
Contents

List of Abbreviations, Acronyms and Symbols	xi
Preface	xv
Chapter 1. Equations of Linear Acoustics	1
1.1. Validity of the assumptions of linear acoustics and a perfect fluid	1
1.2. Linearized equations of fluid dynamics	3
1.3. The wave equation	5
1.3.1. The special case of ideal gases	6
1.3.2. The velocity potential	7
1.3.3. Validity conditions for the linearization of equations	8
1.4. Acoustic energy, acoustic intensity and source power	9
1.4.1. Definition of acoustic energy and acoustic intensity	9
1.4.2. Acoustic sources	10
1.5. Harmonic waves	12
1.5.1. Definition of harmonic waves	12
1.5.2. Average acoustic energy and acoustic intensity	15
1.6. Boundary conditions	16
1.6.1. Fluid–solid and fluid–fluid interfaces	16
1.6.2. Specific acoustic impedance	18
1.7. Exercises	19
Chapter 2. Plane Waves and Spherical Waves	21
2.1. Plane waves	21
2.1.1. Plane waves in the time domain	21
2.1.2. Harmonic plane waves	25
2.1.3. Evanescent plane waves	28
2.1.4. Angular spectrum of plane waves	28

2.1.5. Near-field acoustic holography	29
2.2. Spherical waves	31
2.2.1. Time-averaged intensity and power	33
2.2.2. Harmonic spherical waves	34
2.3. Cylindrical waves	36
2.4. Exercises	37
Chapter 3. Sound Levels, Spectral Analysis and Notions on Human Sound Perception	43
3.1. Energy and average power	44
3.2. Sound levels	45
3.3. Energy and power spectral densities	46
3.4. Correlation functions	47
3.5. Random signals	48
3.6. Random signals and correlations, some examples	50
3.7. Frequency bands	52
3.8. Loudness, equal loudness contours and frequency weightings	55
3.9. Characterization of non-stationary acoustic signals	58
3.9.1. Statistical levels	59
3.9.2. Equivalent level, “Day”, “Evening” and “Night” levels	60
3.9.3. Transient signals: sound exposure level and energy spectral density	61
3.10. Exercises	63
Chapter 4. Reflection and Transmission Phenomena	67
4.1. Reflection and transmission of normally incident plane waves	68
4.2. Reflection of a harmonic plane wave on an impedance surface	69
4.3. Multilayer media	72
4.3.1. Impedance transfer	72
4.3.2. Transmission through three media	73
4.3.3. Transmission of a harmonic plane wave through a thin wall	74
4.4. Reflection and transmission of plane waves at the interface between two fluids: oblique incidence	76
4.5. Plane wave transmission through a thin wall: oblique incidence	81
4.6. Piston-tube coupling	85
4.7. Reflection of spherical waves and image sources	87
4.8. Exercises	92
Chapter 5. Sound Sources and Green’s Functions	97
5.1. Volume sources	98
5.2. Green’s functions for the wave equation	99
5.3. General solution of the wave equation in free-space	100

5.3.1. Monopole sources: far-field and compact source region	101
5.3.2. Dipole sources	104
5.3.3. Quadrupole sources	107
5.4. Green's functions and general solutions of the Helmholtz equation . .	108
5.4.1. Monopole sources	109
5.4.2. Dipole and quadrupole sources	110
5.5. One-dimensional and two-dimensional Green's functions	111
5.5.1. Two-dimensional Green's function of the wave equation	111
5.5.2. One-dimensional Green's function of the wave equation	113
5.5.3. Green's functions of the Helmholtz equation in one- and two-dimensions	113
5.6. Reciprocity of Green's functions	115
5.7. Green's functions for a fluid in uniform subsonic motion	116
5.7.1. Green's function of the convected Helmholtz equation	119
5.8. Moving sources and the Doppler effect	119
5.8.1. Point mass source in arbitrary motion	119
5.8.2. Arbitrarily moving point forces	122
5.8.3. Sources in uniform rectilinear motion	124
5.9. Exercises	126

Chapter 6. Integral Formulations for Sound Radiation and Diffraction 129

6.1. Radially oscillating sphere	130
6.1.1. Harmonic vibrations: radiation impedance	131
6.2. Acoustic radiation from bending vibrations	134
6.2.1. Radiated power and radiation impedance	138
6.2.2. Acoustic radiation from a finite plate	140
6.3. Kirchhoff–Helmholtz integral	141
6.3.1. Irregular frequencies	145
6.3.2. Expressing the surface integral in terms of pressure and velocity	146
6.3.3. Kirchhoff–Helmholtz formula and acoustic field extrapolation . . .	147
6.4. Adapted Green's functions	148
6.5. Integral formulation associated with the wave equation	149
6.5.1. Bursting balloon	150
6.6. Radiation from planar structures: Rayleigh integral	152
6.6.1. Radiation from a circular piston	155
6.7. Rayleigh integral in the time domain	160
6.8. Exercises	161

Chapter 7. Diffraction and Scattering 163

7.1. Diffraction by a semi-infinite screen	163
7.2. Scattering by a rigid cylinder	169

7.2.1. Scattering cross-sections	173
7.3. Rayleigh scattering by a generic obstacle	177
7.4. Scattering by non-rigid obstacles and the Born approximation	180
7.4.1. Scattering by inhomogeneities	180
7.4.2. The Born approximation	183
7.4.3. Validity of the Born approximation	185
7.5. Exercises	186
Chapter 8. Guided Waves	189
8.1. Sound propagation in a duct of constant cross-section	189
8.1.1. Propagating modes and evanescent modes	191
8.2. Duct of rectangular cross-section	192
8.2.1. Phase and group velocities: dispersion of higher modes	193
8.2.2. Modes and pairs of plane waves	195
8.3. Ducts of circular cross-section	196
8.4. Point source in a duct and Green's function	198
8.5. Propagation in a duct with absorbing walls	201
8.6. Influence of a uniform flow on modal propagation	204
8.7. Exercises	208
Chapter 9. One-dimensional Propagation in Ducts	211
9.1. Ducts of piecewise constant cross-section: transfer matrices	211
9.1.1. Impedance transfer	212
9.1.2. Cross-sectional area discontinuities	212
9.1.3. Expansion chambers	215
9.1.4. Bifurcations and acoustic filters	217
9.1.5. Transmission loss and insertion loss	220
9.1.6. End corrections	221
9.1.7. Helmholtz resonators	222
9.2. Webster horn equation	226
9.2.1. Propagation in ducts with a slowly varying cross-section	226
9.2.2. Horn families: exponential horns	227
9.3. Exercises	231
Chapter 10. Acoustics of Enclosures: Room Acoustics	233
10.1. Simple-shaped cavities	234
10.2. Modal approach	235
10.2.1. Distribution of the natural frequencies	238
10.2.2. Room acoustic response to a point source	240
10.3. Energy approach: Sabine's theory	241
10.3.1. Global energy balance	242
10.3.2. Diffuse field	242

10.3.3. Steady-state level: reverberation time	244
10.3.4. Eyring's formula	246
10.4. Influence of the atmospheric absorption	247
10.5. Random incidence absorption coefficient	247
10.6. Schröder frequency	248
10.7. Room critical distance	249
10.8. Coupled rooms: transmission loss of a panel	250
10.9. Measurements in the reverberation room of École Centrale de Lyon	251
10.10. Geometric room acoustics	253
10.11. Subjective effects	256
10.12. Exercises	261
Appendices	267
Appendix 1. Basic Fluid Mechanics and Thermodynamics	269
Appendix 2. Math Refresher	281
References	293
Index	297