Engineering Fluid Mechanics

Edited by

Guo Chuwen, Jimmy L. Smart, Li Deyu, Liu Qi

Engineering Fluid Mechanics

China University of Mining and Technology Press

Engineering Fluid Mechanics

Edited by

Guo Chuwen, Jimmy L. Smart, Li Deyu, Liu Qi

China University of Mining and Technology Press

Abstract

This book could be used as textbook for bilingual course in power engineering, environmental engineering and related majors. Its main contents include fluids and their properties, fluid statics, fluid dynamics, similitude and dimensional analysis, viscous flow and hydraulic calculation, vortex flow, irrotational flow, introduction to theory of boundary layer, and introduction to aerodynamics.

图书在版编目(CIP)数据

工程流体力学=Engineering Fluid Mechanics：英文/郭楚文等编. —徐州：中国矿业大学出版社，2011.9

ISBN 978-7-5646-0905-4

Ⅰ. ①工… Ⅱ. ①郭… Ⅲ. ①工程力学：流体力学—英文 Ⅳ. ①TH126

中国版本图书馆 CIP 数据核字(2010)第 242131 号

书　　名 Engineering Fluid Mechanics
编　　者 Guo Chuwen　Jimmy L. Smart　Li Deyu　Liu Qi
责任编辑 钟　诚　时应征
出版发行 中国矿业大学出版社有限责任公司
（江苏省徐州市解放南路　邮编 221008）
营销热线 (0516)83885307　83884995
出版服务 (0516)83885767　83884920
网　　址 http://www.cumtp.com　**E-mail**：cumtpvip@cumtp.com
印　　刷 徐州中矿大印发科技有限公司
开　　本 850×1168　1/32　**印张** 9.875　**字数** 330 千字
版次印次 2011 年 9 月第 1 版　2011 年 9 月第 1 次印刷
定　　价 28.50 元

Perface

Having bilingual course in engineering fluid mechanics, students will not only study the basic knowledge in fluid mechanics, but also master specialized English vocabulary in the field of fluid mechanics. Students will be familiar with the way of thinking and expressing of native speakers, including scientific terms and classroom language. Through study of bilingual courses, students will be able to use English fluently in academic exchanges.

However, it is hard to meet the requirements of our undergraduate teaching plan by using directly the original English textbook in fluid mechanics due to the difference between the teaching systems. Therefore, we choose proper contents from several original English textbooks based on our teaching plan. By this way, we could not only meet tour teaching requirements, but also ensure the purity and accuracy of language.

This textbook is an introduction to engineering fluid mechanices. It mainly includes fluids and their properties, fluid statics, fluid dynamics, similitude and dimensional analysis, viscous flow and hydraulic calculation, vortex flow, irrotational flow, introduction to theory of boundary layer, and introduction to aerodynamics.

Finally, we would like to express our thanks to Dr. Jim Smart, the second author of this book from the University of

Kentucky, who has contributed a lot to the preparation to this manuscript by not only providing some chapters and problems, but also revising the whole manuscript as a native English speaker.

This book could be used as textbook for the bilingual course in fluid mechanics.

Writers
March 2010

NOMENCLATURE

Dimensions are given in terms of mass (M), length (L), time(T), temperature (Θ), and dimensionless (-). A commonly used example of units is given in parentheses.

Latin

a	acceleration (m/s^2), LT^{-2}
A	area (m^2), L^2
c	sonic velocity (speed of sound is 343. 14 m/s at 20 ℃), LT^{-1}; propagation speed(m/s), LT^{-1}
C	constant of integration, various units
C_a	Cauchy number, (-)
C_c	contraction coefficient for an orifice, $C_C = A_C/A$, (-)
C_d	discharge coefficient, (-)
C_F	flow coefficient, $C_C \cdot \varphi$, (-)
c_p	constant pressure heat capacity (J/g · ℃), $L^2\Theta^{-2}T^{-1}$
c_v	constant volume heat capacity (J/g · ℃), $L^2\Theta^{-2}T^{-1}$
d	diameter (m), L
Eu	Euler number, (-)
f	body force (kg · m/s^2), MLT^{-2}; friction factor, (-); frequency of shedding, T^{-1}
F	force (kg · m/s^2), MLT^{-2}
Fr	Froude number, (-)
g	acceleration due to gravity (9. 880 65 m/s^2), LT^{-2}

g_c gravitational conversion factor (32.174 0 ft • lb_m/lb_f • s^2)

h distance (m), L; enthalpy (J/g), L^2/t^2

h_w energy loss per unit weight of fluid (J/kg), L^2/t^2

$\vec{i}$ unit vector in the x-direction, (-)

ID internal diameter (m), L

$\vec{j}$ unit vector in the y-direction, (-)

$\vec{J}$ vortex flux, $L^{-2}T^{-1}$

$\vec{k}$ unit vector in the z-direction, (-)

k compressibility coefficient (Pa^{-1}), $M^{-1}LT^2$; similitude ratio, (-); ratio of heat capacities, c_p/c_v, (-)

K bulk modulus of elasticity (Pa), $ML^{-1}T^{-2}$

l length (m), L

LHS left hand side, (-)

m mass (kg), M

$\dot{m}$ mass flowrate (kg/s), MT^{-1}

M strength of a doublet (volumetric rate per unit length), L^2T^{-1}

Ma Mach number, (-)

M_a * velocity coefficient, (-)

$\vec{n}$ normal unit vector, (-)

N extensive property; property proportional to amount of mass, various units

Ne Newton number, (-)

OD outside diameter (m), L

p fluid pressure expressed as force/area (Pa), $ML^{-1}T^{-2}$

q flow rate (m^3/s or kg/s), L^3T^{-1} or MT^{-1}

$\frac{dQ}{dt}$ rate of heat transferred (J/s), ML^2T^{-3}

R gas law constant $R = 0.287$ kJ/(kg · K) for air at 1 atm pressure), [kJ/(kg · K)], $L^2T^{-2}\Theta^{-1}$; resultant force (kg · m/s^2), MLT^{-2}

Re Reynolds number, (-)

R_h hydraulic radius (m), L

RHS right hand side, (-)

s entropy [kJ/(kg · K)], $L^2T^{-2}\Theta^{-1}$

S Sutherland constant, (-)

S. G. specific gravity, (-)

St Strouhal number, (-)

T temperature (K or ℃), Θ; tension force (kg · m/s^2), MLT^{-2}

u fluid velocity component in the x-direction (m/s), LT^{-1}; internal energy per unit mass (kJ/kg), L^2T^{-2}

U velocity (m/s), LT^{-1}

v fluid velocity in the y-direction (m/s), LT^{-1}; specific volume (m^3/kg), L^3M^{-1}

$\overline{V}$ average velocity (m/s), LT^{-1}

V volume (m^3), L^3

w fluid velocity in the z-direction (m/s), LT^{-1}

$\frac{dw}{dt}$ rate at which work is performed (J/s), ML^2T^{-3}

W weight (kg · m/s^2), MLT^{-2}

We Weber number, (-)

z distance (m), L

Greek

α kinetic-energy correction factor, (-)

α_i volume fraction of an ideal gas, (-)

α_v volume expansibility coefficient(1/℃), Θ^{-1}

β momentum correction factor (-); angle between the approach flow and the central hole of probe, (-)

δ boundary layer thickness (m), L; thickness of viscous subayer (m), L

ε average height of the projection of wall (m), L; infinitesimal, (-)

ε_p compressibility factor, (-)

φ angle expressed as radians or degrees, (-); velocity coefficient (-), $\varphi = \dfrac{1}{\sqrt{1+\lambda_1}}$; velocity potential function (m/s), LT^{-1}

Γ circulation (m/s), LT^{-1}

γ specific weight (N/m^3), $ML^{-2}T^{-2}$; roughness factor, (-)

η intensive property, that is, the amount of extensive property per unit mass(various units)

λ fraction factor, (-)

μ dynamic viscosity (Pa • s), $ML^{-1}T^{-1}$

υ kinetic viscosity(m^2/s), L^2T^{-1}

π pi variables used in the Buckingham pi theorem, (-); potential energy function(various dimensions)

θ wetting angle between fluid and its solid surface, (-)

ρ density(kg/m^3), ML^{-3}

σ surface tension coefficient (N/m), MT^{-2}

τ shear stress expresed as frictional force (N/m^2), ML^{-1} T^{-2}

τ_{ij} shear strain rate, where the first subscript i of τ_{ij} indicates the direction of the normal to the plane on which the stress acts and the second subscript j of τ_{ij} indicates the direction of the stress (N/m^2), $ML^{-1}T^{-2}$

ω	rate of rotation or angular veloctiy (rad/s), T^{-1}
Ω	vorticity(rad/s), T^{-1}
Ψ	stream function, L^2T^{-1}

Superscripts and Subscripts

a	reference point
b	reference point
c	centroid or correction
cr	parameters of critical state
cv	control volume
cx	cross-sectional
f	fluid, friction, or force
l	length
L	loss
m	manometer
n	normal direction
p	pressure
r	radial
t	time
ν	volume or velocity
x	x-direction
y	y-direction
z	z-direction
o	initial, original, or reference point

Mathematical operations

$\frac{\mathrm{d}}{\mathrm{d}t}$ substantial derivative, T^{-1}

$\sum_{i=1}^{n} x_i$ summation of terms, from $i=1$ to $i=n$

∇ del operator, L^{-1}

∇^2 Laplacian operator$=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}$, L^{-2}

Contents

1 Fluids and Their Properties

The motion of a fluid is, of course, influenced by its surroundings, but also by its inherent physical properties. This chapter will introduce the definition of fluids and their main physical properties.

1.1 Definition of Fluids

Definition: A fluid is defined as a substance that will continuously deform, that is, flow under the action of a shear stress, no matter how small that shear stress may be.

A solid, on the other hand, can resist a shear stress if the shear stress does not exceed the elastic limit of the material. Some materials, like a viscous polymer, may appear to be a solid. However, upon closer examination, these materials are found to deform and flow under some shear stress.

A fluid can be either a gas or a liquid. The molecular structure of liquids is such that the spacing between molecules is essentially constant (this spacing changes slightly with temperature and insignificantly so with pressure), so that a given mass of liquid occupies a definite volume of space. Therefore, when one pours a liquid into a container, it assumes the shape of the container for the volume it occupies. The molecules of solids also have definite spacing. However, the solid's molecules are arranged in a specific lattice formation and their movement is restricted, whereas liquid molecules can move with respect to each other when a shearing force is applied. The spacing of the molecules of gases is more expansive than that of either solids or liquids. Spacing between the gas molecules is also variable. Thus, a gas completely fills the container in which it is placed. The gas molecules travel through space until they either bounce off the walls of the container, or are deflected or influenced by interaction with other gas molecules.

1.2 Fluid as a Continuum

In considering the action of forces on fluids, one can, either (1) account for the behavior of each and every molecule of fluid in a given field of flow, or (2) simplify the problem by considering the average effects of the molecules in a given volume. In most problems in fluid dynamics the latter approach is possible, which means that the fluid can be regarded as a continuum——that is, a hypothetically continuous substance.

The justification for treating a fluid as a continuum depends upon the physical dimensions of the body immersed in the fluid, and on the number of molecules in a given volume. For example, suppose air is flowing past a 1 cm diameter sphere. Use of a continuum is said to be appropriate if the number of molecules in a volume is sufficiently great so that the average effects (pressure, density, and so on) within the volume are either constant or change smoothly, continuously over time. The number of mole-