

Contents

<i>Chapter 1</i>	
<i>The Complexity of Turbulent Fluid Motion</i>	1
<i>Trevor H. Moulden, Walter Frost, and Albert H. Garner</i>	
1.1. Introduction	1
1.2. On Continuum Fluid Motion	5
1.3. Further Remarks on Turbulence	13
1.4. Looking Onward	18
References	21
<i>Chapter 2</i>	
<i>An Introduction to Turbulence Phenomena</i>	23
<i>Trevor H. Moulden</i>	
2.1. Introduction	23
2.2. On the Basic Equations of Motion	26
2.2.1. General Considerations	26
2.2.2. Detailed Development	27
2.3. Reynolds' Decomposition	30
2.3.1. The Mean-Value Equations	32
2.3.2. Some Comments	34
2.3.3. On Pressure Fluctuations	35
2.3.4. Passage to Statistical Theory	36
2.4. Correlations and the Closure Condition	37
2.5. The Turbulent Boundary Layer	40
2.5.1. Preliminary Remarks	41

2.5.2. Comments	43
2.5.3. Further Developments	44
2.6. Final Remarks	49
References	50

Chapter 3

Statistical Concepts of Turbulence 53

Walter Frost and Jürgen Bitte

3.1. Basic Physical Model of Turbulence	53
3.1.1. Vortex Stretching	54
3.1.2. Energy Cascade	57
3.2. Statistical Definitions	59
3.2.1. The Random Process	66
3.2.2. Stationarity and Ergodicity	68
3.2.3. Space-Dependent Random Variables	70
3.2.4. Homogeneous and Isotropic Turbulence	72
3.2.5. The Taylor Hypothesis	72
3.2.6. Random Field	73
3.2.7. Random Scalar and Vector Fields	74
3.3. Statistical Moments	74
3.3.1. Ordinary Moments	75
3.3.2. Central Moments	76
3.3.3. Joint Moments	76
3.3.4. Space-Time Moments	77
3.3.5. Other Terminology	77
3.3.6. Longitudinal and Lateral Correlations	78
3.3.7. Characteristics of Correlation Coefficients	79
References	82

Chapter 4

Spectral Theory of Turbulence 85

Walter Frost

4.1. Introduction	85
4.2. Harmonic Analysis	86
4.2.1. Fourier Series	86
4.2.2. Fourier Integral	91
4.2.3. Stationary Random Process	96
4.2.4. Spectral Representation of a Stationary Random Process	99
4.2.5. Autocorrelation	107

4.3.	Frequency Spectra	109
4.4.	Wave-Number Spectra	112
4.4.1.	From Taylor’s Hypothesis	112
4.4.2.	Three-Dimensional Wave-Number Spectra	116
4.5.	Characteristics of Energy Spectra	119
4.5.1.	Three-Dimensional Energy Spectra	119
4.5.2.	One-Dimensional Energy Spectra	122
	References	125

Chapter 5

Turbulence: Diffusion, Statistics, Spectral Dynamics

127

H. Tennekes

5.1.	Introduction	127
5.2.	Turbulent Diffusion	128
5.3.	Fourier Transforms	129
5.4.	Particle Diffusion	131
5.5.	Another Look at Fourier Transforms	133
5.6.	On the Interpretation of Frequency	135
5.7.	Strong Interactions	136
5.8.	Vorticity and Velocity	137
5.9.	The “First Law” of Turbulence	137
5.10.	The Energy Cascade	138
5.11.	Some Enlightening Errors	140
5.12.	Other Inertial Ranges	141
5.13.	Turbulent Diffusion Revisited	144
5.14.	Conclusions	145
	References	146

Chapter 6

Transition

147

R. Betchov

6.1.	Introduction	147
6.2.	Weak Oscillations of Simple Flow	149
6.3.	Multiple Perturbations of Laminar Flow	155
6.4.	Amplification of Initial Perturbations	157
6.5.	Strong Disturbances of Simple Flows	158
6.6.	Statistical Models	161
6.7.	Comment	163
	References	163

Chapter 7	
Turbulence Processes and Simple Closure Schemes	165
<i>R. G. Deissler</i>	
7.1. Introduction	165
7.2. Theoretical Development	165
7.3. Final Remarks	184
References	185
Chapter 8	
Kinetic Energy Methods	187
<i>P. T. Harsha</i>	
8.1. Introduction	187
8.2. Eddy Viscosity Transport Models	191
8.3. Turbulent Kinetic Energy Models	194
8.3.1. ND Models I: Bradshaw <i>et al.</i>	195
8.3.2. ND Models II: Morel <i>et al.</i>	202
8.3.3. ND Models III: Lee and Harsha	203
8.3.4. PK Models I: Ng and Spalding; Rodi and Spalding	213
8.3.5. PK Models II: Launder <i>et al.</i>	215
8.3.6. Three-Equation Model: Hanjalic and Launder	220
8.3.7. Comparison of Turbulence-Model Predictions with Free Shear Layer Data	221
8.4. Summary and Conclusions	230
References	232
Chapter 9	
Use of Invariant Modeling	237
<i>W. S. Lewellen</i>	
9.1. Introduction	237
9.2. Model Development	238
9.2.1. Closure Requirements	238
9.2.2. Dissipation Terms	239
9.2.3. Pressure Correlations	240
9.2.4. Third-Order Velocity Correlations	242

9.2.5.	Modeled Equations	243
9.2.6.	Scale Determination	244
9.3.	Evaluation of Model Coefficients	247
9.3.1.	Dissipation Coefficient b	247
9.3.2.	Diffusion Coefficient v_c	248
9.3.3.	Scale Determination	248
9.3.4.	Low-Reynolds-Number Dependence	250
9.3.5.	Additional Coefficients Required to Compute Temperature Fluctuations A , s , and s_s	251
9.4.	Model Verification	252
9.4.1.	Axisymmetric Free Jet	253
9.4.2.	Free Shear Layer	254
9.4.3.	Two-Dimensional Wake	254
9.4.4.	Axisymmetric Wake	256
9.4.5.	Flat-Plate Boundary Layer	257
9.4.6.	Flow over an Abrupt Change in Surface Roughness	258
9.4.7.	Temperature Fluctuations in the Plane Turbulent Wake	260
9.4.8.	Stability Influence in the Atmospheric Surface Layer	260
9.4.9.	Shear Layer Entrainment in a Stratified Fluid	262
9.4.10.	Free Convection	264
9.4.11.	Planetary Boundary Layer for Neutral Steady State	266
9.5.	Local Equilibrium Approximations	267
9.6.	Applications	271
9.6.1.	Diurnal Variations in the Planetary Boundary Layer	271
9.6.2.	Stratified Wake	273
9.6.3.	Pollutant Dispersal	274
9.7.	Concluding Remarks	276
	References	277

Chapter 10

Numerical Simulation of Turbulent Flows 281

S. A. Orszag

10.1.	Introduction	281
10.2.	Methods	282
10.3.	Problems	285

10.4. Survey of Applications	292
10.5. Comparison with Other Methods	304
10.6. Prospects	311
References	312

Chapter 11

Laboratory Instrumentation in Turbulence

<i>Measurements</i>	315
---------------------------	------------

V. A. Sandborn

11.1. Introduction	315
11.2. Measurement of Velocity Fluctuations	321
11.2.1. Heat-Transfer Techniques	321
11.2.2. Tracer Techniques	330
11.2.3. Electrochemical Techniques	337
11.2.4. Sonic Anemometer	340
11.2.5. Lift and Drag Sensors	343
11.2.6. Corona-Discharge Anemometer	344
11.3. Measurement of Temperature Fluctuations	346
11.3.1. Resistance Thermometer	346
11.3.2. Measurement of Temperature–Velocity Correlations	348
11.4. Measurement of Density and Pressure Fluctuations	350
11.5. Measurement of Concentration Fluctuations	358
11.5.1. Heat-Transfer Techniques	358
11.5.2. Light Scattering	361
11.6. Measurement of Surface Shear Fluctuations	362
References	365

Chapter 12

Techniques for Measuring Atmospheric

<i>Turbulence</i>	369
-------------------------	------------

J. R. Connell

12.1. Introduction	369
12.2. Measurements: Background, Instruments, Platforms, and Techniques	372
12.2.1. Instrument Response	372
12.2.2. Tower-Based Cup Anemometers	373

12.2.3.	Wave Propagation Methods	376
12.2.4.	Other Measurement Techniques	381
12.3.	Measurements from Aircraft	384
12.3.1.	Introduction	384
12.3.2.	Simple Techniques of Lower Accuracy	384
12.3.3.	Higher-Accuracy Methods	385
12.3.4.	Data Processing and Analysis of Errors	386
12.4.	Aircraft Measurement of Turbulent Airflow Downwind of a Mountain Range	386
12.5.	Elk Mountain PBL Profiles	395
12.6.	Suppression of Mixing Coefficient by Forced Boundary-Layer Upward Curvature	398
12.7.	Turbulent Airflow across a Building	399
12.8.	Concluding Remarks	399
	References	399

Chapter 13

Optical and Acoustical Measuring Techniques 403

William C. Cliff

13.1.	Introduction	403
13.2.	Background and Basic Principles	404
13.3.	Laser Doppler	406
13.3.1.	General Types of Laser Doppler Systems	410
13.3.2.	Typical Wavelengths and Common Uses of Lasers Presently in Use in LDV Systems	422
13.3.3.	Conclusions and Recommendations Concerning Laser Doppler Systems	423
13.4.	Acoustic Doppler	424
13.4.1.	Types	425
13.4.2.	Conclusions and Recommendations Concerning Acoustic Doppler Systems	430
	References	431

Chapter 14

Monte Carlo Turbulence Simulation 433

G. H. Fichtl, Morris Perlmutter, and Walter Frost

14.1.	Introduction	433
14.2.	Control-System Simulation	434

14.3.	Use of Standard System Function Elements	435
14.3.1.	Fitting the Empirical Autocorrelation	436
14.3.2.	The System Function	437
14.3.3.	The State Space System	437
14.3.4.	The Discrete State Space System	438
14.3.5.	Effect of Digitizing on the Autocorrelation	440
14.3.6.	Discrete Autocorrelations	441
14.3.7.	Computer Signal Output	443
14.4.	Digital Filter Simulation	443
14.4.1.	Discretizing the Convolution Integral	444
14.4.2.	Theoretical Correlation for the Control-System Simulation	445
14.5.	Discrete Fourier Series	446
14.5.1.	Discrete Fourier Transform	446
14.5.2.	Discrete Fourier Series Using Randomly Chosen Coefficients	448
14.5.3.	Relationship of the Fourier Spectrum to the Power Spectrum	448
14.5.4.	Discrete Fourier Series Simulation	449
14.5.5.	Theoretical Statistical Moments for Discrete Fourier Series Simulation	450
14.6.	Non-Gaussian Simulation	452
14.7.	Multidimensional Simulation	455
14.8.	Nonhomogeneous Atmospheric Boundary-Layer Simulation	457
14.8.1.	Definition of the Problem	458
14.8.2.	Filter Synthesis	459
14.8.3.	Coherence Matching	461
14.8.4.	Autospectral Density Matching	463
14.8.5.	Phase Angle Matching	464
14.8.6.	Longitudinal Gust Statistics	464
14.8.7.	Longitudinal Autospectra	464
14.8.8.	Standard Deviation and Integral Scale of Turbulence	465
14.8.9.	Coherence and Phase	465
14.8.10.	Longitudinal Gust Simulation and Application ..	465
14.8.11.	Coherence Determination	466
14.8.12.	Autospectra Factorization	466
14.8.13.	Phase Angle Determination	468
14.9.	Self-Similar Simulation	469
14.9.1.	Inverse Fourier Transformation	470
14.9.2.	Transformation to Vehicle Time Domain	471

<i>Contents</i>	<i>xvii</i>
14.10. Conclusions	471
References	473
<i>Chapter 15</i>	
<i>Wind, Turbulence, and Buildings</i>	475
<i>R. C. Elstner</i>	
<i>Author Index</i>	483
<i>Subject Index</i>	489