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Fluid Mechanics with Engineering Applications
Tenth Edition

流体力学及其工程应用

英文版 • 原书第10版

(美) E. John Finnemore
Joseph B. Franzini 编著

机械工业出版社
CHINA MACHINE PRESS

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本书继承并发扬了前9版讲述流体力学物理现象的传统，并以最简单而且尽可能是最清晰，但又不使用复杂数学工具的方式来应用各项基本原理。对工科大学生而言，最重要的事情是把所探讨的物理现象非常清晰地予以形象化。因此，本书大力强调流体力学的物理现象，并且贯穿于全书。在本书中，首先讲述流体力学的基本原理、基本假设以及在其应用方面的条件，然后演示怎样应用这些基本原理来解决实际的工程问题。本书文中有例题，节后有操练题，章后有习题，其中列举了大量的BG制、SI制的例题和习题，使学生熟悉两种单位制的转换。书中的操练题和习题总数已达到了1354题。

本书可作为水利工程、土木工程、航空航天、能源动力工程等专业的流体力学课程教材，也可供相关专业科研人员和工程技术人员参考。

E. John Finnemore, Joseph B. Franzini

FLUID MECHANICS WITH ENGINEERING APPLICATIONS, TENTH EDITION

ISBN: 0-07-243202-0

北京市版权局著作权合同登记号：01-2013-2136。

图书在版编目（CIP）数据

流体力学及其工程应用：第10版：英文/（美）芬纳莫尔，（美）弗朗兹尼编著. —北京：机械工业出版社，2013.7

时代教育·国外高校优秀教材精选

ISBN 978-7-111-43255-5

Ⅰ. ①流…　Ⅱ. ①芬…　②弗…　Ⅲ. ①流体力学—高等学校—教材—英文　Ⅳ. ①035

中国版本图书馆 CIP 数据核字（2013）第156243号

机械工业出版社（北京市百万庄大街22号　邮政编码100037）

策划编辑：姜　凤　责任编辑：姜　凤

版式设计：霍永明　责任印制：杨　曦

封面设计：张　静

保定市中画美凯印刷有限公司印刷

2013年9月第1版第1次印刷

185mm×235mm·51.5印张·818千字

标准书号：ISBN 978-7-111-43255-5

定价：99.00元

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出 版 说 明

随着我国加入WTO，国际间的竞争越来越激烈，而国际间的竞争实际上也就是人才的竞争、教育的竞争。为了加快培养具有国际竞争力的高水平技术人才，加快我国教育改革的步伐，国家教育部出台了一系列倡导高校开展双语教学、引进原版教材的政策。以此为契机，机械工业出版社推出了一系列国外影印版教材，其内容涉及高等学校公共基础课，以及机、电、信息领域的专业基础课和专业课。

引进国外优秀原版教材，在有条件的学校推动开展英语授课或双语教学，自然也引进了先进的教学思想和教学方法，这对提高我国自编教材的水平，加强学生的英语实际应用能力，使我国的高等教育尽快与国际接轨，必将起到积极的推动作用。

为了做好教材的引进工作，机械工业出版社特别成立了由著名专家组成的国外高校优秀教材审定委员会。这些专家对实施双语教学做了深入细致的调查研究，对引进原版教材提出许多建设性意见，并慎重地对每一本将要引进的原版教材一审再审，精选再精选，确认教材本身的质量水平，以及权威性和先进性，以期所引进的原版教材能适应我国学生的外语水平和学习特点。在引进工作中，审定委员会还结合我国高校教学课程体系的设置和要求，对原版教材的教学思想和方法的先进性、科学性严格把关，同时尽量考虑原版教材的系统性和经济性。

这套教材出版后，我们将根据各高校的双语教学计划，及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议，使我们更好地为教学改革服务。

机械工业出版社

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前　言

基本原理及历史发展

《流体力学及其工程应用》(第10版)，继承并发扬了前9版讲述流体力学物理现象的传统，并以最简单而且尽可能是最清晰，但又不使用复杂数学工具的方式来应用各项基本原理。尽管书中也着力介绍了机械与宇航工程的问题，但本书重点讲授的却是建筑、环保及农业工程问题。本书有足够的专业面广度，可用作工科一年级大学生的流体力学课程教材。如果需要，本书的许多方面也可以用作二年级的教材。

全世界已有成千上万的工科大学生和实际工作者使用本书长达85年以上了。本书作为国际版是广泛流传的，并已被翻译成了西班牙文、中文和朝鲜文。本书的现任作者已是第三代了。尽管这次的第10版已经与初版大不相同，但仍然保留了将流体力学作为一门工科主修课程的学术体系和讲授方法，而这正是第1版的作者罗伯特·L. 多尔蒂 (Robert L. Daugherty) 根据其在康奈尔大学以及随后在加州理工学院下属伦塞勒工学院多年教学经验所首创的。多尔蒂教授著作的第1版成书于1916年，当时取名为《水力学》。他对此书作过四次修订。在出第5版时，阿尔弗烈德·C. 英格索尔 (Alfred C. Ingersoll) 博士给他当了助手。他们将书名更改为《流体力学及其工程应用》。第6版和第7版则安全是由费朗兹尼教授一个人修订的。费朗兹尼是多尔蒂在加州理工学院教过的学生，他从本书第4版开始，首次在这门流体力学主修课上亮相。在修订本书的第8版和第9版时，费朗兹尼教授得到了芬纳莫尔的帮助，后者是费朗兹尼在斯坦福大学教过的学生。现在这本第10版是由芬纳莫尔主笔，但其中的第15、16两章则是由费朗兹尼博士修订的。

本书的组织结构

我们认为，对工科大学生而言，最重要的事情是把所探讨的物理现象非常清晰地予以形象化。因此，强调流体力学的物理现象，一直贯穿于本书。在本书中，着重讲述流体力学的基本原理、基本假设以及在其应用方面的限制，然后演示怎样应用这些基本原理来解决实际的工程问题。这里要强调的是，教师要有较高的教学水平，以及师生双方都要有高度的智力。这样，他们才能很容易地掌握这些基本原理及其应用。书中列举了许多例题来证明这些基本原理的用法。当然，这些例题也有助于理解本教材的内容。在最重要的一些节末，附有带答案的操练题，这有助于迅速增强学生对所讲解的主题及概念的理解。各章末所附的习题都是经过仔细挑选的、供学生做的课外作业，使学生能够彻底解决对基本原理的应用问题。只有通过大量运算练习和解题，学生才能感受到学习所必需的循序渐进过程。本书还在第1章中推荐了学习流体力学的方法以及解题方法。

本书实质上是很“全面”的。这样处置，使教师一般不需要依靠其他的资料即可回答学

生在通常情况下可能提出的问题。这就要求对某些仅作了浅显介绍的内容作更加详细的讨论。本书末提供了参考文献，可以指导那些希望深入探讨流体力学不同领域的学生。附录中包含了流体物理属性的内容以及其他有用的数值表。第1章写进了量纲和单位的知识。为了便于引用，本章还列出了各种转换系数以及一些重要的物理量和定义。

即使我们用的是英国重力（BG）单位制（英尺、斯勒、秒、磅）作为基本单位制，本书也列出了相应的SI单位制（国际单位制），本书还分别以BG制和SI制（二者的数值差不多相等的情况）编写了一些例题、操练题及习题。我们还使从BG制到SI制的转换简单易行。本书第1章写了对单位制及其转换的讨论。我们鼓励教师把习题按单位制来分配，使学生熟悉两种单位制的转换。

本版的改进之处

本版最显著的改进之处是增添了许多插图（110幅以上），用来帮助阐明操练题及习题，并帮助解释某些例题的答案。书中有选择性地编入了编程习题及计算机解题，还编写了可用多种方法试凑求解的习题，增添了较多的相互参照条目。

本次改版中，着重改写了前8章。其中，通过课文简洁化以及增添更多的例题使课文更容易理解，并且使语言彻底现代化。同时，增加了很多插图。这8章中的例题及习题，有40%是新编的或更换了旧版中的题。

第5章改写得最多。伯努利方程的推导前移到了很靠前的位置，并增加了另外一种表达形式。该方程所依据的基本假设讲得更清楚了。导管中由壁面摩擦所产生的压头损失和导管的总压头损失之间的明显差别讲得更清楚了。这个结果将在后续章节中用到。关于气蚀怎样导致事故的问题，本版引用内向爆聚的最新显微摄影技术作了更好的解释。

其他单节的一些新增内容：计算流体力学（附图及照片）；对水力效率最佳的渠道流动作了更清晰的讲解；单管流动的各个方面现在分拆成了好几节；向运动水体中排放的淹没式出流；明渠中的输运问题；总结水坝作用的一览表；用激光测量流速的各种方法；大地沉积中的流体传输数据；有关泵的仿射定律的讨论。书中的操练题和习题总数已增加到了1354道。

有两个附录是新编的。其一总结了流体力学所用几类主要方程式的特征和性质；另一个附录则提供了在HP48G计算器上及Excel和MathCad中应用方程求解器和多项式求解器进行求解所选定的范例。此外，对编程和计算机应用方面的附录C进行了升级，办法是增添了应用软件来模拟流动系统、流动组件、流动过程以及流场的许多算例。

本书的用法及课程规划

最出色、最简明的第一门流体力学课程应由本书第1~7章以及第8章的前半部组成；不过也有人希望将第11章（流体的测量）的部分内容以及第14章（理想流体的数学问题），放在前面。对流体力学有迫切需求的有些学校可能希望将本教材全部列入其课程或全体工程师要求的各门课程中。还有一些学校，可能只要求讲授本书的部分内容就够了，而对于一些

特殊的机械类专业的学生来说，可能还要开第二门课来讲授本书的其他内容。因此，对于建筑、环保以及农业工程专业来说，要在第二门课程中强调第 10 章和第 12 章；而对于机械工程专业来说，在第二门课程中大概只要着重讲授第 9 章和第 13 章就够了。有许多学校将本书作为水力机械专业的教科书。

对教师来说，与本书一同发行的《解题手册》可以从 McGraw-Hill 买到。其中有全部操练题和各章末所附习题的答案。为了方便起见，这些答案中重复了问题的描述以及附图。此手册中还提出了一些建议，即，怎样最有效地挑选习题作为课外作业。每一章还附有习题选择指南，它按难度、篇幅、所采用的单位制以及任何其他特点对各章的习题作了分类。

E. 约翰 · 芬纳莫尔

约瑟夫 · B. 弗朗兹尼

About the Authors

E. John Finnemore is Professor of Civil Engineering at Santa Clara University, California. Born in London, England, he received a B.Sc. (Eng.) degree from London University in 1960, and M.S. and Ph.D. degrees from Stanford University in 1966 and 1970, all in civil engineering. Finnemore worked with consulting civil engineers in England and Canada for five years before starting graduate studies, and for another seven years in California after completing his doctorate. He served one year on the faculty of Pahlavi University in Shiraz, Iran, and he has been a member of the faculty at Santa Clara University since 1979. He has taught courses in fluid mechanics, hydraulic engineering, hydrology, and water resources engineering, and has authored numerous technical articles and reports in several related fields. His research has often involved environmental protection, such as in stormwater management and onsite wastewater disposal. Professor Finnemore has served on governmental review boards and as a consultant to various private concerns. He is a Fellow of the American Society of Civil Engineers and a registered civil engineer in Britain and California. He lives with his wife Gulshan in Cupertino, California.

Joseph B. Franzini is Professor Emeritus of Civil Engineering at Stanford University. Born in Las Vegas, New Mexico, he received B.S. and M.S. degrees from the California Institute of Technology in 1942 and 1943, and a Ph.D. from Stanford University in 1950. All his degrees are in civil engineering. Franzini served on the faculty at Stanford University from 1950 to 1986. There he taught courses in fluid mechanics, hydrology, sedimentation, and water resources, and also did research on a number of topics in those fields. Since retirement from Stanford, he has been active as an engineering consultant and an expert witness. He is coauthor of the authoritative and widely used textbook, *Water Resources Engineering,* and of its predecessor, *Elements of Hydraulic Engineering.* Through the years, Franzini has been active as a consultant to various private organizations and governmental agencies in both the United States and abroad; he was associated with Nolte and Associates, a consulting civil engineering firm in San Jose, California, for over 30 years. He is a Fellow of the American Society of Civil Engineers and a registered civil engineer in California. He lives with his wife Gloria in Palo Alto, California.

Preface

Philosophy and History

This tenth edition of the classic textbook, *Fluid Mechanics with Engineering Applications,* continues and improves on its tradition of explaining the physical phenomena of fluid mechanics and applying its basic principles in the simplest and clearest possible manner without the use of complicated mathematics. It focuses on civil, environmental, and agricultural engineering problems, although mechanical and aerospace engineering topics are also strongly represented. The book is written as a text for a first course in fluid mechanics for engineering students, with sufficient breadth of coverage that it can serve in a number of ways for a second course if desired.

Thousands of engineering students and practitioners throughout the world have used this book for over 85 years; it is widely distributed as an International Edition, and translations into Spanish and Korean are available. The book is now in its third generation of authorship. Though this tenth edition is very different from the first edition, it retains the same basic philosophy and presentation of fluid mechanics as an engineering subject that Robert L. Daugherty originally developed over his many years of teaching at Cornell University, Rensselaer Polytechnic Institute, and the California Institute of Technology. The first edition that Professor Daugherty authored was published in 1916 with the title *Hydraulics.* He revised the book four times. On the fifth edition (fourth revision) Dr. Alfred C. Ingersoll assisted him, and they changed the title of the book to *Fluid Mechanics with Engineering Applications.* The sixth and seventh editions were entirely the work of Professor Franzini. A student of Daugherty's at Caltech, Franzini had received his first exposure to the subject of fluid mechanics from the fourth edition of the book. Professor Franzini enlisted the services of Professor Finnemore, a former student of Franzini's at Stanford, to assist him with the eighth and ninth editions. This tenth edition is the work of Dr. Finnemore, with the exception of Chapters 15 and 16, which Dr. Franzini revised.

The Book, Its Organization

We feel it is most important that the engineering student clearly visualize the physical situation under consideration. Throughout the book, therefore, we place considerable emphasis on physical phenomena of fluid mechanics. We stress the governing principles, the assumptions made in their development, and their limits of applicability, and show how we can apply the principles to the solution of practical engineering problems. The emphasis is on teachability for the instructor and on clarity for both the instructor and the student, so that they can readily grasp basic principles and applications. Numerous worked sample problems are presented to demonstrate the application of basic principles. These sample problems also help to clarify the text. Drill exercises with answers provided follow most sections to help students rapidly reinforce their understanding of the subjects and concepts. The end-of-chapter problems presented for assignment purposes were carefully selected to provide the student with a thorough workout in the application of basic principles. Only by working numerous exercises and problems will students experience the evolution so necessary to the learning process. We recommend ways to study fluid mechanics and to approach problem solving in Chapter 1.

The book is essentially "self-contained." The treatment is such that an instructor generally need not resort to another reference to answer any question that a student might normally be expected to ask. This has required more detailed discussion than that needed for a more superficial presentation of certain topics. A list of selected references is provided at the end of the book to serve as a guide for those students who wish to probe deeper into the various fields of fluid mechanics. The appendix section contains information on physical properties of fluids and other useful tables, Chapter 1 contains information on dimensions and units, and, for convenient reference, the insides of the covers contain conversion factors and important quantities and definitions.

Even though we use British Gravitational (BG) units (feet, slugs, seconds, pounds) as the primary system of units, we give the corresponding SI units in the text. We provide sample problems, and exercises and problems in BG and in SI units in near equal numbers. We have made every effort to ease the changeover from BG units to SI units; Chapter 1 includes a discussion of unit systems and conversion of units. We encourage instructors to assign problems in each system so that students become conversant with both.

Improvements to This Edition

Probably the most noticeable improvement made throughout this edition will be our addition of many figures (over 110), to help present exercises and problems, and to help explain solutions of sample problems. Also, throughout we have made the use of programming and computers optional, we have included more ways to solve trial-and-error problems, and we have added more cross-references.

In this revision, we have given special attention to the first eight chapters. There we have improved understandability by simplifying and clarifying text and sample problems that were more involved, and by thoroughly modernizing the language, as well as adding figures. Of the exercises and problems in these chapters, 40% are now new or changed from the previous edition.

Chapter 5 is strongly revised, with the basic derivation of Bernoulli's equation moved to a very early position, alternate forms of the equation added, and the assumptions on which it is based clarified. A new, clear distinction is made between wall (or pipe) friction head loss and total head loss in pipes, and this is carried forward into subsequent chapters. How cavitation causes damage is better explained with the aid of a new microphotograph of an imploding bubble.

New features in other chapters include: information about computational fluid dynamics, with a supporting figure and photograph; various aspects of single-pipe flow are now separated out into different sections; a treatment of submerged discharge into moving water; information about conveyance in open channels; a clarified treatment of optimal hydraulic efficiency of channel flow; a table summarizing damming action; descriptions of methods of measuring fluid velocity using laser light; data on the hydraulic conductivities of major geologic deposits; and a discussion of affinity laws for pumps. We have increased the total number of exercises and problems in the book to 1354.

There are two new appendices. One summarizes the characteristics and properties of the main types of equations used in fluid mechanics. The other provides examples of using equation solvers and polynomial solvers, on HP48G calculators and in Excel and Mathcad, to solve selected sample problems. In addition, Appendix C, on programming and computer applications, is upgraded by the addition of many examples of applications software that model flow systems, components, processes, and flow fields.

Use of the Book, Course Planning

An excellent, brief first course in fluid mechanics could consist of Chapters 1 through 7 and the first half of Chapter 8; however, one might wish to include parts of Chapters 11 (Fluid Measurements) and 14 (Ideal Flow Mathematics) in a first course. Schools having stringent requirements in fluid mechanics might wish to cover the entire text in their course or courses required of all engineers. At other schools only partial coverage of the text might suffice for the course required of all engineers, and they might cover other portions of the text in a second course for students in a particular branch of engineering. Thus civil, environmental, and agricultural engineers would emphasize Chapter 10 and perhaps Chapter 12 in a second course, while mechanical engineers would probably include Chapters 9 and 13 in a second course. A number of schools have used the book for courses in hydraulic machinery.

For instructors only, a companion Solutions Manual is available from McGraw-Hill that contains typed and carefully explained solutions to all the exercises and end-of-chapter problems in the book; for convenience, the problem statements and problem figures are repeated with the solutions. The manual contains suggestions on how to use it most effectively to select problems for assignment, and a Problem Selection Guide for each chapter categorizes the problems by their difficulty, length, units used, and any special features.

Acknowledgments

We appreciate the many comments and suggestions that we have received from users of the book throughout the years, and from numerous anonymous indepth reviews arranged by McGraw-Hill. In particular, we thank the following reviewers for this tenth edition: Kenneth Edwards, Ohio University; Joel Melville, Auburn University; A. R. Rao, Purdue University; Henry Santeford,

Michigan Technological University; Yiannis Ventikos, Georgia Institute of Technology; Vaughan Voller, University of Minnesota; and Mark Widdowson, Virginia Polytechnic Institute and State University. They have all influenced the content and mode of presentation of the material. Further comments and suggestions for future editions of the book are always welcome.

We are very grateful for the care, assistance, and guidance that many people at McGraw-Hill and its subcontractors have provided to us in the preparation of this edition. Particularly, we appreciate the startup support that our developmental editor, Eric Munson, gave us, and the unflagging cooperation and patience of our production manager, Gloria Schiesl.

E. John Finnemore
Joseph B. Franzini

Other conversions

Engineering gas constant, R	1 ft·lb/(slug·°R) = 0.167 226 N·m/(kg·K)
Heat	
SI	1 cal = 4.184* J (heat required to raise 1.0 g of water 1.0 K)
BG	1 Btu = 251.996 cal (heat required to raise 1.0 lb of water 1.0°R)
Temperature	
SI	K = 273.15° + °C (273° + °C for most calculations)
BG	°R = 459.67° + °F (460° + °F for most calculations)
	ΔT of 1°C = ΔT of 1 K = ΔT of 1.8°F = ΔT of 1.8°R

* Exact conversion.

Relationships between temperatures

[celsius (°C), fahrenheit (°F), kelvin (K), and rankine (°R)]

°C = (5/9)(°F − 32); °F = 32 + (9/5)(°C); K = (5/9)(°R); °R = (9/5)(K); K = °C + 273; °R = °F + 460

°C	−30	−20	−10	0	10	20	30	40	50	60	70	80	90	100
°F	−22	−4	14	32	50	68	86	104	122	140	158	176	194	212
K	243	253	263	273	283	293	303	313	323	333	343	353	363	373
°R	438	456	474	492	510	528	546	564	582	600	618	636	654	672

Definition of metric quantities

Hectare (ha)	area	10^4 m² = (100 m square)
Joule (J)	energy (or work)	newton·meter (N·m)
Liter (L)	volume	10^{-3} m³
Newton (N)	force (or weight)	1 kg × 1 m/s²
Pascal (Pa)	pressure	newton/meter² (N/m²)
Poise (P)	absolute viscosity	10^{-1} N·s/m²
Stoke (St)	kinematic viscosity	10^{-4} m²/s
Watt (W)	power	newton·meter/second (N·m/s)

Commonly used prefixes for SI units

Factor by which unit is multiplied	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c**
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n

** Avoid if possible (see Sec. 1.5).

Important quantities

	SI (metric) unit	BG (English) unit
Acceleration due to gravity (sea level), g	9.80665 m/s²	32.1740 ft/sec²
for most calculations, use	9.81 m/s²	32.2 ft/sec²
Density of water (4°C, 39.2°F), ρ	1000 kg/m³ = 1.0 g/cm³ = 1.0 Mg/m³	1.940 slug/ft³ = 1.940 lb·sec²/ft⁴
Specific weight of water (5°C, 40°F), γ	9807 N/m³ or 9.807 kN/m³	62.43 lb/ft³
for most calculations, use	9.81 kN/m³	62.4 lb/ft³
Standard atmosphere at sea level (15°C, 59°F)	101.325 kPa abs	14.696 psia
	760 mmHg	29.92 inHg
	10.34 m H_2O	33.91 ft H_2O
	1013.25 millibars abs	2116.2 psfa

Conversion of SI (metric) units to BG (English) units

	Multiply the number of	By[1]	To obtain the number of
Acceleration	m/s^2	3.280 84	ft/sec^2
Area	mm^2 m^2 hectare (ha) = (100 m)^2	0.001 550 003 10.763 91 2.471 05	in^2 ft^2 acre = 43,560* ft^2
Density, ρ	kg/m^3	0.001 940 32	slug/ft^3
Energy (work or quantity of heat)	joule (J) = N·m = 10^7 erg kWh J = N·m = 0.239 006 cal	0.737 562 2.655 22 × 10^6 0.000 948 451	ft·lb ft·lb Btu = 777.649 ft·lb
Flow rate, Q (of volume)	m^3/s = 10^3 L/s m^3/s = 10^3 L/s L/s = 10^{-3} m^3/s	35.3147 22.8245 15.850 32	cfs = ft^3/sec = 448.831 USgpm mgd = 1.547 229 cfs USgpm = 0.002 228 01 cfs
Force	newton (N) [≡ kg·m/s^2] = 10^5 dyne	0.224 809	lb [≡ slug·ft/sec^2] = 16* oz
Kinematic viscosity, ν	m^2/s = 10^4 stokes (St)	10.763 91	ft^2/sec
Length	mm m = 10^6* micron m km km	0.039 370 1 3.280 84 1.093 613 0.621 371 0.539 957	in = 1000* mil ft = 12* in yard = 3* ft mile = 5280* ft nautical mile = 6076.12 ft
Mass	kg = mass of 9.806 65 N weight on earth	0.068 521 8	slug ≡ lb·sec^2/ft = mass of 32.1740 lb weight
Power	watt (W) = J/s = N·m/s kW	0.737 562 1.341 022	ft·lb/sec hp = 550* ft·lb/sec = 2546.14 Btu/hr
Pressure	pascal (Pa) = N/m^2 Pa = N/m^2 = 10^{-5} bar kPa = kN/m^2 = 10 mb bar	0.000 145 037 7 0.020 885 4 0.145 037 7 14.503 77	psi = lb/in^2 psf = lb/ft^2 psi psi
Specific heat	N·m/(kg·K) [≡ m^2/(s^2·K)]	5.979 95	ft·lb/(slug·°R) [≡ ft^2/(sec^2·°R)]
Specific weight	N/m^3	0.006 365 88	lb/ft^3 = pcf
Velocity	m/s km/h = 0.277 778 m/s m/s km/h m/s	3.280 84 0.621 371 2.236 94 0.539 957 1.943 844	fps = ft/sec mph = mile/hr = 1.466 667 fps (30 mph = 44* fps) mph knot (nautical mph) = 1.150 78 mph knot = 1.687 820 fps
Viscosity, absolute, μ (dynamic)	N·s/m^2 [≡ kg/(m·s)] = 10 poise (P)	0.020 885 4	lb·sec/ft^2 [≡ slug/(ft·sec)]
Volume	m^3 m^3 liter (L) = 10^{-3} m^3 liter (L) = 10^{-3} m^3 milliliter (mL) = 10^{-3} L liter (L) = 10^{-3} m^3	35.3147 0.000 810 713 2 0.264 172 2.113 38 0.033 814 0 0.219 971	ft^3 = 7.480 52 U.S. gal acre-ft U.S. gal = 0.133 681 ft^3 = 231* in^3 = 4* quarts = 8* pints pint = 2* cups = 16* fluid ounces fluid ounce = 2* Tbsp = 6* tsp imperial gal = 277.417 in^3 = 1.200 94 U.S. gal = 10 lb water
Weight (see Force)	metric ton = 1000* kgf metric ton = 1000* kgf	1.102 311 2 0.984 206 40	U.S. (short) ton = 2000* lb British (long) ton = 2240* lb

[1] E.g.: 1 m/s^2 = 3.280 84 ft/sec^2.

* Exact conversion.

List of Symbols

The following table lists the letter symbols generally used throughout the text. Because there are so many more concepts than there are English and suitable Greek letters, certain conflicts are unavoidable. However, where we have used the same letter for different concepts, the topics are so far removed from each other that no confusion should result. Occasionally we will use a particular letter in one special case only, but we will clearly indicate this local deviation from the table, and will not use it elsewhere. We give the customary units of measurement for each item in the British Gravitational (BG) system, with the corresponding SI unit in parentheses or brackets.

For the most part, we have attempted to adhere to generally accepted symbols, but not always.

A = any area, ft^2 (m^2)
= cross-sectional area of a stream normal to the velocity, ft^2 (m^2)
= area in turbines or pumps normal to the direction of the absolute velocity of the fluid, ft^2 (m^2)
A_c = circumferential flow area, ft^2 (m^2)
A_s = area of a liquid surface as in a tank or reservoir, ft^2 or acre (m^2 or hectare)
a = area in turbines or pumps normal to the relative velocity of the fluid, ft^2 (m^2)
= linear acceleration, ft/sec^2 (m/s^2)
B = any width, ft (m)
= width of open channel at water surface, ft (m)
= width of turbine runner or pump impeller at periphery, ft (m)
b = bottom width of open channel, ft (m)
$\mathbf{C}$ = cavitation number $= (p - p_v)/(\frac{1}{2}\rho V^2)$ [dimensionless]
C = any coefficient [dimensionless]
= Chézy coefficient [$ft^{1/2}sec^{-1}$ ($m^{1/2}s^{-1}$)]
C_c = coefficient of contraction
C_d = coefficient of discharge
C_v = coefficient of velocity
(for orifices, tubes, and nozzles [all dimensionless])
C_D = drag coefficient [dimensionless]
C_f = average friction-drag coefficient for total surface [dimensionless]
C_{HW} = Hazen-Williams pipe roughness coefficient, $ft^{0.37}/sec$ ($m^{0.37}/s$)
C_L = lift coefficient [dimensionless]
C_p = pressure coefficient $= \Delta p/(\frac{1}{2}\rho V^2)$ [dimensionless]
c = specific heat of liquid, Btu/(slug·°R) [cal/(g·K) or N·m/(kg·K)]
= wave velocity (celerity), fps (m/s)
= sonic (i.e., acoustic) velocity (celerity), fps (m/s)

c_f = local friction-drag coefficient [dimensionless]
c_j = velocity (celerity) of pressure wave in elastic fluid inside an elastic pipe, ft/sec (m/s)
c_p = specific heat of gas at constant pressure, ft·lb/(slug·°R) [N·m/(kg·K)]
c_v = specific heat of gas at constant volume, ft·lb/(slug·°R) [N·m/(kg·K)]
D = diameter of pipe, turbine runner, or pump impeller, ft or in (m or mm)
$D''V$ = product of pipe diameter in inches and mean flow velocity in fps
$\mathbf{E}$ = Euler number = $V/\sqrt{2\Delta p/\rho}$ [dimensionless]
E = specific energy in open channels = $y + V^2/2g$, ft (m)
= linear modulus of elasticity, psi (N/m^2)
E_j = "joint" volume modulus of elasticity for elastic fluid in an elastic pipe, psi (N/m^2)
E_v = volume modulus of elasticity, psi (N/m^2)
e = height of surface roughness projections, ft (mm)
= 2.718281 82846 . . .
$\mathbf{F}$ = Froude number = $V/\sqrt{gL}$ [dimensionless]
F = any force, lb (N)
F_D = drag force, lb (N)
F_L = lift force, lb (N)
f = friction factor for pipe flow [dimensionless]
G = weight flow rate = $dW/dt = \dot{m}g = \gamma Q$, lb/sec (N/s)
g = acceleration due to gravity = 32.1740 ft/sec^2 (9.80665 m/s^2) (standard)
= 32.2 ft/sec^2 (9.81 m/s^2) for usual computation
H = total energy head = $p/\gamma + z + V^2/2g$, ft (m)
= head on weir or spillway, ft (m)
h = any head, ft (m)
= enthalpy (energy) per unit mass of gas = $i + p/\rho$, ft·lb/slug (N·m/kg)
h' = minor head loss, ft (m)
h_a = accelerative head = $(L/g)(dV/dt)$, ft (m)
h_c = depth to centroid of area, ft (m)
h_f = head loss due to wall or pipe friction, ft (m)
h_L = total head loss due to all causes, ft (m)
h_M = energy *added* to a flow by a machine per unit weight of flowing fluid, ft·lb/lb (N·m/N)
h_O = stagnation (or total) enthalpy of a gas = $h + \frac{1}{2}V^2$, ft·lb/slug (N·m/kg)
h_p = depth to center of pressure, ft (m)
= head added to a flow by a pump, ft (m)
h_t = head removed from a flow by a turbine, ft (m)
I = moment of inertia of area, ft^4 or in^4 (m^4 or mm^4)
= internal thermal energy per unit weight = i/g, ft·lb/lb (N·m/N)