A

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 SOFAR 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,

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

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 μPa)^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 $W_{\mathrm{abs}} = \sigma I_{\mathrm{inc}}$ 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).

acausal response – *of a system* a response that is not CAUSAL; an acausal response begins before the input. An equivalent term is ***non-causal response***.

ac boundary layer – *for oscillatory relative motion of a fluid parallel to a solid boundary* a region near the boundary where the tangential fluid velocity drops toward zero, measured relative to the boundary. In addition, if the unsteady fluid motion is caused by sound, there will be an oscillatory temperature difference between the fluid and the boundary, falling to zero at the boundary itself. An equivalent term is ***viscothermal unsteady boundary layer***. For further detail, see BOUNDARY LAYER (2), THERMAL UNSTEADY BOUNDARY LAYER.

accelerance – *of a point-excited mechanical system* the complex ratio of acceleration to applied force, at a single frequency; for example, a lumped mass m has accelerance $1/m$. Equivalently, it is a frequency response function in which acceleration is the output and force is the input. The alternative term ***inertance*** is not recommended, since it has a conflicting interpretation. *Units* m s^{-2} N^{-1} $\equiv$ kg^{-1}.

acceleration – if a point has position vector $\mathbf{r}(t)$ at time t, its acceleration is $\ddot{\mathbf{r}} = d^2\mathbf{r}/dt^2$. *Units* m s^{-2}.

acceleration of a fluid element – if a fluid flow has a vector velocity field $\mathbf{u}(\mathbf{x}, t)$, where $\mathbf{x}$ is position and t is time, then the acceleration of the fluid element at $(\mathbf{x}, t)$ is given by the MATERIAL DERIVATIVE

$$\frac{D\mathbf{u}}{Dt} = \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\,\mathbf{u}.$$

See also LAGRANGE ACCELERATION FORMULA. *Units* m s^{-2}.

acceleration waves – *in applied mechanics* a generic term that covers ELASTIC WAVES in solids and pressure waves in fluids. Small-amplitude motion is not implied, so acceleration waves may be nonlinear.

accelerometer – an ELECTROMECHANICAL TRANSDUCER that generates an electrical output in response to an acceleration input, usually along a single axis but not necessarily: triaxial and rotational accelerometers are also used in vibration and shock response measurements.

accession to inertia – the same as VIRTUAL MASS. *Units* kg.

acoustic – (1) associated with sound, or more generally with mechanical wave propagation in any medium. However, for coupled structural–acoustic waves in fluid-loaded structures, the term VIBROACOUSTIC is preferred. The adjective "acoustic" (rather than acoustical) is used to form technical terms, as in ACOUSTIC INTENSITY, and to describe effects in which sound is the agent, as in ACOUSTIC TRAUMA. An ***acoustic device*** is one that is driven or actuated by sound, e.g. *acoustic refrigerator*.

acoustic – (2) *describing a musical instrument* not using electronic amplification to enhance the sound produced, as in *acoustic guitar* (as opposed to *electric guitar*); hence a humorous adjective for a device in its original mechanical (pre-electric) form, as in *acoustic typewriter*.

acoustic – (3) *used as a singular noun* the acoustical properties of a concert hall or auditorium, as judged subjectively by either performers or the audience. Compare ACOUSTICS (3).

acoustic, ~al – the meanings of these adjectives overlap. Technical terms are usually modified by ***acoustic***, and non-technical terms by ***acoustical***; thus ~ *impedance*, ~ *signal*, but ~*al society*, ~*al engineer*. Some terms attract either usage: thus ~ or ~*al properties of matter*, ~ or ~*al consultant*, and ~ or ~*al qualities of an auditorium*.

Note: Analogies with *electric/electrical*, or *optic/optical*, do not appear to be helpful in this case.

acoustic ~ – some terms include the prefix "acoustic" as standard terminology, e.g. ACOUSTIC EMISSION, and are listed below in that form. For many other acoustical terms, "acoustic" is an optional qualifier, used only where the context requires it. Such terms are listed without the prefix: e.g. *acoustic particle velocity* (found under PARTICLE VELOCITY), *acoustic interference* (found under INTERFERENCE).

acoustic absorber – an equivalent term for SOUND ABSORBER.

acoustic absorption – see ABSORPTION.

acoustic admittance – *of an acoustic system or transmission line* the complex ratio of volume velocity to pressure, at a single frequency; the reciprocal of ACOUSTIC IMPEDANCE. Equivalently, it is a frequency response function in which volume velocity is the output and pressure is the input. Also known as ***acoustic mobility***. *Units* $m^3\ s^{-1}\ Pa^{-1}$.

acoustic agglomeration – the grouping of suspended particles into larger aggregates by the action of sound waves in the suspending fluid, usually at high intensity.

acoustical – see ACOUSTIC, ~AL.

acoustical ~ – a few terms for which the prefix "acoustical" is essential to the meaning, e.g. ACOUSTICAL CEILING, are listed below in that form. Many other terms can be constructed with "acoustical" as a qualifier, but their definition is generally obvious and they are not given entries in the dictionary.

acoustical ceiling – a ceiling designed to have desirable acoustical properties, e.g. a high ABSORPTION COEFFICIENT.

acoustical consultant – a professional expert who advises clients on issues of noise control, building acoustics, sound reinforcement, or acoustics generally.

acoustical glare – *in a concert hall* a brittle or harsh quality imparted to the sound, which modifies the timbre of music. The cause of acoustical glare is thought to be strong early reflections reaching the listener from smooth, flat surfaces as opposed to diffusing surfaces. See also TONE COLOURATION.

acoustically compact – see COMPACT.

acoustical–mechanical conversion efficiency – *of a mechanically driven fluid-loaded structure* the ratio of the sound power radiated into the fluid, W_{rad}, to the mechanical power input to the structure, W_{in}:

$$\eta_{\mathrm{am}} = \frac{W_{\mathrm{rad}}}{W_{\mathrm{in}}}.$$

As an example, the value of η_{am} for a uniform isotropic plate excited below its CRITICAL FREQUENCY, f_c, by a point normal force, when the plate radiates on both sides into a free field, is

$$\eta_{\mathrm{am}} \approx 0.37 \frac{\rho_0}{\rho_s} \frac{c_P}{c_0} \qquad \text{(independent of thickness for } f < f_c\text{)}$$

provided the plate dimensions (in its plane) are many times the free bending wavelength. Here ρ_0 and c_0 are the density and sound speed of the ambient fluid, ρ_s is the density of the plate material, and c_P is the PLATE LONGITUDINAL-WAVE SPEED. *Units* none.

acoustical oceanography – the use of sound to probe the structure of the oceans and their floor, and thus to produce maps showing (for example) temperature, salinity, and current distributions; also near-surface bubble distributions, bottom topography, and so on.

acoustical well logging – the measurement of sound transmission between two points along a drill hole in the Earth's crust, in order to determine properties of the surrounding material. For example, the porosity of the material can be estimated in this way; rock fractures can be located; and the presence of gas or oil pockets established.

acoustic analogy – a representation of the density fluctuations in a real fluid flow as if they were due to acoustic waves in a uniform stationary fluid, driven by an externally-applied fluctuating stress field. This is expressed mathematically (see D'ALEMBERTIAN OPERATOR) by the equation

$$\Box^2\,[c_0^2(\rho - \rho_0)] = -\mathcal{F}, \quad \text{with} \quad \mathcal{F} = \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j}.$$

Here T_{ij} are the components of the LIGHTHILL STRESS TENSOR (given by the exact equations of fluid motion), and ρ_0, c_0 are the density and sound speed of a hypothetical uniform stationary fluid through which the acoustic waves propagate.

Note (1): By introducing the approximation that T_{ij} is not significantly dependent on the density fluctuations that it excites, Lighthill was able to derive asymptotic scaling laws for sound radiated by turbulent flows. See LIGHTHILL'S U^8 POWER LAW.

Note (2): Variations in pressure, rather than $c_0^2(\rho - \rho_0)$, may be used as the wave equation variable. The resulting source term $\mathcal{F}$ is then different in minor respects, but the same far-field radiation is obtained.

Note (3): **Lord Rayleigh** used a primitive acoustic analogy to describe the scattering of sound by local variations in fluid compressibility and density: see *Theory of Sound* (**1945**), Chapter XV.

acoustic approximation – an approximation to the dynamical equations of the medium in which terms of second order in the perturbation amplitude are ignored, and the density and temperature perturbations are assumed to obey the same linearized wave equation as the pressure. Compare LINEAR ACOUSTICS, LINEARIZATION.

acoustic boundary layer – see BOUNDARY LAYER (2).

acoustic boundary layer thickness – see BOUNDARY LAYER (2), VISCOUS PENETRATION DEPTH, THERMAL PENETRATION DEPTH. *Units* m.

acoustic brightness – ◆ *of a surface viewed from a given point* the field of acoustics lacks a generally agreed term to describe the ANGULAR INTENSITY DISTRIBUTION produced at a point in a room, as a result of partially-diffuse reflection from the room surfaces. In optics the equivalent term is *radiance*, while illumination engineers use *luminance* or *photometric brightness* for the subjectively weighted equivalent in candelas per square metre. These optical terms describe the power density (unweighted or weighted) produced at a given point by a light-reflecting surface, per unit solid angle subtended by the surface. By analogy, the ***acoustic brightness*** of a diffusely reflecting surface may be similarly defined as the acoustic intensity arriving at *P* from a surface element, per unit solid angle subtended at *P* by the element.

A consequence of this definition is that a surface element of acoustic brightness $B(\theta)$ and area dS contributes intensity $dI = B(\theta) \cos\theta \, dS/r^2$, at distance r from the element in a direction at angle θ to the surface normal. Equivalently, the ANGULAR POWER DISTRIBUTION per unit area of surface is $B(\theta) \cos\theta$. The surface is here regarded as a distribution of incoherently reflecting elements, whose contributions to the intensity at *P* are additive. A similar discussion applies to a sound-emitting surface made up of incoherently radiating elements: in the latter case the acoustic brightness is analogous to the *radiant exitance* (in optics) or *luminous exitance* (in photometry) of a self-radiating surface. *Units* W m^{-2} sr^{-1}.

Note: A non-absorbent DIFFUSELY-REFLECTING surface, irradiated with acoustic energy at a rate Φ per unit area and time, has the same brightness $B = \Phi/\pi$ viewed from any direction; see LAMBERT'S COSINE LAW.

acoustic bullets – *in ultrasonics* another name for LOCALIZED WAVES.

acoustic ceiling – alternative (mainly UK) spelling of ACOUSTICAL CEILING.

acoustic centre – *of a source* the point from which outgoing wavefronts appear to diverge in the far field (under free-field conditions). Its position generally depends on the frequency.

Directional sources have a different centre, in general, for each spherical harmonic component of the radiation field (monopole, dipole, etc.). An alternative definition involves assigning each radiation direction two acoustic centres, one for amplitude and one for phase.

acoustic consultant – alternative (mainly UK) spelling of ACOUSTICAL CONSULTANT.

acoustic coupler – (1) *in audiology* a rigid-walled cavity of specified shape and volume that is used for the calibration of an EARPHONE, in conjunction with a calibrated microphone that measures the sound pressure developed within the cavity. Compared to an EAR SIMULATOR, a coupler embodies only a rough approximation to the acoustic properties of the human ear but has the advantage of simple design and construction. It is typically used to calibrate earphones of supra-aural type that fit against the pinna.

acoustic coupler – (2) a rigid-walled cavity in which the active elements of two transducers are coupled by the pressure field in the contained fluid; for example, a microphone in the cavity may be used to pick up the pressure signal driven by a small loudspeaker. Two reciprocal pressure transducers can be calibrated in this way.

acoustic cross-section – *in active sonar* an alternative term for BACKSCATTERING CROSS-SECTION. *Units* m^2.

acoustic daylight – the naturally occurring incoherent ambient noise field in the ocean.

acoustic daylight technique – use of the underwater acoustic "illumination" provided by ACOUSTIC DAYLIGHT to produce acoustic images of underwater objects.

acoustic distance – *between transducers in an acoustic medium* the effective separation in a given direction between two transducers, as measured by the frequency-dependent phase shift between the transducer responses when the excitation consists of plane waves incident from the direction concerned. *Units* m.

acoustic ecologist – a person who studies and records the sounds of wildlife and natural phenomena, and monitors the impact of human civilization on such sounds.

Note: The spelling is taken from *Time* magazine, but it should arguably be ***acoustical ecologist***.

acoustic efficiency – *of a sound source* the acoustic power output of the device, normalized by the power consumed or dissipated. The term ***mechano-acoustic efficiency*** is used for the ratio of acoustic power out to mechanical power in; ***electroacoustic efficiency*** is used for the ratio of acoustic power out to electrical power in. *Units* none.

Note: In the case of a fan, the appropriate normalizing factor is the product of the stagnation pressure rise through the fan and the volume flowrate. For a jet, it is the total mechanical power dissipated in the jet flow; for a reducing valve, it is the power that could have been extracted in lowering the total pressure of the flow from its value upstream to that downstream.

acoustic emission – *in a statically-loaded solid material* the release of stored elastic energy as transient elastic waves within the material, as a result of spontaneously-appearing cracks or microstructural rearrangement. An alternative term is ***stress-wave emission***.

The term also refers to the radiation of sound that accompanies the energy release, and which may provide early warning of impending fracture. The frequency range of acoustic emission is wide, ranging from a few hertz (as in earthquakes) to several megahertz (phase transformations in steels).

acoustic energy – an energy function, based on second-order products of first-order acoustic variables, that obeys a CONSERVATION LAW. Also known as

sound energy. See ACOUSTIC ENERGY DENSITY, ACOUSTIC ENERGY FLUX VECTOR. *Units* J.

acoustic energy density – the time-averaged sum of the kinetic and potential (or compressional) energy densities at a point in an acoustic field, given by $w = w_{\text{kin}} + w_{\text{pot}}$; also known as ***sound energy density***. The ***kinetic energy density*** is $w_{\text{kin}} = \frac{1}{2}\rho\langle u^2\rangle$, where u is the magnitude of the particle velocity vector, $\langle\ldots\rangle$ denotes a time average, and ρ is the density of the fluid. The ***potential energy density*** is $w_{\text{pot}} = \frac{1}{2}\langle p^2\rangle/B$, where p is the acoustic pressure and B is the isentropic BULK MODULUS; in a fluid of sound speed c, B equals ρc^2. The ***instantaneous acoustic energy density*** is defined as above, but with no time averaging. *Units* J m^{-3}.

Note (1): In a REVERBERANT FIELD that is dominated by the resonant response of lightly-damped acoustic modes in an enclosure, the two terms in the expression above have time-average values that are approximately equal; the mean acoustic energy density is then $w \approx (1/\rho c^2)\langle p^2\rangle$.

Note (2): When a mean flow is present, a different expression applies.

acoustic energy flux density, acoustic energy flux vector – alternative terms for the INSTANTANEOUS ACOUSTIC INTENSITY vector. *Units* W m^{-2}.

acoustic environment – (1) the living environment of humans or other species, viewed from an acoustical aspect. Hence ***acoustic environmentalist***, a person concerned with the protection or improvement of such environments.

acoustic environment – (2) the passive acoustic environment that a particular space provides, described in terms of its reflective or modal properties.

acoustic environment – (3) the local sound field to which a person or test object is exposed, usually described in terms of physical measurements (e.g. a spectrum of sound pressure in 1/3-octave bands).

acoustic fatigue – *in structures exposed to intense sound or pseudosound* structural FATIGUE caused by long-term dynamic responses to fluid loading, typically in the range 10 Hz to 10 kHz. The loading may be any kind of unsteady pressure field, including turbulent near-field pressures produced by jets or boundary layers. Acoustic fatigue is typically associated with low stress amplitudes and large numbers of stress reversals (up to 10^9 cycles), implying exposure for at least a day and possibly several months.

acoustic filter – a passive linear device (usually in a one-dimensional system) designed to provide a low acoustic INSERTION LOSS over a specified band of frequencies, and a high insertion loss outside the band. See also FILTER.

Note: An enlarged section (***expansion chamber***) in a rigid-walled pipe acts as a low-pass filter. A Helmholtz resonator connected to the pipe as a side branch acts as a ***notch filter***, with a high insertion loss over a narrow band of frequencies.

acoustic fountain – when a sound beam in one fluid propagates across an interface and into a more compressible fluid of less than half the density, reflection of the beam reverses the normal component of the incident momentum flow carried by the beam. The momentum flow reversal is equivalent to a steady normal force on the interface, proportional to the power in the incident beam. A sufficiently powerful ultrasonic beam, transmitted vertically upwards across a horizontal water–air interface, produces a vertical jet of water (acoustic fountain) where the beam emerges into the air.

acoustic–gravity waves – see INTERNAL WAVES. The term is commonly used to refer to planetary-scale internal waves in the Earth's atmosphere.

acoustic holography – the use of phase and amplitude information, recorded over a closed surface in space, to reconstruct the sound field in the region exterior to the surface.

acoustic horn – a passive device in the form of a hard-walled tapering acoustic waveguide of finite length. When a volume-velocity driver is placed at the narrow end or ***throat*** of the horn, the acoustic coupling between the transducer and the surrounding medium is enhanced. The wide end or ***mouth*** of the horn is usually arranged to be large enough (in comparison with the acoustic wavelength) that most of the incident energy arriving at the mouth is transmitted into the surrounding medium, with the result that the horn also produces a directional far-field response. For a more general description, applicable also to solid horns, see HORN.

acoustician – a specialist in ACOUSTICS (1).

acoustic immittance – a term used in audiology to mean either ACOUSTIC ADMITTANCE or ACOUSTIC IMPEDANCE.

acoustic impedance – *of an acoustic system or transmission line* the complex ratio of pressure to volume velocity, at a single frequency. Equivalently, it is a frequency response function in which pressure is the output and volume velocity is the input. *Units* Pa s m^{-3}.

acoustic inertance – *corresponding to an acoustic lumped element through which the volume velocity is invariant* the complex ratio of the pressure difference across the element to the time derivative of the volume velocity through the element, at a single frequency. See CONDUCTIVITY, LUMPED ELEMENTS. *Units* kg m^{-4}.

acoustic intensity – *at a point in a time-stationary acoustic field* the time-average rate of energy flow per unit area, denoted by the vector **I**. The component of **I** in any direction is the time-average rate of energy flow per unit area normal to that direction. In the absence of mean flow, $\mathbf{I} = \langle p\mathbf{u} \rangle$ where p is the acoustic pressure, **u** is the particle velocity vector, and angle brackets $\langle \ldots \rangle$ denote a time average. Also known as ***sound intensity***. *Units* W m^{-2}.

Note (1): Compare ACTIVE INTENSITY, REACTIVE INTENSITY, COMPLEX ACOUSTIC INTENSITY.

Note (2): When a mean flow is present, a different expression applies. See INSTANTANEOUS ACOUSTIC INTENSITY, BLOKHINTSEV INVARIANT.

acoustic irradiance – ◆ *of a surface exposed to a sound field* the normal component of ACOUSTIC INTENSITY at the surface due to the incident sound field; i.e. the energy incident per unit time on unit area of the surface. For example, at the boundaries of a room containing a DIFFUSE FIELD with mean ENERGY DENSITY w, the acoustic irradiance is $\Phi = cw/4$, where c is the sound speed. Also known as (***acoustic***) ***irradiation strength***. *Units* W m^{-2}.

Note: This is an adaptation of the optical term ***irradiance***, which refers to electromagnetic radiation incident on a surface and is used in the field of radiative heat transfer.

acoustic irradiation strength – *at a point on a boundary* see ACOUSTIC IRRADIANCE. *Units* W m^{-2}.

acoustic levitation – the use of ACOUSTIC RADIATION FORCES to hold objects in position against the effects of other forces (e.g. gravity, buoyancy).

acoustic lumped elements – see LUMPED ELEMENTS.

acoustic Mach number – *at a point in a sound field* the acoustic particle velocity amplitude (or the rms particle velocity, if the sound field is not at a single frequency), divided by the speed of sound. *Units* none.

acoustic mobility – *of an acoustic system or transmission line* an alternative term for either ACOUSTIC ADMITTANCE or acoustic DIFFERENTIAL ADMITTANCE. See MOBILITY (1) and (2). *Units* m^3 s^{-1} Pa^{-1}.

acoustic nerve – the AUDITORY NERVE.

acoustic ohm – see SI ACOUSTIC OHM.

acoustic perfume – an equivalent term for ACOUSTIC WALLPAPER.

acoustic phase coefficient – *for a single-frequency progressive sound wave* the real part of the PROPAGATION WAVENUMBER k. *Units* rad m^{-1}.

Note: An equivalent definition is the imaginary part of the PROPAGATION COEFFICIENT jk. See also PHASE COEFFICIENT (which is not limited to acoustic waves).

acoustic power – the same as SOUND POWER. *Units* W.

acoustic pressure – *in a fluid* a time-dependent pressure disturbance, usually of small amplitude, superimposed on an ambient state. *Units* Pa.

acoustic pulse reflectometry – an experimental technique for determining the acoustic properties of a one-dimensional acoustic system (e.g. a narrow waveguide), by measuring its response to an incident acoustic pulse of known waveform. Response measurements in the time domain are processed to yield either the frequency response function of the system, or its impulse response. The technique has found numerous industrial and medical applications, and has proved useful in the study of musical wind instruments.

acoustic radiance – ◆ *of a surface* the sound power radiated (or reflected) by the surface per unit surface area; it is the integral of the ACOUSTIC BRIGHTNESS with respect to solid angle, over the entire hemisphere of radiation directions. Also known as ***acoustic radiosity***. *Units* W m^{-2}.

Note: This is an adaptation of the optical term ***radiance***, which refers to electromagnetic radiation emitted (or reflected) by a surface and is used in the field of radiative heat transfer.

acoustic radiation force – the net force on an object in a sound field due to the action of ACOUSTIC RADIATION PRESSURE. *Units* N.

acoustic radiation impedance – *of an opening* the complex ratio of the acoustic pressure averaged over the opening to the volume velocity outflow across the opening, at a single frequency:

$$Z_{\mathrm{rad}} = \frac{\bar{p}}{U}, \quad (\bar{p} = \text{average pressure},\ U = \text{volume velocity}).$$

In this definition, the opening is treated as a LUMPED ELEMENT, and its dimensions are assumed to be small compared with the acoustic wavelength. For an alternative definition of radiation impedance that avoids these limitations, see MODAL RADIATION IMPEDANCE. For a complete list of related terms, see under RADIATION IMPEDANCE. *Units* Pa s m^{-3}.

Note (1): The lumped-element approach ignores the fact that, even at low frequencies, $\bar{p}$ is not determined solely by U; the above definition of Z_{rad} is therefore not precise. One can make it rigorous by prescribing the velocity or pressure distribution: e.g. in the idealized case where *uniform pressure* is imposed over the opening, one obtains the low-frequency asymptotic expression

$$Z_{\mathrm{rad}} \approx \frac{j\omega\rho}{C} + \frac{\omega^2\rho}{\Omega c}, \quad (p \text{ uniform over opening}).$$

Here C is Rayleigh's CONDUCTIVITY, ω is the angular frequency, the opening radiates into a solid angle Ω, and ρ, c are the density and sound speed of the radiating medium.

Note (2): For the idealized case where *uniform normal velocity* is imposed over the plane of the opening, see PISTON RADIATION IMPEDANCE. However neither this model, nor the uniform-pressure model of note (1), is sufficient to describe the low-frequency acoustic properties of an opening to better than 10 percent accuracy when the actual variation of pressure (or normal velocity) over the opening is unknown.

Note (3): An alternative definition of the average pressure $\bar{p}$ is $\bar{p} = \langle pu_n \rangle / \langle u_n \rangle$; here the angle brackets denote an average over the opening area, and u_n is the local normal velocity over the opening. This allows the SOUND POWER crossing the opening to be expressed without approximation as the time-average product of $\bar{p}$ and U.

Note (4): One practical case for which precise description is possible is the reflection of plane waves at the open end of a long tube; see END CORRECTION.

acoustic radiation pressure – the time-average excess pressure on a material surface due to a sound field, expressed by $\langle P^{\mathrm{L}} - P_0 \rangle$. Here P^{L} is the Lagrangian pressure, i.e. the pressure of the fluid at a point moving with the surface, and P_0 is the steady ambient pressure, i.e. with the sound field absent. The angle brackets $\langle \ldots \rangle$ denote a time average. *Units* Pa.

Note (1): The excess pressure $\langle P^{\mathrm{L}} - P_0 \rangle$ is not straightforward to evaluate from linear acoustic theory, since it is a second-order quantity. It depends in a subtle way on the Eulerian excess density, $\langle \rho^{\mathrm{E}} - \rho_0 \rangle$, at a fixed point next to the surface. This in turn depends on whether the sound field is confined by rigid boundaries, or exists in an unconfined expanse of fluid. For details, see notes (2) and (3).

Note (2): The ***Rayleigh radiation pressure*** applies in circumstances where $\langle \rho^{\mathrm{E}} - \rho_0 \rangle$ averages to zero over the entire field, which is the case when the sound field is confined by rigid boundaries. Its value at a rigid boundary is βw_{pot}, where β is the COEFFICIENT OF NONLINEARITY of the fluid and w_{pot} is the mean POTENTIAL ENERGY DENSITY.

Note (3): The ***Langevin radiation pressure*** applies when the fluid is unconfined. Its value at any boundary is $w_{\mathrm{pot}} - w_{\mathrm{kin}}$, i.e. the difference between the mean potential energy density and the mean KINETIC ENERGY DENSITY.

acoustic radiation resistance – *of an opening* the real part of the ACOUSTIC RADIATION IMPEDANCE. For an opening whose dimensions are small compared with the external acoustic wavelength, the acoustic radiation resistance $R_{a,\mathrm{rad}}$ is defined without ambiguity by

$$R_{a,\mathrm{rad}} = \frac{W_{\mathrm{rad}}}{U_{\mathrm{rms}}^2};$$

here W_{rad} is the radiated sound power, and U_{rms} is the rms volume velocity through the opening. *Units* Pa s m^{-3}.

acoustic radiation stress tensor – *in a fluid* the second-order quantity defined by

$$\Pi_{ij} = \langle P - P_0 \rangle \, \delta_{ij} + \rho_0 \langle u_i \, u_j \rangle,$$

which represents the time-average flux of *j*-component momentum, per unit surface area, across a fixed surface whose normal points in the *i* direction. Here P is the pressure, ρ is the fluid density, and u_i, u_j are particle velocity components. Subscript 0 denotes steady ambient conditions with the sound field absent, and angle brackets $\langle \ldots \rangle$ denote a time average at a fixed point. *Units* Pa.

Note: The standard definition, as given above, excludes viscous stresses.

acoustic reflex – *in response to loud sounds* a reflex contraction of the muscle attached to the stapes (third in the chain of three OSSICLES). The effect is to limit the vibration amplitude of the stapes and thus to reduce the transmission of loud sounds to the inner ear, particularly at low frequencies. Also known as the ***stapedial reflex*** or ***middle ear muscle reflex***.

acoustic reflex tests – audiological tests in which the acoustic admittance of the ear is monitored during presentation of a moderately intense acoustic stimulus. In normal subjects, the stimulus alters the admittance via reflex contraction of muscles attached to the ossicles. See ACOUSTIC REFLEX, OTOADMITTANCE TESTS.

acoustics – (1) the science and technology of sound in all its aspects. Covers its production, propagation and control; its interaction with materials; its reception by the ear, and its effects on the hearer. Also used to denote a discipline or field of study; hence ***acoustics professor/student***.

Note: A useful chart due to R B Lindsay, showing the broad subdivisions of acoustics, is reproduced in Chapter 1 of A D Pierce's *Acoustics* (**1989**). Also informative is the subject classification scheme (PACS 43) published in each volume of the *Journal of the Acoustical Society of America*.

acoustics – (2) the acoustical principles that underlie a given device or phenomenon, as in *the ~ of the trombone*, or *the ~ of the Rijke tube*.

acoustics – (3) *used as a plural noun* the acoustical properties of a space. Depending on context, either subjective or objective properties may be implied. Compare ACOUSTIC (3).

acoustic scatterer – a passive obstacle (or an inhomogeneity in the medium) that produces a SCATTERED FIELD when irradiated by sound waves.

acoustic signature – a pressure time-history, usually of a transient type (e.g. *acoustic signature of a gunshot*), that is characteristic of a particular sound source. The meaning is sometimes broadened to include any distinctive feature by which an acoustic signal may be recognized, for example (in the case of a periodic signal) a particular harmonic amplitude spectrum.

acoustic sink – an object or region that acts as a net absorber of acoustic energy (under transient conditions), or of acoustic power (under steady-state conditions).

acoustic source – (1) anything that emits sound waves. Examples of acoustic sources in this sense are a radiating transducer, a fan, and a turbulent jet; however, the last two are more likely to be described as ***noise sources*** (= sources of unwanted sound). See SOUND, NOISE.

acoustic source – (2) *as opposed to an acoustic sink* an object or region that emits positive net acoustic energy (under transient conditions), or positive acoustic power (under steady-state conditions), into the surrounding medium.

acoustic source – (3) *as input to the wave equation* an ACOUSTIC SOURCE DENSITY defined over a specific limited region in space; a particular example is a POINT MONOPOLE. See also ACOUSTIC SOURCE STRENGTH.

acoustic source density – the quantity that appears on the right-hand side of the inhomogeneous wave equation that describes sound generation in a uniform fluid at rest. Specifically, if the wave equation for the acoustic pressure, p, is written as

$$\left(\frac{1}{c_0^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)p = \mathcal{F},$$

where t is time and c_0 is the sound speed in the undisturbed fluid, then $\mathcal{F}$ represents the acoustic source density for pressure. *Units* Pa m^{-2}.

Note: Alternative choices for the acoustic variable are the density variation or the velocity potential. Different source densities apply to pressure, density or velocity potential as acoustic variables; their values may be distinguished by writing $\mathcal{F}$, $\mathcal{F}_\rho$, $\mathcal{F}_\varphi$ for the three cases, respectively. See also SOURCE MOMENTS.

acoustic source distribution – (1) a distributed time-dependent VOLUME VELOCITY input applied to an acoustic medium. Expressed as volume velocity per unit volume; symbol Q. Compare ACOUSTIC SOURCE STRENGTH (1). *Units* s^{-1}.

Note: The ***volume velocity distribution*** Q is equivalent to $\mathcal{F}_\varphi$, the ACOUSTIC SOURCE DENSITY for the velocity potential φ, provided one adopts the sign convention that the fluid velocity is given by $-\nabla\varphi$.

acoustic source distribution – (2) an equivalent term for ACOUSTIC SOURCE DENSITY.

acoustic source strength – (1) the instantaneous unsteady VOLUME VELOCITY with which an acoustic source displaces the surrounding medium. *Units* $m^3\,s^{-1}$.

acoustic source strength – (2) *with reference to an acoustic wave equation* the instantaneous volume integral of the corresponding ACOUSTIC SOURCE DENSITY. In mathematical form, the volume integral

$S = \int \mathcal{F} dV$ (or a similar expression with subscript φ on S, $\mathcal{F}$)

relates the source strength S to the source density $\mathcal{F}$. Equivalent terms are ***monopole strength*** and ***simple source strength***. See also SOURCE MOMENTS.

Note: If the acoustic variable is taken to be the velocity potential φ, defined such that the particle velocity is $-\nabla\varphi$, then S_φ is equivalent to a localized volume velocity input U driving the medium; compare ACOUSTIC SOURCE STRENGTH (1). If the acoustic variable is taken to be the pressure p, then $S = \rho_0 \dot{U}$ where $\dot{U}$ is the equivalent local *volume acceleration* input and ρ_0 is the ambient fluid density.

acoustic source strength distribution – *in the context of far-field imaging of line sources* the mean square pressure radiated in a given direction per unit length of source region, multiplied by the square of the measurement radius and expressed as a distribution along a given axis. One way to measure this quantity is the POLAR CORRELATION TECHNIQUE. *Units* $Pa^2\,m$.

acoustic streaming – a steady fluid flow set up by a sound source or oscillating solid boundary.

acoustic taxonomy – the identification and classification of animal species by their acoustic signature.

acoustic telescope – a device for imaging a distributed acoustic source from the far field. It may consist of an ellipsoidal reflector, with the remote focus placed near the source, or alternatively, of an array of microphones whose outputs can be processed to yield an image of the source distribution (see POLAR CORRELATION TECHNIQUE).

acoustic thermometry – the use of acoustic travel time data to infer the temperature along an underwater ray path, by inversion of standard relationships between temperature and sound speed. See ATOC, ACOUSTICAL OCEANOGRAPHY, and SOUND SPEED IN SEAWATER.

acoustic tomography – *in underwater acoustics* the analysis of coded signals exchanged between multiple pairs of transmitting and receiving systems, in order to study ocean or sea bed properties. As an example, travel time information over multiple paths can be inverted to construct a map of sound speed as a function of position in the ocean (see INVERSE PROBLEMS). Compare ACOUSTIC THERMOMETRY, ATOC.

acoustic trauma – instantaneous injury to or destruction of one or more components of the auditory system, caused by exposure to a very high transient sound pressure (e.g. from an explosion or weapons fire). The term is not to be confused with NOISE-INDUCED HEARING LOSS associated with chronic exposure, or with BAROTRAUMA.

acoustic turbulence – a term used to describe the finite-amplitude evolution of a broadband acoustic waveform, as it propagates under the combined effects of nonlinearity and dissipation. The term implies an analogy with hydrodynamic turbulence, where the same two effects operate (although in a more complicated manner, turbulence in fluid flow being three-dimensional). See also BURGERS EQUATION.

acoustic wallpaper – background sound deliberately introduced in order to mask other noise sources, thereby generating a more acceptable acoustic environment.

acoustic wavelength – *for sound at a specified frequency in a given medium* the quantity c/f, where f is the frequency and c is the sound speed in the medium. Equivalent terms are ***wavelength of sound*** and ***sound wavelength***. *Units* m.

acoustic wavenumber – *for single-frequency sound in a lossless medium* the ratio $\omega/c = k_0$, where ω is the angular frequency and c is the sound speed in the medium. See also PROPAGATION WAVENUMBER. *Units* rad m^{-1}.

acoustoelastic effect – the phenomenon in which a static state of stress or strain applied to an elastic medium alters the speed of propagation of small-amplitude elastic waves (shear or compressional).

acoustoelasticity – the science of interactions between acoustic waves (stress waves) and steady strain fields, in a solid.

acoustooptic effect – the modulation of a light beam as it passes through an acoustically excited material, whose optical properties vary with the local state of strain.

ac power – see POWER (3).

action level – *in noise at work regulations* a critical value of some statistical indicator for noise – typically a NOISE EXPOSURE LEVEL but not necessarily a level in the logarithmic sense – at which either an employer is required to take remedial measures, or an employee is required to wear hearing protection.

Note: In Europe, action levels are also set by EU directives. See also PEAK ACTION LEVEL.

active control – *of sound or vibration* the use of secondary sources of excitation to cancel, or reduce, the response of a system to given primary sources; also to suppress self-excited oscillations of a system that is unstable.

active intensity – an equivalent term for ACOUSTIC INTENSITY, interpreted as a time-average quantity. The term is mainly applied to single-frequency sound fields, where it is useful to contrast active and reactive intensity components. See also REACTIVE INTENSITY, COMPLEX ACOUSTIC INTENSITY. *Units* W m^{-2}.

Note (1): If the acoustic pressure and particle velocity in a single-frequency 3D sound field are represented by

$$p = \mathrm{Re}[P(\mathbf{x})\, e^{j\omega t}], \qquad \mathbf{u} = \mathrm{Re}[\mathbf{U}(\mathbf{x})\, e^{j\omega t}],$$

where $P(\mathbf{x})$ and $\mathbf{U}(\mathbf{x})$ are the complex pressure and velocity amplitudes at vector position $\mathbf{x}$, then the ***active intensity vector*** $\mathbf{I}$ is

$$\mathbf{I} = \frac{1}{2}\mathrm{Re}(P^*\mathbf{U}), \qquad (* = \text{complex conjugate}).$$

An equivalent expression based on the rms pressure p_{rms} and the phase gradient $\nabla\varphi$ is

$$\mathbf{I} = -\frac{p_{\mathrm{rms}}^2}{\omega\rho}\nabla\varphi \qquad (\varphi = \arg P),$$

where ρ is the fluid density.

Note (2): These relations apply to lossless fluids with no mean flow. In real situations, they are useful approximations provided the attenuation per wavelength is small, i.e. $\alpha\lambda \ll 1$, and also $M \ll 1$ where M is the mean-flow Mach number. For finite M, see note (2) under INSTANTANEOUS ACOUSTIC INTENSITY.

active noise control – see ACTIVE CONTROL.

active sonar – use of a sound-emitting transducer to project sound waves at objects to be detected underwater; the scattered or reflected signal is then detected either at the emitting location (MONOSTATIC) or at another location (BISTATIC). Subsequent signal processing yields the direction, range, and closing speed of the reflecting object (with simultaneous determination of position and speed subject to the uncertainty principle).

active transducer – a transducer whose operation relies, at least in part, on energy from an external source other than the input signal. Examples are a strain gauge and a condenser microphone. An alternative term is ***modulator***. See TRANSDUCER.

active vibration control – see ACTIVE CONTROL.

acuity – *of hearing* ability to detect faint sounds, especially in the presence of masking sounds or noise.

A-D, A/D – abbreviations for ANALOGUE-TO-DIGITAL, as in ~ ***converter***.

adaptation – a reversible reduction in a particular neurophysiological response to a given stimulus, associated with continued exposure to the stimulus.

adaptive beamforming – *for the detection of incoming acoustic waves in the presence of noise* automatic adjustment of an array's BEAM PATTERN so as to minimize the gain in the noise source direction(s), while maximizing the gain in the direction of the source to be detected. The array weighting factors are calculated adaptively in real time, in response to variations in the signals at each array element.

ADC – abbreviation for ANALOGUE-TO-DIGITAL CONVERTER.

added mass – alternative term for VIRTUAL MASS. *Units* kg.

adiabat – a curve representing the relationship between any pair of state variables at the beginning and end of a thermodynamic process, when the process is ADIABATIC (but not necessarily REVERSIBLE). The compression process across a shock wave, for example, is described by the ***shock adiabat*** in P–V coordinates (P = pressure, V = specific volume).

adiabatic – (1) *in thermodynamics* without heat transfer (~ *compression*); impenetrable to heat (~ *boundary*). During an ***adiabatic process***, a system can exchange energy with its surroundings, but only via WORK.

adiabatic – (2) *in wave propagation* without conversion of wave energy between different modes of propagation, as in a slowly-varying environment (see ~ APPROXIMATION, ~ MODES). The underlying idea is that no energy transfer occurs between modes.

adiabatic approximation – *for sound propagation in a waveguide whose properties vary slowly in the propagation coordinate direction* the assumption that waveguide modes are uncoupled, each mode propagating with the wavenumber it would have in a uniform waveguide with the same local geometry.

adiabatic exponent – alternative term for ISENTROPIC EXPONENT. Compare POLYTROPIC EXPONENT. *Units* none.

adiabatic invariant – a quantity that is conserved under ADIABATIC (2) changes.

adiabatic modes – *in a waveguide whose properties vary slowly in the propagation direction* transverse modes determined by regarding the waveguide as locally uniform. In the limit of slow axial variations in either waveguide geometry or boundary impedance, the mode shapes and amplitudes evolve gradually during propagation, without exchange of energy between modes.

adjoint matrix – see HERMITIAN TRANSPOSE.

admittance – *in acoustics* a generic term for the reciprocal of an IMPEDANCE. Equivalently, it is a FREQUENCY RESPONSE FUNCTION in which velocity u (in a given direction) or volume velocity U (across a specified surface) is regarded as the output, and pressure p or force F (in a given direction) is regarded as the input. See ACOUSTIC ~, MECHANICAL ~, SPECIFIC ACOUSTIC ~.

admittance matrix – the inverse of an IMPEDANCE MATRIX.

admittance ratio – the SPECIFIC ACOUSTIC ADMITTANCE multiplied by ρc, where ρ is the density of the acoustic medium and c is the sound speed. *Units* none.

advection – *in fluid dynamics* convective transport of a passive component in a fluid mixture. The term can also be used for momentum or energy, as in *advective transport of momentum by turbulent eddies*.

aeolian tones – sound with a tonal character, generated by regular vortex shedding from a circular cylinder. Such vortex shedding occurs spontaneously in a certain range of Reynolds numbers (see below), when the cylinder is placed in a steady fluid flow with its axis mounted transversely to the oncoming flow direction. The sound is related to unsteady aerodynamic forces exerted by the cylinder on the fluid; it has an intensity maximum in the direction orthogonal to both the flow and the cylinder axis.

The frequency spectrum of the radiated sound depends on the REYNOLDS NUMBER $Re = ud/\nu$ (u = flow speed, d = cylinder diameter, ν = kinematic viscosity). Over the range $400 < Re < 300\,000$, the spectrum contains a distinctive peak centred on frequency $f = 0.2\ u/d$, i.e. a STROUHAL NUMBER of $S = 0.2$. At higher Reynolds numbers, or with a roughened surface, or in the presence of incident sound, the flow approaches a fully-turbulent state and the Strouhal number shifts to around 0.27.

There is a transitional range of Reynolds numbers, roughly $300\,000 < Re < 3 \times 10^6$, over which the flow past a smooth circular cylinder lacks a regular coherent structure; aeolian tones are then absent, or much less prominent.

Note: A cylinder that can vibrate in the transverse direction will couple to the vortex shedding process when the aeolian tone frequency ($S \approx 0.2$) approaches that of a mechanical resonance. The coupled system produces modified tone frequencies that can "lock on" to successive resonances over a Strouhal number range of an octave or more.

aeroacoustics – the science of sound production by fluid flow, or by the interaction of flows with solid bodies. The term is also used to describe flow–acoustic interaction phenomena generally.

aerodynamic force – the force on an object in a surrounding fluid, due to relative motion between them. The aerodynamic force vector is conventionally divided into two components: the ***lift force*** which acts transversely to the relative velocity, and the ***drag force*** which acts parallel to the relative velocity. *Units* N.

aerodynamic sound – sound that is excited by a region of turbulent or unstable flow, and radiates into the surrounding fluid. At low Mach numbers, the radiation can be greatly amplified through scattering of the hydrodynamic near field, either by solid objects in the flow, or by local regions of different density or compressibility.

A distinguishing feature of aerodynamic sound is that the radiated acoustic energy is derived from the flow itself, rather than being generated directly by motion of the boundaries: these remain fixed, or else act on the sound field as passive acoustic absorbers. Aeroelastic instabilities may nevertheless contribute to aerodynamic sound generation, by extracting energy from a steady flow to set up an unsteady flow which then in turn radiates sound. See AEOLIAN TONES.

aeroelasticity – the study of dynamic interactions between an elastic structure (e.g. an aircraft wing), and a surrounding mean flow; the flow may be steady, or have disturbances superimposed on it. Aeroelastic phenomena include ***flutter***, which is flow-excited instability; ***gust response***, which is structural vibration caused by flow unsteadiness; and ***divergence***, which is static instability under steady aerodynamic loading.

aetiology – scientific study of the factors involved in disease causation; also, for a particular disease, the causative factors themselves. For example, the aetiology of noise-induced hearing loss covers the chain of causation from initial exposure to physiological damage, usually focusing on a particular population at risk.

age variable – *for transmission between two points on a ray path* an integral evaluated along an acoustic ray path, that allows the nonlinear distortion of a signal waveform to be quantified. Specifically, it gives the amplitude-dependent travel time of a wavelet as

$$\Delta t \approx (\Delta t)_{\text{lin}} - p_+ L,$$

where p_+ is the acoustic pressure of the wavelet at the starting point on the ray path, L is the age variable, and $(\Delta t)_{\text{lin}}$ is the travel time given by linear acoustics. *Units* s Pa^{-1}.

Note: The relation between the age variable and the REDUCED PATH LENGTH, $\tilde{x}$, takes the following form in a stationary medium:

$$L = \left(\frac{\beta}{\rho c^3}\right)_+ \tilde{x}.$$

Here β is the nonlinearity coefficient of the medium, and ρ, c are the density and sound speed; the + subscript indicates that these are all evaluated at the start of the ray path.

agglomeration – see ACOUSTIC AGGLOMERATION.

airborne path – a sound transmission path in which energy is carried principally by the fluid (air), and only to a minor extent via structural or solid-borne waves.

airborne sound insulation index – an alternative term for WEIGHTED SOUND REDUCTION INDEX. *Units* dB.

air conduction – *in audiology* the transmission of sound as airborne pressure fluctuations through the external ear to the eardrum, and from there via the ossicles of the middle ear to the cochlea. Abbreviated as ***a-c***.

air-conduction audiometry – see PURE-TONE AUDIOMETRY.

airframe noise – that part of the noise radiated from an aircraft in flight that is not associated with the engines.

aliasing – the apparent conversion of high-frequency signal energy into lower frequencies that results from discrete sampling at a finite rate. Components of the original signal at frequencies $|f| \geq f_s/2$, where f_s is the sampling frequency, are folded back into the range $|f| < f_s/2$ (***aliased***) by addition or subtraction of a multiple of f_s. Components of the original signal at frequencies $|f| < f_s/2$ are not affected. See ANTI-ALIASING FILTER.

ambient – *used as an adjective* prevailing, surrounding. Hence **~ *conditions***, the temperature, pressure, etc. in the surrounding atmosphere (or other fluid environment); see also STANDARD AMBIENT CONDITIONS. In acoustics, the term **~ *value*** (of pressure, velocity, etc.) is commonly used to refer to a steady background value on which acoustic disturbances are superimposed.

ambient noise – (1) *in underwater acoustics* the naturally-occurring acoustic environment in the ocean, caused by wave breaking, marine life, etc. (but not ships or other human activity). For ambient noise in sonar, see definition (2).

ambient noise – (2) *in sonar detection* the noise from all unwanted sources of sound, apart from those directly associated with the sonar equipment and the platform on which it is mounted. Compare SONAR SELF-NOISE.

ambient noise – (3) a generic term for the ACOUSTIC ENVIRONMENT (3) that prevails under normal conditions, for example at a given outdoor location.

Note: In the context of noise measurement or environmental noise assessment, ambient noise is what remains after any noise source being investigated has either been turned off, or suppressed to the point where its contribution is insignificant.

ambient noise level – the SOUND PRESSURE LEVEL due to ambient noise. *Units* dB re p_{ref}^2.

Note: The ambient noise level is commonly expressed for environmental assessment purposes as an EQUIVALENT CONTINUOUS SOUND PRESSURE LEVEL, L_{eq}, with A-weighting applied. Compare RESIDUAL NOISE LEVEL, which is a technical term used in noise assessment standards.

amplification – (1) an increase in signal amplitude or rms value.

amplification – (2) the amount by which the peak or rms value of a signal is increased, expressed in decibels. *Units* dB.

amplitude – the peak value of a sinusoidal signal; more generally, the maximum departure from equilibrium in any oscillation. Mathematically, the amplitude is the positive real coefficient A in the expression $A\cos(\omega t + \alpha)$ for a signal of angular frequency ω; here t is time, and ω, α are real constants.

Note: If a sinusoidal CARRIER SIGNAL is amplitude-modulated, with instantaneous value $A(t)\cos(\omega t + \alpha)$, the time-varying coefficient $A(t)$ may still be called the amplitude, provided it varies slowly compared with the cosine term. For example, with $A(t) = A_0 e^{-\delta t}$ the expression above describes the exponentially decaying amplitude of a lightly-damped mode, during FREE OSCILLATION of a linear system. For a more general approach to defining instantaneous amplitude that applies to non-sinusoidal signals, see ANALYTIC SIGNAL.

amplitude attenuation coefficient – ◆ *of a single-frequency progressive wave system* an alternative term for ATTENUATION COEFFICIENT, by analogy with AMPLITUDE DECAY COEFFICIENT. *Units* Np m^{-1}.

amplitude decay coefficient – *of a linear system, for a single mode of free vibration* the coefficient δ in the temporal decay factor $e^{-\delta t}$, which describes the amplitude decay of damped free oscillations with time, t. Also known as ***damping constant***. See also LOGARITHMIC DECREMENT, COMPLEX NATURAL FREQUENCY. *Units* Np s^{-1}.

amplitude distortion – *of a linear system* refers to distortion of the output waveform that is caused by the system GAIN FACTOR varying with frequency.

amplitude focal gain – *of an acoustic transducer that produces a single-frequency focused beam* the pressure amplitude at the focus divided by the pressure amplitude at the transducer face. Also known as ***amplitude gain***, ***focusing gain***, or ***pressure gain factor***. *Units* none.

amplitude modulation – see MODULATION (1).

amplitude response function – *of a linear time-invariant system* the magnitude of the system FREQUENCY RESPONSE FUNCTION; also known as the ***gain factor*** of the system. Thus if $H(\omega)$ is the frequency response function at angular frequency ω, the amplitude response function is $|H(\omega)|$.

amplitude spectrum – *of a periodic continuous signal* the infinite set of discrete Fourier harmonic magnitudes, plotted against frequency. See FOURIER ANALYSIS, COMPLEX FOURIER AMPLITUDES. For a real periodic signal, the amplitude spectrum is even with respect to frequency.

Note: Compare MAGNITUDE SPECTRUM, which relates to the Fourier transform of a transient signal.

analog ∼ – see ANALOGUE ∼.

analogous circuit, analogous electrical circuit – see EQUIVALENT CIRCUIT.

analogous flow resistance – *of an acoustic lumped element* an equivalent term for FLOW RESISTANCE. *Units* Pa s m^{-3}.

analogue filter – a linear device that converts an analogue input signal $x(t)$ into an analogue output signal $y(t)$. In signal processing, analogue filters are used for pre-processing the input signal prior to A-D conversion; see ANTI-ALIASING FILTER.

analogue signal – a signal whose value over a specified time interval is defined continuously for all times, in contrast to a DIGITAL SIGNAL. Equivalent terms are ***continuous signal*** and ***continuous-time signal***.

analogue system – (1) a hardware device that converts an analogue input signal $x(t)$ into an analogue output signal $y(t)$, or more generally a set of multiple input signals $\mathbf{x}(t)$ into a set of multiple output signals $\mathbf{y}(t)$.

analogue system – (2) a rule or transformation for mapping the set of inputs $\mathbf{x}(t)$ to the set of outputs $\mathbf{y}(t)$.

analogue-to-digital conversion – the process of converting an ANALOGUE SIGNAL into a DIGITAL SIGNAL. It consists of SAMPLING the analogue signal, usually at equal time intervals; quantizing the sampled values; and encoding the sequence thus produced into digital words of finite length. See also SAMPLING THEOREM, ALIASING.

analogue-to-digital converter – a device for converting an analogue signal into a digital signal.

analytic function – *of a complex variable* a function $f(z)$ that is ***differentiable*** with respect to the complex variable z, in the sense that the following limit exists:

$$\lim_{\delta z \to 0} \frac{f(z+\delta z) - f(z)}{\delta z} = f'(z).$$

Note this is more restrictive than saying that $\partial f/\partial x$, $\partial f/\partial y$ exist, where x and y are coordinates in the complex plane such that $z = x + jy$.

Note (1): A function is said to be analytic in domain D if it is differentiable over a limited region D of the complex plane. If $f(z)$ is analytic in D, it is infinitely differentiable (in the sense above) throughout D.

Note (2): The real and imaginary parts, $u(x, y)$ and $v(x, y)$, of any analytic function are related by the ***Cauchy–Riemann equations***

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}, \quad \frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x}.$$

analytic signal – a complex time-domain signal, formed from a real signal $x(t)$ by adding an imaginary component $jx_H(t)$, where subscript H denotes the HILBERT TRANSFORM. Thus the analytic signal $\breve{x}(t)$ based on $x(t)$ is

$$\breve{x}(t) = x(t) + jx_H(t) .$$

As an example, if $x(t)$ equals $\cos \omega t$, then $\breve{x}(t)$ equals $e^{j\omega t}$. Also known as the ***pre-envelope signal***. Compare QUADRATURE FUNCTION.

Note: The analytic signal is obtained by suppressing the negative-frequency components of $x(t)$ and doubling the result. Therefore its energy is twice that of the original signal.

anechoic – non-reflecting with respect to sound waves; totally absorbing.

anechoic boundary condition – *in computational acoustics* an equivalent term for ABSORBING BOUNDARY CONDITION.

anechoic chamber, anechoic room – a room designed to simulate FREE-FIELD acoustic conditions; also known as a ***free-field room***. The surfaces are covered with sound-absorbing material, often in the form of wedges pointing into the room, so that sound waves arriving at the room boundaries are almost entirely absorbed. See also SEMI-ANECHOIC ROOM, DIRECT FIELD.

anechoic tank – the equivalent of an ANECHOIC CHAMBER, but with water as the acoustic medium. The other difference is that the water in the tank usually has a free surface, which is almost perfectly reflecting.

anechoic termination – an ideal termination (e.g. in a duct or waveguide) that reflects none of the acoustic power incident on it. See also IMPEDANCE MATCHING. A true anechoic termination is not achievable in practice, but the term is often used for a real termination that is designed to be as nearly anechoic as possible.

angle – *of a complex number* the angle θ used to represent the complex number in POLAR FORM,

$$z = re^{j\theta} \qquad (r, \theta \text{ real}).$$

Equivalent terms are ***phase*** or ***argument***. In symbols, the statement that θ is the angle of z is written as

$$\theta = \angle z, \quad \theta = \sphericalangle z, \quad \text{or} \quad \theta = \arg z\,.$$

angle of incidence – *of a progressive plane wave arriving at a plane boundary* the angle between the surface normal $\mathbf{n}$ (pointing outward from the boundary into the incident medium) and the direction from which the arriving wave approaches. This is equivalent to saying that if the incident wave has WAVENORMAL $\mathbf{i}$, the angle of incidence θ_{inc} is given by

$$\cos\theta_{\text{inc}} = -\mathbf{i}\cdot\mathbf{n}.$$

See also GRAZING INCIDENCE, NORMAL INCIDENCE. *Units* rad (but commonly expressed in degrees).

angular frequency – *of a sinusoidal oscillation* 2π times the FREQUENCY; equivalently, the rate of change of INSTANTANEOUS PHASE with time. Also known as ***circular frequency*** or ***radian frequenc***y. *Units* rad s^{-1}.

angular intensity distribution – ◆ *at a point in a reverberant sound field* the factor $I_\Omega(\theta, \phi)$ in the expression $dI = I_\Omega(\theta, \phi)\, d\Omega$, which gives the ACOUSTIC INTENSITY due to plane-wave components arriving at the given point within a narrow cone of propagation directions centred on (θ, ϕ). Here (θ, ϕ) are SPHERICAL POLAR COORDINATES, and $d\Omega = \sin\theta\, d\theta\, d\phi$ is the cone SOLID ANGLE.

Underlying this definition is the idea that the REVERBERANT FIELD is made up of infinitely many uncorrelated plane waves, whose contributions to the intensity in any given direction are additive. *Units* W m^{-2} sr^{-1}.

Note: The angular intensity distribution in acoustics is analogous to *radiance* in optics. An alternative term is ***solid-angle distribution of intensity***.

angular momentum – *of a system about a specified point* a vector quantity obtained by taking the MOMENT, about the given point, of the linear MOMENTUM of each particle, and summing the result over the whole system.

In symbols, the contribution of each particle to the angular momentum about point A is $(\mathbf{r} - \mathbf{r}_A) \times \dot{\mathbf{r}}$ per unit mass, where $\mathbf{r}$, $\mathbf{r}_A$ are the positions of the element and point A respectively, and $\dot{\mathbf{r}}$ is the velocity of the element relative to an INERTIAL FRAME OF REFERENCE. If $\mathbf{s}$ denotes the separation vector $\mathbf{r} - \mathbf{r}_A$, the total angular momentum of the system about *A* may be written as

$$\mathbf{L} = \Sigma(\mathbf{s} \times \dot{\mathbf{s}})m_i + (\mathbf{s}_c \times \dot{\mathbf{r}}_A)m_{\mathrm{tot}},$$

where m_i is the mass of the ith particle, m_{tot} is the total mass, and subscript c denotes the MASS CENTRE. *Units* kg m^2 s^{-1} ≡ N m s.

Note: The conservation law for angular momentum states that the angular momentum, **L**, of a closed system about point *A* changes with time according to

$$\frac{d\mathbf{L}}{dt} = \mathbf{G}$$

where **G** is the moment about *A* of the forces applied to the system.

angular power distribution – ◆ *of a sound source* the SOUND POWER per unit SOLID ANGLE in the far field. Suppose a particular radiation direction from the source is specified by (θ, ϕ) in SPHERICAL POLAR COORDINATES. If the angular power distribution is denoted by $W_\Omega(\theta, \phi)$, then the sound power radiated by the source within a narrow cone centred on (θ, ϕ) is

$$dW = W_\Omega(\theta, \phi)\, d\Omega\,,$$

where $d\Omega$ is the cone solid angle. It follows that the far-field radial intensity I_r at distance r from the source is given by

$$I_r(r, \theta, \phi) = \frac{1}{r^2} W_\Omega(\theta, \phi).$$

Units W sr^{-1}.

Note (1): For a related quantity in underwater acoustics, see SOURCE LEVEL.

Note (2): The angular power distribution in acoustics is analogous to *radiant intensity* in optics.

angular radiated-energy distribution – ◆ *of a transient sound source* the acoustic energy (equal to the time-integrated SOUND POWER) radiated from the source into the far field, per unit SOLID ANGLE. The definition is analogous to that for ANGULAR POWER DISTRIBUTION: the acoustic energy radiated by the source within a narrow cone centred on (θ, ϕ) is

$$dE = E_\Omega(\theta, \phi)\, d\Omega,$$

where $d\Omega$ is the cone solid angle. It follows that the radial TIME-INTEGRATED INTENSITY N_r at distance r from the source is given by

$$N_r(r, \theta, \phi) = \frac{1}{r^2} E_\Omega(\theta, \phi).$$

Units J sr^{-1}.

Note: For a related quantity in underwater acoustics, see ENERGY SOURCE LEVEL.

angular velocity – (1) a vector whose component in any direction defines a rotation rate, measured in radians per unit time, about an axis pointing in that direction. *Units* rad s^{-1}.

angular velocity – (2) *of one point in space with respect to another* the vector $(\mathbf{s} \times \dot{\mathbf{s}})/s^2$, where **s** is the separation vector of the two points and s is their separation distance. *Units* rad s^{-1}.

angular velocity – (3) *of a unit vector* if the direction of a UNIT VECTOR **e** changes with time, the angular velocity of the unit vector is $\boldsymbol{\omega} = \mathbf{e} \times \dot{\mathbf{e}}$. *Units* rad s^{-1}.

angular wavenumber – 2π times the number of cycles per unit distance, for a quantity that varies sinusoidally with position along a specified axis. Often referred to in acoustics simply as WAVENUMBER. Angular wavenumber may be considered as the spatial analogue of ANGULAR FREQUENCY. *Units* rad m^{-1}.

anharmonic component – *in a signal consisting of discrete-frequency components* an individual sinusoidal component whose period is not integrally related to the other periods present.

animal bioacoustics – the science that deals with sound production and reception by animals, birds, or fish. The sound may be airborne, groundborne or waterborne. Compare BIOACOUSTICS.

anisotropic – having properties that vary according to direction. An ***anisotropic medium*** in acoustics implies a medium with different wave propagation properties in different directions (e.g. a crystal, or a fibre-reinforced composite with preferential alignment of the fibres). When plane waves propagate in such a medium, the direction of energy propagation is no longer normal to the wavefronts – see GROUP VELOCITY. Compare ISOTROPIC.

anti-aliasing filter – an analogue low-pass FILTER applied to a signal prior to sampling; its purpose is to remove high-frequency components that would otherwise be ALIASED, or folded down to lower frequencies.

anticausal response – having no CAUSAL part; an anticausal response occurs entirely before the input. Compare ACAUSAL RESPONSE.

antinode – a point of maximum amplitude in a one-dimensional standing wave field (e.g. *pressure* ~ *in a standing-wave tube*; *velocity* ~ *on a transversely* *vibrating string*); alternatively, a *line* of maximum amplitude in a 2D field, or a *surface* of maximum amplitude in a 3D field. Compare NODE.

antiphase – two sinusoidal signals at the same frequency are said to be in antiphase if the phase difference between them is π (or 180°). An equivalent statement is that the signals are of ***opposite phase*** or ***opposite polarity***.

antiresonance – the occurrence of a minimum in the magnitude of a driving-point frequency response function, as the frequency is varied. In terms of a transmission line analogy, an antiresonance occurs when waves return to the driving point in antiphase with the original outgoing wave.

anti-sound – the use of secondary acoustic sources to achieve sound cancellation. Equivalent terms are ***active control of sound***, and ***active noise control***. Compare ACTIVE CONTROL.

aperiodic – non-periodic or non-repeating; the opposite of PERIODIC. A transient signal is aperiodic.

aperture shading – *of an acoustic transducer* introduction of a profile of surface vibration amplitude over the transducer face; also known as APODIZATION.

apodization – (1) application of amplitude weighting, or APERTURE SHADING, to the active radiating face of an acoustic transducer, especially in ultrasonics.

apodization – (2) an equivalent word for WINDOWING. In ultrasonics the term is used for spatial windowing, for example by an aperture. Applied to signals in the time domain, apodization can refer either to direct windowing, or to the truncation of a correlogram in order to limit it to finite time delays.

apparent mass – the reciprocal of the real part of the ACCELERANCE. *Units* kg.

apparent sound reduction index – *of a partition separating two rooms* the result of applying the standard level difference measurement procedure (as for LABORATORY TRANSMISSION LOSS), but in the field. This means that measurements are made between two rooms in a building where the sound fields may not be diffuse, and where there may be flanking transmission paths. Symbol R'. *Units* dB.

apparent source width (ASW) – *of a sound source in a room* the apparent angle subtended by the source at the listener's position, measured in degrees in the horizontal plane. The apparent source width provides a geometrical measure of SOURCE BROADENING that can be compared in test situations between listeners. *Units* deg.

architectural acoustics – the ACOUSTICS (1) of the built environment. Some of its elements are: room acoustics, acoustical design of auditoria and concert halls, control of noise transmission into and out of rooms or buildings, and relevant areas of sound perception and psychoacoustics.

arctangent – if $x = \tan\theta$, then the angle $\theta = \tan^{-1}x$ is called the arctangent of x, or alternatively the ***inverse tangent***. See INVERSE CIRCULAR FUNCTIONS.

arg – abbreviation for the ARGUMENT function, arg z, that gives the phase of a complex number z. See also PHASE AND MAGNITUDE REPRESENTATION.

Argand diagram – the complex plane, with coordinates x and y denoting the real and imaginary parts of any complex number (**J R ARGAND 1806**).

argument – *of a complex number* the angle θ used to represent the complex number in POLAR FORM,

$$z = re^{j\theta} \qquad (r, \theta \text{ real}).$$

In symbols, the statement that θ is the argument of z is written as

$$\theta = \arg z\,, \theta = \angle z, \quad \text{or} \quad \theta = \measuredangle z.$$

array – a composite transducer made up of a number of similar elements. Arrays are used both for receiving sound (***receiving array***) and for radiating sound (***transmitting array***, ***source array***).

array gain – a decibel measure of the enhancement in signal-to-noise ratio (SNR) provided by an ARRAY of sensors, as compared with a single sensor element. Enhancement of the overall SNR beyond the capabilities of a single sensor relies on the wanted signal being COHERENT across array elements in a predictable manner. In general, the array gain depends on the properties of the signal and noise fields, as well as the properties of the array.

The simplest situation is where the noise signal has zero coherence between array elements. The array gain in this case, for an N-element array in which signal i is weighted by a factor w_i, is given by $10 \log_{10}\Gamma$ where Γ is defined by

$$\Gamma = \left|\sum_{i=1}^{N} w_i\right|^2 \Big/ \sum_{i=1}^{N} |w_i|^2.$$

For a uniformly weighted array, the array gain equals $10 \log_{10}N$. *Units* dB.

Note: The vector with elements w_i is called the ***weighting function*** of the array.

array impedance matrix – *of elements in a radiating array* see MUTUAL IMPEDANCE.

array processing – simultaneous combined processing of time-domain signals from separate elements of a sensing array, in order to cancel out noise plus interference and enhance a desired incoming signal.

array sensitivity – see BEAM PATTERN. *Units* V Pa^{-1}.

array shading – *of a receiving or transmitting array* the application of a sensitivity profile across the elements of a receiving array, or a voltage profile across a transmitting array. Compare APERTURE SHADING.

articulation index (AI) – a method for predicting the output INTELLIGIBILITY of a speech transmission channel, based on the signal-to-noise ratio at the listener. To some extent it has been replaced by the SPEECH TRANSMISSION INDEX (STI) which takes account of the channel impulse response as well as the signal-to-noise ratio. *Units* none.

artificial ear – *in audiology* an equivalent older term for EAR SIMULATOR; the latter is the preferred term in IEC Standards.

A-scan – *in diagnostic ultrasound* a technique based on detecting signals backscattered from an ultrasound beam; it produces information in one spatial dimension only, namely depth measured along the beam axis. Its output shows the relative amplitude of the reflected signal plotted as a function of time delay, or equivalently as a function of depth into the sample. The use of single A-scans is now largely obsolete; compare B-SCAN.

asdic – obsolete term (UK) for SONAR, in use between the end of WWI and the end of WWII. According to the Longman Dictionary of the English Language, it originated from the acronym for Anti-Submarine Detection Investigation Committee. A similar obsolete term is ***asdics*** (*ASD-ics*, with the ending -ics analogous to that in *physics*).

associated Legendre functions – solutions of the second-order differential equation

$$(1 - x^2)g'' - 2xg' + \left(\lambda - \frac{\mu^2}{1 - x^2}\right)g = 0$$

for the unknown function $g(x)$. Here λ, μ are constants and derivatives of g are denoted by primes. The equation has two linearly independent solutions, $P_\nu^\mu(x)$ and $Q_\nu^\mu(x)$, known as associated Legendre functions of the first and second kind respectively. The upper index μ is sometimes called the ***order***. The lower index ν is then called the ***degree***; it is related to λ by $\nu(\nu + 1) = \lambda$.

Note: In the special case where the order $\mu = 0$, the $P_\nu^\mu(x)$ solutions are called ***Legendre functions***. For positive integer values of ν, say $\nu = n$, these functions are polynomials of degree n in x, called LEGENDRE POLYNOMIALS. See also SPHERICAL HARMONICS.

asterisk (*) – the notation X^* means the COMPLEX CONJUGATE of X. The different notation $x(t) * w(t)$ or $x * w|_t$ means the CONVOLUTION of $x(t)$ and $w(t)$, defined by

$$x(t) * w(t) = x * w|_t = \int_{-\infty}^{\infty} x(\tau)w(t-\tau)d\tau.$$

Both notations are widely used in the fields of acoustics and signal processing.

ASW – (1) *in room acoustics* abbreviation for APPARENT SOURCE WIDTH. *Units* deg.

ASW – (2) *in underwater acoustics* abbreviation for Anti-Submarine Warfare.

asymptotic – refers to a value that is approached in some specified limit. Thus the difference between the total and static pressure in a fluid flow has the *asymptotic value* $\frac{1}{2}\rho u^2$, as $M \to 0$ (low Mach number or incompressible flow limit). A more precise mathematical statement of this result would be

$$\frac{P_{\text{tot}} - P}{\frac{1}{2}\rho u^2} = 1 + O(M^2)$$

which is an example of an ***asymptotic equation***, i.e. one that becomes exact in the indicated limit. The ***order symbol*** $O(M^2)$ indicates that the error divided by M^2 remains finite (or tends to zero) as M is made arbitrarily small. See also ORDER (1).

asymptotically stable – a linear system is called asymptotically stable if its displacement tends to zero whenever the system is perturbed from equilibrium and released; equivalently, its free oscillations are damped. Such a system always has a bounded output for any bounded input.

Note: Lyapunov's definition of stability (broadly, that free oscillations do not diverge without limit) does not ensure asymptotic stability, since it allows the system transfer function in the S-PLANE to have poles on the imaginary axis (examples are a simple integrator, and a system with undamped natural modes). In both these examples, a finite input sustained for infinite time can lead to an infinite output. Compare STABLE SYSTEM.

ATOC – acronym for Acoustic Thermometry of Ocean Climate; the use of ACOUSTIC THERMOMETRY to measure, and monitor, changes in sea temperature on an ocean or global scale.

attached mass – *of an accelerating rigid body in an incompressible fluid* the mass of fluid that, if rigidly attached to the body, would provide the same inertial fluid loading. Equivalently, the coefficient of proportionality between the force required to overcome fluid inertia, and the acceleration of the rigid body. See also the alternative term VIRTUAL MASS, where further details are given. *Units* kg.

attenuation – (1) a generic term for a reduction in the amplitude or rms value of an acoustic field variable, such as sound pressure; the term can also refer to a reduction in a power-like variable, such as sound intensity. Sound waves suffer progressive attenuation with distance during propagation through real media; the principal attenuation mechanisms are ABSORPTION and SCATTERING.

attenuation – (2) the amount by which the LEVEL of a signal is reduced, based on either the mean square value (usually in a specified frequency band) or the squared peak value (for a transient signal). Compare ATTENUATION RATE. *Units* dB.

attenuation coefficient – *of a single-frequency progressive wave system* the coefficient α in the spatial attenuation factor $e^{-\alpha x}$, which describes the reduction in amplitude of a progressive wave with distance, x, in the propagation direction. The alternative term ***amplitude attenuation coefficient*** may be useful where there is risk of confusion with ENERGY ATTENUATION COEFFICIENT. Compare ATTENUATION RATE; see also PROPAGATION FACTOR, PROPAGATION COEFFICIENT. *Units* Np m^{-1}.

Note: The space and time dependence of a single-frequency wave propagating along the x axis may be expressed in phasor notation as $e^{j(\omega t - kx)}$, where k is the complex PROPAGATION WAVENUMBER; the amplitude attenuation coefficient is then given by $\alpha = -\mathrm{Im}\, k$. Equivalently, the attenuation coefficient is the real part of the PROPAGATION COEFFICIENT $\gamma = jk$.

attenuation constant – an alternative term for ATTENUATION COEFFICIENT. The "coefficient" version seems to be widely used, and has been preferred in the present work. *Units* Np m^{-1}.

Note: The 1994 ANSI standard on acoustical terminology recognizes *attenuation constant* (with the prefix "acoustic"), but not *attenuation coefficient*; the 1994 IEC standard recognizes attenuation coefficient but not attenuation constant.

attenuation length – *for linear waves* the distance over which the amplitude of a progressive wave drops by a factor $1/e$, in an absorbing or scattering medium. If α denotes the ATTENUATION COEFFICIENT, the attenuation length is given by $L_a = 1/\alpha$. An alternative term, appropriate in the absence of scattering, is ***absorption length***. *Units* m.

attenuation rate – *at a given frequency* the rate at which the LEVEL of mean square pressure falls off with distance in a progressive sound wave, adjusted (where appropriate) for spreading, and expressed in decibels per unit distance. In a plane progressive wave whose amplitude decays spatially like $e^{-\alpha x}$, where α is the ATTENUATION COEFFICIENT of the signal and x is distance measured in the propagation direction, the attenuation rate a is given by

$$a = 8.686\,\alpha \qquad (8.686 = 20/\ln 10)\,.$$

Units dB m^{-1}.

Note: It is assumed for purposes of the definition above that measurements are made in the far field. In this situation the attenuation rate for mean square sound pressure is the same as that for acoustic intensity.

audibility – *of a given sound* detectability by ear, especially to human listeners. The audibility of sounds depends on their level and frequency content, and may be reduced by the presence of other sounds; see ABSOLUTE THRESHOLD, MASKING.

audio frequency range – (roughly) 15 Hz to 20 kHz; the frequency range over which the normal human ear is sensitive to sound.

audiogram – *in audiology* a chart or table of a person's HEARING THRESHOLD LEVELS for pure tones at different frequencies.

audiology – the science of hearing, especially human hearing, and its dysfunction. Because the INNER EAR contains both hearing and balance organs, audiology is often understood to include the sense of balance as well as hearing.

audiometer – *in audiology* an electroacoustic instrument, usually equipped with earphones, that presents a subject's ear with test signals at known sound pressure levels and is calibrated in a specified manner, using either an ACOUSTIC COUPLER or an EAR SIMULATOR. It is used to determine HEARING THRESHOLD LEVELS, one ear at a time.

audiometric zero – *in pure-tone air-conduction audiometry* a reference set of pure-tone sound pressure levels at specified frequencies, as measured in a specified ACOUSTIC COUPLER or EAR SIMULATOR during calibration of an audiometer. The audiometric zero is intended to typify the threshold of hearing of young otologically normal persons. See also HEARING THRESHOLD LEVEL.

audiometry – measurement of auditory function. The term is general, but is commonly understood to mean the determination of a person's pure-tone AUDIOGRAM. See also PURE-TONE AUDIOMETRY.

Note: Audiometric techniques can be either subjective – involving a voluntary response from the subject – or objective; examples of the latter are ***cortical audiometry***, in which evoked electrical potentials from the cortex of the brain are measured, and ***electrocochleographic audiometry***, which uses potentials measured in the middle ear or external ear canal.

audition – the sense of hearing.

auditorium – a building or part of a building designed to accommodate listeners for concerts, lectures, drama or other audio-visual performances.

auditory – related to hearing, or to the mechanism of hearing; e.g. *auditory filter*, *auditory nerve*. Compare AURAL.

auditory adaptation – *in psychoacoustics* the decline in apparent magnitude of a steady auditory stimulus over time, on a time scale of a few minutes. See ADAPTATION.

auditory critical band – one of a number of contiguous bands of frequency into which the audio-frequency range may be notionally divided, such that sounds in different frequency bands are heard independently of one another, without mutual interference. An auditory critical band can be defined for various measures of sound perception that involve frequency.

auditory critical bandwidth for loudness – *for a given centre frequency* the maximum bandwidth over which an acoustic signal can be spread, with its mean square pressure held constant, without affecting the LOUDNESS. Thus the loudness of a continuous sound that lies entirely within a critical bandwidth depends only on the signal level, and not on the bandwidth of the signal. The critical bandwidth for loudness is an increasing function of frequency. *Units* Hz.

auditory fatigue – *in psychoacoustics* the reduction in response to an auditory stimulus that occurs following exposure to high levels of the stimulus. Also known as ***post-stimulatory auditory fatigue***. The related shift in absolute threshold is called TEMPORARY THRESHOLD SHIFT.

auditory nerve – the eighth cranial nerve, also known as nerve VIII. It consists of two branches, the ***cochlear nerve*** and the ***vestibular nerve***, running respectively from the cochlea and the organs of balance to the brain stem.

aural – via the ear, or via the hearing mechanism or process; e.g. *aural detection*.

auralization – conversion of a digital waveform into audible form.

auricle – alternative medical term for the PINNA.

auscultation – listening to internal body sounds, particularly with the aid of an impedance-matching device such as a stethoscope.

autocorrelation – *in signal processing* abbreviation for AUTOCORRELATION FUNCTION.

autocorrelation coefficient, autocorrelation coefficient function – *of a real time-stationary random signal* the normalized AUTOCORRELATION FUNCTION (1). Thus if a signal $x(t)$ has autocorrelation function $R_{xx}(\tau)$, its autocorrelation coefficient as a function of time shift τ is

$$\rho_{xx}(\tau) = R_{xx}(\tau)/R_{xx}(0) \qquad (-1 \leq \rho_{xx} \leq 1).$$

Note: The autocorrelation coefficient is generally applied to signals whose mean value is zero. It is equivalent, in such cases, to a normalized AUTOCOVARIANCE FUNCTION.

autocorrelation function – (1) *of a real time-stationary continuous signal* the time-averaged product

$$R_{xx}(\tau) = \lim_{T\to\infty}\left\{\frac{1}{T}\int_{t_0}^{t_0+T} x(t)x(t+\tau)dt\right\}$$
$$= \langle x(t)x(t+\tau)\rangle = \langle x(t-\tau)x(t)\rangle,$$

where angle brackets $\langle\ldots\rangle$ denote the time averaging operation, $x(t)$ is the signal as a function of time t, and τ is a time shift or delay. The autocorrelation function is an even function of the time delay, i.e. $R_{xx}(-\tau) = R_{xx}(\tau)$.

Note (1): Putting τ equal to zero gives $R_{xx}(0) = \langle x^2(t)\rangle$.

Note (2): The autocorrelation function defined above is the same as the AUTOCOVARIANCE FUNCTION, if $x(t)$ has zero mean.

autocorrelation function – (2) *of a complex non-stationary stochastic process* the ENSEMBLE-AVERAGED product

$$R_{xx}(t_1, t_2) = E\{(x(t_1)\, x^*(t_2)\},$$

where $x(t)$ is the process in question, * denotes the complex conjugate, and $E\{\ldots\}$ is the EXPECTATION OPERATOR.

autocorrelation function – (3) *of a real time-stationary discrete sequence* the time-averaged product

$$R_{xx}[m] = \langle x[n]\, x[n+m] \rangle = \langle x[n-m]\, x[n] \rangle,$$

where angle brackets $\langle \ldots \rangle$ denote an average with respect to the DISCRETE TIME variable n, $x[n]$ is the discrete sequence, and m is a shift or delay. The autocorrelation function is an even function of the delay, i.e. $R_{xx}[-m] = R_{xx}[m]$.

autocorrelation matrix – *of a vector of real time-stationary continuous signals* the $N \times N$ square matrix defined by

$$\mathbf{R_{xx}}(\tau) = \langle \mathbf{x}(t+\tau)\, \mathbf{x}^T(t) \rangle = \langle \mathbf{x}(t)\, \mathbf{x}^T(t-\tau) \rangle$$
$$= [R_{ij}(\tau)],$$

where angle brackets $\langle \ldots \rangle$ denote the time averaging operation, $\mathbf{x}(t)$ is a column vector of signals $x_1, x_2, \ldots, x_N$ as a function of time t, superscript T denotes the vector TRANSPOSE, and τ is a time shift or delay. The autocorrelation matrix has the property $R_{ji}(\tau) = R_{ij}(-\tau)$; its diagonal elements are autocorrelation functions.

Note: The autocorrelation matrix is the special case of the CROSS-CORRELATION MATRIX that results when the two signal vectors are identical. Both matrices arise in connection with multiple-input multiple-output systems.

autocovariance function – *of a real time-stationary continuous signal* the time-averaged product

$$\langle x'(t)\, x'(t+\tau) \rangle = R_{xx}(\tau) - \bar{x}^2$$

where the brackets $\langle \ldots \rangle$ denote the time averaging operation; $\bar{x}$ is the mean value of the signal, and $x' = x - \bar{x}$ is the departure from the mean. Compare AUTOCORRELATION FUNCTION, which is the same except that the mean value is not subtracted out first.

autospectral density – *of a real time-stationary continuous signal* the Fourier transform of the AUTOCORRELATION FUNCTION of the signal. If the signal is denoted by $x(t)$, and its autocorrelation function for time shift τ is $R_{xx}(\tau)$, its autospectral density is given by

$$S_{xx}(f) = \int_{-\infty}^{\infty} R_{xx}(\tau)\, e^{-2\pi j f \tau}\, d\tau.$$

The autospectral density is an even real function of frequency, and it is continuous provided the signal contains no periodic components. Its integral over all frequencies gives the signal POWER:

$\int_{-\infty}^{\infty} S_{xx}(f)\, df = R_{xx}(0) = \langle x^2(t) \rangle$.

Alternative terms for the autospectral density are ***autospectral density function***, ***power spectrum***, and ***power spectral density***. See also SINGLE-SIDED SPECTRAL DENSITY, AUTOSPECTRAL MATRIX.

Note (1): The omission of the prefix "power" from the term autospectral density (in contrast to ENERGY AUTOSPECTRAL DENSITY) is well established.

Note (2): It follows from the CONVOLUTION THEOREM that the autospectral density can also be expressed as

$$S_{xx}(f) = \lim_{T \to \infty} \frac{1}{T} E\{|X_T(f)|^2\},$$

where X_T is the Fourier transform of the finite RECORD x_T of length T (defined to equal the original signal over the range $t_0 < t < t_0 + T$, where t_0 is arbitrary, and zero otherwise).

autospectral density function – an equivalent term for AUTOSPECTRAL DENSITY. Compare DENSITY FUNCTION.

autospectral matrix – *of a vector of real time-stationary continuous signals* the $N \times N$ square matrix defined by

$$\mathbf{S_{xx}}(f) = \lim_{T \to \infty} \frac{1}{T} E\{\mathbf{X}_T(f)\mathbf{X}_T^H(f)\},$$

where $E\{\ldots\}$ denotes the expectation operator, $\mathbf{X}_T(f)$ is the Fourier transform of $\mathbf{x}_T(t)$, and $\mathbf{x}_T$ is a column vector of N finite RECORDS each of length T (with each record defined to equal the original signal over the range $t_0 < t < t_0 + T$, where t_0 is arbitrary, and zero otherwise). The superscript H denotes the HERMITIAN TRANSPOSE.

Note: The autospectral matrix is the Fourier transform of the AUTOCORRELATION MATRIX. Compare CROSS-SPECTRAL MATRIX.

auxetic material – *in engineering* a material whose Poisson's ratio, ν, lies in the range $-1 < \nu < 0$.

Note: A stable material cannot have ν less than –1 or greater than $\frac{1}{2}$. The limiting value $\nu = -1$ corresponds to a material with a finite bulk modulus but an infinite shear modulus; the ROD LONGITUDINAL-WAVE SPEED remains finite, but the speeds of bulk longitudinal waves, bulk shear waves, and Rayleigh waves are all infinite.

average – *with respect to time* various types of time average are used in acoustics. In the following examples, $q(t)$ refers to any time-dependent quantity. In the first two cases $q(t)$ is stationary, with time average $\langle q \rangle$; in the third, $q(t)$ is non-stationary, with running average $\bar{q}(t)$. See also MEAN.

(1) For *periodic* signals:

$$\langle q \rangle = \frac{1}{T}\int_0^T q(t)dt \qquad \textbf{(\textit{single-period average})}$$

where T is the period.

(2) For *time-stationary* signals:

$$\langle q \rangle = \lim_{T\to\infty} \frac{1}{T}\int_0^T q(t)dt \qquad \textbf{(\textit{long-duration average})}.$$

(3) For signals that are not stationary, one can define a running average over a moving window of finite duration:

$$\bar{q}(t) = \frac{1}{T}\int_{t-T}^t q(t')dt' \qquad \textbf{(\textit{finite-duration running average})}.$$

The expression above uses uniform weighting over a window of duration T; an alternative type of running average uses exponential weighting with a time constant τ, giving

$$\bar{q}(t) = \frac{1}{\tau}\int_{-\infty}^t q(t')e^{-(t-t')/\tau}dt' \qquad \textbf{(\textit{exponentially-weighted running average})}.$$

In many practical applications, the averaging time T or time constant τ is chosen to be short compared with the slowly-varying time scale of the non-stationary signal statistics, but long compared with the oscillatory time scale of the signal itself.

average modal energy – *over a specified frequency band that contains several resonant modes* the time-average energy per mode of a multimode vibrating system, obtained by summing the energy of all the modes resonant within the specified band (total number = N) and dividing by N. *Units* J.

average sound pressure level – *in a reverberant space* the LEVEL calculated from the spatially-averaged mean square sound pressure in the reverberant field. Regions close to a source where the direct field dominates, and regions within a quarter-wavelength of the room boundaries, are normally excluded from the spatial average. Compare TIME-AVERAGE SOUND PRESSURE LEVEL. *Units* dB re (20 μPa)^2.

Avogadro constant – the conversion factor from a number of MOLES to a number of particles:

$$N_A \approx 6.022\,136\,7 \times 10^{23}\ \text{mol}^{-1}$$

(**A AVOGADRO 1811**).

Note: The number above is determined by the number of atoms in 0.012 kg of neutral ^{12}C.

A-weighted sound pressure level – the LEVEL of a sound pressure signal to which A-WEIGHTING has been applied. See also SOUND LEVEL, FREQUENCY WEIGHTING. Symbol L_A (or L_{pA}). *Units* dB re (20 μPa)^2.

A-weighting – a frequency-weighting procedure, in which the power or energy spectrum of a signal is progressively attenuated towards the high and low ends of the audio frequency range. Frequency components around 1–5 kHz are hardly affected, but the attenuation is large at low frequencies (e.g. 70 dB at 10 Hz).

Note: The A-weighting curve was originally based on the shape of the 30-phon equal loudness contour, with no attempt to allow for the ear canal resonance that enhances the free-field sensitivity of the ear by nearly 10 dB in the range 2–5 kHz. The intention was that A-weighting the incident pressure, followed by squaring and averaging with a suitable time constant, would simulate the sensitivity of the human ear to audio-frequency sound at sound pressure levels below about 50 dB re (20 μPa)^2.

axially progressive wave – *in a waveguide* a single-frequency wave field that propagates along the waveguide with a space–time dependence of the form $e^{j(\omega t - kx)}\psi(y, z)$, where k is the axial wavenumber, x is the axial coordinate (i.e. parallel to the waveguide), and (y, z) are transverse coordinates. Compare BLOCH WAVE.

Note: Propagation of individual WAVEGUIDE MODES as axially progressive waves, with separation of the x and (y, z) dependence, strictly requires the waveguide to be uniform in the x direction. For slow axial dependence, asymptotic solutions of axially-progressive type can be obtained; see ADIABATIC MODES, ADIABATIC APPROXIMATION.

axial mode – a mode with no transverse dependence (i.e. the only spatial pressure variation is parallel to the axis), in a hard-walled room of cylindrical or prismatic shape with end walls normal to the room axis.

axial mode count – *in a hard-walled room of cylindrical or prismatic shape with end-walls normal to the room axis* the number of axial-mode EIGENVALUES less than a stated value. A statistical estimate for rooms of rectangular shape, with dimensions (L_x, L_y, L_z), is $N_{ax} \approx (k/\pi)(L_x + L_y + L_z)$; this gives the number of axial-mode eigenvalues less than k^2. For rooms with only one axis, $N_{ax} \approx kL_x/\pi$ where L_x is the distance between the end walls.

Note: To estimate the number of *axial-mode natural frequencies* below a given frequency in such a room, replace k above by ω/c, where ω is the angular frequency and c is the sound speed in the room.

axial phase speed – *of a time-harmonic wave field* the speed at which a point of constant phase moves, along a line parallel to a given axis. *Units* m s^{-1}.

axial propagation wavenumber – *in a waveguide* the coefficient k in the expression $\exp j(\omega t - kx)$, used to describe an AXIALLY PROGRESSIVE WAVE propagating along the waveguide in the axial (x) direction at angular frequency ω. *Units* (real part) rad m^{-1}; (imaginary part) Np m^{-1}.

axial quadrupole – a point quadrupole made up of two collinear DIPOLES of equal and opposite strength. An equivalent term is ***longitudinal quadrupole***. Compare LATERAL QUADRUPOLE.

axial-quadrupole source distribution – an ACOUSTIC SOURCE DENSITY in the form of a double derivative with respect to one cartesian coordinate; e.g.

$$\mathcal{F} = \frac{\partial^2 F_{xx}}{\partial x^2}, \qquad \text{(quadrupoles oriented in the x-axis direction).}$$

axial source level – *in underwater acoustics* the SOURCE LEVEL of a radiating transducer measured along the beam axis. *Units* dB re 1 μPa^2 @ 1 m, or dB re 1 μPa^2 m^2.

axisymmetric – having rotational symmetry about an axis; for example, an *axisymmetric waveguide* has both its geometry and its acoustic properties independent of orientation about the waveguide axis. Also known as ***rotationally symmetric***.

azimuthally symmetric – an equivalent term for AXISYMMETRIC.

azimuth angle – the angle that measures rotation about the coordinate axis, in a CYLINDRICAL or a SPHERICAL POLAR COORDINATE system. *Units* rad (but commonly expressed in degrees).