

Subject Index

A

Aortic valve, 458
 regurgitation, 469
 stenosis, 469

B

Bed friction, 358
Biofluid dynamics
 aortic valve, 458
 domain discretization
 boundary layer meshing, 473
 surface meshing, 472
 flow solution, 473, 476
 human arterial system, flow in, 451–452
 coronary flow, 456
 heart, 452
 reflections, 458
 image-based subject-specific flow modeling
 geometrical potential force (GPF), 471–472
 image segmentation, 471
 numerical solution, 464
 aortic valve regurgitation, 469
 aortic valve stenosis, 469
 cardiomyopathy, 469
 coronary arteriosclerosis, 469
 exercise, 468
 initial and boundary conditions, 472
 initialization, 464–466
 terminal vessels, 462
 vessel branching, 460
Boundary conditions, 489
Boundary data, 486
Boundary layer–inviscid flow coupling
 coupling techniques, 515, 517
 direct couplings, 515
 semi-inverse couplings, 515
Boussinesq assumption, 285
Bristol channel, 334
Buoyancy driven flows, 215

C

Cardiomyopathy, 469
Carotid artery, segmentation of, 472
Characteristic-based split (CBS) algorithm
 artificial compressibility

 for steady problems, 103
 in transient problems, 104
Babuška-Brezzi (BB) restrictions,
 circumvention of, 106
boundary conditions
 discretization using, 112
 fictitious boundaries, 110
 real boundaries, 112
data input module, 486
 boundary data, 486
 data and flags, 487
 mesh data, nodal coordinates and
 connectivity, 486
 preliminary subroutines and checks, 487
first-order pressure error, elimination of, 110
fully explicit form, 100
governing equations, nondimensional
 form of, 89
inviscid problem, two- and single-step
 algorithms on, 114
mass diagonalization, 99
output module, 490
pressure error, dual time stepping to remove, 116
quasi- (nearly) implicit form, 101
semi-implicit form, 100
single-step version, 107
solution module, 487
 boundary conditions, 489
 convergence to steady state, 490
 shock capture, 488
 simultaneous equations, semi-implicit form, 490
 steps, 489
 time step, 488
spatial discretization and solution procedure, 94
split, general remarks, 90
split, temporal discretization, 91
splitting error, 109
time step limits, evaluation of, 101
Closed domains, finite element models, 356–357
Compressible flows, 298
Compressible high-speed gas flow
 boundary conditions, subsonic and supersonic
 flow, 227
 Euler equation, 228
 Navier-Stokes equations, 229
 Euler equation, preliminary examples for, 234
 Euler problems, adaptive refinement and shock
 capture in, 238

- h*-refinement process and mesh enrichment, 243
 - steady-state two-dimensional problems, *h*-refinement and remeshing in, 245
 - governing equations, 226
 - inviscid Euler solution coupling, boundary layer, 271
 - numerical approximations and the CBS algorithm, 230
 - shock capture, 231
 - residual-based methods, 233
 - second derivative-based methods, 232
 - variable smoothing, 234
 - steady state, three-dimensional inviscid examples in, 246
 - complete aircraft, flow patterns, 253
 - THRUST, supersonic car, 255
 - three-dimensional viscous problems, 271
 - transient two- and three-dimensional problems, 256
 - viscous problems, in two dimensions, 260
 - both shock and boundary layer, adaptive refinement in, 262
 - boundary layers and shocks, special adaptive refinement for, 264
 - Conservation of energy, 90, 128
 - Conservation of mass, 89, 127
 - Conservation of momentum, 89, 127
 - Constant porosity medium, 319
 - Convection-diffusion equations
 - vector-valued variables
 - Taylor-Galerkin method, 499
 - two-step predictor-corrector methods, 501
 - Convection-diffusion-reaction equation
 - boundary conditions for, 78
 - characteristic-based methods
 - characteristic-Galerkin procedures, 58
 - mesh updating and interpolation methods, 57
 - radiation, boundary conditions, 66
 - simple explicit characteristic-Galerkin procedure, 60
 - nonlinear waves and shocks, 71
 - pure convection, treatment of, 76
 - scalar variables, Taylor-Galerkin procedures for, 70
 - steady-state condition, 71
 - steady-state problem, multiple dimension, 49
 - GLS and FIC, 53
 - streamline (upwind) Petrov-Galerkin weighting (SUPG), 49
 - steady-state problem, one dimension
 - balancing diffusion in, 43
 - FIC, 47
 - GLS, 45
 - Petrov-Galerkin methods, 39
 - subgrid scale (SGS) approximation, 46
 - variational principle in, 43
 - transients
 - mathematical background, 54
 - possible discretization procedures, 55
 - Convection/wave refraction, 372
 - Convective acceleration effects, 1
 - Coronary arteriosclerosis, 469
- ## D
- Dam break, 334
 - Data, and flags, 487
 - Data input module, 486
 - Delaunay graph method, 444
 - Detached eddy simulation (DES), 305
 - Direct numerical simulation (DNS), 306
 - Discontinuous Galerkin finite elements (DGFE), 414
 - Discretization procedure, 315
 - Domain discretization
 - boundary layer meshing, 473
 - surface meshing, 472
 - Drag calculation, 497
 - Drying areas, 346
 - Dual time stepping approach, 90, 117
 - Dynamic viscosity, 5
- ## E
- Edge-based finite element
 - formulation, 511
 - Electromagnetic scattering problems, 392
 - Element formulation, recasting of, 252
 - Ellipsoidal type infinite elements, 368
 - Energy conservation, 9, 88
 - Energy transfer, 9
 - Engineering judgement, 238
 - Enrichment functions, 398
 - Equation of state, 90
 - Euler equations, 10–11
 - Exploding pressure vessel, 257
- ## F
- FIC. *See* Finite increment calculus (FIC)
 - Finite element formulation

- of fluid equations, 437–438
- of solid dynamics, 438
- Finite elements incorporating wave shapes, 392, 394
 - discontinuous enrichment method, 398–399
 - products of polynomials and waves, 394–395
 - sums of polynomials and waves, 397–398
 - T-complete systems, 404
 - Trefftz-type finite elements, 401
 - ultra weak formulation, 399–400
- Finite increment calculus (FIC), 47, 53
- Finite volume technique, 2
- Flow formulation, 166
- Flow heat transfer
 - discretization procedure, 315
 - forced convection, 316–318
 - generalized porous medium flow approach, 310–313
 - natural convection, 318–319, 321
- Flow solution, 473, 476
- Fluid dynamics
 - finite volume approximation, 25
 - Galerkin and finite elements, 18
 - general remarks and classification of, 1
 - governing equations of
 - boundary conditions, 10
 - constitutive relations for, 6
 - energy conservation and equation of state, 8
 - mass conservation, 7
 - momentum conservation: dynamic equilibrium, 7
 - Navier-Stokes and Euler equations, 10
 - velocity/strain rates and stresses in, 5
 - inviscid/incompressible flow, 12, 14
 - velocity potential solution, 12
 - strong and weak forms, 15
 - weak form of equations, 16
 - weighted residual approximation, 17
- Fluid–structure interaction
 - multidimensional problems, 435
 - equations and discretization, 435–437
 - mesh moving procedures, 441–442
 - segregated approach, 440
 - one-dimensional fluid–structure interaction, 424
 - boundary conditions, 429
 - characteristic analysis, 427–428
 - equations, 424–425
 - results, 433
 - solution method, Taylor-Galerkin method, 430–431

- Forced convection, 316–318
- Free surface flows
 - arbitrary-Lagrangian-Eulerian (ALE) methods, 197, 210
 - implementation, 211
- Eulerian methods, 197, 200
 - hydrostatic adjustment, 203
 - mesh regeneration methods, examples using, 204
 - mesh updating/regeneration methods, 202
- Lagrangian methods, 196–197

G

- Galerkin least-squares approximation (GLS), 45, 53
- Gauss-Lobatto/Gauss-Chebyshev-Lobatto schemes, 414
- Generalized porous medium flow approach, 310–313. *See also* Flow heat transfer
- Geometrical potential force (GPF), 471–472
- GLS. *See* Galerkin least-squares approximation (GLS)

H

- Helmholtz wave equation, 332–333
- Horizontal velocity component distributions, 133
- Human arterial system, flow in, 451–452
 - coronary flow, 456
 - heart, 452
 - reflections, 458
- Hypersonic inviscid flow, 246

I

- Incompressibility constraint, 1
- Incompressible flow, 12
- Incompressible Newtonian laminar flows
 - adaptive mesh refinement
 - element elongation, 146
 - example of, 149
 - first derivative (gradient) based refinement, 149
 - local patch interpolation, superconvergent values, 145
 - nodes second derivatives, estimation of, 146
 - second gradient (curvature) based refinement, 143
 - variables, choice of, 149
 - basic equations, 127

- incompressible flows, CBS algorithm for
 - fully explicit artificial compressibility form, 129
 - quasi-implicit solution, 139
 - semi-implicit form, 129
 - slow flows, mixed and penalty formulations
 - incompressible elasticity, analogy with, 151
 - mixed and penalty discretization, 151
 - transient problems, adaptive mesh generation for, 149
 - Incompressible non-Newtonian flows
 - metal and polymer forming
 - changing boundaries, transient problems with, 170
 - elastic spring-back and viscoelastic fluids, 175
 - forming, steady-state problems of, 167
 - viscoplasticity and plasticity, 163
 - transient metal forming, direct displacement approach to, 186
 - viscoelastic flows, 178
 - governing equations, 180
 - Infinite elements, 366
 - accuracy of, 371
 - ellipsoidal type infinite elements, 368
 - mapped periodic (unconjugated) infinite elements, 366
 - Trefftz-type infinite elements, 372
 - wave envelope (or conjugated) infinite elements, 369–370
 - Intel Nehalem quad-core, 140
 - Internal carotid artery (ICA), 473
 - Internal-external subdivision, 102
 - Interpolation error, 143
 - Inviscid engine intake, 254
 - Inviscid flow, 12, 238, 246
 - Inviscid flow past full aircraft, 253
 - Inviscid shock interaction, 246
 - Isothermal flow, 236
- K**
- $\kappa - l$ model, 290
 - Kolmogorov length scale, 283
 - Kolmogorov velocity, 283
 - Kutta-Joukowski condition, 209
- L**
- Large eddy simulation (LES), 286, 303–304
 - Lawrence Livermore National Laboratory, 187
 - Lid-driven cavity, incompressible flow in, 129
 - Linear tetrahedron, 509
 - Linear triangles, 509
 - Local time stepping, 101
 - Long and medium waves
 - bed friction, 358
 - closed domains, finite element models, 356–357
 - convection and wave refraction, 372
 - ellipsoidal type infinite elements, 368
 - and equations, 355
 - infinite elements, 366
 - infinite elements, accuracy of, 371
 - linking to exterior solutions, 375
 - linking to boundary integrals, 376
 - linking to series solutions, 376
 - local nonreflecting boundary conditions (NRBCs), 363, 365
 - mapped periodic (unconjugated) infinite elements, 366
 - modeling surface waves, 358
 - short-wave problem, 359
 - stokes waves, 381–383
 - three-dimensional effects, 377
 - cnoidal and solitary waves, 381
 - large-amplitude water waves, 379
 - transient problems, 374
 - Trefftz-type infinite elements, 372
 - unbounded domains, 359
 - domain integrals, 362
 - incident waves, 362
 - nodal values, 362
 - wave diffraction, 360–361
 - wave problems, 359
 - unbounded problems, 362
 - wave envelope (or conjugated) infinite elements, 369–370

M

- Mapped periodic (unconjugated) infinite elements, 366
- Mass conservation, 87
- Mass-weighted (Favre) time averaging, 300
- Maxwell model, 178
- Mesh data, nodal coordinates and connectivity, 486
- Mesh moving procedures, 441–442
- Mesh updating, 203
 - and interpolation methods, 57
- Modeling surface waves, 358
- Momentum conservation, 8, 88
- Monotonically integrated LES (MILES), 286, 305
- Multidimensional problems, 435
 - equations and discretization, 435–437

- finite element formulation of fluid equations, 437–438
- finite element formulation of solid dynamics, 438
- monolithic fluid–structure interaction formulation, 439
- mesh moving procedures, 441–442
 - Delaunay graph method, 444
 - Laplacian smoothing, 445
 - solution to partial differential equations, 444
 - spring analogy, 442–443
- segregated approach, 440
- Multigrid method, 252, 519–520
- Multiple wave speeds, 504

N

- Natural convection, 318–319, 321
- Navier-Stokes equations, 10–11, 309, 328
 - in nonconservative form, 495
- Newton-Cotes integration scheme, 412–413
- Nondimensional scales, 313
- Nonlinear waves, and shocks, 71
- Nonreflecting boundary conditions (NRBCs), 363, 365
- Numerical approximation, 332–333

O

- One-dimensional fluid–structure interaction, 424
 - boundary conditions, 429
 - prescribed forward area, pressure, and velocity, 429
 - characteristic analysis, 427–428
 - equations, 424–425
 - results, 433
 - solution method, Taylor-Galerkin method, 430–431
- One-equation models, 287
- Output module, 490

P

- Parallel computation, 252
- Partition of unity finite elements (PUFE), 397
- Periodic wave, 334
- Petrov-Galerkin methods, 39
 - weighting functions, continuity requirements for, 42
- Preliminary subroutines and checks, 487

Q

- Quasi-implicit forms, 315
- Quasi-implicit solution, 139

R

- Reynolds-averaged Navier-Stokes (RANS), 286
- Riemann shock tube, 235

S

- Sailing boat, 209
- Scalar variables, Taylor-Galerkin procedures for, 70
- Secant viscosity, 163–164
- Second-order Runge-Kutta scheme, 503
- Self-adjoint differential equations, 493
- Semi-implicit forms, 198, 315
- Semi-inverse coupling, 515
- Severn Estuary, tsunami wave in, 339
- Shallow-water problems
 - basis of, 328–331
 - drying areas, 346
 - numerical approximation, 332–333
 - shallow-water transport, 346–348
 - steady-state solutions, 343
 - transient one-dimensional problems, 334
 - tsunami waves, 339
 - two-dimensional periodic tidal motions, 344–345
- Shallow-water transport, 346–348
- Shock capture, 488
- Short waves
 - background, 389–390
 - developments in, 391
 - discontinuous Galerkin finite elements (DGFE), 414
 - electromagnetic scattering problems, 392
 - finite elements incorporating wave shapes, 392, 394
 - discontinuous enrichment method, 398–399
 - products of polynomials and waves, 394–395
 - sums of polynomials and waves, 397–398
 - T-complete systems, 404
 - Trefftz-type finite elements, 401
 - ultra weak formulation, 399–400
- problem, 359
- refraction
 - caused by flows, 410
 - wave speed refraction, 405–406
- spectral finite elements for, 412–413
- wave modeling, errors in, 391
- Shuttle launch, 259

Simple explicit characteristic-Galerkin procedure, 60
 Simultaneous equations, semi-implicit form, 490
 Solitary wave, 334
 propagation, 212
 Solution method, Taylor-Galerkin method, 430–431
 Solution module, 487
 Spalart-Allmaras model, 287–288, 290, 521
 Spring analogy, 442–443
 Steady-state flow, 167
 Steady-state rolling process
 with thermal coupling, 170
 Steady-state solutions, 343
 Stokes waves, 381–383
 Stream function, 14, 498
 Stream traces, and pressure contours, 132
 Subgrid scale (SGS) approximation, 46
 Submerged hydrofoil, 204
 Subsonic inviscid flow, 116
 Supercritical flow, 344
 Supersonic inviscid flow, 246

T

T-complete systems, 404
 Three-dimensional effects, 377
 Three-dimensional lid-driven cavity solution, 133
 Thwaites compressible method, 515
 Time domain solutions, 390
 Transient extrusion problem, 175
 Transient metal forming, direct displacement
 approach to, 186
 Transient one-dimensional problems, 334
 Transient problems, 374
 Transonic viscous flow, 267
 Trefftz-type finite elements, 401
 Trefftz-type infinite elements, 372
 Tsunami waves, 339
 Turbulence models, 521
 κ - ω model, 522
 Spalart-Allmaras model, 521
 Turbulent flows
 compressible flows, 298
 detached eddy simulation (DES), 305
 direct numerical simulation (DNS), 305
 large eddy simulation (LES), 303–304
 mass-weighted (Favre) time averaging, 300

monotonically integrated LES (MILES), 305
 nondimensional, 289
 κ - l model, 290
 Spalart-Allmaras model, 290
 one-equation models, 287
 Spalart-Allmaras model, 287–288
 Wolfstein κ - l model, 287
 rectangular channel, 292
 relation between κ , ε , and ν_T , 286
 Reynolds-averaged Navier-Stokes, 286
 shortest distance to solid wall, 291
 solution procedure, 292–293, 296
 standard SGS model, 304
 time averaging, 284–285
 two-equation models, 288
 standard κ - ε model, 288
 Turbulent kinetic energy dissipation rate, 284
 Two-dimensional periodic tidal motions, 334–335
 Two-dimensional transient supersonic flow, 238
 Two-equation models, 288

U

Unbounded domains, 359
 Unbounded problems, 362
 Unconditionally unstable, 502

V

Vertical velocity component distributions, 133
 Vessel branching, 460
 Viscous problems, in two dimensions, 260
 Volume of fluid (VOF) method, 202

W

Wall shear stress (WSS), 476
 Wave envelope (or conjugated) infinite elements,
 369–370
 Wave speed refraction
 plane wave basis finite elements, 407
 problems, 408–409
 stepped cylinder, plane scattered by, 409
 weighted residual scheme, 406
 Weighted residual scheme, 406
 Wolfstein κ - l model, 287