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An Introduction to Engineering Fluid Mechanics

J. A. FOX

*Department of Civil Engineering
University of Leeds*

SECOND EDITION

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Contents

Preface	xi
Principal Symbols	xiii
1 Definitions and Hydrostatics	1
1.1 Basic definitions	1
1.2 Viscosity	2
1.3 Non-newtonian fluids	4
1.4 Specific mass, weight and gravity	5
1.5 Pressure at a point in a fluid	6
1.6 Pressure distribution in the atmosphere	7
1.7 Hydrostatic pressures in incompressible fluids	8
1.8 Force on an inclined plane lamina	10
1.9 Forces acting on curved surfaces	12
1.10 Surface tension	15
1.11 Manometry	16
2 Hydrodynamics	29
2.1 The continuity equation	29
2.2 The Euler equation	31
2.3 Normal strain and deformation of a fluid element	35
2.4 Rotation of a fluid element	37
2.5 The Navier-Stokes equations	38
2.6 The velocity potential	39
2.7 The stream function	40
2.8 Circulation	43
2.9 Vorticity	44
2.10 The source	46
2.11 The sink	48
2.12 The doublet	51
2.13 The vortex	52
2.14 The uniform wind	53
2.15 Combinations of flow patterns	55
2.16 Pressure distribution around a cylinder in a uniform flow	59
2.17 Forces acting on a cylinder	62
2.18 The development of transverse forces	63
2.19 The wake	68

2.20	Pressure distribution over an aerofoil	70
2.21	The graphical addition of stream functions and velocity potentials	72
2.22	The flow net	74
2.23	Percolating flows	76
3	Dimensional Analysis	82
3.1	The Buckingham π theorems	85
3.2	Construction of π groups	87
3.3	The physical significance of some commonly used groups	88
3.4	Models	90
3.5	Examples of dimensional analysis	95
3.6	Units	102
3.7	Dimensional homogeneity of equations	103
4	The Basic Equations of Engineering Fluid Mechanics	110
4.1	Continuity equation	110
4.2	The force equation	111
4.3	The energy equation	114
4.4	Flow through small orifices	116
4.5	The venturimeter	119
4.6	Notches	123
4.7	Pipe diaphragm orifices	128
4.8	The pitot tube	131
4.9	Applications of the force equation	133
4.10	The variation of the Bernoulli constant across stream lines	138
4.11	The free vortex	140
4.12	Radial flow	143
4.13	The free spiral vortex	143
4.14	The forced vortex	144
4.15	The Rankine vortex	147
4.16	Vorticity	149
5	Boundary Layer Theory	157
5.1	Formation of boundary layers	157
5.2	The Prandtl mixing-length hypothesis	159
5.3	Boundary layer separation	162
5.4	Drag on spheres	167
5.5	Secondary flow	168

6	Pipe Flow	176
6.1	Simple experiments	176
6.2	Laminar flow	178
6.3	Turbulent flow	185
6.4	The f number	187
6.5	The Prandtl mixing-length hypothesis applied to pipe flow	193
6.6	The velocity distribution in smooth pipes	193
6.7	The velocity distribution in rough pipes	195
6.8	The universal pipe friction laws	197
6.9	Losses in pipelines other than those due to pipe friction	198
6.10	The energy grade line and the hydraulic grade line	206
6.11	The energy coefficient	208
6.12	The momentum coefficient	210
6.13	Flow in pipe networks	212
6.14	Analysis of pipe networks	215
7	Open Channel Hydraulics	230
7.1	Uniform flow	230
7.2	Formulae for the Chezy C	232
7.3	The Prandtl mixing-length hypothesis applied to uniform free surface flows	234
7.4	'Economic' channels	237
7.5	Flow in circular culverts and pipes	240
7.6	Gradually varied, non-uniform flow in channels	241
7.7	The analysis of gradually varied flow	242
7.8	The specific force equation	245
7.9	The specific energy equation	246
7.10	Flow profiles	249
7.11	The hydraulic jump	253
7.12	The venturi flume	257
7.13	Broad crested weirs and bed humps	261
7.14	The sluice	262
7.15	The prediction of flow profiles in channels	264
7.16	Method of integrating the gradually varied flow differential equation	268
7.17	Surge waves in channels	270
8	Pressure Transients	283
8.1	Rigid pipe theory of waterhammer	283
8.2	Sudden valve opening at the end of a pipeline	285
8.3	Slow uniform valve closure	287

8.4	Elastic pipe theory	291
8.5	Pressure surge caused by instantaneous valve closure	297
8.6	The differential equations of waterhammer	304
8.7	Analysis of pressure transients phenomena, including pipe friction	313
8.8	Modification of the techniques to allow for pipe friction	323
8.9	Complex pipelines	326
9	Surge Tanks	338
9.1	The frictionless analysis	341
9.2	The frictional analysis	343
9.3	Complex surge tanks	347
9.4	Surge tank modelling	348
10	Rotodynamic Machines	355
10.1	Flow through rotating curved passages	355
10.2	The reaction turbine	358
10.3	Impulse turbines	368
10.4	Centrifugal pumps	374
10.5	Types of centrifugal pump	378
10.6	The dimensional analysis of rotodynamic machines	385
10.7	Unit speed, quantity and power	385
10.8	The specific speed	388
10.9	Scaling of results from model tests	391
10.10	Cavitation	392
11	Compressible Flow	405
11.1	Introduction	405
11.2	The equation of state	405
11.3	Specific heats	406
11.4	Entropy	407
11.5	The velocity of a small pressure wave at sonic velocity	409
11.6	The continuity equation	411
11.7	Conservation of momentum (Newton's second law)	413
11.8	Conservation of energy	415
11.9	Isentropic flow	415
11.10	The convergent nozzle	421
11.11	Flow through a venturimeter	424
11.12	Other types of flow	426
11.13	Isothermal flow in pipelines	427

Contents	ix
11.14 Adiabatic flow in pipelines	431
11.15 The normal shock	433
 Further Reading	 437
Index	439

Preface

This book is for undergraduates and HNC/HND students in both civil and mechanical engineering. The accent throughout has been placed upon the engineering aspects of the subject but it is hoped that the more mathematically minded reader will find sufficient to interest him.

Assumptions upon which analyses are based have been carefully specified. Any analysis is only as accurate as its underlying assumptions and so the reader should develop the habit of assessing the value of a piece of theory by considering the applicability of its assumptions in the context of the problem under examination.

Both engineers and mathematicians have contributed to the study of fluid mechanics and of recent years there has been a marked tendency to use mathematical methods in place of the empiricism that was used in the past. I believe that this trend will continue and academic courses will become progressively more mathematical in their approach.

The systems of units that have been used are the British system, which is still used in many sections of industry and in many parts of the world, and the SI system. Even though the SI system has been introduced in the UK and Europe, it is necessary for British engineers designing projects in those areas to know both systems.

At the end of each chapter questions have been included which it is hoped will be of assistance in understanding the chapter. They are set in both systems of units, the SI values being enclosed in square brackets. Some questions come from examination papers of the University of London, the University of Leeds and the Part II hydraulics examinations of the Institution of Civil Engineers, and I gratefully acknowledge permission to use them; others have been evolved for this book. The answers supplied are of course my own.

The subject is very large and it is not possible to cover every topic in detail. The student will need to read further and a list of suggested reading is included.

I would like to thank Mr J. Higgins, of the Faculty of Applied Science, the University of Leeds, who prepared the drawings.

This second edition has been extended. Chapter 8 now contains material which it is unusual to find in a general textbook of this type. The treatment of waterhammer in this chapter now covers the simpler methods of analysing slowly changing hydraulic controls and indicates how pipe friction can be included in the analysis. The graphical treatment of joints in pipelines is also

included. An additional chapter on compressible flow has been added for students wishing to study mechanical engineering. This covers most of the material usually presented in mechanical engineering courses.

Leeds, 1977

J.A.F.

Principal Symbols

As far as possible all symbols used have been defined in the text as they occur, so any ambiguities arising out of the use of the same symbol to denote different variables can be easily resolved by reference to the text. The dimensions are given in parentheses.

a	speed of a gas when expanded down to zero pressure (Chapter 11)
a and A	area of flow (L^2)
A	constant in the pump characteristic equation (Chapter 10) (LT^2)
α	angle (dimensionless)
	constant in the equation that describes the variation of μ with temperature (θ^{-1} , where θ is the dimension of temperature)
	energy coefficient (dimensionless)
b and B	breadth of a channel (L)
	surface breadth of a channel (L)
b	breadth of a lamina (L)
B	constant in the pump characteristic equation (Chapter 10)
	breadth of a runner or impeller in the axial direction (L)
β	the momentum coefficient (dimensionless)
	constant in the equation that describes how μ varies with temperature (θ^{-2})
	exit angle of a moving blade in a rotodynamic machine (dimensionless)
c or C	general constant
c	wave velocity (Chapters 6, 8 and 9) (LT^{-1})
c_p	specific heat of a gas at constant pressure (Chapter 11)
c_v	specific heat of a gas at constant volume (Chapter 11)
C_d	coefficient of discharge of an orifice, notch or weir (dimensionless)
C_D	coefficient of drag (dimensionless)
C_v	coefficient of velocity of an orifice (dimensionless)
C_c	coefficient of contraction of an orifice (dimensionless)
C_l	coefficient of lift (dimensionless)
C	Chezy constant in free-surface flows ($L^{1/2}T^{-1}$)
	constant in the pump equation (Chapter 10) (T^2L^{-5})
d	depth of a flow (L)
	pipe diameter (L)
d_s	height of opening below a sluice gate (Chapter 7) (L)
d_c	critical depth of a free-surface flow (L)
δ	boundary layer thickness (L)
δ'	laminar sublayer thickness (L)
δ^*	boundary layer displacement thickness (L)
$\bar{\delta}$	mean depth of a flow (Chapter 7) (L)
δ	small increment or decrement of a variable
Δ	a finite difference
E	specific energy (energy of flow referred to bed of flow) (L)
	Young's modulus of the pipe wall material (Chapter 8) ($ML^{-1}T^{-2}$)
E_h	ideal or hydraulic efficiency (dimensionless)
E_o	overall efficiency (dimensionless)
E_m	mechanical efficiency (dimensionless)
e	exponential constant (2.71826) (dimensionless)
η	fractional valve opening (dimensionless)
F	fraction of full open valve area
	function of (Chapter 8)

F_n	Froude number (dimensionless)
f	frequency of a vortex trail (T^{-1}) function of (Chapter 8) Darcy friction coefficient (T^{-1})
F	force (MLT^{-2}) strength of a doublet (L^2T^{-1})
ϕ	velocity potential (L^2T^{-1})
g	acceleration due to gravity (LT^{-2})
Γ	circulation around a fluid boundary (L^2T^{-1})
γ	angle of shear deformation in a solid (dimensionless) ratio of specific heats c_p/c_v (Chapter 11)
h	height of a rectangular lamina (L) potential head (pressure head plus height above datum) (L) height of a bed hump (L)
h_f	energy loss/unit weight due to friction (L)
h_i	inertia head (L)
h_m	level difference between the two menisci of a manometer (L)
H	total energy/unit of fluid referred to a horizontal datum (L) total heat or enthalpy (Chapter 11) horizontal component of force acting on a lamina (MLT^{-2})
H_s	static head (L)
I	second moment of area (L^4)
i	bed slope of a channel (dimensionless) hydraulic gradient (dimensionless)
j	energy loss/unit weight/unit length of a channel flow (dimensionless)
k	constant roughness number, Manning's, Kutta's or Strickler's (dimensionless)
k_g	radius of gyration (L)
K	bulk modulus of a fluid ($ML^{-1}T^{-2}$)
l	length of pipe (L) distance along a channel (L)
L	lift force (MLT^{-2})
λ	kineticity of a flow (Chapter 7) (dimensionless)
m	hydraulic mean radius (in pipe flow) (L) hydraulic mean depth (in free-surface flows) (L)
M	total momentum flow rate (MLT^{-1}) mach number
μ	coefficient of dynamic viscosity ($ML^{-1}T^{-1}$)
n	index (dimension variable) roughness number
N	rotational speed of a pump or turbine (T^{-1})
N_s	specific speed of a pump or turbine (dimensionless)
ν	coefficient of kinematic viscosity (L^2T^{-1})
Ω	angular velocity of a forced vortex, a rotodynamic machine or a fluid element (T^{-1})
p	pressure ($ML^{-1}T^{-2}$)
P	force (MLT^{-2}) wetted perimeter of a flow channel (L) total force acting on a curved lamina (MLT^{-2})
π	constant (3.14159) (dimensionless)
π	dimensionless groups
ψ	stream function (L^2T^{-1}) constant defining a valve characteristic parabola (Chapter 8)
q	flow per unit width of a rectangular channel (L^2T^{-1}) flow leaving per unit length of a pipe (L^2T^{-1}) flow entering or leaving a channel per unit length (Chapter 7) (L^2T^{-1})
Q	flow (L^3T^{-1}) heat transfer involved in a transaction (Chapter 11)

r	radius (L)
R	radius (L)
	area ratio (Chapter 9) (dimensionless)
	gas constant (Chapter 11)
Re	Reynolds number (dimensionless)
ρ	mass density (ML^{-3})
	pipe characteristic (Chapter 8) (ML^{-3})
s	specific gravity of a fluid (dimensionless)
	distance (L)
	slope of sides of a channel (dimensionless)
	entropy (Chapter 11)
S	specific force of a free surface flow (L^2)
σ	coefficient of surface tension (MT^{-2})
	Poisson's ratio (Chapter 8) (dimensionless)
t	time (T)
	thickness (L)
T	pipe period (T)
	temperature (Chapter 11)
τ	viscous shear stress ($ML^{-1}T^{-2}$)
τ_0	viscous shear at a boundary ($ML^{-1}T^{-2}$)
θ	angle (dimensionless)
u	local velocity (LT^{-1})
	velocity component in the x direction (LT^{-1})
	peripheral velocity of a rotating blade (LT^{-1})
u'	time varying component of velocity in x direction in turbulent flow (LT^{-1})
$\bar{u}$	steady component of velocity in x direction in turbulent flow (LT^{-1})
U	undisturbed stream velocity (LT^{-1})
v	stream velocity (LT^{-1})
	velocity component in the y direction (LT^{-1})
v'	time varying velocity component in the y direction in a turbulent flow (LT^{-1})
$\bar{v}$	mean velocity of a flow (LT^{-1})
V	velocity of a fluid particle on the centreline of a pipe velocity (LT^{-1})
	vertical component of a force acting upon a lamina (MLT^{-2})
V^*	shear velocity (LT^{-1})
V_w	velocity of a surge wave in a free-surface flow (LT^{-1})
	velocity of whirl (Chapter 10) (LT^{-1})
V_f	velocity of flow (Chapter 10) (LT^{-1})
V_r	relative velocity (Chapter 10) (LT^{-1})
w	specific weight of fluid ($ML^{-2}T^{-2}$)
	component of velocity in the z direction (MLT^{-1})
w'	time varying velocity component in z direction in turbulent flow (LT^{-1})
$\bar{w}$	steady velocity component in z direction in turbulent flow (LT^{-1})
W	weight of a fluid body (MLT^{-2})
	weight flow (MLT^{-3})
x	distance (L)
$\bar{X}$	body force acting in the x direction (MLT^{-2})
$\bar{x}$	distance along a lamina from its point of intersection with the free surface to the centroid (L)
y	distance, usually in the direction of the earth's gravity field (L)
	distance from a pipe wall (L)
Y	body force acting in the y direction (MLT^{-2})
z	elevation of a point above a datum (L)
	distance down from the surface of an area element (L)
$\bar{z}$	depth below the centroid of the cross sectional area of a flow (L)
ξ	vorticity (T^{-1})
ζ	square root of ratio of head at valve to static head (Chapter 8)