TABLE OF CONTENTS

1 INTRODUCTION **1**
1.1 Brief history 1
1.2 Nature and major qualitative universal features of turbulent flows 2
1.2.1 Representative examples of turbulent flows 2
1.2.2 In lieu of definition: major qualitative universal features of turbulent flows 15
1.3 Why turbulence is so impossibly difficult? The three N's . . 19
1.3.1 On the Navier-Stokes equations 19
1.3.2 On the nature of the problem 21
1.3.3 Nonlinearity 22
1.3.4 Noninegrability 22
1.3.5 Nonlocality 23
1.3.6 On physics of turbulence 24
1.3.7 On statistical theories 24
1.4 Outline of the following material 25
1.5 In lieu of summary 26

2 ORIGINS OF TURBULENCE **27**
2.1 Instability 27
2.2 Transition to turbulence versus routes to chaos 29
2.3 Many ways of creating turbulent flows 31
2.4 Summary 32

3 METHODS OF DESCRIBING OF TURBULENT FLOWS **33**
3.1 Deterministic versus random/stochastic or how 'statistical' is turbulence? 34
3.2 On statistical theories, reduced (low dimensional) representations and related matters 37
3.3 Turbulence versus deterministic chaos 40
3.4 Statistical methods of looking at the data only? Or what kind of statistics one needs? 41

3.5 Decompositions/representations 43
3.6 Summary 45

4 KINEMATICS **47**
4.1 Passive objects in random fluid flows 47
4.1.1 Geometrical statistics 53
4.2 Kinematic/Lagrangian chaos/advection 56
4.3 On the relation between Eulerian and Lagrangian fields . . 59
4.4 On analogies and relations between passive and active fields 60
4.5 Summary 62

5 PHENOMENOLOGY **65**
5.1 Introductory notes 65
5.2 Kolmogorov phenomenology and related subjects 66
5.3 Cascade 73
5.3.1 Introduction 74
5.3.2 Is there cascade in physical space? 75
5.4 What are the 'small scales' in turbulent flows? 77
5.5 Cascade of passive objects? 80
5.6 Summary 81

6 DYNAMICS **83**
6.1 Introduction 83
6.2 Why velocity derivatives? 85
6.2.1 Vortex stretching and enstrophy production 86
6.2.2 Why strain too? 89
6.3 Self-amplification of the field of velocity derivatives 92
6.4 Geometrical statistics 98
6.4.1 Alignments 100
6.4.2 The geometry of vortex stretching 101
6.5 Depression of nonlinearity 113
6.5.1 Relative depression of nonlinearity in regions with concentrated vorticity 114
6.5.2 Are regions of concentrated vorticity quasionedimensional? 115
6.6 Nonlocality 118
6.6.1 Introduction and simple examples 118
6.6.2 Different aspects of nonlocality 121
6.7 Acceleration and related matters 130
6.7.1 The relation between the total acceleration and its local and convective components 131

6.7.2 The relation between the total acceleration and its irrotational and solenoidal components 135
6.7.3 Scale dependence 138
6.7.4 Kinematical versus dynamical effects 139
6.8 Non–Gaussian nature of turbulence 140
6.8.1 Odd moments 141
6.8.2 Quasi–Gaussian manifestations 143
6.8.3 Irreversibility of turbulence 147
6.9 Summary 148

7 STRUCTURE(S) OF TURBULENT FLOWS 151
7.1 Introduction 151
7.2 Intermittency 152
7.2.1 What is small scale intermittency? 153
7.2.2 Measures/manifestations of intermittency 154
7.2.3 On possible origins of small scale intermittency . . . 162
7.3 What is(are) structure(s) of turbulent flows? 165
7.3.1 On the origins of structure(s) of/in turbulence . . . 165
7.3.2 How does the structure of turbulence 'look'? 168
7.3.3 Structure versus statistics 170
7.3.4 Examples of statistics weakly sensitive to structure(s) 173
7.3.5 Structure sensitive statistics 174
7.4 Which quantities possess structure in turbulence and how to 'dig' them out? 176
7.4.1 Structure(s) versus scales and decompositions 178
7.5 Summary 178

TURBULENCE UNDER VARIOUS INFLUENCES AND PHYSICAL CIRCUMSTANCES 181
8.1 Introduction 181
8.2 Shear flows 183
8.3 Partly turbulent flows – entrainment 192
8.4 Variable density 196
8.4.1 Convection 196
8.4.2 Stable stratification 199
8.4.3 Compressible flows 203
8.5 Rotation 203
8.5.1 Helicity 206
8.6 Negative eddy viscosity phenomena 206
8.6.1 Laboratory experiments 207
8.6.2 Examples from geophysics 210
8.6.3 Possible explanations 211

8.7 Magnetohydrodynamic flows 211
8.8 Two-dimensional turbulence 214
8.8.1 Pure two-dimensional versus quasi-two-dimensional . 216
8.8.2 Some additional differences between two-dimensional and three-dimensional turbulence 218
8.9 Additives 220

9 CONCLUSION/CLOSE 227
9.1 Universality 227
9.1.1 On universal aspects of turbulence structure 228
9.1.2 Reynolds number dependence 230
9.1.3 Self-amplification of velocity derivatives 232
9.1.4 Depression of nonlinearity 233
9.2 Some mathematical and related aspects 233
9.3 On the goals of basic research in turbulence 235

10 APPENDIX A. WHAT IS TURBULENCE? 237

11 APPENDIX B. ABOUT THE 'SNAGS' OF THE PROBLEM 243

12 APPENDIX C. GLOSSARY OF ESSENTIAL FLUID MECHANICS 247
12.1 Kinematics 247
12.2 Dynamics 248
12.2.1 Basic equations and their consequences 248
12.2.2 Some additional consequences from the NSE and invariant quantities 254
12.2.3 Symmetries of Euler and Navier–Stokes equations . . 256
12.3 Passive objects 257
12.3.1 Passive scalars 257
12.3.2 Passive vectors 257
12.4 Some basic relations for the statistical description of turbulent flows 259
12.4.1 Scaling, scales and related matters 260
12.4.2 Reynolds averaged Navier–Stokes equations and related 263
12.4.3 Filter decomposition 266
12.4.4 Equations governing the dynamics of 'error' 267

13 APPENDIX D. IT IS A MISCONCEPTION THAT 269

14 APPENDIX E. ON METHODS OF STUDING TURBULENT FLOWS 271
14.1 Direct numerical simulations of the Navier-Stokes equations 271
14.2 Physical experiments 272

15 APPENDIX F. GLOSSARY OF SOME TERMS 275

15 BIBLIOGRAPHY 277

16 AUTHOR INDEX 313

17 SUBJECT INDEX 321