AN INTRODUCTION TO FLUID MECHANICS AND HEAT TRANSFER

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WITH APPLICATIONS IN CHEMICAL & MECHANICAL PROCESS ENGINEERING

BY

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AND

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THIRD
EDITION

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Tokyo, Mexico City

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by
Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521098809

First published 1957
Second edition 1963
Reprinted 1965
Third edition 1974
Re-issued 2013

A catalogue record for this publication is available from the British Library

Third edition	0 521 20533 6 hard covers
	0 521 09880 7 paper back
(Second edition	0 521 05467 2 hard covers
	0 521 09210 8 paperback)

ISBN 978-0-521-20533-7 Hardback
ISBN 978-0-521-09880-9 Paperback

PREFACE TO THE THIRD EDITION

This book is based on lectures which have been given in the Department of Chemical Engineering at Cambridge over a period of years. The first edition was published in 1957. The new edition incorporates some additional material and has been completely revised with the introduction of SI units throughout. The book falls into three main sections. Chapters 1–11 constitute an elementary introduction to fluid mechanics, heat conduction and heat transfer. Chapters 12–18 form a hard core of basic theory covering the generalized principles of fluid flow and convective transfer. Chapters 19–23 are concerned with certain special applications which are of interest in process engineering.

On re-reading the original text after a number of years, the authors of the new edition were conscious of the fact that the book presented a highly condensed account of the basic physical and mathematical principles which are relevant to fluid flow and transfer processes in actual engineering applications. We have deliberately retained this style in the new edition. One advantage of this degree of concentration is that the text can be kept short while at the same time a large amount of ground can be covered. To this extent the book should be regarded as an introduction to the subject and should ideally be read in conjunction with other more specialized texts which deal with individual topics in greater detail and which can give comprehensive information on experimental data.

The author of the first edition would like to put on record his acknowledgment to Sir Melvill Jones for first arousing his interest in the subject and for convincing him of the importance of identifying clearly the basic physical principles in problems of aerodynamics and fluid flow. He would also like to record his debt to the late Professor T. R. C. Fox whose rigorous analytical approach exerted a profound influence on the preparation of the lecture courses in the early years of the Chemical Engineering Department at Cambridge.

The joint authors of the new third edition hope that the book will continue to be useful to a wide range of readers with interests in chemical and mechanical engineering. The revised text also covers the syllabus in Fluid Mechanics and Transfer Processes which now forms an optional subject in part IB of the Natural Sciences Tripos.

The authors wish to thank the Council of the Senate of Cambridge University and the Council of Engineering Institutions for permission to reproduce questions set in their examinations.

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R. M. N.

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CONTENTS

LIST OF SYMBOLS

a	Cross-sectional area of stream tube, radius of a pipe, velocity of sound
A	Area
b	Linear dimension, e.g. breadth of pump impeller
c	A coefficient, constant, concentration
c_A	Concentration of component (A)
c_f	Skin friction coefficient
c_p	Specific heat at constant pressure
c_v	Specific heat at constant volume, velocity coefficient
C	A constant, discharge coefficient
C_A	Molal concentration of component (A)
C_D	Drag coefficient
d	Diameter
D	Diameter
$\mathscr{D}$	Diffusion coefficient
e	Exponential constant
E	Internal energy
f	Flow component of velocity in a pump
F	Force
g	Gravitational acceleration
G	Mass velocity $= \rho u$
G_A	Mass transfer rate for (A)
h	Height, head, heat transfer factor
H	Enthalpy, dimension of heat, head
$\mathbf{i}$	Unit vector in x direction
$\mathbf{j}$	Unit vector in y direction
k	A coefficient, thermal conductivity
$\mathbf{k}$	Unit vector in z direction
K	A constant
l	Length
l'	Mixing length
L	Dimension of length, latent heat
m	Mass, hydraulic mean depth
M	Mass, dimension of mass, molecular weight, momentum

n	Number
$\mathbf{n}$	Unit vector normal
N	Number, rotational speed
N_A	Molal transfer rate for (A)
O	Order of magnitude
p	Pressure
P	Power
q	Heat flux
Q	Volumetric flow, heat quantity, rate of heat supply
r	Radius
$\mathbf{r}$	Position vector
R	Radius, gas constant
$\bar{R}$	Universal gas constant per mole
s	Distance
S	Surface area
t	Time
T	Temperature, torque, dimension of time
u, v, w	Velocity components in x, y, z directions
$\mathbf{u}$	Vector velocity
u_m	Mean velocity in a pipe
U	Velocity
v	Velocity, specific volume
$\tilde{v}$	r.m.s. velocity in turbulent flow
V	Volume
w	Velocity of whirl
W	Work
x, y, z	Space coordinates
α	An angle, coefficient, thermal diffusivity
β	An angle, coefficient
γ	Ratio of specific heats c_p/c_v
δ	Element of length, thickness of boundary layer
δ^*	Displacement thickness of boundary layer
Δ	Incremental quantity
ε	Roughness size, fraction void
η	Efficiency
θ	Angle, temperature, momentum thickness of boundary layer
Θ	Dimension of temperature
λ	A parameter, depth of flow in open channel

μ	Coefficient of viscosity
ν	Kinematic viscosity, molecular density
Π	Dimensionless ratio
ρ	Density
σ	Surface tension
τ	Skin friction, shearing stress
τ_0	Skin friction at surface or boundary
ϕ	Angle, coefficient, thermal thickness of boundary layer, potential function
ω	Angular velocity
ψ	Stream function
Ω	Angular velocity
∇	Vector operator 'nabla'

DIMENSIONLESS RATIOS

Fr	Froude number $\dfrac{U^2}{gL}$
Gr	Grashof number $\dfrac{\beta g \Delta\theta L^3}{\nu^2}$
M	Mach number U/a
Nu	Nusselt number $\dfrac{hd}{k}$
Pe	Peclet number $\dfrac{\rho U c_p d}{\kappa}$ or $\dfrac{Ud}{\alpha}$
Pr	Prandtl number $\dfrac{\mu c_p}{\kappa}$ or $\dfrac{\nu}{\alpha}$
Re	Reynolds number $\dfrac{\rho U d}{\mu}$ or $\dfrac{Ud}{\nu}$
Sc	Schmidt number $\dfrac{\nu}{\mathscr{D}}$
St	Stanton number $\dfrac{h}{\rho U c_p}$
We	Weber number $\dfrac{\rho U^2 L}{\sigma}$