

MECHANICS OF FLUIDS AND TRANSPORT PROCESSES

M. Lesieur

Turbulence in Fluids

MARTINUS NIJHOFF PUBLISHERS

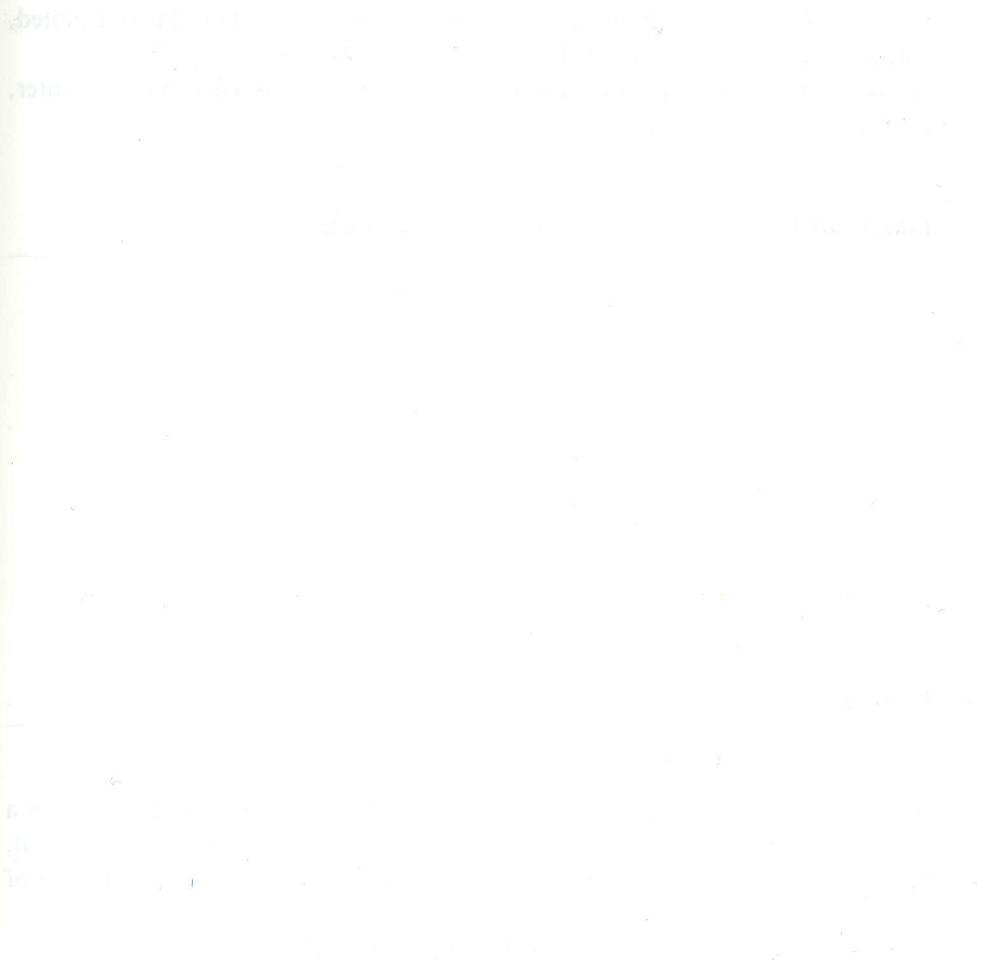
Turbulence in fluids

Stochastic and numerical modelling

By

Marcel Lesieur

*National Polytechnic Institute
School of Hydraulics and Mechanics
Grenoble, France*



1987 MARTINUS NIJHOFF PUBLISHERS
a member of the KLUWER ACADEMIC PUBLISHERS GROUP
DORDRECHT / BOSTON / LANCASTER



Contents

I Introduction to turbulence in fluid mechanics	1
1 Is it possible to define turbulence?	1
2 Examples of turbulent flows	4
3 Fully developed turbulence	11
4 Fluid turbulence and “chaos”	12
5 “Deterministic” and statistical approaches	13
6 Why study isotropic turbulence?	14
II Basic fluid dynamics	17
1 Eulerian notation and Lagrangian derivatives	17
2 The continuity equation	18
3 The conservation of momentum	18
4 The thermodynamic equation	21
5 The incompressibility assumption	23
6 The dynamics of vorticity	24
7 The generalized Kelvin theorem	26
8 The Boussinesq equations	28
9 Internal inertial-gravity waves	30
10 Barré de Saint-Venant equations	34
III Transition to turbulence	37
1 The Reynolds number	37
2 The Rayleigh number	44
3 The Rossby number	45
4 The Froude Number	46
5 Turbulence, order and chaos	48
IV The Fourier space	51
1 Fourier representation of a flow	51
4.1.1 flow “within a box”:	51
4.1.2 Integral Fourier representation	52
2 Navier-Stokes equations in Fourier space	54
3 Boussinesq equations in the Fourier space	56
4 Craya decomposition	57
5 Complex helical waves decomposition	58

V Kinematics of homogeneous turbulence	61
1 Utilization of random functions	61
2 Moments of the velocity field, homogeneity and stationarity	62
3 Isotropy	64
4 The spectral tensor of an isotropic turbulence	69
5 Energy, helicity, enstrophy and scalar spectra	70
6 Alternative expressions of the spectral tensor	73
7 Axisymmetric turbulence	76
VI Phenomenological theories	79
1 The closure problem of turbulence	79
2 Karman-Howarth equations in Fourier space	80
3 Transfer and Flux	83
4 The Kolmogorov theory	86
5 The Richardson law	89
6 Characteristic scales of turbulence	90
7 The skewness factor	92
8 The internal intermittency	96
6.8.1 The Kolmogorov-Oboukhov-Yaglom theory	97
6.8.2 The Novikov-Stewart model	98
VII Analytical theories and stochastic models	101
1 Introduction	101
2 The Quasi-Normal approximation	103
3 The Eddy-Damped Quasi-Normal type theories	106
4 The stochastic models	109
5 Phenomenology of the closures	114
6 Numerical resolution of the closure equations	117
7 The enstrophy divergence and energy catastrophe	122
8 The Burgers- <i>M.R.C.M.</i> model	124
9 Isotropic helical turbulence	126
10 The decay of kinetic energy	130
11 <i>E.D.Q.N.M.</i> and <i>R.N.G.</i> techniques	134
VIII Diffusion of passive scalars	137
1 Introduction	137
2 Phenomenology of the homogeneous passive scalar diffusion	138
3 The <i>E.D.Q.N.M.</i> isotropic passive scalar	144
4 The decay of temperature fluctuations	150
5 Lagrangian particle pair dispersion	159
IX Two-dimensional and quasi-geostrophic turbulence	163
1 Introduction	163
2 The quasi-geostrophic theory	166
9.2.1 The geostrophic approximation	167
9.2.2 The quasi-geostrophic potential vorticity equation	169

	XI
9.2.3 The n -layer quasi-geostrophic model	171
9.2.4 Interaction with an Ekman layer	175
9.2.5 Barotropic and baroclinic waves	178
3 Two-dimensional isotropic turbulence	180
9.3.1 Fjortoft's theorem	182
9.3.2 The enstrophy cascade	183
9.3.3 The inverse energy cascade	185
9.3.4 The two-dimensional <i>E.D.Q.N.M.</i> model	188
9.3.5 Freely-decaying turbulence	192
4 Diffusion of a passive scalar	196
5 Geostrophic turbulence	199
X Absolute equilibrium ensembles	205
1 Truncated Euler Equations	205
2 Liouville's theorem in the phase space	206
3 The application to two-dimensional turbulence	209
4 Two-dimensional turbulence over topography	211
XI The statistical predictability theory	215
1 Introduction	215
2 The <i>E.D.Q.N.M.</i> predictability equations	219
3 Predictability of three dimensional turbulence	220
4 Predictability of two-dimensional turbulence	223
XII Large-eddy simulations	227
1 The direct numerical simulation of turbulence	227
2 The Large Eddy Simulations	228
12.2.1 large and subgrid scales	228
12.2.2 L.E.S. and the predictability problem	230
3 L.E.S. of 3-D isotropic turbulence	231
4 L.E.S. of two-dimensional turbulence	238
XIII Towards "real world turbulence"	241
1 Introduction	241
2 Stably Stratified Turbulence	242
13.2.1 The so-called "collapse" problem	242
13.2.2 A numerical approach to the collapse	244
3 The Mixing Layer	249
13.3.1 Generalities	249
13.3.2 Two dimensional turbulence in the <i>M.L.</i>	250
13.3.3 Three dimensionality growth and unpredictability	252
13.3.4 Recreation of the coherent structures	256
4 Conclusion	257
References	259
Index	279