

Index

- 1-D flow modeling, 144–153
- absolute reference frame. *See* inertial reference frame
- absolute velocity, 56
- adiabatic expansion factor, 149
- adiabatic wall, 111
- adiabatic wall temperature, 111
- aerodynamic power transfer, 60
- air properties. *See* air thermophysical properties
- air thermophysical properties
 - equation for density, 322
 - equation for dynamic viscosity, 322
 - equation for Prandtl number, 322
 - equation for specific heat at constant pressure, 322
 - equation for thermal conductivity, 322
- angular momentum, 55
- angular momentum equation, 55–57
- ATEX certification, 119
- axial rotor thrust, 218–221
 - on blades, 220–221
 - on rotor disks, 220–221
- Bernoulli equation, 65
- Biot number, 119
- blades, 6
- branch. *See* element
- Brayton cycle, 41
- calorically perfect gas, 35
- carry-over coefficient, 242
- cavity, 186–190, *See also* rotating cavity; rotor-stator cavity
- centrifugal force, 56, 81–84
- centrifugally-driven buoyant convection, 106
- centripetal acceleration, 84
- CFD, 17–18, 268–291
 - 1-D CFD, 17, *See also* 1-D flow modeling
 - 2-D CFD, 17
 - 3-D CFD, 18
 - methodology, 271–272
 - role in multiphysics modeling, 268–270
- CFD boundary conditions, 281–285
 - alternate wall treatments, 285
 - inlet and outlet, 281–282
 - wall functions, 282–285
- chamber. *See* junction
- channel. *See* duct
- chargeable internal flow, 13
- choking, 66
- circular isobars, 83
- circular streamlines, 83
- code validation, 143
- code verification, 143
- combined-cycle thermal efficiency, 3
- compressibility effect, 66
- compressible flow network modeling, 153–156
- compressible flow review, 65–77
- compressor drum cavity. *See* compressor rotor cavity
- compressor isentropic efficiency, 41, *See also* isentropic efficiency
- compressor polytropic efficiency, 45, *See also* polytropic efficiency
- compressor rotor cavity, 200–206, 270
 - flow and heat transfer physics in, 202–204
 - heat transfer modeling, 207–209
 - in closed cavity, 206
 - with bore flow, 204–206
 - radially inward flow in, 270
- computational fluid dynamics. *See* CFD
- conduction, 106–109
 - 1-D steady, 107
 - 1-D unsteady, 107–109
- conjugate heat transfer, 118–119
- continuity equation, 52
- control volume analysis, 51–60
- convection, 109–113
 - forced, 110
 - free, 110
 - mixed, 110
- convection links, 261–268, *See also* nonlinear
 - convection links
 - junction of, 268
 - linear versus nonlinear, 261–263
- convergent-divergent nozzle, 65–66, 148
- Coriolis force, 56, 81–84
- corrected carry-over coefficient, 242
- coupling correction term, 148
- curl, 319
- cycle efficiency. *See* thermal efficiency
- cycles. *See* thermodynamic cycles

- damping parameter, 160
- Darcy friction factor, 146
- direct numerical simulation (DNS), 18
- Dirichlet type thermal boundary condition, 118
- disc. *See* rotor disk
- discharge coefficient, 102, *See also* loss coefficient
- disk. *See* rotor disk
- Dittus-Boelter equation, 164
- divergence, 319
- duct, 144–149
 - continuity equation, 144–145
 - energy equation, 147–148
 - internal choking, 148
 - linear momentum equation, 145–146
 - normal shock within, 148, *See also* normal shock
- dummy index in tensor notation, 317
- dynamic enthalpy, 63
- dynamic pressure, 10, 51, 101, 139, 149
- dynamic temperature, 65
- dynamic viscosity, 141
- Eckert’s reference temperature, 110
- effective area, 148
- Ekman boundary layer, 89–92
- Ekman number, 87
- Ekman spiral, 92
- element, 153–155
- energy equation, 57–59
- enthalpy, 35
- entropy, 37
- entropy change computation, 38–39
- entropy equation, 59–60
- entropy map generation, 290–291
- equation of state, 78
- Euler work transfer, 58
- Euler’s turbomachinery equation, 60–65
 - alternate form of, 62–63
- Eulerian viewpoint, 51
- extensive property, 51
- external flow energy, 66
- Fanning friction factor. *See* shear coefficient
- Fanno flow, 74–75
- finite element analysis. *See* thermal FEA; thermomechanical FEA
- first law of thermodynamics, 35
- flow network model (FNM), 261
- flow network solution, 156–161
 - element flow direction, 159
 - initial solution generation, 158
 - modified Newton-Raphson method, 160–161
 - Newton-Raphson method, 160
- fluid mechanics review, 46–92
- free index in tensor notation, 317
- free stream temperature, 111
- frictional choking, 75
- gas constant, 36
- Gaussian error function, 109
- GE’s 9H/7H machines, 5
- GE9X, 1
- geostrophic flow, 88
- GE’s 9HA/7HA machines, 3
- governing conservation equations of CFD, 272–274
 - chemical species, 273
 - continuity, 272
 - energy, 273
 - linear momentum, 272
 - the common equation form, 274
- gradient, 318
- Grashof number, 110
- gravitational body force, 204
- heat rate, 40
- heat transfer coefficient, 109
- heat transfer review, 105–119
- hot gas ingestion, 209–218
 - 1-D modeling, 213
 - multiple-orifice spoke model, 216–218
 - single-orifice model, 213–216
 - ingress and egress, 209–210
 - physics of, 210–212
- hydrodynamic boundary layer, 111
- impulse functions, 70
 - static-pressure-based, 70
 - total-pressure-based, 70
- impulse pressure, 51
- index of isentropic compression. *See* ratio of specific heats
- index of isentropic expansion. *See* ratio of specific heats
- index of polytropic compression, 44
- index of polytropic expansion, 45
- inertial reference frame, 63, 79–81
 - Cartesian coordinates, 79
 - cylindrical coordinates, 79
- intensive property, 51
- internal air system (IAS), 8, *See also* internal flow system (IFS)
- internal energy, 35
- internal flow concepts, 92–105
- internal flow energy, 66
- internal flow system (IFS), 8–15
 - cycle penalty, 13–15
 - efficiency impact, 11–13
 - key components of, 8–11
 - cavity, 11, *See also* cavity channel, 10, *See also* duct orifice, 10, *See also* orifice vortex, 10, *See also* vortex
- internet of things (IoT), 258
- isentropic compressible flow, 66–67
 - with area change, 73–74
 - with rotation, 74

- isentropic efficiency, 41–44
- isentropic process, 41
- isobaric compressibility, 110
- isochoric process, 35
- Jacobian matrix, 161
- junction
 - boundary junction, 156
 - internal junction, 155–156
- kinematic viscosity, 141
- kinetic energy, 35
- kinetic energy carry-over factor, 239
- Kronecker delta, 318
- labyrinth seals
 - flow physics, 238–239
 - leakage mass flow rate, 239–242
 - stepped design, 238
 - straight-through design, 238
 - tooth-by-tooth modeling, 242–245
 - orifice-cavity model, 245–248
- Lagrangian viewpoint, 51
- Laplacian, 319
- large eddy simulation (LES), 18
- Levenberg-Marquardt method, 161
- linear momentum equation, 53–55
- link. *See* element
- loss coefficient, 101–105, *See also* discharge
 - coefficient
 - compressible flow, 103
 - incompressible flow, 101
 - relation with discharge coefficient, 103
- Mach number, 65–66
- major loss, 154
- Martin’s formula, 240
- mass conservation. *See* continuity equation
- mass flow functions, 67–70
 - static-pressure-based, 68
 - total-pressure-based, 68
- mass velocity, 54
- material derivative. *See* total derivative
- mathematics review, 317–321
- mechanical area, 148
- minor loss, 101
- moment coefficient, 184
- momentum velocity, 54
- Moody friction factor. *See* Darcy friction factor
- multimode heat transfer, 114–116
 - coupling with rotational work transfer, 116
 - electrical analogy, 114–115
- multiphysics modeling, 261–268
- Navier-Stokes equations, 78–92
- Neumann type thermal boundary condition, 118
- node. *See* junction
- non-inertial reference frame, 63, 81–84
 - cylindrical coordinates, 85
- nonlinear convection links, 263–268, *See also*
 - convection links
 - in multisided duct, 263–265
 - with uniform internal heat generation, 265
 - without internal heat generation, 265
 - multisurface forced vortex with windage, 266–267
- normal shock, 77
- normal shock function, 71–72
- nozzle, 6
- number of transfer units (NTU), 112
- numerical heat transfer, 117–119
- Nusselt number, 110
- orifice, 149–152
 - generalized, 151–152
 - sharp-edged, 149–151
- overdetermined system of linear algebraic equations, 340–346
 - Golub’s Householder reflection method, 340
 - HOME subroutine in FORTRAN, 341–346
 - linear least-squares data fitting, 340–341
- path variables, 34
- perfect gas law. *See* equation of state
- physics-based modeling, 15–18
- pipe. *See* duct
- polytropic efficiency, 44–46
- postprocessing of CFD results, 287–290
- potential energy, 35
- Prandtl number, 110
- pressure force, 145
- pressure ratio, 42
- preswirl system, 206–209
 - heat transfer modeling, 207–209
- preswirl. *See* preswirl system
- primary flow path, 4–7
- probabilistic design. *See* robust design methodology
- properties of air. *See* air thermophysical properties
- radial equilibrium equation, 83
- radiation, 113–114
- radiation heat transfer, 106
- rate of entropy production, 59
- ratio of specific heats, 141
- Rayleigh flow, 75–76
- Rayleigh-Ritz method, 303–305
- recovery factor, 111
- reduced static pressure, 82
- reduced-order modeling. *See* 1-D flow modeling
- reference fluid temperature, 110
- reference temperature, 36, 110, 204, 290
- Regula Falsi algorithm. *See* Regula Falsi method
- Regula Falsi method, 334–335
 - REGULA subroutine in FORTRAN, 335
- relative reference frame. *See* non-inertial reference frame

- relative total enthalpy, 62
- relative total pressure, 207
- relative total temperature, 207
- relative velocity, 56
- Reynolds number, 110
- Reynolds transport theorem, 51
- rim seals. *See* hot gas ingestion
- Robin type thermal boundary condition, 118
- robust design methodology, 18–22
 - Box-Behnken design (BBD), 21
 - central composite design (CCD), 21
 - design of experiments (DOE), 21
 - Monte Carlo simulation (MCS), 20–21
 - response surface equation (RSE), 21
 - response surface modeling (RSM), 21–22
- Rossby number, 87
- rotating cavity, 188–190
 - radial inflow, 190
 - radial outflow, 188
- rotating Couette flow, 85–87
- rotating orifice, 152, *See also* orifice
- rotational body force, 146
- rotational speed, 56
- rotational work transfer, 147
- rothalpy, 61–62
- rotor disc. *See* rotor disk
- rotor disk, 182–186, 323–332
 - disk pumping beneath a forced vortex, 184–185
 - free disk pumping, 183–184
 - in an enclosed cavity, 186
 - transient heat transfer in, 332
 - analytical solution, 326–327
 - boundary conditions, 325
 - governing equation, 323–325
 - initial condition, 325
 - numerical solution, 328–333
- rotor reference frame. *See* noninertial reference frame
- rotor-stator cavity, 187–188
 - radial inflow, 187–188
 - radial outflow, 187
- seal clearance, 241
- seals. *See* labyrinth seals
- second coefficient of viscosity, 78
- second law of thermodynamics, 37
- secondary air system (SAS), 8, *See also* internal flow system (IFS)
- secondary flows, 47
 - of the first kind, 47
 - of the second kind, 47
- shaft work, 58
- shear coefficient, 193–195, 197–199
- shear force, 146
- similarity solution, 108
- solution. *See* flow network solution
- sonic flow, 68
- specific flow work, 34–35, 58
- specific heat at constant pressure, 36
- specific heat at constant volume, 36
- specific internal energy, 35
- specific kinetic energy, 36
- specific total energy, 35
- specific total enthalpy, 62
- specific work, 6
- speed of sound, 65
- Stanton number, 110
- state properties, 34
- static enthalpy. *See* enthalpy
- static pressure, 50, 65, 67
- static temperature, 64–65
- stator and rotor reference frames, 63–65
 - total pressure and temperature, 63–65
 - conversion from RRF to SRF, 65
 - conversion from SRF to RRF, 64
- stator reference frame. *See* inertial reference frame
- Stefan-Boltzmann constant, 113
- Stefan-Boltzmann’s law, 113
- Stewartson boundary layer, 202–203
- stream thrust, 50
- subsonic flow, 68
- substantial derivative. *See* total derivative
- sudden contraction pipe flow, 50
- sudden expansion pipe flow, 48–50
 - with swirl, 48
 - without swirl, 48
- suffix notation, 317
- summation convention, 317
- supersonic flow, 68
- surface emissivity, 113
- surface forces, 54
- swirl factor, 93
- Taylor column, 88
- Taylor-Proudman theorem, 87–88
- tensor algebra, 317
- thermal barrier coating (TBC), 105
- thermal boundary layer, 111
- thermal choking, 76
- thermal conductivity, 107
- thermal diffusivity, 108
- thermal efficiency, 40
- thermal FEA, 296–302
- thermal resistances, 115
- thermodynamic cycles, 39–41
- thermodynamics review, 34–46
- thermomechanical analysis, 291–305
- thermomechanical FEA, 302–305
 - element equilibrium equations, 303–305
 - element shape function, 302
 - element strain-displacement equations, 303
 - element stress-displacement equations, 303
- Thomas algorithm, 337–338
- THOMAS subroutine in FORTRAN, 338
- torque, 55
- total derivative, 320
 - dyad, 320

- total enthalpy, 59
- total pressure, 50, 63, 65
- total temperature, 65, 67
- tri-diagonal matrix algorithm (TDMA). *See* Thomas algorithm
- tube. *See* duct
- turbine exhaust diffuser, 6
- turbine isentropic efficiency, 42, *See also* isentropic efficiency
- turbine polytropic efficiency, 45, *See also* polytropic efficiency
- turbine rim seal design. *See* hot gas ingestion
- turbulence model selection, 285–287, *See also* turbulence modeling
 - flow and heat transfer in a rotor cavity, 287
 - flow in a noncircular duct, 286
 - flow in a sudden pipe expansion, 286, *See also* sudden expansion pipe flow
 - swirling flow in a sudden pipe expansion, 286, *See also* sudden expansion pipe flow
- turbulence modeling, 274–281
 - algebraic stress model, 280–281
 - Boussinesq hypothesis, 275
 - one-equation model, 277
 - Prandtl mixing length model, 276–277
 - Reynolds averaging, 274
 - Reynolds Equations, 274–276
 - Reynolds stress transport model, 279–280
 - the closure problem, 275
 - two-equation model, 277–279
- under-relaxation parameter, 160
- validation with engine test data, 305–306
- valves, 149
- vanes, 6
- vector identities, 321
- vena contracta, 50, 149
- viscous dissipation, 111
- vortex, 47, 93–99, 152–153
 - forced, 48
 - free, 48
 - isentropic forced vortex, 96–98
 - isentropic free vortex, 93–96
 - isothermal forced vortex, 98–99
 - nonisentropic generalized vortex, 99
- vorticity, 47
- whole engine modeling (WEM). *See* multiphysics modeling
- windage, 99–101, 190–200
 - bolts on cavity surfaces, 199–200
 - cavity surface orientation, 197–199
 - definition of, 99