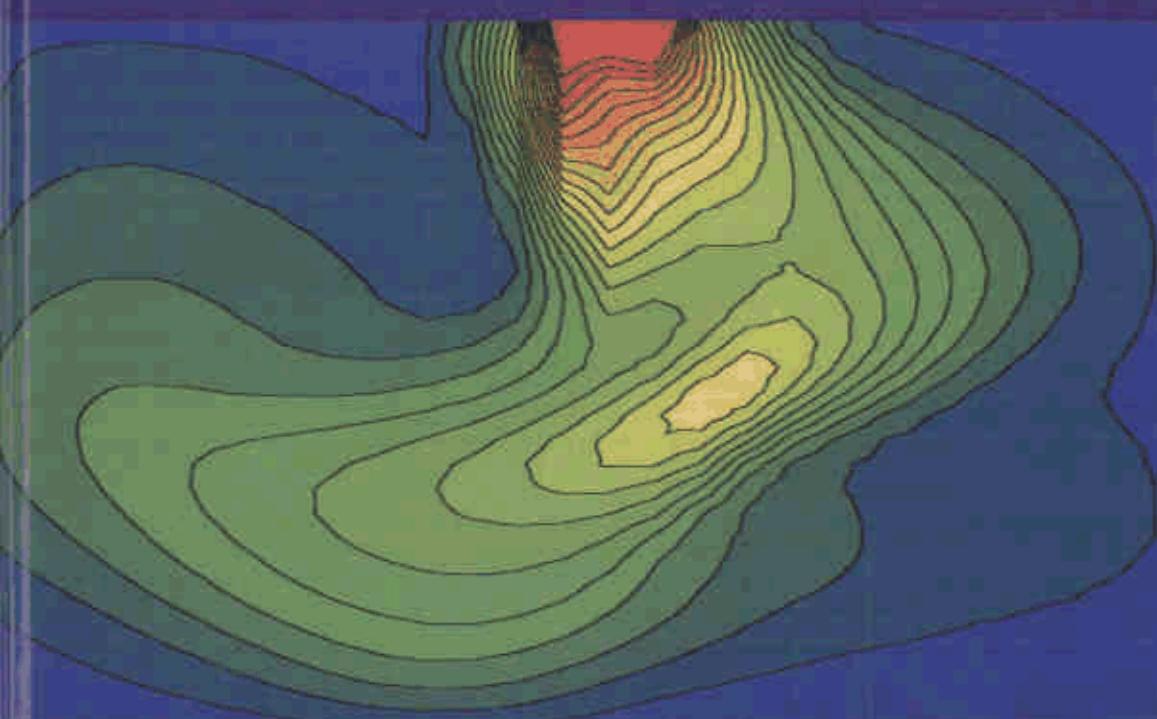


Modeling and Simulation of Turbulent Flows



Roland Schiestel

ISTE

 **WILEY**

Table of Contents

Foreword.	xi
Preface	xv
Acknowledgements	xix
Introduction	xxi
Chapter 1. Fundamentals in Statistical Modeling:	
Basic Physical Concepts	1
1.1. The nature of turbulence	1
1.2. The various approaches to turbulence	8
1.3. Homogenous and isotropic turbulence (HIT).	18
1.4. Kolmogorov hypotheses and the local isotropy theory	34
1.5. One point closures.	42
1.6. Functional description of turbulence	52
1.7. Turbulent diffusion and Lagrangian description	54
1.8. Two-dimensional turbulence	56
Chapter 2. Turbulence Transport Equations for an Incompressible Fluid	
2.1. General transport equations	59
2.2. Equations specific to the main types of turbulent flows.	69
Chapter 3. Mathematical Tools	
3.1. Tensors	79
3.2. Euclidian space in curvilinear coordinates, tensor fields	85
3.3. Orthogonal curvilinear coordinates.	88
3.4. Conformal transformation	92

3.5. Invariants	94
3.6. Representation of tensorial functions	101
3.7. Fourier transform in the fluctuating field	110
3.8. Wavelet transform	114
Chapter 4. Methodology for One Point Closures	115
4.1. Order of magnitude estimate of terms in the turbulence transport equations	116
4.2. Application to the momentum equations, and the k and ϵ equations	119
4.3. Derivation of closure hypotheses	120
4.4. The formalist approach: Lumley's invariant modeling	121
4.5. Examples of application	126
4.6. Realizability problem	131
4.7. Objectivity and material indifference	146
4.8. Diffusive correlations	149
4.9. Probability densities and stochastic models	152
4.10. Intermittency	156
4.11. Practicing with the development tools	158
Chapter 5. Homogenous Anisotropic Turbulence	159
5.1. The Craya equation	159
5.2. One-dimensional spectral properties in homogenous turbulent shear flows	163
5.3. Rapid part of pressure correlations in the rapid distortion of isotropic turbulence	164
5.4. Spectral models	166
5.5. Turbulence associated to a passive scalar	166
5.6. One point correlation equations in HAT	167
5.7. Examples of anisotropic homogenous turbulent flows	167
5.8. Rapid distortion theory for an homogenous turbulent flow	173
5.9. Additional information on linear solutions	177
5.10. Interdependency between differing closure levels: the spectral integral approach	178
Chapter 6. Modeling of the Reynolds Stress Transport Equations	183
6.1. The Reynolds stress transport equations and their trace	183
6.2. Modeling viscous dissipation terms	187
6.3. Modeling turbulent diffusion terms	188
6.4. Pressure-strain correlations	192
6.5. Determination of numerical constants	208
6.6. The realizability of the basic models	212

Chapter 7. Turbulence Scales	217
7.1. The turbulent kinetic energy dissipation rate equation	218
7.2. Modeling of diffusive terms	220
7.3. Modeling of source and sink terms	221
7.4. Determination of numerical constants	226
7.5. Corrective changes introduced on the dissipation equation	228
7.6. Reconsidering the ε equation: an asymptotic behavior with finite energy?	230
7.7. Tensorial volumes	232
7.8. Case of generation of turbulence injected at a fixed wavenumber	234
7.9. Modeling the dissipation tensor	234
Chapter 8. Advanced Closures: New Directions in Second Order Modeling	241
8.1. A new generation of second order models	242
8.2. Constraints related to the invariance properties with respect to the frame of reference	252
8.3. Other methods of approach for the pressure-strain correlations	254
8.4. Elimination of topographical parameters	257
8.5. Models based on the renormalization group (RNG models)	259
8.6. Memory effects	260
8.7. Pressure-velocity correlations	261
8.8. Internal variable models, structural models	262
Chapter 9. Modeling the Turbulent Flux Evolution Equations for a Passive Scalar	269
9.1. Evolution equations of the turbulent fluxes of a passive scalar	269
9.2. Order of magnitude of terms	271
9.3. Modeling dissipative terms	272
9.4. Modeling the turbulent diffusion terms	272
9.5. Modeling the pressure-passive scalar gradient correlations	274
9.6. Determination of numerical constants	278
9.7. New generation of modeling	284
Chapter 10. The Passive Scalar Variance and its Dissipation Rate	285
10.1. Transport equation for the variance of a passive scalar	285
10.2. Modeling the turbulent diffusion terms	286
10.3. Modeling the dissipation rate	287
10.4. Equation for the dissipation rate of the passive scalar variance	288
10.5. New directions of research	290

Chapter 11. Simplified Closures: Two and Three Transport Equation Models	293
11.1. The $k-R_{12}-\epsilon$ model for turbulent thin shear flows	293
11.2. Two equation models	295
11.3. Algebraic modeling of the Reynolds stresses and the turbulent fluxes of a passive scalar	313
11.4. Non-linear models	317
11.5. Explicit algebraic models	323
Chapter 12. Simplified Closures: Zero and One Transport Equation Models	331
12.1. One equation models	332
12.2. Zero equation models	337
Chapter 13. Treatment of Low Reynolds Number Turbulence	347
13.1. Reynolds stress equations	348
13.2. Equation for the dissipation rate	349
13.3. The $k-R_{12}-\epsilon$ model for wall flows	351
13.4. Modification of the turbulent fluxes in low intensity turbulence	353
13.5. Lower order models	355
13.6. Advanced modeling	363
13.7. Transition and laminarization	384
Chapter 14. Wall Treatment: Methods and Problems	385
14.1. The turbulent flow near a wall	385
14.2. Wall functions	388
14.3. Simple models for the viscous sublayer	398
14.4. Models using several transport equations for the viscous sublayer	403
14.5. New directions in the wall function formulation	403
Chapter 15. Influence of Archimedean Forces	407
15.1. Transport equations of turbulence in the Boussinesq approximation	407
15.2. Influence of buoyancy terms in the pressure-strain correlations	411
15.3. Influence of buoyancy forces on the pressure-temperature gradient correlations	412
15.4. Influence of buoyancy forces on the turbulence length scales or the dissipation rate	414
15.5. Two-dimensional horizontal flows in the presence of buoyancy forces	415
15.6. Algebraic modeling	416
15.7. Simplified models	419
15.8. Advanced models of the new generation	421

Chapter 16. Notes on the Problems Posed by the Study of Complex Flows	423
16.1. Curvature effect	424
16.2. Secondary motions.	428
16.3. Rotation effects.	430
16.4. Examples of complex turbulent flows for which the traditional one point closures fail	432
16.5. More on the Navier-Stokes equations in a relative frame of reference	433
16.6. Algebraic modeling of turbulence submitted to rotation	437
16.7. Implicit effects of rotation on the turbulent field	444
16.8. Rotating turbulence in the presence of active thermal effects	450
16.9. Coherent structures and modeling.	452
16.10. Laminar/turbulent interface, free boundaries	452
Chapter 17. Variable Density Turbulent Flows	457
17.1. Averaging	458
17.2. Transport equations	459
17.3. Reynolds stress transport modeling in the framework of mass weighted averaging.	464
17.4. Dissipation rate equation	466
17.5. Turbulent heat flux equations	467
17.6. Equation for the variance of temperature fluctuations	468
17.7. Two equation models and simplified models	469
17.8. Approach in non-weighted variables	470
17.9. Continuity	471
17.10. Statistical equations and modeling.	472
17.11. Dissipation rate equation	475
17.12. Other approaches	475
17.13. Note on compressed turbulence	477
Chapter 18. Multiple Scale Models	481
18.1. Intuitive approach	487
18.2. Foundations of the method	493
18.3. Practical formulations and extensions	516
18.4. Other multiple scale models: models using spectral weighted integration	536
Chapter 19. Large Eddy Simulations	539
19.1. The filters	542
19.2. The filtered Navier-Stokes equations	546
19.3. Subgrid-scale modeling	551
19.4. Some remarks on the numerical methods	559
19.5. Simulation of homogenous flows	560
19.6. Simulation of non-homogenous turbulent wall flows	562

x Modeling and Simulation of Turbulent Flows

19.7. Estimate of subgrid-scale energy	566
19.8. Variable filters	567
19.9. Advanced subgrid-scale models	568
19.10. Flows undergoing laminar-turbulent transition.	579
19.11. Other transport equation models.	580
19.12. Approximate deconvolution methods	581
19.13. Simulations based on POD or on wavelets.	584
19.14. Hybrid methods	586
Chapter 20. Synopsis on Numerical Methods	601
20.1. Numerical techniques	602
20.2. Plates	604
Exercises	645
Bibliography	661
Nomenclature	715
Index	719