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工程流体力学

ENGINEERING FLUID MECHANICS

(英文版·原书第4版)

Merle C.Potter
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机械工业出版社
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序

2001 年，教育部在《关于加强高等学校本科教学工作提高教学质量的若干意见》中明确指出：按照“教育面向现代化、面向世界、面向未来”的要求，为适应经济全球化和科技革命的挑战，本科教育要创造条件使用英语等外语进行公共课和专业课教学。

近年来，为配合高等院校双语教学的需求，国内一些出版社引进了不少国际知名的本科教材，取得了很好的使用效果。

优秀的本科专业教材，不仅要求语言简洁、条理明晰，还要求数理描述与推导过程严谨，论述深入浅出、引人入胜。如果能有一本合适的英文教材配合专业课程的教学，学生的双语学习效果定会事半功倍。

针对高等院校流体力学课程的双语教学，机械工业出版社与世界著名的圣智（Cengage）学习出版公司合作影印出版了波特（Potter）、威格特（Wiggert）、莱曼丹（Ramadan）所著的《流体力学》（Mechanics of Fluids）第 4 版。为了减轻读者的负担，在不影响教材整体质量的前提下，机械工业出版社约请领域内专家对原版教材中的某些内容进行了适当的删减，并将教材更名为《工程流体力学》（Engineering Fluid Mechanics）。

尽管本影印版有一些删节，但其更符合我国的流体力学课程教学，仍很好地保持着原著的内容逻辑和知识框架体系，保留了所有有价值的演变线索，尤其保留了所有重要的修订和适应创新需求的新内容。相信本书精彩的编写和论述不仅会给读者展现科学技术的魅力，其优雅的英文文字也会给读者带来美的享受。相信这本教材会为读者营造一个认识、学习和掌握流体力学的英文语言环境。

王 立
北京科技大学

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 sand by the water on the upstream side of an abutment? 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? Or the trailing vortices observed from a large aircraft? 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.

Many 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 fourth edition would be of interest. We have:

- Added many examples and problems, most of which have real-life applications.
- Collected all the multiple-choice problems to the front of the problem sets. They can be used to review the subject of Fluid Mechanics for the Fundamentals of Engineering and the GRE/Engineering exams.
- Deleted the chapter on Environmental Fluid Mechanics in an attempt to shorten the book.
- Simplified the chapter on Computational Fluid Mechanics.
- Made numerous changes to clarify the presentation.

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 11. Much of the material is of interest to all engineers, although several of the chapters are of interest only to 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, 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 at the beginning of the chapters. 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 **ppi2pass.com.**

The book is written emphasizing SI units;

The authors are very much indebted to both their former professors and to their present colleagues. 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. Thanks to Richard Prevost for writing the MATLAB® solutions. We would also like to thank our reviewers: Sajjed Ahmed, University of Nevada; Mohamed Alawardy, Louisiana State University; John R. Biddle, California State Polytechnic University; Nancy Ma, North Carolina State University; Saeed Moaveni, Minnesota State University; Nikos J. Mourtos, San Jose (CA) State University; Julia Muccino, Arizona State University; Emmanuel U. Nzewi, North Carolina A&T State University; and Yiannis Ventikos, Swiss Federal Institute of Technology.

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Nomenclature

for quick reference

A - area
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 - bulk modulus of elasticity, free surface width
b - channel bottom width
C - centroid, Chezy coefficient, Hazen-Williams coefficient
C_1, C_3 - profile type
C_D - drag coefficient
C_d - discharge coefficient
C_f - skin-friction coefficient
C_H - head coefficient
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
$C_{\dot{W}}$ - power coefficient
c - specific heat, speed of sound, chord length, celerity
c_f - local skin-friction coefficient
c_p - constant pressure specific heat
c_v - constant volume specific heat
c.s. - control surface
c.v. - control volume
D - diameter
$\frac{D}{Dt}$ - substantial derivative
d - diameter
dx - differential distance
$d\theta$ - differential angle
E - energy, specific energy, 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
$\hat{\mathbf{j}}$ - unit vector in the y-direction
$\hat{\mathbf{k}}$ - unit vector in the z-direction
K - thermal conductivity, flow coefficient
K_c - contraction coefficient
K_e - expansion coefficient
K_{uv} - correlation coefficient
k - ratio of specific heats
L - length
L_E - entrance length
L_e - equivalent length
ℓ - length
ℓ_m - mixing length
M - molar mass, Mach number, momentum function

M - Mach number
M_1, M_2, 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
$\dot{mom}$ - momentum flux
N - general extensive property, an integer, number of jets
$NPSH$ - 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, radius of curvature
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
$\mathbf{r}$ - position vector
S - specific gravity, entropy, distance, slope of chennel, slope of EGL
S_1, S_2, 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
U - average velocity
U_∞ - free-stream velocity away from a body
u - x-component velocity, circumferential blade speed
u' - velocity perturbation
$\tilde{u}$ - 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_θ, v_ϕ - velocity components
W - work, weight, change in hydraulic grade line
$\dot{W}$ - work rate (power)
$\dot{W}_f$ - actual power
We - Weber number
$\dot{W}_S$ - shaft work (power)
ω - 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 top 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
β - angle, momentum correction factor, fixed jet angle, blade angle
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
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
$\sigma_{xx}, \sigma_{yy}, \sigma_{zz}$ - normal stress components
τ - stress vector
$\bar{\tau}$ - time average stress
$\tau_{xy}, \tau_{xz}, \tau_{yz}$ - shear stress components
ω - angular velocity, vorticity
$\boldsymbol{\omega}$ - vorticity vector
ψ - stream function
$\frac{\partial}{\partial x}$ - partial derivative

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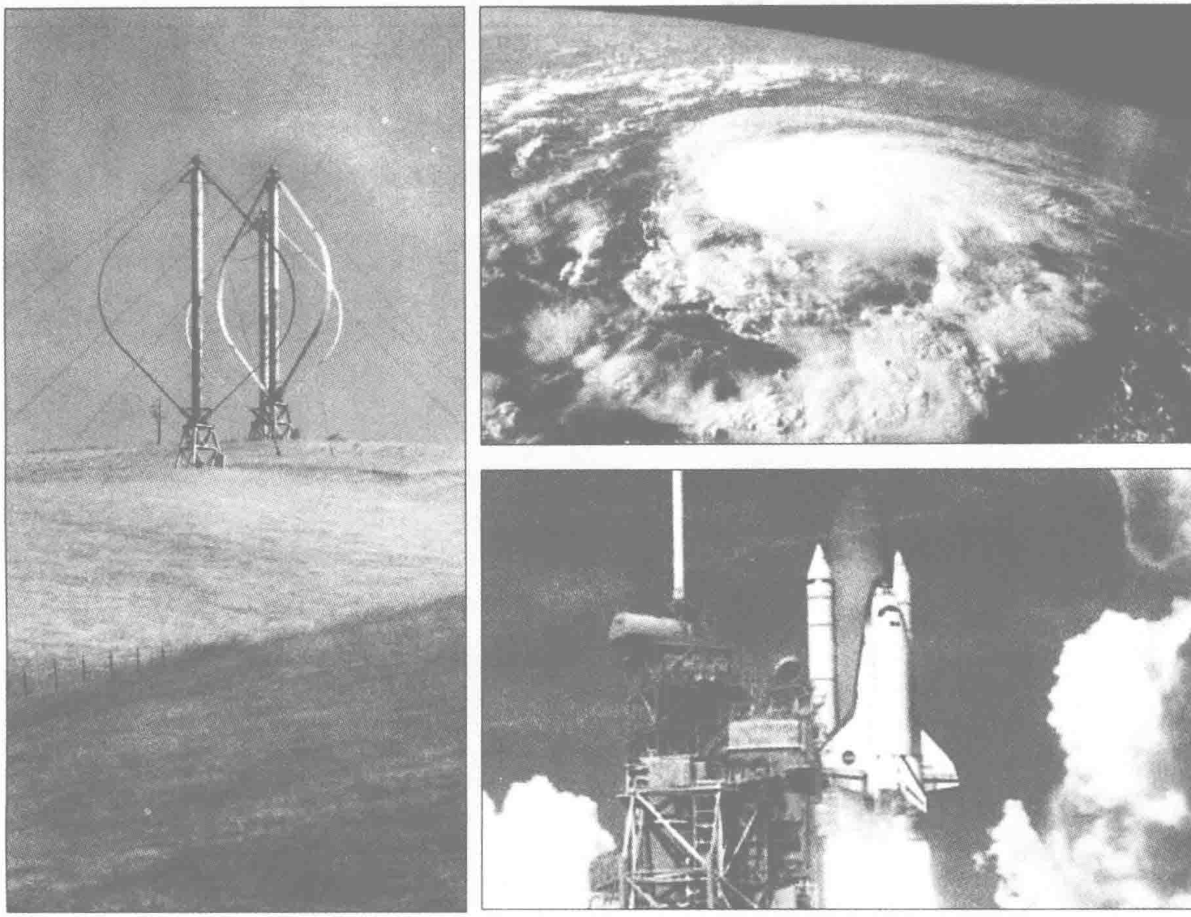

Left: Contemporary windmills are used to generate electricity at many locations in the United States. They are located in areas where consistent prevailing winds exist. (IRC/Shutterstock) **Top right**: Hurricane Bonnie, Atlantic Ocean about 800 km from Bermuda. At this stage in its development, the storm has a well-developed center, or "eye," where air currents are relatively calm. Vortex-like motion occurs away from the eye. (U.S. National Aeronautics and Space Administration) **Bottom right**: The Space Shuttle Discovery leaves the Kennedy Space Center on October 29, 1998. In 6 seconds the vehicle cleared the launch tower with a speed of 160 km/h, and in about two minutes it was 250 km down range from the Space Center, 47 km above the ocean with a speed of 6150 km/h. The wings and rudder on the tail are necessary for successful reentry as it enters the earth's atmosphere upon completion of its mission. (U.S. National Aeronautics and Space Administration)