时代教育·国外高校优秀教材精选

流体力学

Mechanics of Fluids

（英文版·原书第3版）

（美）M. C. 波特（Merle C. Potter）
D. C. 维格特（David C. Wiggert） 著

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CHINA MACHINE PRESS

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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，国家教育部近来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，机械工业出版社拟于近期推出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，举办原版教材的教师培训，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

2002年3月

序

如何从众多的国外流体力学教材中选出一本适合我国工科本科和研究生用的流体力学双语教学教材？当翻阅了刚出版的 M. C. Potter 和 D. C. Wiggert 合著的“Mechanics of Fluids(3rd Edition)”，深为它的内容丰富、编排精细、结合实际、结合时代所吸引，仔细读后，更觉得有很多特色，所以毫不迟疑地选中了它。

它有如下几个主要特点：

1. 21 世纪各类工程遇到的流体力学问题或对自然界中遇到的各种有关流体力学的物理现象已远不能用一维理论分析来解决，很多问题需要引入场的概念，建立数学物理模型，采用二维、特别是三维理论分析(即理论流体力学)、数值模拟(即计算流体力学，Computational Fluid Dynamics，简称 CFD)或实验研究（即实验流体力学）来解决，经常是需要三者结合起来解决。现有国内外许多流体力学教材均不能兼有这三方面的内容。本书不仅兼有这三者内容，而且紧密结合实际又符合时代要求。如果掌握了本书的主要内容，不仅能理解流体力学的主要物理现象、基本定理和控制方程及其应用，能分析和解决一些不太复杂的流体力学工程实际问题，如叶轮机械(主要是泵和透平)的工作原理和相似律，管流和管网设计，明渠流动，大气和水环境中的质量、动量和热量的输运过程(如水质处理)等，而且还具备了分析和解决工程实际中复杂流体力学问题的基础和能力。

2. 教材内容紧密结合实际，摒弃了过时无用的内容，引入了符合时代的计算流体力学和环境流体力学的基本内容。全书系统性好，涉及面广，有内流和外流，还有考虑自由面影响的明渠流动和压缩性影响的可压缩流，然而具体取材却少而精。每章有前言和小结，说明重点内容，文中对重点概念还有特别提示，并附有相应例题和相当数量的流体力学重要现象的清晰照片作进一步说明等等。这些很方便于老师教学和学生学习，在一定程度上缓解了流体力学课程老师难教和学生难学的问题。

3. 对于学习流体力学的普遍反映是习题难做。本书除对每一个重要内容有例题说明外，每章均有不同难度的大量习题，对其中可选作为家庭作业的习题，附有答案；另外，还有结合实际的设计类型题目和选择题。这些不仅有助于解决习题难做的问题，而且培养了学生对解决实际生活中遇到的流体力学问题的兴趣和能力。

4. 本书选材全面，包括必要的基础理论、CFD 入门、基本的流体力学量测技术(包括一些近代量测技术)和一些常用的流体力学专门问题，各章前言和编排有助于教学大纲选材。本书除作为通常的流体力学课程教材外，还可作为流体力学入门(或称初等流体力学)、中级流体力学和一些流体力学专门课程教材，所以适用面很广。

5. 本书使用方便，书前有详细的符号说明，书后有丰富、实用的附录，包括图表、习题答案、主要参考书和索引；书中同时采用国际单位和英制两种单位制(重点是前者)；又采用流行的计算软件和程序语言；引用的实际流动现象的照片均有出处等等，这些对读者学习带来很大方便。

综上所述，本书适合作为工科院校小学时(48 学时左右)、中学时(80 学时左右)和高学时(120 学时左

右）本科和研究生用的流体力学或工程流体力学课程用的双语教学教材或主要参考书。可适用于很多类的工程专业，如机械、能源、环境、航空、力学、船舶、水利、化工、电子、自动化、海洋、生物、气象等。对从事于有关流体力学教学和科研的工作者也是一本很好的参考书。

朱之墀
清华大学
2002年10月

Preface

The motivation to write a book is difficult to describe. Most often the authors suggest that the other texts on the subject have certain deficiencies that they will correct, such as an accurate description of entrance flows and flows around blunt objects, the difference between a one-dimensional flow and a uniform flow, the proper presentation of the control volume derivation, or a definition of laminar flow that makes sense. New authors, of course, introduce other deficiencies that future authors hope to correct! And life goes on. This is another fluids book that has been written in hopes of presenting an improved view of fluid mechanics so that the undergraduate can understand the physical concepts and follow the mathematics. This is not an easy task: Fluid mechanics is a subject that contains many difficult-to-understand phenomena. For example, how would you explain the hole scooped out in the snow by the wind on the upwind side of a tree during a snowstorm? Or the high concentration of smog contained in the Los Angeles area (it doesn't exist to the same level in New York)? Or the unexpected strong wind around the corner of a tall building in Chicago? Or the vibration and subsequent collapse of a large concrete-steel bridge due to the wind? We have attempted to present fluid mechanics so that the student can understand and analyze many of the important phenomena encountered by the engineer.

The mathematical level of this book is based on previous mathematics courses required in all engineering curricula. We use solutions to differential equations and vector algebra. Some use is made of vector calculus with the use of the gradient operator, but this is kept to a minimum since it tends to obscure the physics involved.

Most popular texts in fluid mechanics have not presented fluid flows as fields. That is, they have presented primarily those flows that can be approximated as one-dimensional flows and have treated other flows using experimental data. We must recognize that when a fluid flows around an object, such as a building or an abutment, its velocity possesses all three components which depend on all three space variables and often, time. If we present the equations that describe such a general flow, the equations are referred to as field equations and velocity and pressure fields become of interest. This is quite analogous to electrical and magnetic fields in electrical engineering. In order for the difficult problems of the future, such as large-scale environmental pollution, to be analyzed by engineers, it is imperative that we understand fluid fields. Thus in Chapter 5 we introduce the field equations and discuss several solutions for some relatively simple geometries. The more conventional manner of treating the flows individually is provided as an alternate route for those who wish this more standard approach. The field equations can then be included in a subsequent course.

Perhaps a listing of the additions made in this third edition would be of interest. We have:

- added a new chapter on computational fluid dynamics.
- deleted the duplicate examples and problems using SI and English units.
- added multiple-choice problems similar to those found on the Fundamentals of Engineering Exam.
- replaced the BASIC computer program for gradually varied flow in Chapter 10 with Microsoft® Excel spreadsheet solutions.
- replaced the BASIC computer code for pipe network analysis in Chapter 11 with EPANET output.
- added Mathcad® and MATLAB® solutions where applicable.
- improved many of the figures.
- highlighted important information in the margins.
- added chapter outlines and summaries.
- included a Nomenclature list after the Preface.
- added additional photos.
- improved the text material following suggestions by several reviewers.
- added additional explanatory material to the examples.
- added the names of scientists and engineers who have contributed to this subject.

The introductory material included in Chapters 1 through 9 has been selected carefully to introduce students to all fundamental areas of fluid mechanics. Not all of the material in each chapter need be covered in an introductory course. The instructor can fit the material to a selected course outline. Some sections at the end of each chapter may be omitted without loss of continuity in later chapters. In fact, Chapter 5 can be omitted in its entirety if it is decided to exclude field equations in the introductory course, a relatively common decision. That chapter can then be included in an intermediate fluid mechanics course. After the introductory material has been presented, there is sufficient material to present in one or two additional courses. This additional course or courses could include material that had been omitted in the introductory course and combinations of material from the more specialized Chapters 9 through 15. Much of the material is of interest to all engineers, although several of the chapters are of interest to only particular disciplines.

We have included examples worked out in detail to illustrate each important concept presented in the text material. Numerous home problems, many having multiple parts for better homework assignments, then provide the student with ample opportunity to gain experience solving problems of various levels of difficulty. Answers to selected home problems are presented just prior to the Index. We have also included design-type problems in several of the chapters. After studying the material, reviewing the examples, and working several of the home problems, students should gain the needed capability to work many of the problems encountered in actual engineering situations. Of course, there are numerous classes of problems that are extremely difficult to solve, even for an experienced engineer. To solve these more difficult problems, the engineer must gain considerably more information than is included in this introductory text. There are, however, many problems that can be solved successfully using the material and concepts presented herein.

Many students take the FE/EIT exam at the end of their senior year, the first step in becoming a professional engineer. The problems in the FE/EIT exam are all four-part, multiple choice. Consequently, we have included this type of problem in the appropriate chapters and they are noted by use of the exam icon. Multiple-choice problems will be presented using SI units since the FE/EIT exam uses SI units exclusively. Additional information on the FE/EIT exam can be obtained from a website at glpbooks.com.

The book is written emphasizing SI units, however, all properties and dimensional constants are given in English units also. Approximately one-fifth of the examples and problems are presented using English units.

The authors are very much indebted to both their former professors and to their present colleagues. Professors C. S. Yih and V. L. Streeter of the University of Michigan demanded that each of us learn this subject well! Chapter 10 was written with inspiration from F. M. Henderson's book titled *Open Channel Flow* (1996), and D. Wood of the University of Kentucky encouraged us to incorporate comprehensive material on pipe network analysis in Chapter 11. Several illustrations in Chapter 11 relating to the water hammer phenomenon were provided by C. S. Martin of the Georgia Institute of Technology. R. D. Thorley provided some of the problems at the end of Chapter 12. Miki Hondzo of the University of Minnesota wrote Chapter 14 on Environmental Fluid Mechanics, and Tom Shih of Michigan State University wrote Chapter 15 on Computational Fluid Dynamics. Thanks to Richard Prevost for writing the MATLAB® solutions, and to Lori Hasse for typing the solutions manual. We would also like to thank our reviewers: Mohamed Alawady, Louisiana State University; John R. Biddle, California Polytechnical Institute—Pomona; Saeed Moaveni, Minnesota State University, Mankato; Julia Muccino, Arizona State University; Emmanuel U. Nzewi, North Carolina A & T State University; and Yiannis Ventikos, Swiss Federal Institute of Technology.

Merle C. Potter
David C. Wiggert

Nomenclature

for quick reference

A - area, constant
A_2, A_3 - profile type
a - acceleration, speed of a pressure wave
$\mathbf{a}$ - acceleration vector
a_x, a_y, a_z - acceleration components
B - constant, bulk modulus of elasticity, free surface width
b - channel bottom width
C - centroid, Chezy coefficient, Hazen-Williams coefficient, constant for curve fit, molar concentration
$\overline{C}$ - time average concentration
C - concentration fluctuation
C_1, C_3 - profile type
C_D - drag coefficient
C_d - discharge coefficient
C_f - skin friction coefficient
C_H - head coefficient
C_i - molar concentration
C_L - lift coefficient
C_P - pressure recovery factor, pressure coefficient
C_{NPSH} - net positive suction head coefficient
C_Q - flow rate coefficient
C_V - velocity coefficient
C_W - power coefficient
c - specific heat, speed of sound, chord length, celerity
c_1, c_2 - constants
c_f - local skin friction coefficient
c_p - constant pressure specific heat
c_s' - deviation from average concentration
c_v - constant volume specific heat
c.s. - control surface
c.v. - control volume
D - diameter, mass diffusion coefficient
D_t - turbulent diffusion coefficient
$\frac{D}{Dt}$ - substantial derivative

$\frac{d}{dx}$ - ordinary derivative
d - diameter
dx - differential distance
$d\theta$ - differential angle
E - energy, specific energy, modulus of elasticity, logitudinal heat dispersion coefficient
E_c - critical energy
EGL - energy grade line
Eu - Euler number
e - the exponential, specific energy, wall roughness height, pipe wall thickness
exp - the exponential e
$\mathbf{F}$ - force vector
F - force
F_B - buoyant force
F_H - horizontal force component
F_V - vertical force component
F_W - body force equal to the weight
f - friction factor, frequency
G - center of gravity
$\overline{GM}$ - metacentric height
$\mathbf{g}$ - gravity vector
g - gravity
H - enthalpy, height, total energy
H_2, H_3 - profile type
H_D - design head
H_P - pump head
H_T - turbine head
HGL - hydraulic grade line
h - distance, height, specific enthalpy
h_j - head loss across a hydraulic jump
I - second moment of an area
$\bar{I}$ - second moment about the centroidal axis
I_{xy} - product of inertia
$\hat{\mathbf{i}}$ - unit vector in the x-direction
$\mathbf{J}$ - mass flux vector
J - mass flux
$\hat{\mathbf{j}}$ - unit vector in the y-direction
$\hat{\mathbf{k}}$ - unit vector in the z-direction
K - thermal conductivity, flow coefficient, dispersion coefficient
K_c - contraction coefficient
K_e - expansion coefficient
K_y - tranverse dispersion coefficient
K_{uv} - correlation coefficient
k - ratio of specific heats
k_s - settling rate coefficient
L - length
L_E - entrance length

L_e - equivalent length
L_t - transverse length scale
L_x - distance between effluent injection and equilibrium zone
ℓ - length
ℓ_m - mixing length
M - molar mass, Mach number, momentum function
$\dot{M}$ - total mass flux of dye
M - Mach number
$\mathrm{M}_1, \mathrm{M}_2, \mathrm{M}_3$ - profile type
m - mass, side-wall slope, constant for curve fit
$\dot{m}$ - mass flux
$\dot{m}_r$ - relative mass flux
m_a - added mass
m_1, m_2 - side-wall slopes
$m\dot{o}m$ - momentum flux
N - general extensive property, an integer, number of jets, stability frequency
$NPSH$ - net positive suction head
n - normal direction number of moles, power-law exponent, Manning number
$\hat{\mathbf{n}}$ - unit normal vector
P - power, force, wetted perimeter
p - pressure
Q - flow rate (discharge), heat transfer
Q_D - design discharge
$\dot{Q}$ - rate of heat transfer
q - source strength, specific discharge, heat flux
R - radius, gas constant, hydraulic radius, resistance coefficient, radius of curvature
$\overline{R}_i$ - modified resistant coefficient
Re - Reynolds number
$\mathrm{Re}_{\mathrm{crit}}$ - critical Reynolds number
R_u - universal gas constant
R_x, R_y - force components
r - radius, coordinate variable, rate of generation
$\bar{r}$ - time average rate of generation
$\mathbf{r}$ - position vector
S - specific gravity, entropy, distance, slope of chennel, slope of EGL, thermal energy source
$\mathrm{S}_1, \mathrm{S}_2, \mathrm{S}_3$ - profile type
S_c - critical slope
St - Strouhal number
$\mathbf{S}$ - position vector
S_0 - slope of channel bottom
s - specific entropy, streamline coordinate
$\hat{\mathbf{s}}$ - unit vector tangent to streamline
sys - system
T - temperature, torque, tension
t - time, tangential direction
t_{ad} - advection transport time

t_{diff} - diffusion time scale
U - average velocity
U_∞ - free-stream velocity away from a body
u - x-component velocity, circumferential blade speed
u' - velocity perturbation
u_s' - deviation from average velocity
$\tilde{u}$ - specific internal energy
$\overline{u}$ - time average velocity
u_τ - shear velocity
V - velocity
V_c - critical velocity
V_{ss} - steady-state velocity
$\mathbf{V}$ - velocity vector
$\overline{V}$ - spatial average velocity
$\forall$ - volume
V_B - blade velocity
V_n - normal component of velocity
V_r - relative speed
V_t - tangential velocity
v - velocity, y-component velocity
v' - velocity perturbation
$v_r, v_z, v_\theta, v_\phi$ - velocity components
W - work, weight, change in hydraulic grade line
$\dot{W}$ - work rate (power)
$\dot{W}_f$ - actual power
$\mathrm{W_e}$ - Weber number
$\dot{W}_S$ - shaft work (power)
w - z-component velocity, velocity of a hydraulic bore
X_T - distance where transition begins
x - coordinate variable
x_m - origin of moving reference frame
$\tilde{x}$ - distance relative to a moving reference frame
$\overline{x}$ - x-coordinate of centroid
Y - upstream water height above tope of wier
y - coordinate variable, flow energy head
y_p - distance to center of pressure
$\overline{y}$ - y-coordinate of centroid
y_c - critical depth
z - coordinate variable

α - angle, angle of attack, lapse rate, thermal diffusivity, kinetic-energy correction factor, blade angle
α_x - an empirical constant
β - angle, momentum correction factor, fixed jet angle, blade angle, diameter ratio
Δ - a small increment
∇ - gradient operator
∇^2 - Laplacian

δ - boundary layer thickness
$\delta(x)$ - Dirac-delta function
δ_d - displacement thickness
δ_ν - viscous wall layer thickness
δR - overall uncertainty interval
δK - precision
ε - a small volume
ε_{xx}, ε_{xy}, ε_{xz} - rate-of-strain components
ϕ - angle, coordinate variable, velocity potential function, speed factor
Γ - circulation, vortex strength
γ - specific weight
η - a general intensive property, eddy viscosity, efficiency, a position variable
η_P - pump efficiency
η_T - turbine efficiency
λ - mean free path, a constant, wave length
μ - viscosity, doublet strength
ν - kinematic viscosity
π - a pi term
θ - angle, momentum thickness, laser beam angle
ρ - density
Ω - angular velocity
Ω_P - specific speed of a pump
Ω_T - specific speed of a turbine
$\mathbf{\Omega}$ - angular velocity vector
σ - surface tension, cavitation number, circumferential stress, standard deviation
σ^2 - variance
σ_t^2 - temporal variance
σ_x^2 - spatial variance
σ_{xx}, σ_{yy}, σ_{zz} - normal stress components
τ - stress vector
$\bar{\tau}$ - time average stress
τ_{xy}, τ_{xz} - shear stress components
ω - angular velocity, vorticity
$\boldsymbol{\omega}$ - vorticity vector
ψ - stream function
$\frac{\partial}{\partial x}$ - partial derivative

Contents