



Index

- θ - β - M relation, 457
- Acceleration, 4
- Acoustic kinetic energy, 391
- Acoustic potential energy, 390
- Acoustic power, 389
- Acoustic theory, 384
- Added mass
 - for cylinder, 146
 - for sphere, 189
- Analytic function, 123
- Angular momentum
 - balance of, 15
 - control volume form, 15
 - implication of, 15
- Area-velocity relation, 472
- Bernoulli's equation, 65
- Bipolar cylindrical coordinates, 257
- Blasius force theorems, 142
- Blasius solution, 330
- Body force, 12
 - conservative, 24
 - transformation relation, 19
- Boundary conditions
 - dynamical, 42
 - temperature, 52
 - velocity, 39
- Boundary layer
 - definition, 326
 - equations, 327
 - thermal, 343
 - uniform flow over a flat plate, 330
- Boundary-layer separation, 336
- Bulk viscosity, 32
- Buoyancy
 - center of, 109
 - force, 108
- Capillary waves, 209
- Cauchy stress tensor, 13
- Cauchy–Gorsat theorem, 124
- Cauchy–Riemann equations, 121, 123
- Cauchy's theorem, 13
- Center of buoyancy, 109
- Center of pressure, 105
- Channel flow, 270
- Characteristic curves, 220, 483
- Choking flow, 440, 476
- Circle theorem, 151
- Circulation, 8
- Clausius–Duhem inequality, 26
- Coleman–Mizel theorem, 27
- Complex function
 - analytic, 123
 - Cauchy–Gorsat theorem, 124
 - directional derivative of, 123
 - Laurent series, 124
 - residue theorem, 125
 - singular point of, 125
- Complex potential
 - definition, 124
 - examples, 126
- Complex velocity, 124
- Conformal mapping
 - definition, 154
 - Joukowski transformation, 155
 - Schwartz–Cristoffel transformation, 158
- Contact angle, 45
- Contact discontinuity, 484
- Convective derivative, 4
- Couette flow
 - steady, 246
- Creeping flows, 352
 - internal, 352
 - Three-Dimensional, 357
- Curved surface
 - center of pressure, 107
 - hydrostatic force on, 106
- D'Alembert paradox, 137, 183
- Dam breaking problem, 227
- Deformation gradient, 3
- Detached shock wave, 459

566 Index

- Dilatational viscosity coefficient, 31
- Dimensionless parameters, 53
- Dispersion relation, 207, 209
- Displacement thickness, 338
- Domain of dependence, 224
- Doublet
 - three-dimensional, 179
 - two-dimensional, 129
- Drag coefficient, 334, 347
- Drag
 - skin-friction, 468
 - wave, 468
- Dynamic viscosity coefficient, 31

- Eckert number, 54
- Ekman layer, 313
- Elliptic equations, 39
- Energy equation, 25
 - Newtonian fluid, 36
 - perfect gas, 35
- Enthalpy
 - definition, 23
 - state variable, 34
- change for perfect gas, 36
- equation of state, 33
- governing differential equation
 - in fluid, 34
 - material rate of change in fluid, 34
- Equipresence
 - consequences of adopting, 30
 - principle of, 27
- Euler equations, 119
- Eulerian derivative, 4
- Eulerian description, 2, 3
- Expansion wave, 451

- Falkner–Skan solutions, 334
- Finite waves, 217, 482
- First integral of the momentum
 - equation, 56
 - rotating frame, 62
- Flow separation
 - in channel flow, 273
- Flow
 - around a sphere, 182
 - around a wedge, 131
 - axial laminar, 256
 - between axially symmetric bodies, 371
 - between rotating cylinders, 273
 - choking, 440, 476
 - compressible
 - one-dimensional equations, 382
 - through variable-area ducts, 470
- Couette, 246
- down an incline, 249
- fully developed, 242
- homentropic, 34
- hypersonic, 381
- in a converging or diverging channel, 270
- in a sector, 130
- inviscid, 29
- isentropic, 34
- laminar, 54
- over a bump, 78
- over a flat plate, 76, 330
- past a cylinder with point vortex
 - at the center, 148
- past a cylinder, 73
- Poiseuille, 248, 250
- potential, 119
- subsonic, 381
- supersonic, 381
- through a sprinkler, 63
- transonic, 381
- turbulent, 54
- two-dimensional with vorticity, 171
- uniform, 178
- Fluid
 - constitutive relations, 26
 - definition of, 21
 - incompressible, 11
 - inviscid, 29
 - isotropic, 21
 - Newtonian, 31
 - Reiner–Rivlin, 31
 - symmetry group, 22
 - with short-range memory, 27
- Fluid–fluid interface, 41
- Force
 - body, 12
 - buoyancy, 108
 - on a cylinder in inviscid fluid, 137, 145, 181
 - traction, 12
- Fourier law of heat conduction, 32
- Free energy, 26
- Free-streamline theory, 162
- Friction coefficient, 355
- Froude number, 54, 82
- Fully developed flow, 242

- Galilean transformation, 19

- Gas constant, 35
- Gegenbauer functions, 360
- Gerstner waves, 237
- Gibbs relation, 33
- Governing equations
 - elliptic, 39
 - hyperbolic, 39
 - in cylindrical coordinate system, 492
 - in spherical coordinate system, 494
 - nature of, 38
 - parabolic, 39
- Gravity waves, 210
- Group velocity, 214
 - capillary waves, 216
 - deep water waves, 216
 - shallow water waves, 216
- Head loss
 - definition, 25
- Heat conduction inequality, 31
- Heaviside formula, 508
- Helmholtz equation, 390
 - axisymmetric solutions, 421
 - polar coordinates solution, 426
- Helmholtz's vorticity equation, 72
- Hodograph transformation, 163
- Homentropic flow, 34
- Hydraulic jump
 - moving, 234
 - stationary, 231
- Hydrostatics, 103
- Hyperbolic equations, 39
- Hypersonic flow, 381
- Ideal fluid
 - definition, 119
 - governing equations, 119
- Images
 - method of, 139
- Impulse turbine, 88
- Incompressible fluid, 11
- Internal energy, 23
 - material rate of change, 25
 - state variable, 34
- Inviscid fluid, 29
- Isentropic flow, 34
 - one-dimensional relations, 434
 - relation for perfect gas, 36
- Jet
 - impacting on a moving plate, 83
 - through an orifice, 162
- Joukowski transformation, 155
- Kelvin's circulation theorem, 70
- Kinematic viscosity coefficient, 31
- Kutta condition, 157
- Kutta–Joukowski law, 151
- Lagrangian description, 2, 3
- Laminar flow, 54
- Laplace equation, 120, 121
 - General solution, 174
 - Laurent series, 124
 - Legendre equation, 175
 - Legendre functions, 176
 - Lift force
 - on a cylinder, 151
- Linear momentum
 - balance of, 12
 - control volume form, 13
 - differential form, 13
 - first integral, 56
- Lubrication theory, 352
- Mach cone, 453
- Mach number, 387
- Mach wave, 452
- Mass conservation
 - control volume form, 11
 - differential equation form, 11
 - Eulerian form, 11
 - Lagrangian form, 11
- Material coordinates, 3
- Material derivative, 3
- Material frame-indifference, 15
- Material volume, 9
- Mechanical dissipation inequality, 31
- Mechanical energy balance
 - control volume form, 23
 - differential form, 23
- Mechanical energy balance, 23
- Method of characteristics, 223, 483
 - example, 227, 484
- Modified pressure, 243
- Momentum thickness, 77, 338
- Navier–Stokes equations, 36
- Newtonian fluid, 31
 - summary of governing equations, 37
- Noninertial frames, 19
- Normal shock

568 Index

- moving, 444
- reflected, 446
- stationary, 442
- structure of, 447
- width of, 451
- Normal shock, 442
- No-slip condition, 40
 - relaxation for inviscid fluids, 41
- Nusselt number, 54
- Oblique shock wave, 451
- Ocean currents, 313
- Oseen equation, 379
- Parabolic equations, 39
- Particle derivative, 3
- Pathline, 5
- Peclet number, 54
- Pelton turbine, 90
- Phase velocity, 206
 - deep water waves, 210
 - shallow water waves, 210
- Pitot tube, 443
- Point vortex, 128
- Poiseuille flow, 248, 250
 - between concentric cylinders, 256
 - force exerted, 252
 - head loss in, 251
 - through circular pipe, 253
 - through elliptic conduit, 260
 - through rectangular conduit, 266
- Poisson equation, 245
- Potential flow
 - definition, 119
 - kinetic energy, 185
 - three-dimensional, 173
 - two-dimensional, 120
- Potential function
 - examples, 178
 - three-dimensional flow, 174
 - two-dimensional flow, 119
- Prandtl number, 54
- Prandtl–Meyer expansion waves, 462
- Pressure coefficient, 136
- Pressure gradient
 - adverse, 327
 - favorable, 327
- Pressure
 - barotropic, 56
 - center of, 105
 - mean, 30
 - modified, 243
 - stagnation, 435
 - thermodynamic
 - equation of state for perfect gas, 35
 - thermodynamic
 - equation of state, 33
 - thermodynamic, 29
 - total, 435
- Pulsatile flow, 295
- Rankine oval, 133
- Rate-of strain tensor, 6
- Rate-of-deformation tensor, 6
- Rayleigh–Plesset equation, 279
- Reflected shock wave, 446
- Reiner–Rivlin fluid, 31
- Residue theorem, 125
- Reynolds equation, 313
- Reynolds number, 54
- Rocket motion, 87
- Rodrigues formula, 176
- Schwartz–Cristoffel transformation, 158
- Separation point of boundary layer, 327
- Shear viscosity coefficient, 31
- Shock wave
 - detached, 459
- Shock-expansion theory, 465
- Similarity solution
 - Falkner–Skan solutions, 334
 - squeeze-film flow, 309
 - uniform flow over a flat plate, 331
- Singular point, 125
- Sink
 - three-dimensional, 178
 - two-dimensional, 127
- Skin-friction drag, 468
- Sommerfeld radiation condition, 387
- Sound
 - speed, 386
- Source
 - three-dimensional, 178
 - two-dimensional, 127
- Spatial coordinates, 3
- Specific enthalpy, 23
- Specific heat
 - at constant pressure, 34
 - at constant volume, 34
 - difference, 34
 - ratio, 35
- Specific volume, 23

- Speed of sound, 386
- Spherical bubble
 - drag force on, 367
 - motion of, 365
- Sprinkler, 63
- Squeeze-film flow, 306
 - with rotation, 311
- Stagnation pressure, 435
- Stagnation-point flow, 267
- Standing waves, 210
- State equation, 29
- Stokes' first problem, 219
- Stokes' law, 364
- Stokes' paradox, 378
- Stokes' second problem, 279
- Streak-line, 5
- Stream function
 - two-dimensional flow, 121
 - three-dimensional flow, 176
- Streamline, 5
- Stress coefficient, 3331
- Stress tensor
 - symmetric, 15
- Strouhal number, 54
- Subcritical approach, 82
- Subsonic flow, 381
- Supercritical approach, 82
- Supersonic flow, 381
- Surface tension, 42
 - spinning drop method, 47
- Tensor
 - divergence theorem, 1
 - Stokes' theorem, 2
- Terminal velocity, 367
- Thermal boundary layer, 343
- Thermodynamics
 - first law, 23
 - control volume form, 23
 - differential form, 25
 - second law
 - differential form, 26
 - integral form, 26
 - statement of, 26
- Total derivative, 4
- Total pressure, 435
- Traction
 - in fluid, 30
- Transonic flow, 381
- Traveling waves
 - at the interface of two liquids, 211
- Turbine
 - impulse, 88
 - Pelton, 90
 - wind-driven, 92
- Turbulent flow, 54
- Unidirectional steady flow, 246
- Unsteady flow
 - Stokes' first problem, 279
- Upthrust, 108
- Velocity gradient, 5
- Velocity, 4
- Virtual mass
 - for cylinder, 146
 - for sphere, 189
- Viscosity coefficient
 - dynamic, 31
 - kinematic, 31
 - shear, 31
- Viscosity
 - bulk, 32
- Viscous dissipation, 29
- Viscous stress, 28
- Von Karman momentum integral, 76, 339
- Vortex line, 8
- Vortex tube, 8
- Vorticity tensor, 6
- Vorticity vector, 7
- Wave drag, 468
- Wave equation, 219, 384
- Waves
 - capillary, 209
 - characteristic curves, 220
 - deep water approximation, 209
 - dispersion relation, 207, 209
 - finite, 217, 482
 - governing equations, 203
 - gravity, 210
 - group velocity, 214
 - method of characteristics, 223
 - phase velocity, 206
 - shallow water approximation, 209
 - small amplitude & two-dimensional, 203
 - standing, 211
 - time period, 205
 - traveling
 - at the interface of two liquids, 211

570 Index

particle paths, 207	Weber number, 54
stream function, 208	Wind turbine, 92
wave equation, 219	
wavelength, 205	Zone of action, 453
wavenumber, 205	Zone of silence, 453