Contents

	Pre	face	page ix	
1	Intr	1		
	1.1	Modelling in engineering	1	
	1.2	CFD simulations	1	
	1.3	Applications in engineering	2	
	1.4	Flow	2	
		1.4.1 Laminar flow	3	
		1.4.2 Turbulent flow	3	
		1.4.3 Single-phase flow	4	
		1.4.4 Multiphase flow	4	
	1.5	CFD programs	4	
2	Mod	8		
	2.1	Mass, heat and momentum balances	9	
		2.1.1 Viscosity, diffusion and heat conduction	9	
	2.2	The equation of continuity	12	
	2.3	The equation of motion	14	
	2.4	Energy transport	16	
		2.4.1 The balance for kinetic energy	16	
		2.4.2 The balance for thermal energy	18	
	2.5	The balance for species	18	
	2.6	Boundary conditions	18	
		2.6.1 Inlet and outlet boundaries	19	
		2.6.2 Wall boundaries	19	
		2.6.3 Symmetry and axis boundary conditions	20	
		2.6.4 Initial conditions	20	
		2.6.5 Domain settings	21	
	2.7	Physical properties	21	
		2.7.1 The equation of state	22	
		2.7.2 Viscosity	22	

3	Num	Numerical aspects of CFD		
	3.1	Introduction		
	3.2	Numerical methods for CFD	25	
		3.2.1 The finite-volume method	25	
		3.2.2 Geometrical definitions	26	
	3.3	Cell balancing	26	
		3.3.1 The convective term	27	
		3.3.2 The diffusion term	28	
		3.3.3 The source term	28	
	3.4	Example $1 - 1D$ mass diffusion in a flowing gas	29	
		3.4.1 Solution	29	
		3.4.2 Concluding remarks	33	
		The Gauss–Seidel algorithm	33	
		Example 2 – Gauss–Seidel	34	
		Measures of convergence	37	
	3.8	Discretization schemes	38	
		3.8.1 Example 3 – increased velocity	39	
		3.8.2 Boundedness and transportiveness	40	
		3.8.3 The upwind schemes	40	
		3.8.4 Taylor expansions	42	
		3.8.5 Accuracy	43	
		3.8.6 The hybrid scheme	44	
		3.8.7 The power-law scheme	45	
		3.8.8 The QUICK scheme	45	
	2.0	3.8.9 More advanced discretization schemes	46	
	3.9	Solving the velocity field	47	
	2.10	3.9.1 Under-relaxation	49 50	
		0 Multigrid		
	3.11	Unsteady flows	51	
		3.11.1 Example 4 – time-dependent simulation	52	
	2.12	3.11.2 Conclusions on the different time discretization methods	57	
	3.12	Meshing	58	
		3.12.1 Mesh generation	58	
		3.12.2 Adaptation	60	
	2.12	3.12.3 Numerical diffusion	60	
	3.13	Summary	61	
4	Turbulent-flow modelling			
	4.1	The physics of fluid turbulence	62	
		4.1.1 Characteristic features of turbulent flows	63	
		4.1.2 Statistical methods	66	
		4.1.3 Flow stability	69	
		4.1.4 The Kolmogorov hypotheses	70	

		4.1.5 The energy cascade	72	
		4.1.6 Sources of turbulence	74	
		4.1.7 The turbulent energy spectrum	75	
	4.2	Turbulence modelling	76	
		4.2.1 Direct numerical simulation	79	
		4.2.2 Large-eddy simulation	79	
		4.2.3 Reynolds decomposition	81	
		4.2.4 Models based on the turbulent viscosity hypothesis	86	
		4.2.5 Reynolds stress models (RSMs)	96	
		4.2.6 Advanced turbulence modelling	99	
		4.2.7 Comparisons of various turbulence models	99	
	4.3	Near-wall modelling	99	
		4.3.1 Turbulent boundary layers	101	
		4.3.2 Wall functions	104	
		4.3.3 Improved near-wall-modelling	107	
		4.3.4 Comparison of three near-wall modelling approaches	109	
	4.4		110	
	4.5	Summary	112	
5	Turbulent mixing and chemical reactions			
	5.1	Introduction	114	
	5.2	Problem description	115	
	5.3	The nature of turbulent mixing	117	
	5.4	Mixing of a conserved scalar	119	
		5.4.1 Mixing timescales	119	
		5.4.2 Probability density functions	120	
		5.4.3 Modelling of turbulent mixing	124	
	5.5	Modelling of chemical reactions	130	
		$5.5.1$ $Da \ll 1$	130	
		$5.5.2 Da \gg 1$	131	
		5.5.3 $Da \approx 1$	138	
	5.6	Non-PDF models	141	
	5.7	Summary	142	
6	Multiphase flow modelling			
	6.1	Introduction	144	
		6.1.1 Characterization of multiphase flows	144	
		6.1.2 Coupling between a continuous phase and a dispersed phase	146	
	6.2	Forces on dispersed particles	147	
	6.3	Computational models	149	
		6.3.1 Choosing a multiphase model	150	
		6.3.2 Direct numerical simulations	151	
		6.3.3 Lagrangian particle simulations, the point-particle approach	152	

		6.3.4 Eu	ler–Euler models	155		
		6.3.5 The	e mixture model	156		
		6.3.6 Mc	odels for stratified fluid–fluid flows	158		
		6.3.7 Mc	odels for flows in porous media	160		
	6.4	Closure models		161		
		6.4.1 Into	erphase drag	161		
		6.4.2 Par	rticle interactions	163		
		6.4.3 He	at and mass transfer	168		
	6.5	6.5 Boundaries and boundary conditions				
		6.5.1 Lag	grangian dispersed phase	169		
		6.5.2 Eu	lerian dispersed phase	170		
	6.6	Summary	Summary			
		6.6.1 Gu	idelines for selecting a multiphase model	172		
7	Best-practice guidelines			174		
	7.1	Applicatio	n uncertainty	175		
		7.1.1 Ge	ometry and grid design	175		
	7.2	Numerical	uncertainty	175		
		7.2.1 Co		175		
			hancing convergence	176		
		7.2.3 Nu	merical errors	176		
		7.2.4 Ter	mporal discretization	177		
	7.3	Turbulence	e modelling	177		
			undary conditions	177		
	7.4	Reactions		178		
	7.5	Multiphase	178			
	7.6	Sensitivity	analysis	180		
	7.7	Verification	n, validation and calibration	180		
	App	181				
	Refe	References				
	Inde	186				