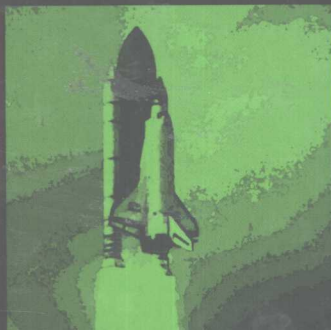


DICTIONARY OF ACOUSTICS



CHRISTOPHER L MORFEY



DICTIONARY OF ACOUSTICS

CHRISTOPHER L MORFEY

Institute of Sound and Vibration Research
University of Southampton
Southampton, UK



ACADEMIC PRESS

A Harcourt Science and Technology Company

San Diego San Francisco New York
Boston London Sydney Tokyo

This book is printed on acid-free paper.

Copyright © 2001 by ACADEMIC PRESS

All Rights Reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Academic Press

A Harcourt Science and Technology Company

Harcourt Place, 32 Jamestown Road, London NW1 7BY, UK

<http://www.academicpress.com>

Academic Press

A Harcourt Science and Technology Company

525 B Street, Suite 1900, San Diego, California 92101-4495, USA

<http://www.academicpress.com>

ISBN 0-12-506940-5

Library of Congress Catalog Number: 00-102542

A catalogue record for this book is available from the British Library

Typeset by Paston Prepress Ltd, Beccles, Suffolk, UK

Printed and bound in Great Britain by Redwood Books Ltd, Trowbridge, UK

01 02 03 04 05 06 RB 9 8 7 6 5 4 3 2 1

DICTIONARY OF ACOUSTICS

7011961

Subject Consultants and Reviewers

Consultants

Michael Fisher, ISVR, University of Southampton, UK, *Aeroacoustics* [1]

Douglas Robinson[†], formerly of ISVR, University of Southampton, UK, *Audiology and Human Effects* [2]

Mike Barron, Dept of Architecture & Civil Engineering, University of Bath, UK, *Auditorium Acoustics* [3]

Ian Flindell, ISVR, University of Southampton, UK

Mike Lower, ISVR Consultancy Services, University of Southampton, UK, *Environmental Noise* [4]

Marc Bedford, Aerospace Engineering and Engineering Mechanics, University of Texas at Austin, USA

Maurice Petyt, ISVR, University of Southampton, UK, *Mathematics and Applied Mechanics* [5]

Alan Cummings, School of Engineering, University of Hull, UK, *Porous Materials for Sound Absorption* [6]

Paul White, ISVR, University of Southampton, UK

Garvin Wills, PA Consulting Group, Cambridge Technology Centre, UK, *Signal Processing and Linear Systems* [7]

Stanley Ehrlich, Stan Ehrlich Associates, USA

Keith Holland, ISVR, University of Southampton, UK, *Transducers and Measurements* [8]

Tim Leighton, ISVR, University of Southampton, UK, *Ultrasonics, Physical Acoustics* [9]

Michael Ainslie, Principal Consultant (Ocean Acoustics), CORDA Ltd, UK, *Underwater Acoustics* [10]

Frank Fahy, ISVR, University of Southampton, UK, *Vibroacoustics, Acoustics* [11]

Reviewers

Michael Ainslie, 10*, Principal Consultant (Ocean Acoustics), CORDA Ltd, UK

Mike Barron, 3, Dept of Architecture & Civil Engineering, University of Bath, UK

[†] Deceased.

* Numbers refer to subject areas reviewed, cross-referenced to the preceding list of consultants.

John Chapman, 5, Dept of Mathematics, University of Keele, UK
Robert Chivers, 9, 11, ISVR, University of Southampton and DAMTP,
University of Cambridge, UK
Alan Cummings, 6, 11, School of Engineering, University of Hull, UK
Stephen Elliott, 7, ISVR, University of Southampton, UK
Frank Fahy, 11, ISVR, University of Southampton, UK
Stuart Gatehouse, 2, MRC Institute of Hearing Research, Glasgow, UK
Joe Hammond, 7, ISVR, University of Southampton, UK
Tony Herbert, 4, 11, Anthony Herbert Acoustics, Lyndhurst, UK
Finn Jacobsen, 7, Dept of Acoustic Technology, Technical University of
Denmark, Lyngby, DK
Tim Leighton, 9, 10, ISVR, University of Southampton, UK
Geoffrey Lilley, 1, School of Engineering Sciences, University of Southampton,
UK
Mark Lutman, 2, ISVR, University of Southampton, UK
John Post, 7, Applied Research Laboratories, University of Texas at Austin,
USA
Victor Sparrow, 3, 5, 11, Graduate Program in Acoustics, Pennsylvania State
University, USA
Wayne Wright, 11, Physics Dept, Kalamazoo College, Michigan, USA

Additional technical contributions

Anthony Atchley, Yves Aurégan, Joseph Beaman, Philippe Béquin, Bernard
Berry, Ioannis Besieris, David Blackstock, Niven Brown, Murray Campbell,
David Chapman, Argy Chatzipetris, Stuart Colam, Gary Coleman, Leszek
Demkowicz, John Dixon, Jim Greenleaf, Michael Griffin, Mark Hamilton,
Dean Hewlett, Michael Howe, Phillip Joseph, Jian Kang, Sarosh Kapadia, Ben
Lawton, Denys Mead, Pennia Menounou, Kevin Munro, Philip Nelson, Brian
Olsen, Allan Pierce, Roger Pinnington, Stewart Radcliffe, Sjoerd Rienstra,
Nicholas Rott, Neil Sandham, Christine Shadle, Viggo Tarnow, Ron Verrillo,
Erik Vigran, Evan Westwood, Bob White, Matthew Wright, Philippe Young.

Preface

‘The language of science is incredibly interesting; it’s a natural language under stress. The language is put under stress to explain things that are difficult to explain, that perhaps are explainable in terms of mathematical equations and structures. In this language simple words like power, energy, force, stable, unstable, acquire a host of alternative meanings. . . .’

Roald Hoffmann, joint winner of the 1981 Nobel Prize in chemistry,
in conversation with Lewis Wolpert.*

Although Hoffmann was thinking of theoretical chemistry, his remarks apply with equal force to the cross-disciplinary field of acoustics. It took me several years of teaching the subject to senior engineering undergraduates to recognize that the language of acoustics, however straightforward it might seem to experienced practitioners, represents a significant obstacle to students. Fortunately, when in 1987 I began compiling definitions of acoustical terms for my students, Douglas Robinson had recently retired from the UK National Physical Laboratory and was occupying a nearby office as research professor in the Institute of Sound and Vibration Research (ISVR). When I asked his advice, he lent me his copy of the *Glossary of Acoustical Terms*, produced in 1969 by the British Standards Institution[†]. The BSI Glossary became the model for the present work.

Although well written, the Glossary was already out of date when I first saw it; the technology had moved on, and the theoretical underpinning was that of the acoustics textbooks of the 1950s. The publication in 1981 of Allan Pierce’s *Acoustics*[‡] had set a new standard for graduate texts in engineering acoustics, and any dictionary of the subject would need to match that standard to do justice to the rapidly growing field. I also decided it was desirable to try to define specialist acoustical terms in as informative a manner as possible, so that the student of acoustics would recognize interconnections among the various branches of the subject.

The project had not advanced beyond a hundred or so terms when, in 1994, two events provided a fresh impetus: the IEC published Chapter 801 of its International Electrotechnical Vocabulary, and the Acoustical Society of America published its revised American National Standard on Acoustical Terminology. The scope of these documents was impressive, with 431 and 601 entries respectively; they made the task of assembling the dictionary a great deal easier, and I acknowledge the dedicated efforts of the standards committees

* Reported in *Passionate Minds: The Inner World of Scientists*, by Lewis Wolpert and Alison Richards (1997). By permission of Oxford University Press.

[†] BSI 661:1969, long since withdrawn.

[‡] See Bibliography for references.

responsible. Wherever possible I have sought to be consistent in my expanded definitions with what they wrote. Over the following two years, prompted by the enthusiastic interest of my younger ISVR colleagues Phillip Joseph and Matthew Wright, a draft of the present dictionary was assembled (covering A–L) that addressed the aims set out in the previous paragraph.

In 1997 Gioia Ghezzi of Academic Press decided that the dictionary project was worth supporting. The University of Southampton provided me with a timely four-month sabbatical, and a generous invitation from the University of Texas at Austin (UT) provided the ideal environment for converting a rough version of A–L into a more respectable A–Z. Nevertheless a further 21 months of sustained effort were needed to turn the resulting draft into a finished product. I am profoundly grateful to David Blackstock, Mark Hamilton and ARL Director Mike Pectorius for their support from the UT side, and to my ISVR colleagues for their encouragement and forbearance as the project approached completion.

Robert T Beyer, writing a few years ago as Series Editor of the *AIP Series on Modern Acoustics and Signal Processing*, penned some wise words[§] on the interdisciplinary nature of modern acoustics. Anyone who has attended meetings of the Acoustical Society of America will be aware of the fascinating variety of topics covered. Yet, despite this variety, communication among acousticians remains possible. Although one can see a tendency for the terminology to fragment between subdisciplines, we still share a largely common vocabulary, one that I have sought to document in the following pages. The attempt has been partial, in that terms relating to speech and music have been omitted entirely. This failing apart, the scope of the dictionary is fairly broad. Altogether nearly 3000 terms are included, ranging from the elementary to the highly specialized. My hope is that the result will be of real benefit to the international acoustical community.

The knowledgeable reader will inevitably notice mistakes, despite my own best efforts and those of the reviewers. Please send comments and corrections to Chris Morfey, ISVR, University of Southampton, Southampton SO17 1BJ, fax +44 23 8059 3190, or email me at <dict@isvr.soton.ac.uk>.

Southampton, 10 May 2000
Christopher L Morfey

[§] See *Computational Ocean Acoustics*, Jensen *et al.* (1994), p. xiii.

Acknowledgments

Specific technical contributions are acknowledged elsewhere, but there is more to be said. Thanks first to friends in Austin who took care of me during my four-month visit – your love and care are appreciated; and also to my wife – who I think knows this anyway – for unfailingly providing other topics of conversation over the past 3 years. The task of entering my handwritten notes on the keyboard, complete with equations, was cheerfully undertaken by Sue Brindle at ISVR who has seen the project through from the beginning. Joe Hammond, ISVR Director, and my colleague Phil Nelson, Fluid Dynamics and Acoustics Group Chairman, have been immensely supportive. My former mentors Philip Doak and Peter Davies loaned me office space among the retired professors, where a quiet hour could be spent and papers could be left undisturbed. Emma Roberts and Roopa Baliga at Academic Press were a pleasure to work with at all times. Finally, it is fair to acknowledge that the subject consultants and reviewers listed in the front of the book have contributed enormously to the value and credibility of the present work. Out of the 27 listed, 20 have some connection with ISVR. The first to offer his services was the late Douglas Robinson, who patiently educated me in the terminology of hearing measurement, and then in January 1998 provided a complete set of draft audiological definitions for inclusion in the dictionary. I am indebted to them all for their enthusiasm, patience and attention to detail; any errors that remain are my responsibility alone.

Dictionary Guide and Abbreviations Used

1. Alphabetization

Entries are arranged in alphabetical order. The order is determined by spelling out the terms letter by letter, with spaces and other characters ignored: for example

acoustic reflex tests

acoustics

acoustic scatterer.

2. Spelling

Terms are spelled according to the *Longman Dictionary of the English Language* (1995) (see the Bibliography for details).

3. Typographic conventions

(1) Headwords are capitalized only where standard usage requires it: e.g.

dB

decibel

Fermat's principle

leaky Rayleigh wave.

(2) Italic labels immediately following the headword help to define the area of meaning: examples are

acoustic bullets – *in ultrasonics*

bias – *in spectral analysis*

(3) Small capitals are used for cross-references to other entries in the dictionary:

acoustic power – the same as SOUND POWER.

(4) Bold italics highlight subsidiary definitions within the main entry: for example

chi-square distribution – a family of continuous PROBABILITY DENSITY FUNCTIONS, with a parameter *N* called the *degrees of freedom*.

(5) Often an equation, theorem, or result is named after an individual, as in HELMHOLTZ EQUATION. The year in which the result first appeared is given

wherever possible, preceded by the name in bold small capitals: (**H L F VON HELMHOLTZ 1860**).

(6) Sometimes a term is named after a famous scientist, but for less specific reasons (as in **MACH NUMBER**). In such cases the name is followed by dates in italics giving the individual's life span: (**E MACH 1838–1916**).

(7) To save unnecessary repetition, a swung dash (~) is sometimes used to represent the headword within a definition: for example

scattering coefficient – see **BULK ~**, **SURFACE ~**, **VOLUME ~**.

4. Units

Entries for quantitative terms generally list the appropriate SI unit symbol*, or combination of unit symbols, at the end:

acoustic impedance – ... *Units* Pa s m⁻³.

sound power – ... *Units* W.

For generic terms like radiation impedance or cross-spectral density, where the units depend on the context, no units are specified. Some dimensionless quantities are assigned special units: for example

phase angle – ... *Units* rad.

Otherwise, where the quantity is measured by a pure number, the units are listed as 'none':

acoustic Mach number – ... *Units* none.

5. Non-SI units

In a few cases, non-SI units are specified at the end of an entry (e.g. Np, B, h, °, %) or appear as entries in their own right (e.g. phon, octave). Most of these non-SI units are accepted for use with the SI system (% is not); the adoption of the neper and bel as SI units is under discussion in ISO as the dictionary goes to press.

6. Notes

Many of the dictionary definitions are supplemented by additional information appended in the form of notes as in the example below.

diffraction – non-specular reflection or SCATTERING of sound waves by an object or boundary, particularly into the SHADOW ZONE. Diffraction generally involves the distortion of incident wavefronts.

Note: It is not easy to draw a sharp distinction between diffraction and scattering. Roughly speaking, diffraction is limited to wave phenomena

* These unit symbols have the useful feature of being the same in all languages.

that cannot be accounted for, even approximately, by RAY ACOUSTICS. On the other hand scattering can refer to any reflection process, whether specular or not.

7. Multiple meanings

Where a term has more than one accepted meaning in acoustics, the separate meanings are listed; for example

damping – (1) the absorption of energy in a propagating wave

damping – (2) *of a room* the addition of sound-absorbing material to the room surfaces

damping – (3) *of a structure* the addition of damping material to the vibrating parts of the structure

damping – (4) abbreviation for DAMPING TREATMENT.

8. Synonyms

Where two or more versions of a term exist they are entered separately, but the definition is usually given at only one entry, and a cross-reference is then supplied at the others: for example

acoustic intensity – *at a point in a time-stationary acoustic field* the time-average rate of energy flow per unit area, Also known as **sound intensity**. *Units* W m^{-2} .

sound intensity – an equivalent term for ACOUSTIC INTENSITY. *Units* W m^{-2} .

9. New terms

During the compilation of the dictionary, the author and his consultants have occasionally suggested new terms where the current acoustics vocabulary seemed imprecise, inconsistent, or lacking. The 'new' terms offered to readers are indicated by a warning sign (◆) following the headword; an example is

undisturbed-field equivalent sound level – ◆ *for an individual exposed to sound through headphones* the sound level of a diffuse sound field, incident on the head, that would produce the same level at the listener's eardrums as is produced by the headphones. *Units* dB re $(20 \mu\text{Pa})^2$.

Altogether 27 such proposals are included in the present dictionary. Several of our ideas continue the honourable tradition of acoustics borrowing its terminology from other fields (e.g. optics, electrical engineering).

10. Abbreviations and unit symbols

The following unit symbols are used:

Symbol	Unit name
%	percent
B	bel
°C	degree Celsius
d	day
dec	decade
h	hour
Hz	hertz
J	joule
K	kelvin
kg	kilogram
m	metre
mol	mole
N	newton
Np	neper
oct	octave
Pa	pascal
phon	phon
rad	radian
s	second
sone	sone
sr	steradian
V	volt
W	watt
°	degree

Other, non-technical abbreviations used in the dictionary are listed below.

e.g.	for example
etc.	and so on
i.e.	that is
<i>NAm</i>	North American
UK	United Kingdom

Contents

Subject Consultants and Reviewers	vii
Preface	ix
Acknowledgments	xi
Dictionary Guide and Abbreviations Used	xiii
DICTIONARY A–Z	1
Select Bibliography	427



abnormal audibility zone – in *long-range atmospheric propagation* a region, usually observed at ground level, in which the transmission loss from a distant source (e.g. an explosion near the ground) is abnormally low. The mechanism is similar to that responsible for the **SO FAR CHANNEL**, in that sound is received via downward reflection from the stratosphere where the sound speed is higher than at source height. At the same time, the usual lapse in temperature with height in the lower atmosphere causes upward refraction close to the ground, with the result that a **SHADOW ZONE** appears at intermediate ranges. See also **STRATOSPHERIC DUCT**.

absolute phase – of a system *frequency response function* the **UNWRAPPED PHASE** of the response. See also **PHASE-SHIFT FUNCTION**. *Units* rad.

Note: Compare **RELATIVE PHASE**.

absolute temperature – the thermodynamic temperature T , measured in kelvins from absolute zero. A temperature of $T = 273.15$ K on the thermodynamic scale corresponds to zero on the Celsius scale; a temperature of $T = 273.16$ K corresponds to the triple point of water. *Units* K.

Note: In acoustics, the absolute temperature appears explicitly in the expression for the sound speed of an ideal gas,

$$c = (\gamma RT)^{1/2},$$

where γ is the **SPECIFIC-HEAT RATIO** and R is the **SPECIFIC GAS CONSTANT**. It also appears in the differential coefficient that connects temperature changes to pressure changes in a fluid, when the fluid is compressed isentropically:

$$dT = \frac{\alpha T}{\rho C_p} dP.$$

Here α is the **VOLUME THERMAL EXPANSIVITY** of the fluid, ρ is the fluid density, and C_p the specific heat at constant pressure.

absolute threshold – for a particular listener presented with a specified acoustic signal the minimum level at which the acoustic signal (e.g. a pure tone) is detectable by the listener, in a specified fraction of trials (conventionally 50%). The term implies quiet listening conditions: that is, it represents the irreducible absolute threshold. In the presence of a **MASKING** sound or noise, the term **masked threshold** is appropriate. *Units* dB re $(20 \mu\text{Pa})^2$.

Note (1): The method of measuring the threshold sound pressure level can vary: see **MINIMUM AUDIBLE PRESSURE**, **MINIMUM AUDIBLE FIELD**.

Note (2): An equivalent term is *threshold of hearing*. Compare HEARING THRESHOLD LEVEL.

absolute value – of a complex number the quantity $\sqrt{a^2 + b^2} = |z|$, where a and b are the real and imaginary parts of the complex number z . In the complex plane, $|z|$ is the distance of the point representing z from the origin. An alternative term is *modulus*. See also POLAR FORM.

absorbance – for sound waves incident on a boundary an equivalent term for ABSORPTION COEFFICIENT (1). Units none.

absorber – in acoustics abbreviation for SOUND ABSORBER. See also VIBRATION ABSORBER.

absorbing area – (1) of a room an older term for ROOM ABSORPTION. Units m^2 .

absorbing area – (2) of an object in a room an older term for EQUIVALENT ABSORPTION AREA. Units m^2 .

absorbing boundary condition – in computational acoustics a condition that is applied at the computational domain boundary to simulate extension of the domain to infinity, i.e. FREE-FIELD RADIATION. The domain boundary should ideally be transparent to incident acoustic waves; although perfect transparency is not generally achievable, absorbing boundary conditions can often provide a practical simulation of free-field conditions. Also known as *anechoic boundary condition*.

absorbing power of a room an older term for ROOM ABSORPTION. Units m^2 .

absorption – (1) of sound in a medium the dissipation of acoustic energy that occurs in a lossy medium; it contributes, along with SCATTERING, to the ATTENUATION (1) of freely-propagating sound waves. Compare VOLUME ABSORPTION.

absorption – (2) of sound at a boundary the loss or escape of acoustic energy from a sound field that occurs when the boundary is not perfectly reflective. Compare BOUNDARY ABSORPTION.

absorption coefficient – (1) at a boundary the fraction of the incident acoustic power arriving at the boundary that is not reflected, and is therefore regarded as being absorbed by the boundary. Equivalent terms are *absorbance* and *absorption factor*. Compare SABINE ABSORPTION COEFFICIENT. Units none.

Note (1): The IEC and ANSI 1994 terminology standards do not recognize this term, preferring *sound power absorption coefficient*. The abbreviation

given here is widely used by acousticians, however, and is generally unambiguous. (Shortening SOUND POWER REFLECTION COEFFICIENT or SOUND POWER TRANSMISSION COEFFICIENT in a similar way would lead to problems, since REFLECTION COEFFICIENT and TRANSMISSION COEFFICIENT commonly refer to pressure.)

Note (2): The absorption coefficient is a function of frequency and incident wave direction. For practical purposes it is often quoted in one-third octave bands. Unless otherwise stated, a single plot or table of absorption coefficient as a function of frequency is assumed to refer to the STATISTICAL ABSORPTION COEFFICIENT (i.e. for random incidence).

absorption coefficient – (2) *of an acoustic medium* an abbreviation sometimes used in ultrasonics for BULK ABSORPTION COEFFICIENT; otherwise known as the ENERGY ATTENUATION COEFFICIENT. *Units* m^{-1} .

Note: This abbreviation risks confusion with the first definition of absorption coefficient given above, i.e. the fraction of incident power absorbed at a boundary; it is therefore not recommended.

absorption cross-section – *of an object in an acoustic medium* the area σ in the equation $W_{\text{abs}} = \sigma I_{\text{inc}}$ that gives the net sound power absorbed (within the object or the immediately surrounding medium), when the object is irradiated by plane progressive waves of intensity I_{inc} . Usually σ depends on the frequency and direction of the incident waves. Compare EQUIVALENT ABSORPTION AREA, which is defined similarly except that the incident field is diffuse. *Units* m^2 .

absorption length – *for a parametric array* the effective length of the array as determined by attenuation of the primary beam; it is given by $L_a = 1/(\alpha_1 + \alpha_2 - \alpha_-)$. Here the symbol α denotes the linear plane-wave ATTENUATION COEFFICIENT in the medium; α_1 and α_2 refer to the two primary frequencies, and α_- to the difference frequency. See PARAMETRIC ARRAY. *Units* m.

absorption loss – the component of the TRANSMISSION LOSS between two points that comes from acoustic energy absorption, either within the medium or at absorbing boundaries. Separation of transmission loss into absorption loss and other components (e.g. DIVERGENCE LOSS) is feasible only under conditions where INTERFERENCE phenomena average out within the frequency band concerned, so that ENERGY ACOUSTICS becomes a valid approximation. *Units* dB.

a-c – *in audiology* abbreviation for AIR CONDUCTION.

ac, AC – oscillatory (by analogy with alternating current).