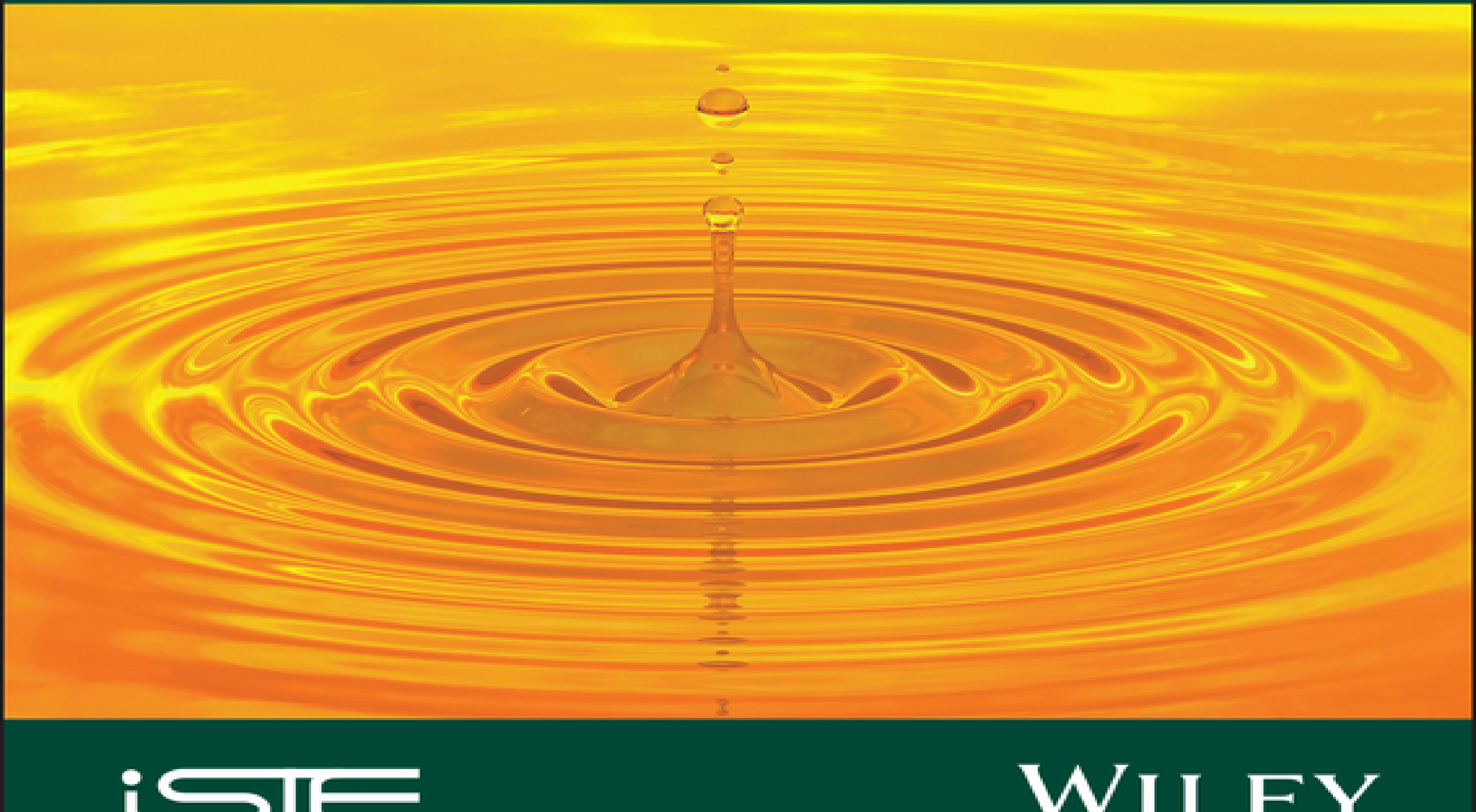
WAVES SERIES

Acoustics of Fluid Media 1

Principles and Applications

Daniel Juvé
Marie-Annick Galland
Vincent Clair



iSTE

WILEY

Table of Contents

- Cover
- Table of Contents
- Title Page
- Copyright Page
- List of Abbreviations, Acronyms and Symbols
- Preface
- 1 Equations of Linear Acoustics
    - 1.1. Validity of the assumptions of linear acoustics and a perfect fluid
    - 1.2. Linearized equations of fluid dynamics
    - 1.3. The wave equation
    - 1.4. Acoustic energy, acoustic intensity and source power
    - 1.5. Harmonic waves
    - 1.6. Boundary conditions
    - 1.7. Exercises
- 2 Plane Waves and Spherical Waves
    - 2.1. Plane waves
    - 2.2. Spherical waves
    - 2.3. Cylindrical waves
    - 2.4. Exercises
- 3 Sound Levels, Spectral Analysis and Notions on Human Sound Perception
    - 3.1. Energy and average power
    - 3.2. Sound levels
    - 3.3. Energy and power spectral densities

- 3.4. Correlation functions
- 3.5. Random signals
- 3.6. Random signals and correlations, some examples
- 3.7. Frequency bands
- 3.8. Loudness, equal loudness contours and frequency weightings
- 3.9. Characterization of non-stationary acoustic signals
- 3.10. Exercises

4 Reflection and Transmission Phenomena
- 4.1. Reflection and transmission of normally incident plane waves
- 4.2. Reflection of a harmonic plane wave on an impedance surface
- 4.3. Multilayer media
- 4.4. Reflection and transmission of plane waves at the interface between two fluids: oblique incidence
- 4.5. Plane wave transmission through a thin wall: oblique incidence
- 4.6. Piston-tube coupling
- 4.7. Reflection of spherical waves and image sources
- 4.8. Exercises

5 Sound Sources and Green’s Functions
- 5.1. Volume sources
- 5.2. Green’s functions for the wave equation
- 5.3. General solution of the wave equation in free-space

- 5.4. Green’s functions and general solutions of the Helmholtz equation
- 5.5. One-dimensional and two-dimensional Green’s functions
- 5.6. Reciprocity of Green’s functions
- 5.7. Green’s functions for a fluid in uniform subsonic motion
- 5.8. Moving sources and the Doppler effect
- 5.9. Exercises

6 Integral Formulations for Sound Radiation and Diffraction
- 6.1. Radially oscillating sphere
- 6.2. Acoustic radiation from bending vibrations
- 6.3. Kirchhoff-Helmholtz integral
- 6.4. Adapted Green’s functions
- 6.5. Integral formulation associated with the wave equation
- 6.6. Radiation from planar structures: Rayleigh integral
- 6.7. Rayleigh integral in the time domain
- 6.8. Exercises

7 Diffraction and Scattering
- 7.1. Diffraction by a semi-infinite screen
- 7.2. Scattering by a rigid cylinder
- 7.3. Rayleigh scattering by a generic obstacle
- 7.4. Scattering by non-rigid obstacles and the Born approximation
- 7.5. Exercises

8 Guided Waves

- 8.1. Sound propagation in a duct of constant cross-section
- 8.2. Duct of rectangular cross-section
- 8.3. Ducts of circular cross-section
- 8.4. Point source in a duct and Green’s function
- 8.5. Propagation in a duct with absorbing walls
- 8.6. Influence of a uniform flow on modal propagation
- 8.7. Exercises

9 One-dimensional Propagation in Ducts

- 9.1. Ducts of piecewise constant cross-section: transfer matrices
- 9.2. Webster horn equation
- 9.3. Exercises

10 Acoustics of Enclosures: Room Acoustics

- 10.1. Simple-shaped cavities
- 10.2. Modal approach
- 10.3. Energy approach: Sabine’s theory
- 10.4. Influence of the atmospheric absorption
- 10.5. Random incidence absorption coefficient
- 10.6. Schroder frequency
- 10.7. Room critical distance
- 10.8. Coupled rooms: transmission loss of a panel
- 10.9. Measurements in the reverberation room of Ecole Centrale de Lyon
- 10.10. Geometric room acoustics
- 10.11. Subjective effects
- 10.12. Exercises

Appendices

- Appendix 1 Basic Fluid Mechanics and Thermodynamics
  - A1.1. The equations of motion
  - A1.2. The equation of state and thermodynamic relations
  - A1.3. Boundary conditions at a fluid-solid interface
  - A1.4. Equations of motion of ideal fluids
  - A1.5. Physical properties of some gases
- Appendix 2 Math Refresher
  - A2.1. Differential operators in the main coordinate systems
  - A2.2. Dirac delta function, Fourier transforms and convolution product
  - A2.3. Bessel functions

References

Index

Other titles from ISTE in Waves

End User License Agreement

List of Tables

Chapter 3

- Table 3.1 Center, lower and upper frequencies of octave and one-third octave b...
- Table 3.2 A-weighting values for octave bands
- Table 3.3 Example of computing the A-weighted sound pressure level from an oct...
- Table 3.4 Noise generation by an industrial fan
- Table 3.5 Scenario of noise exposure at work

Chapter 8

- Table 8.1 Normalized eigenvalues $\chi_{mn}a$ associated with the first modes o...

Chapter 10

- Table 10.1 First natural frequencies of a rectangular cavity, whose dimensions...
- Table 10.2 Comparison between the frequencies of the first peaks of the sound ...
- Table 10.3 Acoustic indicators computed for the modeled movie theater
- Table 10.4 Absorption coefficients of materials present in the library
- Table 10.5 Atmospheric absorption coefficients
- Table 10.6 Reverberation times as a function of the frequency
- Table 10.7 Speech sound pressure levels atlmasa function of the frequency

Appendix 1

- Table A1.1 Physical properties of some gases at 300 K and atmospheric pressure

List of Illustrations

Chapter 1

- Figure 1.1 Integration surfaces used to define the power radiated by one or ...
- Figure 1.2 Boundary conditions at the interface between an impermeable solid...

Chapter 2

- Figure 2.1 Patterns at two successive instants of a plane wave propagating i...
- Figure 2.2 Harmonic plane traveling wave of unit amplitude. The plot of the ...
- Figure 2.3 Linear microphone array

Chapter 3

- Figure 3.1 Evolution versus time of the signals p′1, p′2, and p′3 defined in...
- Figure 3.2 Correlation functions: on the left side, the autocorrelations Rıı...
- Figure 3.3 Representation of lower and upper frequencies for octave (black) ...
- Figure 3.4 Narrowband (left) and octave-band (right) spectra of white noise ...
- Figure 3.5 Narrowband, one-third octave and octave band spectra computed fro...
- Figure 3.6 Equal loudness level contours defined in the ISO 226:2003 standar...
- Figure 3.7 A-, B- and C-weighting curves
- Figure 3.8 Time recording of sound pressure levels and corresponding statist...
- Figure 3.9 Example of a transient signal (on the left) and of the correspond...

Chapter 4

- Figure 4.1 Reflection and transmission of plane waves at normal incidence at...
- Figure 4.2 Impedance tube for measuring the surface impedance of a sample us...

Figure 4.3 Real (resistance) and imaginary (reactance) parts of the reduced ...

Figure 4.4 On the left side: Absorption coefficient of two foam samples with...

Figure 4.5 Plane wave reflection at a normal incidence on a thin wall

Figure 4.6 Reflection and transmission for an obliquely incident plane wave ...

Figure 4.7 Reflection and transmission of a harmonic plane wave at the inter...

Figure 4.8 Amplitudes of the reflection and transmission coefficients for a ...

Figure 4.9 Transmission loss of an aluminum plate with a thickness h =8mmina...

Figure 4.10 Transmission loss in air of an 8-mm-thick aluminum plate. The do...

Figure 4.11 A single degree-of-freedom oscillator coupled to a fluid contain...

Figure 4.12 Eigenfrequencies of an oscillator coupled to a tube with a rigid...

Figure 4.13 A spherical wave source placed above a perfectly rigid plane. Th...

Figure 4.14 The directivity patterns of a spherical source placed above of a...

Figure 4.15 Evolution with k0h of the ratio between the power emitted by a s...

Figure 4.16 Point source in underwater acoustics: Lloyd’s mirror

Figure 4.17 Acoustic tunnel effect

Chapter 5

Figure 5.1 Extended acoustic sources. Geometrical far-field and compact sour...

Figure 5.2 On the left, directivity diagram of a compact dipole with a verti...

Figure 5.3 Schematic representation of compact multipole sources as combinat...

Figure 5.4 Three-dimensional views of the directivity patterns of a longitud...

Figure 5.5 Arbitrarily moving point source and the Doppler effect

Figure 5.6 Evolution of the frequency and amplitude measured in the far-fiel...

Figure 5.7 Source in uniform subsonic rectilinear motion. Emission and recep...

Figure 5.8 Wavefronts from a source moving from left to right. On the left, ...

Chapter 6

Figure 6.1 Reduced radiation impedance of a pulsating sphere as a function o...

Figure 6.2 Acoustic radiation from an infinite plate subjected to harmonic b...

Figure 6.3 Dispersion relations for air (dashed line) and a 5-mm thick alumi...

Figure 6.4 Generation of a propagative plane wave excited by a supersonic be...

Figure 6.5 Generation of an evanescent plane wave excited by a subsonic flex...

Figure 6.6 Evolution with the frequency (normalized by the critical frequenc...

Figure 6.7 Radiation of the first bending modes of a rectangular baffled pla...

Figure 6.8 Integral formulation of the Helmholtz equation. Volume sources lo...

Figure 6.9 Geometry for the Kirchhoff-Helmholtz formulation

Figure 6.10 Acoustic response to a uniform overpressure P0 initially present...

Figure 6.11 Radiation of a vibrating planarstructure surrounded by an infini...

Figure 6.12 Directivity patterns for the circular piston, plotted for increa...

Figure 6.13 Variation of the acoustic pressure amplitude along the axis of a...

Figure 6.14 Near-field pressure amplitude generated by a circular piston (k0...

Figure 6.15 Reduced radiation impedance of the circular piston plotted as a ...

Chapter 7

Figure 7.1 Plane wave diffraction by a semi-infinite rigid thin screen

Figure 7.2 Diffraction of a harmonic plane wave of unit amplitude by a semi-...

Figure 7.3 Plane wave diffraction by a semi-infinite rigid screen. The field...

Figure 7.4 Diffraction of a spherical wave by a semi-infinite rigid thin scr...

Figure 7.5 Diffraction of a spherical wave by a semi-infinite rigid screen (...

Figure 7.6 Diffraction by a thin screen. The paths connecting the source and...

Figure 7.7 Diffraction of a spherical wave by a thin barrier. The real part ...

Figure 7.8 Diffraction of a spherical wave by a thin barrier. The sound leve...

Figure 7.9 Diffraction of a plane wave by a circular cylinder

Figure 7.10 Scattering of a plane wave by a rigid cylinder: directivity patt...

Figure 7.11 Scattering of a plane wave by a rigid cylinder: evolution of the...

Figure 7.12 Plane wave scattering by a rigid cylinder: directivity pattern o...

Figure 7.13 Plane wave scattering by a rigid cylinder. Plot of the amplitude...

Figure 7.14 Plane wave scattering by an inhomogeneous fluid inclusion

Figure 7.15 Geometry for the far-field scattering of a plane wave

Chapter 8

Figure 8.1 Cylindrical duct with arbitrary cross-section

Figure 8.2 Axial phase velocities (dashed-dotted lines) and group velocities...

Figure 8.3 Real part of the pressure fluctuation in the cross-section of a r...

Figure 8.4 From left to right and top to bottom, plots of the real part of t...

Figure 8.5 Reduced radiation resistance of a point source in a rectangular d...

Figure 8.6 Non-normalized modal shapes (n=2, k0b =10) in a lined rectangular...

Figure 8.7 Evolution with the frequency of the imaginary part of the axial w...

Figure 8.8 Plots of the two branches of the real part of the axial wavenumbe...

Figure 8.9 Phase (gray curves) and group (black curves) velocities in a duct...

Chapter 9

Figure 9.1 Reflection and transmission of a plane wave at a junction between...

Figure 9.2 Real part of the pressure field for a sudden change in area in a ...

Figure 9.3 Geometry of an expansion chamber-type reactive silencer. The term...

Figure 9.4 Evolution with the frequency of the transmission loss induced by ...

Figure 9.5 Evolution of the transmission loss due to an expansion chamber (m...

Figure 9.6 Compact junction between several ducts. The diameter of the dashe...

Figure 9.7 Y-shaped bifurcationy

Figure 9.8 Evolution of the transmission loss due to a resonant bifurcation ...

Figure 9.9 Real part of the pressure field at the resonant frequency of a qu...

Figure 9.10 Sound radiation from a flanged duct opening into an otherwise un...

Figure 9.11 Helmholtz resonator excited by an external pressure field. The m...

Figure 9.12 Transmission loss due to a Helmholtz resonator connected to a du...

Figure 9.13 Model for a duct of slowly varying cross-section leading to the ...

Figure 9.14 Evolution of the phase (solid line) and group (dotted dashed lin...

Figure 9.15 Geometry of the exponential and conical horns used for comparing...

Figure 9.16 Transmission factors of an exponential horn (dashed curve) and a...

Figure 9.17 Real part of the reduced radiation impedance of a finite length ...

Chapter 10

Figure 10.1 Acoustic field in a rectangular room. Direct path, image sources...

Figure 10.2 Mode (2,1,3) of a rectangular room which size is close to that o...

Figure 10.3 Distribution function of the eigenfunctions in a rectangular roo...

Figure 10.4 Representation of the modes of a rectangular room in wavenumber,...

Figure 10.5 Frequency response of a rectangular room excited by a point sour...

Figure 10.6 Representation of the reverberant field by superposition of unco...

Figure 10.7 Power spectral density of sound pressure fluctuations measured i...

Figure 10.8 Measurement of the reverberation time using the interrupted nois...

Figure 10.9 Plot of a ray emitted from a source and arriving at a receiver a...

Figure 10.10 Direct ray and rays joining the source (labeled A0) and a recei...

Figure 10.11 Model of the movie theater at Ecole Centrale de Lyon. The volum...

Figure 10.12 Echogram of the movie theater in the 1-kHz octave. For this plo...

Figure 10.13 Sound pressure level distribution in the movie theater (1-kHz o...

Figure 10.14 Distribution of the sound pressure level in the movie theater w...

Figure 10.15 Geometry of coupled rooms

Figure 10.16 Evolution of energy densities overtime

Appendix 2

Figure A2.1 Cylindrical coordinate system

Figure A2.2 Spherical coordinate system

Figure A2.3 Illustration of the mth-order Bessel functions of the first kind...

Series Editor
Frédérique de Fornel

Acoustics of Fluid Media 1

Principles and Applications

Daniel Juvé

Marie-Annick Galland

Vincent Clair

First published 2024 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc.

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms and licenses issued by the CLA. Enquiries concerning reproduction outside these terms should be sent to the publishers at the undermentioned address:

ISTE Ltd
27-37 St George’s Road
London SW19 4EU
UK

www.iste.co.uk

John Wiley & Sons, Inc.
111 River Street
Hoboken, NJ 07030
USA

www.wiley.com

© ISTE Ltd 2024
The rights of Daniel Juvé, Marie-Annick Galland and Vincent Clair to be identified as the authors of this work have been asserted by them in accordance with the Copyright, Designs and Patents Act 1988.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s), contributor(s) or editor(s) and do not necessarily reflect the views of ISTE Group.

Library of Congress Control Number: 2024940982

British Library Cataloguing-in-Publication Data
A CIP record for this book is available from the British Library
ISBN 978-1-78630-932-7

List of Abbreviations, Acronyms and Symbols

(ρ,φ,z)	cylindrical coordinates
$(r, \theta, \varphi$	spherical coordinates
(x_1, x_2, x_3)	Cartesian coordinates
α_m	random incidence absorption coefficient
α_r	energy reflection coefficient
α_t	energy transmission coefficient
β	thermal dilation coefficient
$\boldsymbol{I}$	(vector) acoustic intensity
$\boldsymbol{k}$	wave vector
M	Mach number
δ	Dirac distribution
γ	adiabatic index
k_s	adiabatic compressibility coefficient
k_T	isothermal compressibility coefficient
λ	wavelength
λ_{th}	thermal conductivity coefficient
μ	dynamic viscosity coefficient
μB	volume viscosity coefficient
∇	nabla differential operator
ν	kinematic viscosity coefficient
ω	angular frequency
ϕ	acoustic potential
ρ	density
He	Helmholtz number
Pr	Prandtl number
Re	Reynolds number

σ	diffusion cross-section
$\zeta = Z/Z_0$	reduced acoustic impedance
c_0	speed of sound
c_f	bending wave velocity
c_p	constant pressure specific heat
c_v	constant volume specific heat
E	Young’s modulus
E	signal energy
e	acoustic energy density
f	frequency
f_{coin}	coincidence frequency
f_{cr}	critical frequency
G_0	Green’s function of the Helmholtz equation in free space
g_0	Green’s function of the free-space wave equation
H	Heaviside function
h	specific enthalpy
$H_n^{(2)}$	nth-order Hankel function of the second kind
J_n	nth-order Bessel function of the first kind
k_0	acoustic wavenumber
k_f	bending wavenumber
L_i	acoustic intensity level (dB)
L_p	sound pressure level (dB)
L_w	sound power level (dB)
$p'(t)$	acoustic pressure
$p(f)$	complex amplitude of sound pressure

P_{ref}	reference sound pressure
p_{rms}	r.m.s. value of sound pressure fluctuations
R	ideal gas constant
r	gas constant
R_{pp}	autocorrelation of pressure fluctuations
s	specific entropy
T	power spectral density of pressure fluctuations
T	absolute temperature
t	amplitude transmission coefficient
T_c	temperature in degrees Celsius
T_{60}	reverberation time
$u'(t)$	acoustic velocity fluctuation
$u(f)$	complex amplitude of acoustic velocity
U	flow velocity
V_g	group speed
$V\varphi$	phase speed
Y_n	nth-order Bessel function of the second kind
Z	specific acoustic impedance
Z_0	characteristic impedance
Z_{ray}	radiation impedance
Z_s	surface impedance

Preface

This book is based on courses taught by the authors at the École Centrale de Lyon and at the Université de Lyon, both at the undergraduate and graduate levels. It has also benefited from their interactions with the audience of professional training sessions, held in particular at the College de Polytechnique.

The book is intended for undergraduate students and engineering students, as well as graduate students and professionals in industry who are increasingly faced with the need to consider acoustic constraints when developing new products. It is limited to acoustics in fluids, with applications to atmospheric and underwater acoustics.

The book is divided into two volumes. The first is devoted to fundamental elements, the knowledge of which allows for a good mastery of acoustics in fluids. The second is an introduction to more advanced aspects, some of which are the subject of active research and whose status is sometimes still evolving (aeroacoustics, propagation in a moving medium, nonlinear acoustics). Some synthesis problems are also presented, focusing on noise control issues.

Volume 1 consists of 10 chapters plus an appendix of fluid mechanics reminders and a second one with some mathematical elements.

The first two chapters establish the equations of acoustics in homogeneous fluids and describe the properties of plane waves and spherical waves, as fundamental elements in the construction of more general solutions.

Chapter 3 is an interlude in the physical analysis offered throughout the book. It is devoted to elements of signal processing useful to the acoustician, to the definition of sound levels and decibel scales, and to notions of human sound perception and the characterization of the associated nuisances.

Chapter 4 describes the phenomena of reflection and transmission of plane and spherical waves at the interface between two fluids or between a fluid and a solid. In particular, the transmission of plane waves through a thin wall subjected to bending vibrations is discussed.

In Chapter 5, volume acoustic sources associated with mass, force or heat contributions within the fluid are introduced. The powerful method of Green’s functions is then extensively discussed and used.

Integral methods, which complement the local formulations used so far, are introduced in Chapter 6, as well as their application to radiation from vibrating surfaces and diffraction by obstacles.

Chapter 7 describes these diffraction phenomena in more detail with their application to the characterization of the efficiency of sound barriers. This is followed by a description of wave scattering exerted by rigid obstacles, with emphasis on low-frequency (Rayleigh scattering) and high-frequency (geometric limit) behavior. The effect of fluid inclusions of low contrast relative to the surrounding medium is addressed within the framework of the Born approximation.

Chapters 8 and 9 deal with guided propagation in ducts, first in the general form using the notion of propagation modes, and then in the low-frequency version of one-dimensional networks. This simplified formulation is very useful for defining acoustic filters such as Helmholtz resonators and passive silencers for selective reduction of sound levels.

Chapter 10 is devoted to the acoustics of confined spaces and applications in room acoustics. The concept of diffuse field and the important notion of reverberation time are introduced, as well as elements for characterizing the acoustic quality of rooms from the point of view of human perception.

Each of these chapters is accompanied by a limited number of exercises, ranging from the simple application of definitions and formulas to problems requiring more advanced theoretical analyses or numerical solutions.

Throughout the book, we have striven to illustrate the theoretical results with many figures obtained from measurements and numerical simulations resulting from the evaluation of complex theoretical formulas or the use of a finite element solver. The purpose of these illustrations is to facilitate the physical interpretation of the phenomena involved by making our own Richard Hamming’s aphorism, “The purpose of computing is insight, not numbers”. They do not, of course, replace the theoretical developments that allow us to highlight the influence of the most influential parameters. However, theoretical formulations are all too often limited to highly simplified or asymptotic situations. Rather than resorting to too often unintuitive expressions using series of special functions, we have found it preferable, for example, to plot maps of acoustic levels that are much more meaningful.

This aspect distinguishes our work somewhat from the vast existing bibliography. The main works upon which we have relied while writing this book are listed in the references section, which is of course very far from exhaustive. In the text, we sometimes refer to some of these books or articles for additional elements or computational details that we felt it was unnecessary to develop.

We would like to warmly thank all our colleagues at the Acoustic Center of the LMFA at École Centrale de Lyon with whom we have had extensive interactions during our teaching and research activities.

July 2024

1
Equations of Linear Acoustics

In this chapter, we establish the equations that govern the propagation of small-amplitude acoustic waves in fluids under the simplest possible conditions. The fluid is considered as perfect, that is non-viscous and non-heat-conductive. Acoustic disturbances are regarded as small-amplitude perturbations of the ambient state of a time-independent homogeneous fluid at rest. External forces, such as gravity, are not taken into account.

These assumptions may seem very strong, and we will have to relax some of them in later chapters. However, they offer considerable advantages in terms of simplicity, while often remaining unrestrictive in practice. This simplicity makes it possible to emphasize the fundamental properties of acoustic waves, which are generally only slightly modified in more complex situations where, for example, the inhomogeneous nature of the medium will have to be taken into account. They also allow the construction of analytical solutions with very wide applications, which also serve as references for the numerical simulations that become necessary when the geometries of the problems under consideration become complex.

1.1. Validity of the assumptions of linear acoustics and a perfect fluid

It is important to form a first qualitative idea on the legitimacy of the assumptions of a perfect fluid and linearization of fluid dynamics equations by performing order-of-magnitude analyses in a simplified situation. We

SAVAUX Vincent, LOUËT Yves
MMSE-based Algorithm for Joint Signal Detection, Channel and Noise
Variance Estimation for OFDM Systems

THOMAS Jean-Hugh, YAAKOUBI Nourdin
New Sensors and Processing Chain

TING Michael
Molecular Imaging in Nano MRI

VALIÈRE Jean-Christophe
Acoustic Particle Velocity Measurements using Laser: Principles, Signal
Processing and Applications

VANBÉSIEN Olivier, CENTENO Emmanuel
Dispersion Engineering for Integrated Nanophotonics

2013

BENMAMMAR Badr, AMRAOUI Asma
Radio Resource Allocation and Dynamic Spectrum Access

BOURLIER Christophe, PINEL Nicolas, KUBICKÉ Gildas
Method of Moments for 2D Scattering Problems: Basic Concepts and Applications

GOURE Jean-Pierre
Optics in Instruments: Applications in Biology and Medicine

LAZAROV Andon, KOSTADINOV Todor Pavlov
Bistatic SAR/GISAR/FISAR Theory Algorithms and Program Implementation

LHEURETTE Eric
Metamaterials and Wave Control

PINEL Nicolas, BOURLIER Christophe
Electromagnetic Wave Scattering from Random Rough

Surfaces: Asymptotic Models

SHINOHARA Naoki
Wireless Power Transfer via Radiowaves

TERRE Michel, PISCHELLA Mylène, VIVIER Emmanuelle
Wireless Telecommunication Systems

2012

LALAUZE René
Chemical Sensors and Biosensors

LE MENN Marc
Instrumentation and Metrology in Oceanography

LI Jun-chang, PICART Pascal
Digital Holography

2011

BECHERRAWY Tamer
Mechanical and Electromagnetic Vibrations and Waves

BESNIER Philippe, DÉMOULIN Bernard
Electromagnetic Reverberation Chambers

GOURE Jean-Pierre
Optics in Instruments

GROUS Ammar
Applied Metrology for Manufacturing Engineering

LE CHEVALIER François, LESSELIER Dominique, STARAJ Robert
Non-standard Antennas

2010

BEGAUD Xavier
Ultra Wide Band Antennas

MARAGE Jean-Paul, MORI Yvon
Sonar and Underwater Acoustics

2009

BOUDRIOUA Azzedine
Photonic Waveguides

BRUNEAU Michel, POTEL Catherine
Materials and Acoustics Handbook

DE FORNEL Frédérique, FAVENNEC Pierre-Noël
Measurements using Optic and RF Waves

FRENCH COLLEGE OF METROLOGY
Transverse Disciplines in Metrology

2008

FILIPPI Paul J.T.
Vibrations and Acoustic Radiation of Thin Structures

LALAUZE René
Physical Chemistry of Solid-Gas Interfaces

2007

KUNDU Tribikram
Advanced Ultrasonic Methods for Material and Structure Inspection

PLACKO Dominique
Fundamentals of Instrumentation and Measurement

RIPKA Pavel, TIPEK Alois
Modern Sensors Handbook

2006

BALAGEAS Daniel *et al.*
Structural Health Monitoring

BOUCHET Olivier *et al*.
Free-Space Optics

BRUNEAU Michel, SCELO Thomas
Fundamentals of Acoustics

FRENCH COLLEGE OF METROLOGY
Metrology in Industry

GUILLAUME Philippe
Music and Acoustics

GUYADER Jean-Louis
Vibration in Continuous Media