

## ***Contents***

|  |      |
|--|------|
| PREFACE  | xi   |
| ACKNOWLEDGEMENTS   | xiii |
| GLOSSARY   | xv   |
| CHAPTER 1. THE PHYSICS OF TURBULENCE                             | 1    |
| 1.1. "Control-volume" Analysis for the Equations of Motion       | 1    |
| 1.2. Newton's Second Law of Motion                               | 4    |
| 1.3. The Newtonian Viscous Fluid                                 | 5    |
| 1.4. Possible Solutions of the Equations of Motion               | 7    |
| 1.5. The Reynolds Stresses                                       | 10   |
| 1.6. Vortex Stretching   | 12   |
| 1.7. Compressible Flow   | 17   |
| 1.8. Flow-visualization Experiments                              | 18   |
| CHAPTER 2. MEASURABLE QUANTITIES AND THEIR PHYSICAL SIGNIFICANCE | 21   |
| 2.1. Statistics of Random Processes                              | 21   |
| 2.2. Turbulent Energy  | 24   |
| 2.3. Spatial Correlations  | 28   |
| 2.4. Time Correlations   | 29   |
| 2.5. Frequency Spectra   | 30   |
| 2.6. Wave Number Spectra   | 34   |
| 2.7. Space-Time Correlations                                     | 40   |
| 2.8. Cross-correlations and Cross-spectra                        | 43   |
| 2.9. Higher-order Correlations and Spectra                       | 43   |
| 2.10. Probability Distributions and Intermittency                | 44   |
| CHAPTER 3. EXAMPLES OF TURBULENT FLOWS                           | 47   |
| 3.1. Turbulence behind a Grid of Bars                            | 47   |
| 3.2. "Infinite" Shear Flow                                       | 49   |
| 3.3. Couette Flow  | 50   |
| 3.4. Two-dimensional Boundary Layers                             | 55   |
| 3.5. Three-dimensional Boundary Layers                           | 63   |

|   |         |
|---|---------|
| 3.6. Duct Flows   | 64      |
| 3.7. Jets, Wakes and Plumes   | 68      |
| 3.8. Atmospheric and Oceanic Turbulence                                       | 72      |
| 3.9. Separated Flows  | 75      |
| 3.10. Heat and Mass Transfer  | 79      |
| 3.11. Turbulence in Non-Newtonian Fluids                                      | 82      |
| <br>CHAPTER 4. MEASUREMENT TECHNIQUES   | <br>85  |
| 4.1. Hot Wires, Films and Thermistors   | 86      |
| 4.2. Constant-current and Constant-temperature Operation                      | 87      |
| 4.3. Doppler-shift Anemometers  | 92      |
| 4.4. Glow-discharge or Corona-discharge Anemometers                           | 96      |
| 4.5. The Pulsed-wire Anemometer   | 97      |
| 4.6. Particle Visualization   | 98      |
| 4.7. Use of Steady-flow Techniques for Fluctuation Measurement                | 99      |
| 4.8. Measurement of Surface Pressure Fluctuations                             | 102     |
| 4.9. Specialized Techniques of Turbulence Measurement                         | 103     |
| <br>CHAPTER 5. THE HOT-WIRE ANEMOMETER  | <br>106 |
| 5.1. Heat Transfer  | 109     |
| 5.2. The Effect of Fluid Temperature  | 117     |
| 5.3. The Effect of Flow Direction   | 119     |
| 5.4. Contamination of Probes  | 123     |
| 5.5. Probe Design and Manufacture   | 126     |
| 5.6. Spatial Resolution   | 130     |
| 5.7. Frequency Response   | 131     |
| <br>CHAPTER 6. ANALYSIS OF FLUCTUATING SIGNALS                                | <br>134 |
| 6.1. Analogue Computing Elements  | 134     |
| 6.2. Input and Output Impedance, and Frequency Response                       | 143     |
| 6.3. Noise and Hum  | 146     |
| 6.4. Averaging Time   | 148     |
| 6.5. Automatic Recording of Time-average Quantities                           | 149     |
| 6.6. Digital Recording of Fluctuating Signals                                 | 150     |
| <br>CHAPTER 7. TEMPERATURE AND CONCENTRATION MEASUREMENTS                     | <br>155 |
| 7.1. Separation of Velocity and Temperature Fluctuations                      | 155     |
| 7.2. High-speed Flow  | 157     |
| 7.3. Probes for Supersonic Flow   | 159     |
| 7.4. Sensitivity of a Hot Wire to Velocity and Total-temperature Fluctuations | 160     |
| 7.5. Small Temperature Differences  | 163     |
| 7.6. Measurements in the Presence of Concentration Differences                | 164     |

|  |     |
|--|-----|
| CONTENTS   | ix  |
| CHAPTER 8. SUMMARY OF PRACTICAL DETAILS                  | 167 |
| 8.1. Choice of Anemometer                                | 167 |
| 8.2. Choice of Probe                                     | 168 |
| 8.3. Calibration   | 170 |
| 8.4. Errors  | 175 |
| 8.5. Arrangements of Apparatus                           | 181 |
| 8.6. Distortion of the Flow by the Presence of the Probe | 184 |
| APPENDIX 1. The Equations of Motion                      | 186 |
| APPENDIX 2. Turbulence Research                          | 194 |
| NOTATION   | 201 |
| REFERENCES   | 204 |
| FURTHER READING  | 208 |
| INDEX  | 211 |