
FLUID DYNAMICS

Theory, Computation, and Numerical Simulation

Accompanied by the software library *FDLIB*

by

C. Pozrikidis

*University of California, San Diego
La Jolla, California 92093-0411
U.S.A.*

Email: cpozrikidis@ucsd.edu

Internet URL: http://stokes.ucsd.edu/c_pozrikidis



Springer Science+Business Media, LLC



Electronic Services <<http://www.wkap.nl>>

Library of Congress Cataloging-in-Publication Data

Pozrikidis, C.

Fluid dynamics: theory, computation, and numerical simulation / by C. Pozrikidis
p.cm.

"Accompanied by the software library FDLIB. "

Includes bibliographical references and index.

1. Fluid dynamics. I. Title

QA911 .P63 2001

532'.05—dc21

ISBN 978-1-4757-3325-9

ISBN 978-1-4757-3323-5 (eBook)

DOI 10.1007/978-1-4757-3323-5

2001029458

Copyright © 2001 by Springer Science+Business Media New York

Originally published by Kluwer Academic Publishers in 2001

Softcover reprint of the hardcover 1st edition 2001

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher, Springer Science+Business Media, LLC.

Printed on acid-free paper.

Table of Contents

	<i>Page</i>
Preface	ix
1. Fluid motion: Introduction to kinematics	1
1.1 Fluids and solids	1
1.2 Fluid parcels and flow kinematics	2
1.3 Coordinates, velocity, and acceleration	4
1.4 Fluid velocity and streamlines	15
1.5 Point particles and their trajectories	18
1.6 Material surfaces and elementary motions	27
1.7 Interpolation	38
2. Fluid motion: More on kinematics	49
2.1 Fundamental modes of fluid parcel motion	49
2.2 Fluid parcel expansion	61
2.3 Fluid parcel rotation and vorticity	62
2.4 Fluid parcel deformation	68
2.5 Numerical differentiation	72
2.6 Areal and volumetric flow rate	77
2.7 Mass flow rate, mass conservation, and the continuity equation	87
2.8 Properties of point particles	93
2.9 Incompressible fluids and stream functions	101
2.10 Kinematic conditions at boundaries	106
3. Flow computation based on kinematics	111
3.1 Flow classification based on kinematics	111
3.2 Irrotational flows and the velocity potential	114
3.3 Finite-difference methods	122
3.4 Linear solvers	131
3.5 Two-dimensional point sources and point-source dipoles	135
3.6 Three-dimensional point sources and point-source dipoles	149
3.7 Point vortices and line vortices	154

4. Forces and stresses	164
4.1 Body forces and surface forces	164
4.2 Traction and the stress tensor	166
4.3 Traction jump across a fluid interface	173
4.4 Stresses in a fluid at rest	181
4.5 Viscous and Newtonian fluids	185
4.6 Simple non-Newtonian fluids	194
4.7 Stresses in polar coordinates	198
4.8 Boundary condition on the tangential velocity	203
4.9 Wall stresses in Newtonian fluids	205
5. Hydrostatics	208
5.1 Equilibrium of pressure and body forces	208
5.2 Force exerted on immersed surfaces	217
5.3 Archimedes' principle	224
5.4 Shapes of two-dimensional interfaces	227
5.5 A semi-infinite interface attached to an inclined plate	231
5.6 Meniscus between two parallel plates	235
5.7 A two-dimensional drop on a horizontal plane	241
5.8 Axisymmetric shapes	246
6. Equation of motion and vorticity transport	252
6.1 Newton's second law for the motion of a parcel	252
6.2 Integral momentum balance	258
6.3 Cauchy's equation of motion	263
6.4 Euler's and Bernoulli's equations	270
6.5 The Navier-Stokes equation	281
6.6 Vorticity transport	288
6.7 Dynamic similitude, the Reynolds number, and dimensionless numbers in fluid dynamics	296
7. Channel, tube, and film flows	306
7.1 Steady flow in a two-dimensional channel	306
7.2 Steady film flow down an inclined plane	315
7.3 Steady flow through a circular or annular tube	319

7.4 Steady flow through channels and tubes with various cross-sections	327
7.5 Steady swirling flow	336
7.6 Transient flow in a channel	339
7.7 Oscillatory flow in a channel	347
7.8 Transient and oscillatory flow in a circular tube	354
8. Finite-difference methods	364
8.1 Choice of governing equations	364
8.2 Unidirectional flow; velocity/pressure formulation	366
8.3 Unidirectional flow; velocity/vorticity formulation	377
8.4 Unidirectional flow; stream function/vorticity formulation	382
8.5 Two-dimensional flow; stream function/vorticity formulation ..	386
8.6 Velocity/pressure formulation	395
8.7 Operator splitting and solenoidal projection	399
9. Flows at low Reynolds numbers	410
9.1 Flows in narrow channels	411
9.2 Film flow on a horizontal or down plane wall	424
9.3 Two-layer channel flow	436
9.4 Flow due to the motion of a sphere	443
9.5 Point forces and point sources in Stokes flow	450
9.6 Two-dimensional Stokes flow	459
9.7 Flow near corners	465
10. Flows at high Reynolds numbers	475
10.1 Changes in the structure of a flow with increasing Reynolds number	476
10.2 Prandtl boundary-layer analysis	479
10.3 Prandtl boundary layer on a flat surface	485
10.4 Von Kàrmàn's integral method	501
10.5 Instability of shear flows	512
10.6 Turbulent motion	525
10.7 Analysis of turbulent motion	539

11. Vortex motion	548
11.1 Vorticity and circulation in two-dimensional flow	549
11.2 Motion of point vortices	551
11.3 Two-dimensional flow with distributed vorticity	566
11.4 Vorticity, circulation, and three-dimensional flow induced by vorticity	581
11.5 Axisymmetric flow induced by vorticity	586
11.6 Three-dimensional vortex motion	600
12. Aerodynamics	606
12.1 General features of flow past an aircraft	607
12.2 Airfoils and the Kutta-Joukowski condition	609
12.3 Vortex panels	612
12.4 Vortex panel method	620
12.5 Vortex sheet representation	629
12.6 Point-source-dipole panels	638
12.7 Point-source panels and Green's third identity	645
<i>FDLIB</i> Software Library	651
<i>FDLIB</i> Directories	653
References	666
Subject index	668