

TABLE OF CONTENTS

CHAPTER	PAGE
Preface	v
I. FUNDAMENTALS OF TURBULENT FLOW	1
1. Introduction	1
2. Reynolds' experiments and other facts about turbulent flows	3
3. Origin of turbulence—Mechanism of turbulence	6
4. The turbulent field and mean flow	7
5. Reynolds rules of averages	10
6. Reynolds equations and Reynolds stresses	11
7. Various theories of turbulence	12
8. Comparison of theory with experiments	15
9. Hotwire anemometer	17
References	20
II. SEMI-EMPIRICAL THEORIES OF TURBULENCE	23
1. Introduction	23
2. Prandtl's momentum transfer theory	25
3. Taylor's vorticity transport theory	26
4. Von Kármán's similarity hypothesis	27
5. Universal velocity distribution (Logarithmic profile)	28
6. Mixing length theory in a compressible fluid and for an inhomogeneous fluid	29
7. Improvements on the mixing length theory	30
8. Dimensional analysis	31
9. Solution of the Reynolds equations	33
10. Reichardt's inductive theory of free turbulence	37
References	38
III. TURBULENT FLOW IN PIPES AND CHANNELS	40
1. Introduction	40
2. Turbulent flow in a straight smooth circular pipe	41
3. Turbulent flow between parallel plates (Channel)	45
4. The logarithmic velocity profile and general resistance law	46
5. Flow in pipe with non-circular cross-section	48

CHAPTER	PAGE
6. Flow in divergent and convergent channels	49
7. Flow in rough pipes and channels	50
8. Flow in curved pipes and channels	54
9. Flow between rotating cylinders	56
10. Turbulent fluctuations in two-dimensional channels and in straight circular pipes	57
References	58
 IV. TURBULENT FLOW OVER A FLAT PLATE	 60
1. Introduction	60
2. The turbulent boundary layer over a smooth flat plate	61
3. The logarithmic velocity profile and general resistance law	64
4. The turbulent boundary layer over a rough flat plate .	67
5. Effect of roughness on transition from laminar to tur- bulent flow	70
6. Turbulent flow over a rotating disc	72
7. Some experimental facts concerning the flow in the tur- bulent boundary layer of a flat plate	74
References	76
 V. THE TURBULENT BOUNDARY LAYER WITH A PRES- SURE GRADIENT	 78
1. Introduction	78
2. Equations of the turbulent boundary layer	79
3. Similar solutions of turbulent boundary layer	81
4. The turbulent boundary layer in accelerated and re- tarded flows—Buri method	83
5. Gruschwitz's method	85
6. Tetervin and von Doenhoff's method	87
7. Tetervin and Lin's method	88
8. The turbulent boundary layer over a body of revolu- tion	91
9. Some experimental facts concerning a turbulent bound- ary layer with a pressure gradient—Separation	91
References	93
 VI. THE TURBULENT BOUNDARY LAYER OF A COM- PRESSIBLE FLUID	 94
1. Introduction	94
2. The fundamental equations of the turbulent boundary layer of a compressible fluid	95

TABLE OF CONTENTS

ix

CHAPTER	PAGE
3. A solution of the energy equation	97
4. The turbulent boundary layer of a compressible fluid over a flat plate—Van Driest's analysis	99
5. Insulated flat plate—Wilson's analysis	102
6. The turbulent boundary layer over a flat plate—Fer- rari's analysis	104
7. Application of the results for the flow in a pipe to that on a flat plate—Eckert's analysis	107
8. Similarity theory—Lin-Shen's analysis	108
9. Temperature recovery factor	109
10. The turbulent boundary layer over a cone	111
11. Skin friction and heat transfer of a turbulent boundary layer flow	112
References	113
VII. TURBULENT JET MIXING REGIONS AND WAKES	115
1. Introduction	115
2. General properties of free turbulence problems	116
3. Plane jet of an incompressible fluid—Tollmien's solution	119
4. Free jet boundary—Goertler's solution	121
5. Axially symmetric jet mixing	123
6. Wakes	126
7. Reichardt's inductive theory for free turbulence	129
8. Jet mixing of a compressible fluid	129
9. Jet mixing of two different gases	133
10. Determination of the profile drag from the wake meas- urement	135
References	138
VIII. FUNDAMENTALS OF THE STATISTICAL THEORY OF TURBULENCE	140
1. Introduction	140
2. The phase space	142
3. Uniqueness theorem	144
4. Liouville's theorem	145
5. Ergodic theorem	146
6. Stationary random function	146
7. Correlation functions	149
8. Spectrum	150
9. Probability distribution in turbulence	153
10. Homogeneous and isotropic turbulence	154
References	155

CHAPTER	PAGE
IX. PROBABILITY DISTRIBUTION IN TURBULENCE	156
1. Elements of probability theory	156
2. Normal distribution	159
3. Statistical representation of random variables	160
4. Probability distribution in turbulence	164
5. Counting method in turbulence investigation	167
References	169
X. TURBULENT DIFFUSION	171
1. Introduction	171
2. Turbulent diffusion—Lagrangian analysis	172
3. Mean concentration by turbulent diffusion in an in- compressible fluid flow	176
4. Semi-empirical analysis of turbulent diffusion	178
5. Turbulent diffusion—Eulerian method	179
6. Random walk	183
7. Goldstein's turbulent diffusion equation—Telegraph equation	186
References	188
XI. THE CORRELATION TENSOR	189
1. Introduction	189
2. The correlation tensor	190
3. The correlation tensor in isotropic turbulence	192
4. Decay of isotropic turbulence	197
5. Vorticity in isotropic turbulence	197
6. Von Kármán-Howarth equation	200
7. Loitsiansky's invariant	205
8. The correlation tensor in axially symmetric turbulence	206
References	208
XII. THE SPECTRUM OF TURBULENCE	209
1. Introduction	209
2. Fourier transform, correlation function and spectrum of a truncated function	210
3. Fourier transform, correlation function and spectrum of a function in an infinite interval	213
4. Correlation tensor and spectral tensor of a velocity field depending on time at a given point in space	214
5. Correlation tensor and spectral tensor of a velocity field at a given time in a three-dimensional space	216
6. Homogeneous turbulence of an incompressible fluid	221
7. Fourier transform of correlation equation	224

TABLE OF CONTENTS

xi

CHAPTER	PAGE
8. The spectrum of isotropic turbulence	227
9. The similarity spectrum and extensions	231
References	232
XIII. LOCALLY ISOTROPIC TURBULENCE AND NON-ISOTROPIC TURBULENCE	234
1. Introduction	234
2. Correlations of locally isotropic turbulence	235
3. Spectrum of locally isotropic turbulence	238
4. Turbulent fluctuations of a flow in a two-dimensional channel	240
5. Turbulent fluctuations of a flow in a circular pipe	245
6. Turbulent fluctuations in the wake of a cylinder	246
7. Turbulent fluctuations in an axially symmetric jet	247
8. Turbulent fluctuations in a half jet mixing region	249
9. Turbulent fluctuations in a boundary layer over a flat plate	249
References	250
XIV. TURBULENCE IN A COMPRESSIBLE FLUID FLOW AND IN MAGNETOHYDRODYNAMICS	252
1. Introduction	252
2. Perturbation field of a viscous compressible fluid	253
3. Isotropic turbulence in a compressible flow	256
4. Some experimental results of turbulence of a compressible fluid	260
5. Fundamental equations of magnetohydrodynamics	262
6. A spontaneous magnetic field in a conducting liquid in turbulent motion	267
7. Isotropic turbulence in magnetohydrodynamics	268
References	271
Author Index	273
Subject Index	275