

Contents

11	Creeping Motion Around Spheres at Rest in a Newtonian Fluid	1
11.1	Motivation	3
11.2	Mathematical Preliminaries	5
11.3	Stokes Flow Around a Stagnant Sphere	9
11.3.1	Rigid Sphere and No-Slip Condition on the Surface of the Sphere	9
11.3.2	Cunningham's Correction	14
11.3.3	Rigid Infinitely Thin Spherical Shell Filled with a Fluid of Different Viscosity	16
11.4	Oseen's Theory	22
11.4.1	Governing Equations of the Oseen Theory	22
11.4.2	Construction of a Particular Integral of (11.58)	25
11.4.3	'Stokes-Lets' and 'Oseen-Lets'	27
11.5	Theory of Lagerstöm and Kaplun	30
11.5.1	Motivation	30
11.5.2	Stokes Expansion	32
11.5.3	Oseen Expansion	34
11.5.4	Matching Procedure	35
11.6	Homotopy Analysis Method—The Viscous Drag Coefficient Computed for Arbitrary Reynolds Numbers	38
11.6.1	The Mathematical Concept	39
11.6.2	Selection of ψ_0 , \mathcal{H} , h and Approximate Solution	41
11.7	Conclusions and Discussion	43
	References	44

12	Three-Dimensional Creeping Flow—Systematic Derivation of the Shallow Flow Approximations	47
12.1	Introductory Motivation	49
12.2	Model Equations	52
12.2.1	Field Equations	52
12.2.2	Boundary Conditions	54
12.3	Scaling Procedure	56
12.4	Lowest Order Model Equations for Flow Down Steep Slopes (Strong Steep Slope Shallow Flow Approximation)	66
12.5	A Slightly More General Steep Slope Shallow Flow Approximation (Weak Steep Slope Shallow Flow Approximation)	71
12.6	Phenomenological Expressions for Creeping Glacier Ice	74
12.7	Applications to Downhill Creeping Flows	77
12.7.1	Computational Procedure	77
12.7.2	Profiles and Flows for Isothermal Conditions	79
12.7.3	Remarks for Use of the Shallow Flow Approximation for Alpine Glaciers	82
12.8	Free-Surface Gravity-Driven Creep Flow of a Very Viscous Body with Strong Thermomechanical Coupling—A Rigorous Derivation of the Shallow Ice Approximation	84
12.8.1	The Classical Shallow Flow Approximation	84
12.8.2	Applications	97
12.9	Discussion and Conclusions	107
	References	108
13	Shallow Rapid Granular Avalanches	113
13.1	Introduction	115
13.2	Distinctive Properties of Granular Materials	119
13.2.1	Dilatancy	120
13.2.2	Cohesion	121
13.2.3	Lubrication	122
13.2.4	Liquefaction	125
13.2.5	Segregation, Inverse Grading, Brazil Nut Effect	129
13.3	Shallow Flow Avalanche Modeling	131
13.3.1	Voellmy's Avalanche Model	132
13.3.2	The SH Model, Reduced to Its Essentials	134
13.4	A Three-Dimensional Granular Avalanche Model	141
13.4.1	Field Equations	141
13.4.2	Curvilinear Coordinates	144
13.4.3	Equations in Dimensionless Form	147
13.4.4	Kinematic Boundary Conditions	149
13.4.5	Traction Free Condition at the Free Surface	150
13.4.6	Coulomb Sliding Law at the Base	150
13.4.7	Depth Integration	151

13.4.8	Ordering Relations	154
13.4.9	Closure Property	155
13.4.10	Nearly Uniform Flow Profile	158
13.4.11	Summary of the Two-Dimensional SH Equations	159
13.4.12	Standard Form of the Differential Equations	162
13.5	Avalanche Simulation and Verification with Experimental Laboratory Data.	165
13.5.1	Introduction.	165
13.5.2	Classical and High Resolution Shock Capturing Numerical Methods	165
13.6	Attempts of Model Validation and Verification of Earthquake and Typhoon Induced Landslides.	184
	References	192
14	Uniqueness and Stability	197
14.1	Introduction.	198
14.2	Kinetic Energy of the Difference Motion.	201
14.3	Uniqueness	205
14.4	Stability	206
14.5	Energy Stability of the Laminar Channel Flow	210
14.6	Linear Stability Analysis of Laminar Channel Flow	216
14.6.1	Basic Concepts	216
14.6.2	The Orr–Sommerfeld and the Rayleigh Equations.	218
14.6.3	The Eigenvalue Problem	221
	References	224
15	Turbulent Modeling.	227
15.1	A Primer on Turbulent Motions.	229
15.1.1	Averages and Fluctuations.	231
15.1.2	Filters	233
15.1.3	Reynolds Versus Favre Averages	234
15.2	Balance Equations for the Averaged Fields	236
15.3	Turbulent Closure Relations	239
15.3.1	Reynolds Stress Hypothesis and Turbulent Dissipation Rate.	239
15.3.2	Averaged Density Field ρ	240
15.3.3	Turbulent Heat Flux q_t and Turbulent Species Mass Flux j_t	241
15.3.4	One- and Two-Equation Models.	245
15.4	$k - \varepsilon$ Model for Density Preserving and Boussinesq Fluids.	247
15.4.1	The Balance Equations	247
15.4.2	Boussinesq Fluid Referred to a Non-inertial Frame	252

15.4.3	Summary of the $k - \varepsilon$ Equations	254
15.4.4	Boundary Conditions	256
15.4.5	Closing Remarks	259
	References	260
16	Turbulent Mixing Length Models and Their Applications to Elementary Flow Configurations.	263
16.1	Motivation/Introduction.	265
16.2	The Turbulent Plane Wake	271
16.3	The Axisymmetric Isothermal Steady Jet.	278
16.4	Turbulent Round Jet in a Parallel Co-flow.	295
16.5	A Study of Turbulent Plane Poiseuille Flow	300
16.6	Discussion	310
	Appendix A: Prandtl's Mixing Length	313
	References	315
17	Thermodynamics—Fundamentals	317
17.1	Concepts and Some Historical Remarks	320
17.2	General Notions and Definitions	337
17.2.1	Thermodynamic System	337
17.2.2	Thermodynamic States, Thermodynamic Processes.	341
17.2.3	Extensive, Intensive, Specific and Molar State Variables.	345
17.2.4	Adiabatic and Diathermic Walls	347
17.2.5	Empirical Temperature, Gas Temperature and Temperature Scales.	349
17.3	Thermal Equations of State	353
17.3.1	Ideal Gas.	354
17.3.2	Real Gases	355
17.3.3	The Phenomenological Model of van der Waals.	357
17.4	Reversible and Irreversible Thermodynamic Processes	362
17.4.1	Diffusion.	362
17.4.2	Reversible Expansion and Compaction of a Gas.	366
17.5	First Law of Thermodynamics	366
17.5.1	Mechanical Energies.	366
17.5.2	Definitions, Important for the First Law	370
17.5.3	Caloric Equations of State for Fluids and Gases.	378
17.5.4	Simple Applications of the First Law	382
17.5.5	Specific Heats of Real Gases	390
17.6	The Second Law of Thermodynamics—Principle of Irreversibility.	392
17.6.1	Preamble.	392
17.6.2	The Second Law for Simple Adiabatic Systems	395

17.6.3	Generalizations for Non-adiabatic Systems.	410
17.7	First Applications of the Second Law of Thermodynamics	412
	References	418
18	Thermodynamics—Field Formulation	421
18.1	The Second Law of Thermodynamics for Continuous Systems	423
18.2	Two Popular Forms of the Entropy Principle.	429
18.2.1	Entropy Principle 1: Clausius–Duhem Inequality	430
18.2.2	Entropy Principle of Ingo Müller	440
18.3	Thermal and Caloric Equations of State	452
18.3.1	Canonical Equations of State	452
18.3.2	Specific Heats and Other Thermodynamic Quantities	458
18.3.3	Application to Ideal Gases.	464
18.3.4	Isentropic Processes in Caloric Ideal Gases	466
18.4	Thermodynamics of an Inviscid, Heat Conducting Compressible Fluid—Toward a Hyperbolic Heat Conduction Equation	467
18.4.1	The Coleman–Noll Approach	468
18.4.2	The Rational Thermodynamics of Ingo Müller.	472
	Appendix: Proof of Liu’s Theorem	479
	References	481
19	Gas Dynamics	483
19.1	Introductory Remarks	485
19.2	Propagation of Small Perturbations in a Gas	486
19.2.1	Fundamental Equations	486
19.2.2	Plane and Spherical Waves	493
19.2.3	Eigen Oscillations Determined with Bernoulli’s Method	502
19.3	Steady, Isentropic Stream Filament Theory	506
19.4	Theory of Shocks.	520
19.4.1	General Concepts	520
19.4.2	Jump Conditions	523
19.4.3	Stationary Shocks in Simple Fluids Under Adiabatic Conditions.	527
19.5	Final Remarks	536
	References	536
20	Dimensional Analysis, Similitude and Physical Experiments at Laboratory Scale	537
20.1	Introductory Motivation	541
20.1.1	Dimensional Analysis	541
20.1.2	Similitude and Model Experiments	543

20.1.3	Systems of Physical Entities	545
20.2	Theory of Dimensional Equations	547
20.2.1	Dimensional Homogeneity.	547
20.2.2	Buckingham's Theorem	551
20.2.3	A Set of Examples from Fluid Mechanics	556
20.3	Theory of Physical Models	571
20.3.1	Analysis of the Downscaling of Physical Processes.	571
20.3.2	Applications	577
20.4	Model Theory and Differential Equations	583
20.4.1	Avalanching Motions down Curved and Inclined Surfaces	584
20.4.2	Navier–Stokes–Fourier–Fick Equations	584
20.4.3	Non-dimensionalization of the NSFF Equations	586
20.5	Discussion and Conclusions	591
	Appendix A: Algebraic Theory of Dimensional Analysis	592
	References	605
	List of Biographies	609
	Name Index	611
	Subject Index	617

Fluid and Thermodynamics

Volume 2: Advanced Fluid Mechanics and

Thermodynamic Fundamentals

Hutter, K.; Wang, Y.

2016, XX, 633 p. 196 illus., 50 illus. in color., Hardcover

ISBN: 978-3-319-33635-0