Pressure Field	38
2.2.2	Equipressure Surface	40
2.3	Pressure Variation in a Fluid at Rest	40
2.3.1	Fundamental Equation of a Fluid at Rest	40
2.3.2	Incompressible Fluid	41
2.4	Standard Atmosphere	44
2.5	Measurement of Pressure	46
2.6	Manometry	47
2.6.1	Piezometer Tube	48
2.6.2	U-Tube Manometer	48
2.6.3	Inclined-Tube Manometer	52
2.6.4	Mechanical and Electronic Pressure Measuring Devices	53
2.7	Hydrostatic Force on a Plane Surface	54
2.7.1	Force on a Plane Surface	54
2.7.2	Pressure Prism	61
2.8	Hydrostatic Force on a Curved Surface	64

2.9	Buoyancy, Flotation, and Stability	68
2.9.1	Archimedes' Principle	68
2.9.2	Stability	70
2.10	Pressure Variation in a Fluid with Rigid-Body Motion	72
2.10.1	Linear Motion	73
2.10.2	Rigid-Body Rotation	75
2.11	Chapter Summary and Study Guide	78
	References	78
	Review Problems	79
	Problems	79
Chapter 3	Introduction to Fluids in Motion	94
3.1	The Velocity Field	94
3.1.1	Eulerian and Lagrangian Flow Descriptions	95
3.1.2	One-, Two-, and Three-Dimensional Flows	97
3.1.3	Steady and Unsteady Flows	98
3.1.4	Streamlines, Streaklines, and Pathlines	98
3.2	The Acceleration Field	103
3.2.1	The Material Derivative	103
3.2.2	Unsteady Effects	105
3.2.3	Convective Effects	105
3.3	The Bernoulli Equation along a Streamline	107
3.3.1	The Bernoulli Equation along a Streamline	108
3.3.2	Physical Interpretation	112
3.3.3	Static, Stagnation, Dynamic, and Total Pressure	114
3.4	Examples of Use of the Bernoulli Equation	119
3.4.1	Free Jets	119
3.4.2	Confined Flows	121
3.4.3	Flowrate Measurement	127
3.5	The Energy Line and the Hydraulic Grade Line	132
3.6	Chapter Summary and Study Guide	135
	References	136
	Review Problems	136
	Problems	136
Chapter 4	Finite Control Volume Analysis	155
4.1	Control Volume and System Representations	156
4.2	The Reynolds Transport Theorem	157
4.2.1	Derivation of the Reynolds Transport Theorem	158
4.2.2	Selection of a Control Volume	162
4.3	The Continuity Equation	162
4.3.1	Derivation of the Continuity Equation	162
4.3.2	Fixed, Nondeforming Control Volume	169
4.3.3	Moving, Nondeforming Control Volume	170
4.4	The Linear Momentum Equation	172
4.4.1	Derivation of the Linear Momentum Equation	172
4.4.2	Application of the Linear Momentum Equation	175
4.5	The Energy Equation	191

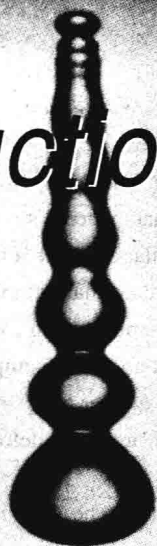
4.5.1	Derivation of the Energy Equation	191
4.5.2	The Energy Equation for Steady Uniform Flow	193
4.6	Chapter Summary and Study Guide	206
	References	207
	Review Problems	207
	Problems	207
Chapter 5	Differential Analysis of Fluid Flow	227
5.1	Fluid Element Kinematics	228
5.1.1	Linear Motion and Deformation	229
5.1.2	Angular Motion and Deformation	230
5.1.3	Irrotational Flow	232
5.2	Differential Form of Continuity Equation	234
5.2.1	Differential Form of Continuity Equation	234
5.2.2	The Stream Function	237
5.3	Equations of Motion	240
5.3.1	Description of Forces Acting on the Differential Element	240
5.3.2	Equations of Motion	242
5.3.3	The Navier-Stokes Equations	242
5.4	Inviscid Flow	244
5.4.1	Euler's Equations of Motion	244
5.4.2	The Bernoulli Equation along a Streamline	245
5.4.3	The Bernoulli Equation for Irrotational Flow	246
5.4.4	The Velocity Potential	247
5.5	Plane Potential Flows	250
5.5.1	Some Basic, Plane Potential Flows	252
5.5.2	Source in a Uniform Stream — Half-Body	257
5.5.3	Rankine Ovals	261
5.5.4	Flow around a Circular Cylinder	263
5.6	Chapter Summary and Study Guide	266
	References	267
	Review Problems	267
	Problems	267
Chapter 6	Similitude, Dimensional Analysis, and Modeling	276
6.1	Introduction	277
6.2	Dimensional Analysis	279
6.2.1	Buckingham Pi Theorem	279
6.2.2	Determination of Pi Terms	280
6.3	Common Dimensionless Groups in Fluid Mechanics	286
6.4	Correlation of Experimental Data	289
6.4.1	Problems with One Pi Term	289
6.4.2	Problems with Two or More Pi Terms	291
6.5	Modeling and Similitude	294
6.5.1	Theory of Models	294
6.5.2	Model Scales	298
6.5.3	Flow through Closed Conduits	299
6.5.4	Flow around Immersed Bodies	301

6.5.5	Flow with a Free Surface	303
6.6	Normalized Governing Differential Equations	307
6.7	Chapter Summary and Study Guide	309
	References	310
	Review Problems	310
	Problems	310
Chapter 7	Internal Flow and External Flow	321
7.1	General Characteristics of Pipe Flow	322
7.1.1	Laminar or Turbulent Flow	323
7.1.2	Entrance Region and Fully Developed Flow	325
7.1.3	Pressure and Shear Stress	326
7.2	Fully Developed Laminar Flow	327
7.2.1	Fluid Element Approach	327
7.2.2	Energy Considerations	333
7.3	Fully Developed Turbulent Flow	336
7.3.1	Transition from Laminar to Turbulent Flow	336
7.3.2	Turbulent Shear Stress	338
7.3.3	Turbulent Velocity Profile	341
7.4	Head Losses in Pipe Flow	346
7.4.1	Major Losses	346
7.4.2	Minor Losses	352
7.5	Fundamentals of Boundary layer	360
7.5.1	Introduction of External Flows	360
7.5.2	Characteristics of Flow Past an Object	361
7.5.3	Boundary Layer Structure and Thickness on a Flat Plate	365
7.5.4	Effects of Pressure Gradient	368
7.6	Lift and Drag Concepts	372
7.7	Chapter Summary and Study Guide	376
	References	377
	Review Problems	379
	Problems	379
Chapter 8	Pipe Flow, Orifice Flow and Nozzle Flow	388
8.1	Single Pipes	389
8.2	Multiple Pipe Systems	403
8.2.1	Series Pipe System	404
8.2.2	Parallel Pipe System	405
8.2.3	Loop Pipe System	406
8.2.4	Branching System	406
8.2.5	Pipe Network	410
8.3	Pipe Flowrate Measurement	411
8.4	Orifice Flow	416
8.4.1	General Characteristics of Orifice Flow	416
8.4.2	Outflow through Sharp-edged Small Orifice	417
8.4.3	Outflow through Sharp-edged Big Orifice	419
8.5	Nozzle Flow	420

8.5.1	Introduction	420
8.5.2	Steady Flow through Cylindrical Outer Nozzle	420
8.5.3	Vacuum in Cylindrical Outer Nozzle	421
8.6	Chapter Summary and Study Guide	422
	References	422
	Review Problems	423
	Problems	423
Chapter 9	Open-Channel Flow	432
9.1	Introduction	433
9.1.1	General Characteristics of Open-Channel Flow	433
9.1.2	Channel Geometry	434
9.2	Uniform Flow	435
9.2.1	Uniform Flow Approximations	435
9.2.2	The Chezy and Manning Equations	437
9.2.3	Uniform Flow Examples	439
9.2.4	Best Hydraulic Cross Section	446
9.3	Surface Waves	449
9.3.1	Wave Speed	449
9.3.2	Froude Number Effects	451
9.4	Fundamental of Nonuniform Flow	452
9.4.1	Specific Energy	453
9.4.2	Channel Depth Variations	458
9.5	Gradually Varied Flow	459
9.5.1	Water Surface Profiles	460
9.5.2	Some Representations of Surface profiles	463
9.5.3	Numerical Solution of Water Surface Profiles	465
9.6	Rapidly Varied Flow	465
9.6.1	The Hydraulic Jump	466
9.7	Chapter Summary and Study Guide	473
	References	473
	Review Problems	474
	Problems	474
Chapter 10	Weir Flow	485
10.1	General Characteristics of Weir Flow	485
10.1.1	General Characteristics of Weirs	485
10.1.2	Classification of Weirs	486
10.2	Sharp-Crested Weirs	487
10.2.1	Basic Flowrate Formula	487
10.2.2	Rectangular Weir	488
10.2.3	Triangular Weir	489
10.3	Ogee-crested weirs	491
10.4	Broad-Crested Weirs	492
10.5	Underflow Gates	496
10.6	Chapter Summary and Study Guide	498
	References	498
	Review Problems	499

Problems	499
Chapter 11 Seepage Flow	501
11.1 Basic Principle of Seepage Flow	501
11.1.1 Seepage Flow Model	502
11.1.2 Darcy Law	502
11.1.3 Coefficient of Permeability	504
11.2 Steady Gradually Varied Seepage Flow	504
11.2.1 General Formula for Gradually Varied Seepage Flow	504
11.2.2 Differential Equation of Gradually Varied Seepage Flow	505
11.2.3 Water Surface Profiles of the Gradually Varied Seepage Flow	505
11.3 Seepage Flow of Storage Gallery	508
11.4 Seepage Flow of Well	508
11.4.1 Completely General Well	508
11.4.2 Completely Artesian Well	510
11.4.3 Multiple-well	511
11.5 Chapter Summary and Study Guide	514
References	514
Problems	514
Chapter 12 One Dimensional Compressible Flow	517
12.1 Ideal Gas Relationships	518
12.2 Mach Number and Speed of Sound	521
12.3 Categories of Compressible Flow	524
12.4 Isentropic Flow of an Ideal Gas	529
12.4.1 Effect of Variations in Flow Cross-Sectional Area	530
12.4.2 Converging-Diverging Duct Flow	532
12.4.3 Constant Area Duct Flow	535
12.5 Adiabatic Constant Area Duct Flow with Friction	536
12.6 Chapter Summary and Study Guide	545
References	546
Review Problems	547
Problems	547
Appendix A	550
Appendix B	554
Appendix C	559
Appendix D	561
Online Appendix List	564
Answers to Selected Homework Problems	565
Index	570

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