A Dictionary of Mechanical Engineering

SECOND EDITION

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AND

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**ablation cooling** The cooling of a surface exposed to very high external gas temperature which causes the surface material to sublime, melt or decompose. The chemical process absorbs heat while the mass flow of material away from the surface blocks the heat flux from the hot gas. A **heat shield (ablation shield)** on a space vehicle consists of sacrificial cladding in the form of ceramic tiles that vaporize under the extreme frictional heat generated on re-entry into the Earth's atmosphere, thus limiting the rise in temperature of the vehicle itself. See also HEAT OF ABLATION; LASER ABLATION.

**abradant** The differently sized grits of hard materials such as emery employed for grinding, polishing, etc. The abrasive grade is determined by the grit size (grit number) originally related to the hole sizes in wire sieves. Higher numbers indicate smaller abrasive particles and hence finer finishes and, in the FEPA (Fédération Européenne des Fabricants de Produits Abrasifs) standards, include number 16 (1.0–1.4 mm) designated ‘coarse’; 46 (0.3–0.4 mm), medium; 90 (0.13–0.18 mm), fine; and 600 (0.008–0.010 mm), very fine.

**abrasion** The removal of surface material by the scratching action of hard particles, either deliberately (abrasive papers, abrasive cleaning, abrasive machining) or as a consequence of operation (wear). For intentional abrasion, grits may be fixed to a rigid or flexible backing or be airborne. See also SANDBLASTING; EROSION.

**ABS** See ANTI-LOCK BRAKING SYSTEM.

**ABS plastic** See ACRYLONITRILE-BUTADIENE-STYRENE.

**absolute encoder** A device which provides a continuous digital output representing angle or position. The output is normally obtained from a number of photocells mounted along a radial line and detecting circumferential patterns on a rotating glass disc. For example, for a resolution of 1 part in $2^{10}$ (1 part in 1 024), 10 photocells would be mounted over the disc shown in the diagram and the output would be 10 parallel binary digits representing the angle of the disc.

**absolute entropy** (Unit kJ/K) The entropy value for a substance relative to absolute zero. For any pure crystalline substance at absolute zero the absolute entropy is zero. See also ENTROPY; PRACTICAL ENTROPY.

**absolute expansion** The true volumetric expansion of a liquid with temperature, after account is taken of any expansion of the container in which it is held. See also APPARENT EXPANSION.

**absolute humidity** See SPECIFIC HUMIDITY.
**absolute manometer**  A manometer that measures **absolute pressure**, i.e. pressure measured relative to a perfect vacuum. Absolute pressure cannot be negative.

**absolute specific gravity**  The ratio of the weight of any volume of a substance to the weight of an equal volume of a reference substance at the same temperature, often water at 4°C, both measured in a vacuum to avoid any effect of buoyancy.

**absolute temperature**  (Unit K) A temperature $T$ measured relative to **absolute zero**, 0 K or $-273.15°C$, the lowest temperature achievable at which molecular motion vanishes so that a body would have zero heat energy. The *kelvin* is equal in magnitude to the degree Celsius (°C). The *kelvin temperature scale* (kelvin absolute temperature scale) is an absolute or thermodynamic temperature scale derived from the Celsius scale: $T(K) = T(°C) + 273.15$. The **Rankine absolute scale** is derived from the *Fahrenheit* scale such that $T(R) = T(°F) + 459.67$, i.e. a scale relative to 0 R or $-459.67°F$ where R is the **Rankine** degree symbol and °F is the Fahrenheit symbol.

**absolute viscosity**  See *dynamical viscosity*.

**absorber**  1. An auxiliary vibratory system that favourably modifies the vibration characteristics of a main system. *See also damper* (2). 2. Part of an absorption refrigeration system in which the refrigerant is absorbed by a transport medium. *See also vapour-absorption refrigeration cycle*. 3. The **absorber plate** is the receiver of a concentrating solar collector where the radiation is absorbed.

**absorptance**  (absorptivity, absorption coefficient, $\alpha$) The fraction of radiant flux incident on a surface that is absorbed by the surface. The term also applies to absorption of radiation by a volume of fluid. For a semi-transparent surface, $\alpha + \rho + \tau = 1$, where $\rho$ is the reflectance and $\tau$ is the transmittance.

**absorption**  The process whereby a fluid permeates a porous solid, or a gas is dissolved by a liquid. *See also adsorption*.

**absorption column**  *See packed column.*
accelerating frame of reference

absorption cycle See vapour-absorption refrigeration cycle.

absorption dynamometer A dynamometer in which input work or power is dissipated by mechanical friction, electrical resistance, hydraulic resistance, etc. See also hydraulic dynamometer, transmission dynamometer.

absorption hygrometer An instrument that determines the content of water vapour in the atmosphere by it being absorbed into a hygroscopic medium.

absorption refrigeration (absorption cycle, absorption refrigerator) See vapour-absorption refrigeration cycle.

absorption tower See packed column.

ABS polymer A class of thermoplastic co-polymer consisting of the three monomers acrylonitrile, butadiene and styrene that has improved properties (particularly toughness) over the individual constituents.

accelerated testing A type of testing, for rates of wear, fatigue, corrosion etc., in which failure times are reduced by employing greater loads, more frequent power cycling, higher vibration levels, higher humidity, higher temperatures, greater potential differences etc. than would be encountered in normal operation.

accelerating frame of reference (moving frame of reference, non-inertial frame of reference) When the frame of reference of an observer is accelerating with respect to a fixed (inertial or Newtonian) frame of reference, it appears to the moving observer that additional terms are required to satisfy Newton’s second law of motion. Where a reference frame S’ has, relative to a fixed frame S, motion of translation only, let \( a_o \) be the acceleration of S’ relative to S. If a particle has acceleration \( a \) relative to frame S and \( \dot{a}' \) relative to S’, then \( a = a_o + \dot{a}' \). In the fixed frame S, the law of motion is \( F = ma \) where \( m \) is the mass of the particle and \( F \) is the force acting on it. In S’, the law is \( ma' = F - ma_o \) and it appears that it holds in the linearly accelerating frame providing that a fictitious force \( -ma_o \) is added to \( F \). This applies for every particle of a body. Fictitious forces that bring frame S’ to rest are variously called the d’Alembert force, inertial force, effective force, or pseudo force. Where a moving frame S’ rotates with variable angular velocity \( \omega \) about an axis fixed in a fixed frame S, the acceleration \( \ddot{a} \) of a particle with respect to the fixed frame S is given by \( \ddot{a} = \ddot{a}' + \dot{a}_i + a_c \), where \( \ddot{a}' \) is the acceleration with respect to S, \( \dot{a}_i \) is called the acceleration of transport and \( a_c \) is the Coriolis acceleration, both given with respect to S’. \( \dot{a}_i = \left( \frac{d\omega}{dt} \right) \times r + \omega (\omega \times r) - \omega \omega \times r \) and \( a_c = 2\omega \times \dot{v} \) where \( \dot{r} \) is time, \( r \) is the position vector of the particle with respect to the fixed frame and \( \dot{v} \) is the velocity of the particle with respect to the moving frame. In S the force \( F \) applied to a particle of mass \( m \) is given by \( F = ma \), but to an observer moving with the particle in frame S’ \( ma' = F - ma - ma_o \) giving rise to two fictitious forces \( -ma_o \) (centrifugal force) and \( -ma \) (Coriolis force). Even when \( \omega \) is constant, frame S’ is still accelerating owing to the vector \( \omega \) of constant magnitude continuously changing direction. In this case, \( ma' = F + m\omega \omega \times \dot{v} \) and the true forces \( X \) and \( Y \) along fixed Cartesian axes, the origin of which passes through the centre of rotation, are \( X = m(x - 2\omega Y - \omega^2 x) \) and \( Y = m(y + 2\omega x - \omega^2 y) \) in which \( 2m\omega Y \) and \( -2m\omega x \) are the components of the Coriolis force, and \( m\omega^2 x \) and \( m\omega^2 y \) are the components of the centrifugal force. When the point of rotation is itself accelerating at \( a_o \) in the Newtonian frame S, \( ma' = F - ma_o - ma - ma_\omega \). The frame of reference that we employ in everyday life is the Earth, which rotates with respect to the astronomical frame with an angular velocity \( 7.29 \times 10^{-5} \) rad/s. For such slow-moving frames, the fictitious forces \( -ma_o \), \( -ma \), and \( -ma_\omega \) may not be noticeable, although they are important geographically, the
centrifugal force being responsible for the equatorial bulge on the Earth and the Coriolis force for the trade winds. Fictitious forces also become important for an aeroplane making a sharp turn or pulling out of a dive where the accelerations are of order $g$ or greater. See also angular acceleration; Poinset method; tangential acceleration.

**acceleration** (Unit m/s$^2$) The rate of change of linear velocity with respect to time. It is a vector quantity. See also angular acceleration.

**acceleration due to gravity (acceleration of free fall, gravitational acceleration, $g$)** (Unit m/s$^2$) The acceleration of a freely-falling body in a vacuum, with a mean value at sea level of approximately 9.81 m/s$^2$. See also standard acceleration due to gravity.

**acceleration-error constant** When the reference (demand) input to a control system is parabolic, the output signal will also be parabolic in steady state. The signal that is constant in this situation is the acceleration and thus for a parabolic input the steady-state error, referred to as the acceleration-error constant, is the error in the acceleration.

**acceleration of transport** See accelerating frame of reference.

**accelerator pump** A pump which injects additional fuel when the throttle is opened rapidly to maintain constant the equivalence ratio of the mixture delivered to the cylinder of a piston engine.

**accelerometer** An electro-mechanical transducer used to measure acceleration. See also piezoresistive accelerometer.

**accessible resource (technical potential)** The maximum annual energy that could be extracted from the accessible part of the available resource carried by a renewable energy resource using current mature technology.

**accommodation** The ability of a robot to respond to changes in the environment.

**accumulator** 1. A fluid-energy storage device, analogous to a capacitor in an electric circuit. See also fluid capacitor. 2. An electrical battery.

**accuracy** See error.

**acetal resins (acetals, polyacetals, polyoxymethylene, POM)** Hard, rigid, strong, tough, and resilient engineering thermoplastics. The physical properties of general-purpose copolymer grade are relative density 1.41, Young’s modulus 3.1 GPa, and tensile strength 76 MPa. The service range is $-30$ to $120°C$. They have excellent resistance to common solvents but poor resistance to strong acids and alkalis; good electrical properties; and fair resistance to UV radiation. Glass-filled grades have higher strength and stiffness. Unmodified acetal resins are translucent white but are readily coloured. Acetal resins may be processed by conventional forming techniques, including injection moulding, blow and rotational moulding, and extrusion, and machined by turning, milling, drilling, etc.

**acetylene torch** See oxy-acetylene torch.

**acfm** See actual cubic feet per minute.

**ACHE** See air-cooled heat exchanger.

**acid rain** Any form of precipitation, including rain, snow, sleet, fog, dew, and particulates, which contains higher than normal levels of sulfuric and nitric acids.
These acids result from natural and man-made emissions of sulfur dioxide and oxides of nitrogen, respectively. **Acid soot** consists of unburned carbon particles, typically larger than 10 μm, in the atmosphere contaminated with sulfuric acid. The particles result from poor combustion of fossil fuels.

**Ackerman linkage** A steering linkage on a motor vehicle that approximately gives rolling without slipping of both wheels about the turning point. This is achieved by having the inner stub axle (on the inside of the turning curve) move through a greater angle than the outer stub axle.

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**acoustic energy density (sound energy density, \( w \))** (Unit J/m³) The sum of the kinetic-energy density \( w_{\text{kin}} = \frac{1}{2} \rho u^2 \) and the compressional-energy density \( w_{\text{comp}} = \frac{1}{2} \langle p^2 \rangle / B_S \) at a point in an acoustic field, where \( \rho \) is the fluid density, \( u \) is the magnitude of the particle velocity, \( p \) is acoustic pressure, \( B_S \) is the isentropic bulk modulus of the fluid, and \( \langle \cdots \rangle \) denotes a time average. In a fluid of sound speed \( c \) we have \( B_S = \rho c^2 \).

**acoustic fatigue** See **fatigue**.

**acoustic levitation of droplets** The use of acoustic-radiation forces to suspend liquid droplets.

**acoustic power (sound power)** (Unit W) The rate of flow of acoustic energy across a specified surface.

**acoustic pyrometer** A non-intrusive pyrometer based on the principle that the sound speed in a gas is proportional to the square root of its absolute temperature.

**acoustics** The science and engineering of sound; its production, propagation, control, interaction with materials, etc.

**acoustic separation** (Unit m) The separation of particles in a fluid using standing acoustic waves, typically ultrasound, to drive them to nodal points (**acoustic particle concentration**).

**acoustic streaming** A steady fluid flow that results from a sound source or oscillating boundary.
acoustic velocity

acoustic velocity  See sound speed.

acrylics (acylate polymers, polyacrylates) A group of polymers based upon the structure of acrylic acid. Acrylic resins is a group of plastic substances (either thermoplastic or thermostetting) derived from acrylic acid, methacrylic acid, and related compounds. It includes polymethyl methacrylate and other acrylate polymers. Acrylates can be processed by moulding, extrusion, and casting into a wide variety of shapes. They can be transparent (92%; having a good resistance to shattering, a major use is as a glass substitute), translucent, or opaque. The upper service temperature is 90°C. They have good resistance to UV radiation and dilute alkalis, fair resistance to concentrated acids, but poor resistance to aromatic hydrocarbons, oils, halogens, and ketones.

acrylite  See polymethyl methacrylate.

acrylonitrile-butadiene-styrene (ABS plastic) A class of styrenic thermoplastics made from acrylonitrile, butadiene, and styrene. There are five common variants: unfilled ABS, 40% glass fibre ABS, transparent ABS, high-impact ABS, and heat-resistant ABS. Physical properties of unfilled ABS are relative density 1.1, glass transition temperature 100°C, Young’s modulus 2.0 GPa, and ultimate tensile strength 41 MPa. Service temperature range −20 to +80°C. ABS is a good electrical-insulating material, is resistant to acids, alkalis, and oils, but has moderate resistance to aliphatic hydrocarbons, and poor resistance to aromatic hydrocarbons and UV radiation. ABS can be processed by a variety of extrusion and moulding techniques, can be machined, and is plateable.

actinide  See periodic table.

actinometer An instrument that measures the intensity of radiant energy, such as a pyrheliometer or solarimeter.

action The direct application of a force. See also Newton’s laws of motion; reaction.

activation energy ($E_a, U$) (Unit kJ/mol) The minimum energy for a chemical reaction to occur or for processes such as diffusion to take place in crystals.

active accommodation The use of information from sensors, for example, in a vision system, that allows a robot to show accommodation to the environment.

active-cavity radiometer An instrument that gives an absolute reading of solar radiation. The solar beam falls on an absorbing surface, the temperature rise of which is compared with that of an identical absorber heated electrically.

active solar system (active solar-heating system, active space heating) A solar-powered heating or cooling system. For operation, it requires mechanical components, such as motors, pumps, thermosiphons, and valves.

active vibration suppression The reduction of undesirable vibration in components by feedback control.

actual cubic feet per minute (acfm) An obsolete (i.e. non-SI) measure of volumetric flow rate; the volume of a gas flowing per minute at actual operating pressure and temperature, as opposed to the corresponding volume flow rate at STP.

actual power (actual horsepower) (Unit W or hp) The power delivered at the output shaft of an engine, before subsequent transmission through a gearbox etc. See also brake power.
**actual value** The output of a plant that is being controlled, i.e. the controlled variable. Not directly accessible by the control system, as it can only be measured by a sensor which may distort the measurement.

**actuating system** A system in which an electrical, pneumatic or hydraulic input supplied to an actuator produces force, torque, or displacement, usually in a controlled way.

**adaptive branch** A robot programming instruction which can cause a branch in programme execution in response to signals from one or more sensors, and is thus used to provide accommodation to the environment.

**adaptive control function** That part of a control system which, by responding to measurement of changes in the controlled plant, adapts the parameters of the controller so as to improve the performance of the system (adaptive control).

**adaptive robot** A robot which responds to changes in the environment, i.e. a robot which shows accommodation.

**adaptive system** The ability of any engineering system to respond to changes in the environment, thus improving the performance in that environment.

**ADC** See Analogue-to-Digital Converter.

**added mass (induced mass, virtual inertia)** (Unit kg) The mass which has to be added to that of a body being accelerated through a fluid to account for the fact that some of the fluid surrounding the body is also accelerated. The calculation of added mass in general is complicated but, for a sphere in potential flow, the added mass is \( \frac{1}{2} \rho V \) where \( \rho \) is the fluid density and \( V \) is the volume of the sphere.

**addendum** In a spur gear, the radial distance between the pitch circle and the addendum circle. There are corresponding definitions for bevel gears, worm gears, and screw threads. See also dedendum; screw; toothed gearing.

**addendum angle** See toothed gearing.

**additive-layer manufacturing (additive manufacturing, ALM, AM)** A development of versatile three-dimensional printing processes employed for rapid prototyping, to manufacture actual production components from metals and plastics. Layers are generated by software that has taken a series of digital slices through a computer-aided design of the object. Adhesion between powdered layers, each 20–30 \( \mu \)m thick, is achieved by application of a liquid binder or by sintering with a laser or an electron beam. Some machines deposit filaments of molten plastic. See also subtractive manufacturing.

**adhesion** The normal or tangential grip between surfaces in contact. Adhesive strength, with unit Pa, is the normal or shear stress required to separate components bonded together by an adhesive. Adhesion work, with unit J, is the work done by forces when surfaces are separated. See also bond strength.

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**Adhesives terminology**

**adhesive (glue)** A liquid or gel that hardens and bonds together surfaces (adherends) to which it is applied.
adiabat

adiabat A curve representing the relationship between any pair of state variables at the beginning and end of an adiabatic thermodynamic process. See also SHOCK ADIABAT.

adiabatic elastic modulus See MECHANICAL HYSTERESIS.

adiabatic film-cooling effectiveness See FILM-COOLING EFFECTIVENESS.

adiabatic index See SPECIFIC HEAT.

adiabatic lapse rate ($\Gamma$) (Unit K/km) The rate of decrease of an atmospheric variable, usually air temperature $T$, with altitude $z$ assuming changes are adiabatic. For dry air, the adiabatic lapse rate is given by $\Gamma_D = -dT/dz = g/C_P$ where $g$ is the acceleration due to gravity and $C_P$ is the specific heat of air at constant pressure. With $g = 9.81$ m/s$^2$ and $C_P = 1.005$ kJ/kg.K, $\Gamma_D = 9.8$ K/km whereas the normal or environmental lapse rate is usually taken to be 6.5 K/km.

adiabatic process A thermodynamic process in which there is no heat transfer to or from the system.

adiabatic saturator A device for determining relative and specific humidity by adding water continuously to a stream of unknown humidity and measuring the temperature and pressure of the entering and exiting streams.

adiabatic wall temperature (adiabatic surface temperature, recovery temperature) (Unit K) In high-speed gas flow over an insulated surface, the temperature attained by the surface as a consequence of viscous dissipation within the boundary layer. See also RECOVERY FACTOR.

adjustable-pitch propeller See PROPELLER.

admission The instant when the inlet valve allows the working fluid to enter the cylinder of an internal-combustion engine or a steam engine. See also FULL ADMISSION; PARTIAL ADMISSION.

admission port The passage by which a working fluid enters the cylinder of an engine.

adsorption The adhesion of gas or liquid molecules or dissolved solids to a surface. Silica gel and activated charcoal (also called active carbon) are widely used adsorbers. See also ABSORPTION.

adsorption dehumidifier A dehumidifier that operates by bringing moist air into contact with the surface of a hygroscopic solid such as silica gel.

advance 1. See ANGLE OF ADVANCE. 2. See PROPELLER.

advanced ceramics Materials developed for new technologies to exploit their special electrical, magnetic, mechanical, or optical properties. Examples include alumina (Al$_2$O$_3$), aluminium nitride (AlN), boron carbide (B$_4$C), boron nitride (BN), silicon carbide (SiC), silicon nitride (Si$_3$N$_4$), and zirconia (ZrO$_2$). Applications include components and thermal barrier coatings in internal combustion and turbine engines; armoured protection for personnel and vehicles; cutting tips in machine tools; electronic and optoelectronic components; information storage devices; communication systems; and satellite and aerospace applications.

advanced gas-cooled reactor See NUCLEAR FISSION.
**advanced ignition** A phenomenon in which the spark in a spark-ignition engine ignites the fuel-air mixture close to the end of the compression stroke before the piston reaches top dead centre.

**advance ratio (advance coefficient)** See propeller.

**advection** 1. The transport of a substance or conserved property, such as enthalpy, by a fluid flow such as a boundary-layer flow. Advection differs from convection, which encompasses both advection and diffusion. In meteorology, oceanography, and river flows, advection is primarily horizontal. 2. In the finite-element method (FEM), advection is the process of mapping solution variables from an old mesh to a new mesh. In the ALE approach, advective terms appear in the conservation equations to account for independent mesh motion as well as material motion.

**adverse pressure gradient** (Unit Pa/m) In a boundary-layer, a streamwise pressure gradient that opposes the flow of a fluid, reduces the wall shear stress and leads to earlier transition to turbulence. If the gradient is severe, flow separation may occur. In the case of an aerofoil, flow separation leads to stall. See also FAVOURABLE PRESSURE GRADIENT.

**aeolian anemometer** (eolian anemometer) An instrument used to estimate flow speed $V$ based on the measurement of the frequency of vortex shedding $f$ from a cylinder of diameter $d$ in cross flow. Over a limited range of Reynolds numbers, the Strouhal number ($= fd/V$) is constant with a value of about 0.2 so that $V = 5fd$.

**aeolian tones** Sound generated by vortex shedding from a long circular cylinder of diameter $d$ in a steady crossflow with velocity $V$ and kinematic viscosity $\nu$. In the range $400 < Re < 3 \times 10^5$, where $Re = Vd/\nu$ is the Reynolds number, the frequency of vortex shedding $f$ corresponds with a constant value of the Strouhal number $St \approx 0.2$, where $St = fd/V$.

**aerated flow** A flow of a liquid in which air is either dissolved or dispersed throughout as bubbles.

**aeration** The process whereby air is mixed with a liquid or slurry. The air, usually in bubble form, may be passed through the fluid or the fluid passed through the air. Some of the air dissolves in the fluid. Among other effects are reduced density. Water treatment is a major application. Venturi tubes, spray nozzles, and compressed-air jets are all used as aerators.

**aerobic digestion** Digestion by micro-organisms, in the presence of oxygen, of matter dissolved or suspended in waste. See also ANAEROBIC DIGESTION.

**aerodynamic balance** An instrument that measures the forces and moments on a model in a wind tunnel.

**aerodynamics** The mechanics of motion of air and other gases, including the interaction of the air and solid surfaces moving relative to it.

**aerodyne** A heavier-than-air aircraft where lift is produced either by forward movement through the air or by direct engine thrust. See also AEROSTAT.

**aeroelasticity** The elastic deformation of bodies subjected to aerodynamic loads.

**aeroengine** The power unit of an aircraft, including a piston, gas turbine, turboprop, jet, or rocket engine.
**aerofoil (airfoil)** A thin structure, the shape of which gives rise to lower pressures on one surface (suction surface) compared with the other (pressure surface) when moving through a fluid. The leading edge is the front part of an aerofoil about which an oncoming flow divides, while the trailing edge is the rear edge. The camber line is a curve constructed midway between the upper and lower surfaces of an aerofoil, while the chord line (chord) is a straight line between the leading and trailing edges, the length of which is termed the chord length. The angle of attack \((\alpha)\) is the angle between the chord line and the vector direction of the relative velocity between the body and the fluid through which it is moving. Aircraft wings, propeller, turbine, and compressor blades all have aerofoil cross sections. Vertical lift (upthrust) forces are produced on the wing of an aircraft when moving through the air or vertical downforce on the spoiler (inverted aerofoil) of a road vehicle. See also SUBSONIC LEADING EDGE; SUPersonic LEADING EDGE.

**aerogenerator** Any device, such as a wind turbine, which uses wind energy to generate electricity.

**aerometer** See HYDROMETER.

**aerosol** A colloidal suspension of fine solid particles or liquid droplets in air or any other gas. In a typical aerosol generator, liquid is passed through a nozzle or sprayed on to a rapidly spinning disc.

**aerospace engineering** The design and construction of aircraft, rockets, Earth satellites, space vehicles, and their power units. It includes control, launching and guidance.

**aerostat** A lighter-than-air system for which the aerodynamic lift is provided by buoyancy. The main structural component is a bag-like envelope filled with a low-density gas, such as helium or hydrogen. Examples include airships (dirigibles), gas balloons and hot-air balloons. See also AERODYNE.

**aerostatics** The study of gases in which there is no relative motion between gas particles. For a gas at rest, it concerns the variation of pressure, density, and temperature with altitude. See also FLUID MECHANICS.

**AFM** See ATOMIC FORCE MICROSCOPE.

**A-frame** See SHEAR LEGS.

**afterburner** An extension of the exhaust of a turbofan or turbojet engine into which additional fuel is injected and burned to provide increased thrust. Primarily used on supersonic military aircraft. See also REHEAT.
aftercondenser A condenser used to condense the atmospheric stage of process fluid in a multi-stage ejector. Employed in air-conditioning and refrigeration systems and steam power plants.

afterfilter The final filter in a gas-flow system, such as in air-conditioning, ventilation, and machining processes, that removes fine (typically sub-micrometre) solid particles and liquid droplets from the flow.

after running (run on, dieseling) Continued running of an internal-combustion engine after the ignition is switched off due to continued supply of fuel.

after top dead centre The position of the piston in a reciprocating engine during downward strokes. See also top dead centre.

Ag The symbol for the uniform strain in a tension test specimen before necking or fracture. See also Rp; Rm.

age hardening (age strengthening) See precipitation hardening.

ageing (aging) Changes in microstructure, and hence physical properties, as supersaturated solid solutions formed by quenching change with time towards equilibrium phases. This phenomenon is used in the processing of precipitation-hardened alloys. See also precipitation hardening; strain ageing.

aggregative fluidization (boiling fluidization) The type of fluidization that occurs when the fluid and solids have significantly different densities, as occurs in gas/solid systems and some liquid/solid systems. Particle-free voids rise through the fluidized bed, the surface of which takes on the appearance of a boiling liquid.

agitator A device to mix fluids and suspensions or keep them in motion by stirring or shaking.

AGR See nuclear fission.

air aspirator valve See aspirated air injection.

air-atomizing oil burner A burner employing oil as a fuel that is dispersed into fine droplets by passing the fuel and compressed air through an atomizing nozzle.

air bearing See bearing.

air bleeder A valve for removing air from a hydraulic system.
**airborne waste**  Gases, particulates and vapours in the atmosphere resulting from evaporation, chemical, or combustion processes. See also pollutants; smog.

**air-bound**  Said of an air blockage in a pipe that restricts liquid flow. See also airlock (1).

**air box**  A plenum chamber with a forward-facing inlet duct connected to an internal-combustion engine that directs evenly distributed, positive-pressure air to the engine intakes. Typically used on Formula 1 cars and other high-performance motor vehicles.

**air brake**  1. A brake on a vehicle that is operated by compressed air. 2. An absorption dynamometer that dissipates power through a fan or propeller. 3. A flap on an aeroplane or racing car that increases drag to reduce speed.

**air-breathing**  An air-breathing engine is one for which air is the oxidant in the combustion process.

**air chamber**  See pulsation damper.

**air classifier (air elutriator)**  A device in which an airstream, which may be swirling, sorts particles by a combination of size, shape, and mass.

**air cleaner**  A device, such as a filter, hydrocyclone, or electrostatic precipitator, that removes particles and aerosols from a flow of air.

**air composition**  The sea-level composition (in per cent by volume) of air at a temperature of 15°C and a pressure of 1 atm is mainly 78.084% nitrogen, 20.947% oxygen and 0.934% argon. The remaining 0.035% consists of carbon dioxide, neon, helium, methane, krypton, hydrogen, oxides of nitrogen, xenon, ozone, iodine, carbon monoxide, and ammonia. Different sources give slightly different figures for the composition. Not included are water vapour (typically 0.4%) and pollutants such as sulfur dioxide.

**air compressor**  A turbomachine that draws in air and delivers it at higher pressure, temperature, and density. It can be of axial, fan, reciprocating, or rotary design.

**air conditioning**  The process of controlling the temperature and humidity in rooms, buildings, aircraft, passenger vehicles, etc. More generally it includes control of dust, levels of radiant heat, etc.

**air-cooled condenser**  A heat exchanger, in which the cooling medium is air, used to condense the exhaust steam from a steam turbine, the condensate being returned to the boiler.

**air-cooled engine**  An internal-combustion engine directly cooled by airflow, rather than by water flowing through the engine block being cooled by a radiator.

**air-cooled heat exchanger (ACHE)**  A pressure vessel in which fluid flowing through finned tubes is cooled by ambient air forced over the exterior surfaces of the tubes. Examples include the radiator of a motor vehicle, lubrication-oil coolers, and steam condensers.

**air curtain (air door)**  A stream of temperature-controlled air blown, usually downwards, across an open entrance to limit heat transfer with the environment and allow the interior space to be air conditioned.
air-cushion vehicle  A vehicle that rides over land or water on a cushion of air maintained by rotors or fans. See also HOVERCRAFT.

air cycle  See AIR-STANDARD CYCLE.

air-cycle refrigeration  See GAS REFRIGERATION CYCLE.

air ejector  A Venturi nozzle in which low pressure is created at the throat by high-speed air flow. The low pressure can be used to suck another fluid into the Venturi for transport or mixing. See also JET PUMP.

air eliminator  A device used in liquid-flow systems to remove air and other gases. An important application is to flow metering, where air or gas in the flow can lead to large errors.

air elutriator  See AIR CLASSIFIER.

air engine (air motor)  A heat engine, of either reciprocating or rotary design, for which the energy source is compressed air.

air filter  A device that reduces the concentration of solid particles in a stream of air. Applications include ventilation, engine intakes, and air-conditioning.

air–fuel mixture  The mixture of air and fuel in the combustion chamber of an engine. The mixture may be either pre-mixed or mixed in the chamber. See also STOICHIOMETRIC.

air–fuel ratio (air/fuel ratio)  The ratio of air to fuel in an air-fuel mixture. For a gaseous fuel the ratio is expressed by volume; for a solid or liquid fuel, by mass. See also STOICHIOMETRIC.

air gauge  A non-contact device that uses a stream of compressed air to measure the clearance between a precision orifice or plug and a workpiece.

air injection  See ASPRIRATED AIR INJECTION.

air-line lubricator (line oiler)  A device used to add lubricant via an air line to compressed-air-driven equipment.

airlock  1. (air pocket)  A pocket of gas trapped at a high point in a liquid-filled piping system that restricts or even prevents flow. See also AIR-BOUND; AIR-RELEASE VALVE; BLEED VALVE. 2. A chamber between two systems at different pressures, to enable movement of people between the two to take place.

air-mixing plenum  The chamber in an air conditioning system in which fresh outdoor air is mixed with recirculating air.

air motor  See AIR ENGINE.

air nozzle  A convergent nozzle with one or more exit holes through which compressed air flows at high speed and entrains a large volume of ambient air. Applications include liquid blowoff, chip removal in cutting, cleaning, cooling, and drying.

air-pollution control  The treatment of exhaust gases from piston engines, gas turbines, furnaces, boilers, etc., so as to limit the release of gaseous and particulate pollutants into the atmosphere to acceptable levels. Control devices include wet and dry scrubbers, filters, cyclones, baghouses, electrostatic precipitators, catalytic converters, adsorption systems, and exhaust-gas recycling.
air preheater  See PREHEATER.

air pump  A machine for providing a flow of air or for increasing or decreasing the mass and pressure of air in a closed container. The term pump is more usual when the working fluid is a liquid, while compressor is more usual for gases. See also VACUUM PUMP.

air purge  Removal of gas or particulate contaminants in a piping system or pressure vessel by passing clean air through it.

air receiver (receiver)  A pressure vessel in a compressed-air system which stores the air received from a compressor, condenses and traps moisture in the air, prevents short-cycle loading and unloading of the compressor, and equalizes pressure throughout the system.

air regulator  A valve that supplies air, from a compressor or pressure vessel, at constant pressure regardless of flow variation or upstream pressure. See also PRESSURE REGULATOR.

air reheater  A heat exchanger employed to reheat the working fluid from a turbine or from a compressor after drying. See also RANKINE CYCLE WITH REHEAT.

air-release valve (air valve)  1. A valve that releases air trapped at a high point in a pressurized pipeline filled with a liquid. See also AIRLOCK. 2. A valve that prevents liquid in a water-supply, wastewater, or sewage system from coming in contact with the sealing mechanism by creating an air gap.

air resistance  (Unit N) The drag force on a body moving through air, or the forces imposed on a stationary body or other structure by air flow, including wind.

air scoop  1. A cowl or duct projecting from an aircraft or motor vehicle and facing the airflow that allows ambient air direct access at increased pressure (ram effect) to the engine air intake or to create an interior flow, for example for ventilation. 2. A device inserted into a water pipeline that reduces the water speed so that any air in the flow rises above the water surface and can be removed.

airscrew  See PROPELLER.

air separator  See AIR CLASSIFIER.

airship (dirigible)  An aerostat with forward thrust provided by propellers or other engines and steered by rudders. The main types are blimps, which are large gas balloons with no internal support structure, and rigid airships, which have a full internal frame.

airspeed indicator  An instrument that displays the speed of an aircraft through the air, usually in knots, based on the output of a pitot-static tube.

air spring (pneumatic spring)  A spring whose stiffness is provided by compression of air in a cylinder or bellows.

air-standard assumptions  In an air-standard cycle: 1. The working fluid is air that circulates in a closed loop and behaves as an ideal gas; 2. All the processes that make up the cycle are reversible; 3. The combustion process is replaced by a heat-addition process from an external source; 4. The exhaust process is replaced by a heat-rejection process to an external sink that restores the working fluid to its initial state. See also COLD-AIR-STANDARD ASSUMPTIONS.
air-standard cycles (heat-engine cycles)  Thermodynamic cycles for which the air-standard assumptions are applicable. They provide simplified models of the gas processes that occur in an internal-combustion engine, and can be used to study qualitatively the influence of major parameters on the performance of an actual engine. Examples of air-standard cycles are the Otto cycle for petrol engines, the Diesel cycle, the Joule or Brayton cycle for gas-turbine engines, the Sabathé dual-combustion cycle, the Stirling cycle, and the Ericsson cycle. See also GAS CYCLE.

air-standard efficiency  The efficiency of any air-standard cycle.

air-standard engine  Any heat engine operating on an air-standard cycle.

air starting valve  A valve that admits compressed air to the cylinders of a Diesel engine for starting purposes.

air-suspension system  Suspension of a vehicle by air springs.

air thermometer  See GAS THERMOMETER.

air valve  See AIR-RELEASE VALVE.

air washer  A combined humidifier and air purifier.

Airy points  The locations along a nominally straight horizontal bar at which the bar should be supported to minimize deflexions under its own weight. For a bar of rectangular cross section and length $L$, if there are two symmetrically spaced supports, they should be separated by the distance $L/\sqrt{3}$.

Airy stress function  One of a number of stress functions by means of which elasticity problems are solved. In two dimensions, a stress function $\phi$ satisfies $\nabla^4 \phi = 0$ that is the same as the equations of equilibrium and compatibility when the normal and shear stress components are written as second partial derivatives of $\phi$. See also BIHARMONIC EQUATION.

AISI-SAE steels  Steels the compositions of which have been standardized by the American Iron and Steel Institute and the Society of Automotive Engineers. They are primarily plain-carbon and/or low- to medium-alloy steels. The AISI-SAE designation is a four-digit number system in which the first two numbers indicate the alloy content, and the last two the nominal carbon content, e.g. AISI-SAE 1060 is a plain-carbon steel containing 0.60 wt% carbon. Other numbers and/or digits are used for alloy steels, such as manganese steels (13xx); nickel steels (23xx and 25xx); and nickel-chromium steels (31xx, 32xx, 33xx, and 34xx).

albedo  A measure of how strongly an object reflects the Sun’s radiation. Defined as the ratio of total reflected to incident electromagnetic radiation.

alcohol thermometer (alcohol-in-glass thermometer)  A liquid-in-glass thermometer using ethyl alcohol as the working fluid, usually dyed red or blue.

ALE  See ARBITRARY LAGRANGIAN EULERIAN METHODOLOGY.

aliasing  The generation of spurious low-frequency signals in sampled data due to sampling at intervals longer than required by the Nyquist–Shannon sampling theorem.

aligning drift  See DRIFT.
**alignment**

The adjustment of the relative positions and orientation of one or more objects. See also **shaft alignment**.

**alkali metals** See periodic table.

**Allen® screw** A screw or bolt having a hexagonal recess in the head for tightening using an Allen® key.

**allowable load** (Unit N) The maximum load at a given location, and in a given direction, that may safely be applied to a component or structure.

**allowable stress** ($\sigma_{\text{ALLOW}}$) (Unit Pa) The maximum stress permitted at any point in a component or structure, taking into account a factor of safety, $f$. Possible choices are $\sigma_{\text{ALLOW}} = \sigma_Y/f$ and $\sigma_{\text{ALLOW}} = \sigma_{\text{UTS}}/f$ where $\sigma_Y$ is the yield stress of the material and $\sigma_{\text{UTS}}$ is its ultimate tensile strength. See also **fatigue**.

**allowance** An intentional difference in sizes of mating components, prescribed to give different grades of fit. See also **tolerances**.

**alloy** 1. A metallic material composed of two or more elements, one of which is usually a metal to which the other elements are added, e.g. iron-carbon or aluminium-copper (binary alloy); nickel-chromium-iron (ternary alloy). 2. A plastic produced as a blend of two or more immiscible polymers. This results in material that cannot be achieved by polymerization.

**alloy components** See microconstituent.

**alloy steels** Steels that contain alloying elements such as chromium, nickel, molybdenum, manganese, silicon, tungsten, and vanadium. These are added to improve properties such as the hardenability, toughness, strength, wear resistance, and corrosion resistance compared with those of plain-carbon steel. Low-alloy steels have a total alloy content (including carbon) of less than about 8%. They are hardenable and have strength up to 30% higher than plain-carbon steels. High-alloy steels contain considerably more alloy content and are developed for specific properties such as superior corrosion and chemical resistance. See also **steel microstructures**; **stainless steels**.

**all-translational system** A robot with no rotational joints such that the movement of each joint is along a straight-line path.

**ALM** See additive-layer manufacturing.

**alpha phase** See steel microstructures.

**alpha-type Stirling engine** See Stirling engine.

**alternating stress** (Unit Pa) Originally, stresses of changing sign (tension-to-compression-to-tension, etc.) in a component produced by alternating forces acting in opposite directions, but now generally used to describe stresses that vary but may keep the same sign, as produced by periodic, out-of-balance, or vibrational loads. See also **fatigue**.
alternative energy (alternate energy)  Energy sources that are renewable and do not have the undesired consequences of fossil fuels and nuclear energy. See also RENEWABLE ENERGY.

alternative-fuel engine  An internal-combustion engine that can operate either as a Diesel engine using diesel fuel or as a gas engine using gaseous fuel. See also DUAL-FUEL ENGINE.

alternator  A relatively small electrical generator, usually driven by an internal-combustion engine to operate its ignition and charge the battery.

altitude  (Unit m) Vertical height measured relative to a specified datum such as sea level.

altitude chamber (hypobaric chamber)  A chamber in which conditions at different altitudes are simulated by a combination of appropriate pressures, temperatures and relative humidity. See also HYPERBARIC CHAMBER.

AM  See ADDITIVE-LAYER MANUFACTURING.

Amagat’s law (Amagat’s law of additive volumes, Leduc’s law)  The volume $V$ of a mixture of ideal gases is equal to the sum of the volumes (partial volumes, also termed component volumes) each gas would occupy if it existed alone at the same temperature and pressure. If $V_i$ is the volume a component would occupy if it existed alone at the temperature and pressure of the mixture, the ratio $V_i/V$ is termed the volume fraction. See also DALTON’S LAW.

ambient conditions  The thermodynamic properties, including pressure, temperature, and humidity, of the environment surrounding a body or system.

American valve  See SCHRADE VALVE.

ammonia absorption refrigerator  See VAPOUR-ABSORPTION REFRIGERATION CYCLE.

Amontons friction (Coulomb friction)  Friction between surfaces where the ratio of the frictional force $F$ to the normal force $N$ is constant and independent of the area in contact. See also ANGLE OF FRICTION; COEFFICIENT OF FRICTION.

amorphous metals (metallic glasses)  Non-crystalline alloys prepared under non-equilibrium processing conditions by methods such as rapid solidification (cooling rate typically faster than 10^6 °C/s), vapour deposition, electrodeposition, or mechanical alloying. They lack long-range crystallographic order and have many properties not found in crystalline counterparts of the same composition. Lacking dislocations (crystal defects), they have high strength and resilience, but low ductility. Applications range from soft magnets to wear- and corrosion-resistant coatings.

amplifier  A device by which the output of a hydraulic, pneumatic, or electrical source is increased. See also ATTENUATION; GAIN.

amplitude  For a sinusoidal signal, the amplitude is the peak value. More generally, the peak-to-peak amplitude may be defined as the difference between the highest and lowest values of a periodically-varying quantity. An alternative is the root-mean square (RMS) amplitude, which is the square root of the time average of the squared signal.

amplitude-decay coefficient  See DAMPING CONSTANT.
anaerobic digestion A process whereby organic waste is broken down by naturally-occurring bacteria in a controlled, oxygen-free environment to produce biogas. See also AEROBIC DIGESTION.

analogue readout A display on a meter or other measuring device where the reading is taken from a pointer on a scale, rather than being shown in digital form.

analogue-to-digital converter (ADC) A device which converts a continuous quantity to a sampled digital representation of that quantity.

anechoic chamber A room having all surfaces covered with sound-absorbing material, often in the form of wedges pointing into the room. The aim is to simulate echo-free acoustic conditions.

anelastic Literally ‘not elastic’, but in practice used for materials that display time-dependent recovery on unloading. See also INELASTIC.

anemometer (velocimeter) Any instrument that measures speed, and in some cases also direction, usually of a fluid flow but also applicable to surface movement. See also LASER-DOPPLER ANEMOMETER; LASER 2-FOCUS ANEMOMETER; PARTICLE-IMAGE VELOCIMETER.

aneroid Liquid free.

aneroid barometer An instrument that measures and records changes in atmospheric pressure using the expansion and contraction of a sealed bellows vacuum unit that is kept open by an internal spring.

aneroid calorimeter A calorimeter that uses a metal of high thermal conductivity such as silver, rather than stirred water, to absorb the heat released by a chemical reaction within the calorimeter.

angle factor See view factor

angle of advance (Unit °) 1. For a propeller, the angle between the relative velocity of the airstream and the plane of the propeller. The relative velocity is the vector sum of the free-stream velocity (in flight, the aircraft speed) and the propeller rotational velocity. 2. See ignition system.

angle of approach (arc of approach) See toothed gearing.

angle of attack (α) (Unit °) The angle between a reference line on a lifting body and the vector direction of the relative velocity between the body and the fluid through which it is moving. In the case of an aerofoil, turbine, or compressor blade, the usual reference line is the chord line.

angle of contact (Unit °) The angle subtended at the centre of a pulley or sprocket wheel by the circumferential contact of a belt or chain.

angle of friction (friction angle, β) (Unit °) For a body in contact with a plane surface, the angle between the normal to the surface and the resultant force between the body and the surface. If the friction force is \( F \) and normal force is \( N \), \( β \) is given by \( F/N = \mu = \tan β \) where \( \mu \) is the coefficient of friction. See also AMONTONS FRICTION.

angle of inclination See screw.

angle of obliquity (angle of pressure) See toothed gearing.
angle of recess (arc of recess) See toothed gearing.

angle of torsion (angle of twist) (Unit ° or rad) The angle relative to a chosen section, normal to the axis of twist, through which another part of a component rotates when subjected to a torque.

angle-ply laminate A fibre-reinforced composite structure made up of anisotropic layers, usually with as many orientated one way with respect to a reference axis as to the other in order to produce more uniform in-plane properties.

ångström (Å) An obsolete (non-SI) unit of length, sometimes still employed for atomic and crystallographic measurements. The conversion to SI is 1 Å = 10⁻¹⁰ m.

angular acceleration (Unit rad/s²) A vector quantity equal to the rate of change of angular velocity of a rotating body with respect to time. See also ACCELERATION; INSTANTANEOUS CENTRE; TANGENTIAL ACCELERATION.

angular accelerometer An instrument that measures angular acceleration.

angular-contact bearing See bearing.

angular displacement (Unit ° or rad) For a rotating body, the angle through which a point on the body has rotated about the axis of rotation in a given time.

angular distortion (Unit ° or rad) Longitudinal warping in the torsion of a non-circular section.

angular frequency (circular frequency, ω) (Unit rad/s) The rate of change of phase in a sinusoid, i.e. ω = 2πf, where f is the frequency.

angular gear See toothed gearing.

angular impulse (Unit N.m.s) The integral with respect to time of a torque applied to a body. If the body is free to rotate, the angular impulse is equal to the change in angular momentum of the body.

angular momentum (moment of momentum) (Unit N.m.s) A vector quantity. For a rigid body rotating about an axis of symmetry with angular velocity ω, the angular momentum is equal to the product of ω and the moment of inertia about the same axis.

angular pitch See toothed gearing.

angular velocity (tangential velocity, ω, Ω) (Unit rad/s) For an object moving along a curved path, the rate of change with respect to time of angular displacement. In terms of tangential velocity \( V_θ \), \( \omega = V_θ/r \) where \( r \) is the local radius of curvature of the path. See also RPM.

anion See INTERATOMIC BONDING.

anisotropy The characteristic of being directionally dependent, which can apply to physical properties of fluids and solids, such as thermal conductivity, elastic moduli, and yield strengths, as well as to flow properties such as turbulence intensities. See also HOMOGENEOUS.

annealing 1. In metal alloys, the process of restoring ductility and lowering the strength of cold-worked components, by heating above the recrystallization temperature
annular flow

and cooling slowly. 2. With glasses, heating to some 400°C in order to relieve residual stresses imparted by working. The corresponding metallurgical term is stress relieving. See also LEHR.

annular flow (annular-flow regime) A gas–liquid or vapour–liquid pipe flow in which the dispersed gas or vapour phase occupies the central part of the cross section while the liquid forms a layer on the pipe wall. See also BOILING; BUBBLY FLOW; SLUG FLOW.

annular gear See TOOTHED GEARING.

annular nozzle A nozzle consisting of a circular centrebody and a concentric outer tube. If the annular cross section first decreases, then increases, the nozzle is said to be convergent–divergent.

annulus The space between two circles or circular cylinders, which may be concentric or eccentric.

anodize (anodizing) See CORROSION.

anomalous expansion A decrease in the volume of a fixed mass of material resulting from an increase in temperature, such as the behaviour of water between 0 and 4°C.

ANSI The acronym for American National Standards Institute.

anthropomorphic configuration See ARTICULATED ROBOT.

anti-backlash gear A gear arrangement in which backlash is reduced or eliminated. The diagram shows a double (split) gear, one part of which is spring-loaded against the other that is fixed to the same shaft, which eliminates backlash when engaged to a gear wheel or rack. Two nuts, keyed together but spring loaded apart (a split-and-sprung nut) perform the same function for the lead screw on a lathe.

antiferromagnetism See MAGNETIC MATERIALS.
anti-freeze A substance such as ethylene glycol added to the cooling system of a water-cooled engine to lower the freezing point of the cooling water and also inhibit the formation of rust and other deposits.

antifriction bearing (antifriction material) See bearing.

anti-knock index (anti-knock rating) A measure of a fuel’s ability to resist spontaneous ignition in an internal-combustion engine. See also octane rating; engine knock.

anti-lock braking system (ABS) Sensor-controlled brakes on a motor vehicle that prevent wheel lockup when braking. See also traction-control system.

antinode In a system of stationary waves, a location where the displacement is a maximum. See also node.

antiphase Where the phase difference between two sinusoidal signals at the same frequency is $\pi$ (i.e. 180°). See also sine wave.

anti-roll bar A device that reduces the outwards roll of the body of a motor vehicle when turning a corner.

anti-torque rotor See tail rotor.

anti-vibration mounting A device to reduce or isolate the transmission of vibrations. See also damper.

aperiodic An oscillation which has non-periodic or non-repeating cycles in either time or space.

apparent expansion The expansion of a liquid when the expansion of the container in which it is held is not accounted for. See also absolute expansion.

apparent force See accelerating frame of reference.

apparent motion See relative motion.

apparent slip In near-wall flow of a multiphase fluid such as a suspension, apparent departure from the no-slip boundary condition. Attributed in slurry flow to depletion of solid particles (the disperse phase) in the near-wall region (typically 0.1 to 10 μm thick) leaving low-viscosity liquid which appears to act as a lubricant. In microchannel flow the phenomenon is attributed to a near-wall hydrophobic layer. See also no-slip condition.

apparent viscosity See non-Newtonian fluid.

apparent weight (apparent immersed weight) (Unit N) The difference between the actual weight of a body submerged in a fluid and the upthrust (buoyancy force) which it experiences. See also Archimedes principle.

applied mechanics (engineering mechanics, mechanics) The application of physical principles to practical problems, including the response of components, materials and structures to applied forces. The field is traditionally divided into statics and dynamics but may also include fluid mechanics. Statics is concerned with the analysis of the forces and moments on a body, structure or physical system in static equilibrium. Kinematics is the aspect of dynamics concerned with the displacements, velocities (velocity analysis) and accelerations of a mechanism or system without
regard to the forces required for the motion. **Kinetics** is the aspect of dynamics that relates the unbalanced forces applied to particles, bodies and systems to the resulting velocities and accelerations through Newton’s second law of motion, **rigid-body dynamics** being the study of the forces and couples required to produce motions of a rigid body. The assumption that a body is rigid (i.e. undeformable) simplifies dynamic analyses, but consideration of elastic and plastic deformations is often necessary to obtain physically realistic solutions.

**applied thermodynamics** (engineering thermodynamics, thermodynamics)
The science of the relationship between heat, work and the properties of systems and the ways in which heat energy from fuels can be converted into mechanical work. It involves the study of all aspects of energy use and energy transformation, including power generation, refrigeration, the relevant properties of the substances involved and the relationships between them. The principle of conservation of energy is a fundamental law of nature. In thermodynamics it is expressed as the first law of thermodynamics: in any process or interaction, energy can change from one form to another, such as thermal energy into mechanical energy, but the total amount of energy remains constant. The second law of thermodynamics is more concerned with the quality of energy, with all physically realistic processes occurring in the direction of decreasing energy quality.

Although the properties of any substance depend on the behaviour of its molecules, for the purposes of engineering a macroscopic approach is usually adequate. It is usual, therefore, to consider the behaviour of matter contained within a region of space termed a system, which may be closed, with energy but no material crossing its boundary, or open (a control volume), through which there is flow of material and energy. Any characteristic of a system is called a property. Intensive properties, such as pressure, density and temperature, are independent of the size of the system concerned in contrast to extensive properties, such as mass, volume and total energy.

Thermodynamics is concerned with equilibrium states. A system is in thermal equilibrium if the temperature is the same throughout. A system is in mechanical equilibrium if there is no change in pressure with time, although the pressure may vary from point to point. If a system involves two or more phases, it is in phase equilibrium when the mass of each phase is at an equilibrium level. A system in which no chemical reactions occur is in chemical equilibrium. Any change of a system from one equilibrium state to another is called a process, and it is usually the case that processes proceed sufficiently slowly that the system is practically in equilibrium at all times (a quasi-equilibrium process). Engineering thermodynamics is concerned with the quasi-equilibrium processes that occur in such devices as internal-combustion engines, steam and gas turbines, rocket engines, refrigerators, pumps, heat exchangers, and cooling towers. **See also** HEAT TRANSFER.

**CODATA key values for thermodynamics**

**approach vector** In the kinematic analysis of robots, a $4 \times 4$ matrix is obtained representing the position and direction of the end effector. The third column of this is the approach vector $\mathbf{A}$, a unit vector running in the direction that the end effector approaches the task. For example, where the end effector is a gripper, as shown in the diagram, the approach vector is parallel to the gripper fingers. **See also** NORMAL VECTOR; ORIENTATION VECTOR.

**APU** See auxiliary power unit.
Araldite  See EPoxy.

aramid fibre  A strong, heat-resistant fibre prepared from a long-chain synthetic aromatic polyamide. It is marketed under such tradenames as kevlar, which is used to make body armour fabric, and nomex, for flame-resistant clothing (melting point > 500°C). The fibres have an ultimate tensile strength of about 3.5 GPa. It has good resistance to organic solvents, poor resistance to acids, salts, and UV radiation, and good electrical-insulating properties. See also NYLONS.

Arbitrary Lagrangian Eulerian methodology (ALE)  An FEM modelling procedure that reduces to Lagrangian form on free boundaries, while maintaining Eulerian form at locations where significant deformation occurs, thus avoiding the need for re-meshing.

arbor  A spindle of a milling machine used to hold a revolving cutting tool or, sometimes, the workpiece. See also quill.

Archimedean spiral  See spiral.

Archimedes number (Ar, Best number, Galileo number)  A non-dimensional parameter that arises in the study of the motion of a solid object and a fluid where the density difference between the two is important, as in a fluidized bed. It is defined by $Ar = \frac{\rho_f g L^2 (\rho_s - \rho_f)}{\mu^2}$ where $\rho_f$ is the fluid density and $\mu$ is its viscosity, $\rho_s$ is the solid density, $L$ is a characteristic length of the solid object and $g$ is the acceleration due to gravity. The factor $3/4$ sometimes appears on the right-hand side of the definition.

Archimedes principle  A body, wholly or partly immersed in a fluid, experiences an upthrust (the buoyancy force or apparent loss of weight) equal to the weight of the fluid displaced. The buoyancy force acts vertically upwards through the centroid of the submerged volume.

Archimedes screw  A machine which comprises a rotating helical blade inside a close-fitting tube, which may be used to pump liquids, slurries (such as sewage), granular materials, etc. If water flows into the top of an inclined or vertical Archimedes screw, the screw will rotate and can be used to drive an electrical generator.
Archimedes Wave Swing

Archimedes Wave Swing A machine for tidal-power energy generation consisting of two concentric, air-filled submerged cylinders. The inner lower cylinder is tethered to the ocean floor while the upper floater unit, which is closed at the top, moves up and down due to the variations in hydrostatic pressure caused by the wave motion. The relative movement of the two cylinders is used to generate electricity in which linear motion replaces the more common rotary motion of an electromagnetic generator.

arc of approach See toothed gearing.

arc of contact (arc of action) See toothed gearing.

arc spraying A high-productivity thermal-spraying process in which a material is melted by a DC electric arc struck between two consumable wire electrodes and propelled by a gas jet on to a substrate to form a coating. See also flame spraying; plasma.

arc welding See welding.

arm The part of a robot that carries the wrist and end effector and is used to make large movements of the robot.

Armco iron Iron that is almost pure ferrite (less than 0.03% carbon).

arm solution See inverse kinematics.

Arrhenius equation An empirical relation that represents the dependence of the rate constant $k$ of a chemical or physical reaction on the absolute temperature $T$ according to $k = A \exp(-E_a/RT)$ where the pre-exponential factor $A$ is a constant, $E_a$ is the activation energy (in J/mol), and $R$ is the universal gas constant (value 8.314 626 71 J/mol.K). When the reaction is quantified at the atomic or molecular scale, it is usually more convenient to express the right-hand side of the equation as $A \exp(-E_a/k_BT)$ with $E_a$ in eV. The Boltzmann constant $k_B = R/N_A$, where $N_A$ is the Avogadro constant (6.022 140 76 \times 10^{23} /mol), can be regarded as the gas constant per atom or molecule (8.617 330 3 \times 10^{-5} eV/K = 1.380 649 \times 10^{-23} J/K). Minor adjustments to the values of the Avogadro and Boltzmann constants were made effective on 20 May 2019.

articulated blade A helicopter rotor blade that can move in three ways as the rotor turns: vertically up and down (flapping), back and forth in the horizontal plane and tilt or feather (change pitch angle).

articulated robot (revolute configuration robot) A robot having a rotational waist joint, joint angle $\theta_1$, with a vertical axis; a rotational shoulder joint, joint angle $\theta_2$, with a horizontal axis; and a rotational elbow joint, joint angle $\theta_3$, also with a horizontal axis. This configuration is termed anthropomorphic, as it emulates that of the human body. The diagram shows an idealized articulated robot.

articulated vehicle A motor vehicle, such as a lorry, bus, tram, or train, which has one or more vertical pivots to allow one part to turn relative to another, such as the cab of a lorry relative to its trailer.

articulation The joints and links of a robot, hence a description of the articulation of a robot gives a description of its configuration.
**aspect ratio** The ratio of the longest to the shortest dimension of a shape or object e.g. the chord-to-thickness ratio of an aerofoil or the span-to-chord ratio of a wing.

**aspirated air injection (air injection, secondary air injection)** An emissions-control technique involving the injection of fresh air into the exhaust gases from an internal-combustion engine using the sub-atmospheric pressure between exhaust-pressure pulses to draw the air through a one-way aspirator valve. The air oxidizes unburned hydrocarbons and carbon monoxide in the exhaust gas.

**aspirator (eductor jet pump, jet pump)** Any device that produces a partial vacuum using the Venturi effect. See also FILTER PUMP; JET PUMP.

**assembly drawing** An engineering drawing that shows how parts are assembled to produce a component or a complete machine. It may include sections to show internal features, dimensions that are critical for assembly, manufacturing information, and part numbers.

**assembly line** A system of mass production in which work is moved progressively from one operation to another, ultimately to give the final complete product.

**asymmetric rotor** A rotor for which the axis of rotation is not coincident with the centroid of its cross section.

**asymptotic approximation** In Bode plotting, the approximation of the gain and phase plots as straight lines derived from the poles and zeros of the transfer function by making the substitution \( s = i\omega \), where \( s \) is the Laplace transform variable, \( i = \sqrt{-1} \) and \( \omega \) is the angular frequency.

**asynchronous control** In a control system, a method of control where the time allocated to a particular activity is not fixed in advance but depends on the actual time taken. For example, a CNC machine tool operates asynchronously because each step in the control programme is taken after the previous step is completed rather than after a fixed time.

**at** See TECHNICAL ATMOSPHERE.
Atan2  The two-argument inverse tangent function used in robot inverse kinematic analysis. By using two arguments corresponding to \( x \) and \( y \) coordinates, the function determines the angle \( \theta \) within the range \( -\pi \leq \theta \leq \pi \) from the tangent. This is unlike the standard inverse tangent function, which can only determine angles in the range \( -\pi/2 \leq \theta \leq \pi/2 \).

athodyd  See pulse-jet engine.

Atkins number (At)  The non-dimensional number required to satisfy the same scaling law for inertia forces and cracking forces when modelling ice forces on structures or on vessels in ice-covered towing tanks. \( At = V^2/\rho a/K_C \) where \( V \) is velocity, \( \rho \) is ice density, \( a \) is a characteristic length of crack, and \( K_C \) is the critical stress intensity for fracture of the ice. It is \( K_C \) in model and prototype ice that should be scaled, not ice ‘strength’. \( At \) is a generalization of the Cauchy number \( C_n \) to include cracks in a continuum since \( At = C_n^2 \sqrt{Ea/R} \) where \( E \) is Young’s modulus and \( R \) is the fracture toughness of ice.

Atkinson cycle  An air-standard thermodynamic cycle for an internal combustion engine, theoretically more efficient than the Otto cycle, in which the expansion ratio \( v_6/v_3 \) exceeds the compression ratio \( v_1/v_3 \). As shown on the diagram of pressure (\( p \)) vs specific volume (\( v \)), it consists of six internally reversible processes: isentropic compression (1-2), isopycnic heat addition (2-3), isobaric heating (3-4), isentropic expansion (4-5), isopycnic heat rejection and isobaric cooling (6-1). This is an overexpanded cycle in which the gas in the cylinder is expanded to the exhaust pressure \( p_5 \). A number of hybrid vehicles use an Atkinson-cycle engine combined with an electric motor.

atm  See atmosphere (1).

atmometer (atmidometer, evaporimeter)  An instrument that measures the rate of evaporation of water from a surface into the atmosphere.

atmosphere  1. (atm) An obsolete (non-SI) unit of pressure equal to 101 325 Pa or 1.013 25 bar and approximately equal to the atmospheric pressure (barometric pressure) measured at mean sea level. See also bar. 2. See standard atmosphere.
**atmospheric pollution**  See pollutants.

**atom**  The smallest unit of matter that has the properties of a chemical element. The simplest description of an atom (Bohr model) is of a compact nucleus surrounded by one or more orbiting electrons. From the separation of nuclei of adjacent atoms in solids, the atomic radius of most elements is estimated to lie in the range from 0.1 to 0.2 nm. The nucleus is more than 10,000 times smaller but provides more than 99.9% of the mass of an atom. The nucleus consists of one or more protons and typically a similar number of neutrons. An electron has a negative electric charge \((1.602 \times 10^{-19} \text{ C})\), a proton has a positive electric charge of the same magnitude, and a neutron has no electric charge. An atom with a different number of electrons and protons has an overall charge and is called an ion.

The chemical element an atom belongs to is defined by the number of protons in the nucleus (the atomic number). The number of neutrons in atoms of the same element is variable and characterizes the isotopes of the element.

The atomic weight (relative atomic mass) of an element is the weighted average of the atomic mass of its naturally occurring isotopes, expressed in terms of either the unified atomic mass unit \((u, \text{ Unit dalton, Da})\) or the mass per mole of atoms. One unified atomic mass unit is defined as one twelfth of the mass of an atom of C\(^{12}\), the most common isotope of carbon, and has a value of \(1.660 539 040 \times 10^{-27} \text{ kg}\). One mole (mol) is the amount of an element in grams numerically equal to its atomic weight or the amount of a compound in grams numerically equal to its molecular weight (relative molecular mass), which is the sum of the atomic weights of atoms in a molecule. For example, the atomic weight of carbon (C) is 12.01 u or 12.01 kg/kmol. The atomic weights (with unit omitted) of some other common elements are: hydrogen (H), 1.01; oxygen (O), 16.00; aluminium (Al), 26.98; iron (Fe), 55.85; nickel (Ni), 58.69; tungsten (W), 183.84. The molecular weights of some molecules are: water (H\(_2\)O), 18.02; methane (CH\(_4\)), 16.04; butane (C\(_4\)H\(_{10}\)), 58.12. Polymers with long molecular chains can have molecular weights ranging from thousands to millions. See also interatomic bonding; kilomole; periodic table.

[WEB LINKS]
- Values of frequently used constants

**atomic force microscope (AFM)**  A device for inspecting surfaces at the nano-level, in which a sharp tip mounted on a cantilever is raster-scanned over an area of a sample. Close-range attractive forces between tip and surface deflect the cantilever, monitoring of which enables an image of the surface to be generated.

**atomic number**  See atom.

**atomic weight**  See atom.

**atomization**  The production of a spray of fine droplets from a liquid, such as diesel oil or petrol, by injection through a nozzle (an atomizer).

**atomizing humidifier**  A humidifier that functions by spraying fine droplets of water into an airstream.

**atom percent (at%)**  See composition.

**atom probe tomography (atom probe microscopy)**  A technique to investigate the distribution of individual atoms of different elements in alloys and other materials. Magnification is achieved by highly curved electric fields. Samples in the form of sharp
needles are cooled to cryogenic temperature in a vacuum. Ionized atoms are ejected by field evaporation and attracted to detectors. Their time of flight allows their mass-to-charge ratio, and hence their identity, to be determined. Three-dimensional images of samples are created by computational methods. Material volumes of up to one billion atoms can be reconstructed.

**attemperation of steam** See steam desuperheating.

**attenuation** The reduction of the amplitude and power of a signal or vibration. See also amplifier.

**attenuator wave-energy device** A wave-energy converter in which the principal axis is perpendicular to the incident wave fronts.

**attraction gripper** A robot end effector that picks up components using an attractive force such as magnetism or suction.

**Atwood number (A)** A non-dimensional number that arises in situations where a layer of fluid of high density \( \rho_H \) lies above one of lower density \( \rho_L \). It is defined by
\[
A = \frac{\rho_H - \rho_L}{\rho_H + \rho_L}
\]
The configuration leads to the Rayleigh–Taylor instability.

**auger** See screw conveyor.

**ausforming** A thermomechanical treatment that produces cold-worked tempered-martensite microstructures in certain alloy steels that have extremely high strengths (of order 2.5 GPa UTS).

**austempered steels** Medium to high carbon steels with improved mechanical properties as a result of austempering. After heating to between 800° and 900°C to form the austenite phase, they are quenched to, and held at, just above the martensite transformation range (between 260° and 370°C) to form bainite, before cooling further. Austempering of ductile cast irons results in a microstructure of bainite and spheroidal graphite. Austempered ductile irons have excellent toughness and wear properties. See also steel microstructures.

**austenite phase** See steel microstructures.

**autoadaptivity** The ability of a robot to respond to signals from one or more sensors and thus accommodate to changes in the environment.

**autoclave 1.** An oven containing gas (nitrogen, air, or carbon dioxide) at high temperature and pressure used in the bonding and curing of composite materials. 2. An oven containing water vapour at high temperature (> 120°C) and pressure used for sterilization of medical equipment, glassware, waste, etc.

**autoclave curing** A means of producing fully-cured adhesives, polymers, composites, etc., in an autoclave.

**autofrettage** The shrinking of one thick-walled cylinder on to another so as to make more efficient use of material by inducing residual stresses that, when the component (a pressure vessel, large gun barrel, etc.) is under pressure, working stresses are distributed more evenly throughout.

**autogyro (gyrocopter, gyroplane, rotaplane)** A type of rotorcraft with an unpowered rotor in autorotation to develop lift, and an engine-powered propeller, usually in the pusher configuration, to provide thrust.
**autoignition** Premature ignition of the fuel in the combustion chamber of an internal-combustion engine in the absence of an external ignition source. It produces an audible noise called knock.

**autoignition temperature** The lowest temperature at which a substance will spontaneously ignite in air in the absence of a spark or flame. See also FLASH POINT.

**automatic control (automatic regulation)** The control of a plant using a control system.

**automatic-control block diagram** See BLOCK DIAGRAM (2).

**automatic-control error coefficient** See ERROR CONSTANT.

**automatic-control frequency response** See FREQUENCY RESPONSE.

**automatic controller** See CONTROL SYSTEM.

**automatic-control servo valve** See SERVOMECHANISM.

**automatic-control stability** See STABILITY.

**automatic-control system** See CONTROL SYSTEM.

**automatic-control transient analysis** See TRANSIENT.

**automatic indexing** In robotics, the process of automatically determining the position and orientation of a component with respect to the robot base frame, so as to allow the component to be picked up or otherwise processed.

**automatic regulation** See AUTOMATIC CONTROL.

**automation** Mechanisms and systems that reduce or eliminate human labour; often applied specifically to manufacture and inspection on production lines.

**automechanism** A mechanical system or component that operates automatically, usually when a predetermined condition occurs: for example, a pump and a float switch that operates when a liquid rises above a pre-determined level.

**autonomous energy system (stand-alone energy system)** A sole source of electricity, usually small-scale for applications remote from a grid, especially with energy storage in the system. Hydroelectric, photovoltaic, wind-power and other renewable systems are well suited to stand-alone applications.

**autonomous robot** A robot which can, by sensing information about its environment, work for a prolonged period of time, learn and adapt without human or other external intervention. For example, the NASA Mars Rover robot senses the surrounding terrain and can thus avoid such hazards as collision with boulders or falling over cliffs.

**autorotation** Rotation of a body caused by aerodynamic forces. In the operation of a helicopter, if there is no drive to the main rotor but it is free to rotate, autorotation is the state of flight where the rotor is turned by the action of air moving up through it and creating lift. An autogyro relies on autorotation to generate lift as the main rotor is unpowered. For fixed-wing aircraft, if the angle of attack exceeds the stalling angle, the situation is unstable and autorotation results in the aircraft spinning. Windmills and ram-air turbines also function on the basis of autorotation.
auxetic materials  Those man-made materials for which Poisson’s ratio is negative, so that the cross section expands when subjected to a longitudinal tensile stress and contracts when subjected to a longitudinal compressive stress.

auxiliary power unit (APU)  In aircraft–gas–turbine applications, a small gas turbine used to provide start-up power, electrical and hydraulic power, and compressed air for cabin ventilation. In other applications, an APU may be a gas turbine or internal-combustion engine used to provide emergency power.

auxiliary rotor  See anti-torque rotor.

availability  1. (available energy)  See exergy.  2. The fraction of time for which a wind turbine is available to generate electrical power when the wind is blowing within its operating range.

available draught  (Unit Pa)  The reduced pressure of combustion gases in a furnace or boiler, either forced or due to the buoyancy of hot gases, which is used to draw in combustion air and remove products of combustion. See also draught; forced draught; balanced draught.

available head  (Unit m)  In a hydroelectric power system, the difference between the vertical height of the water level in the supply reservoir above the turbine inlet less the head loss due to friction and fittings in the duct leading to the turbine.

available resource (total resource)  (Unit J)  The total annual energy theoretically available from a renewable-energy source, such as ocean waves, the wind, or the total incident solar energy. See also accessible resource.

average mechanical pressure  See mechanical pressure.

average velocity  See bulk velocity.

averaging  In instrumentation and control, improving the signal-to-noise ratio of the output of a sensor by taking a time average of a number of readings.

averaging Pitot tube  A cylindrical flow sensor which is installed spanwise across a pipe or duct in which there is flow. A number (typically 6) of upstream-facing holes in the cylinder communicate with an internal chamber to provide an average stagnation pressure which is sensed by one side of a differential pressure transducer. A single downstream hole is connected to the other side of the transducer to give an approximation to the static pressure. When calibrated, the difference between the pressures can be used to provide a measure of the flow rate through the duct. See also Pitot tube.

aviation fuel  For gas–turbine engines, either unleaded kerosene (Jet A-1) or a naphtha–kerosene blend (Jet B) with higher calorific value (HCV), about 43 200 kJ/kg. For piston engines, a high-octane fuel called Avgas with HCV about 44 700 kJ/kg. See also calorific value of a fuel.

avionics  Aviation electronics.

Avogadro constant (Avogadro number, \(N_a\))  A fundamental physical constant with the fixed numerical value  6.022 140 76 × 10^{23} \text{mol}^{-1} . The mole contains exactly this number of elementary entities. A minor adjustment to the value of the Avogadro constant was made effective on 20 May 2019. See also atom.
**Avogadro’s law (Avogadro’s hypothesis)** Equal volumes of perfect gases, at the same temperature and pressure, contain the same number of molecules. The number of molecules $n$ contained in volume $V$ of a perfect gas at absolute pressure $p$ and absolute temperature $T$ is given by $n = N_A p V / RT$ where $N_A$ is the Avogadro number and $R$ is the universal gas constant. The law is approximately valid for real gases.

**avoirdupois weight** Obsolete (non-SI) imperial units of weight based on the pound (lb) including the imperial long ton (2,240 lb), the US short ton (2,000 lb) and the ounce (1/16th lb).

**axial engine** See swashplate.

**axial fan** (axial-flow fan) A fan with blades that cause a gas, usually air, to flow primarily coaxial with the shaft around which the blades rotate.

**axial-flow compressor** A compressor with aerofoil-shaped rotor and stator blades which cause the working fluid to flow primarily coaxial with the axis of rotation. See also compressor blades.

**axial-flow meter** See turbine flow meter.

**axial-flow pump** A pump in which an impeller causes a liquid to flow primarily coaxial with the pump shaft.

**axial hydraulic thrust** (Unit N) An unbalanced axial force caused mainly by the differences in pressure between the suction side and the discharge side of a pump impeller.

**axial interference factor** The ratio of the undisturbed relative airspeed ahead of a propeller or wind-turbine rotor to the relative airspeed behind the propeller or rotor.

**axial load** (Unit N) In general, a tensile or compressive load directed along the axis of a component. Strictly the load should pass through the centroid of the cross section to avoid inducing bending moments and be perpendicular to the plane of the section.

**axial modulus** See Young’s modulus.

**axial moment of inertia** See polar second moment of area.

**axial pitch** (Unit m) The pitch of a screw or gear measured along its axis. See also screw; toothed gearing.

**axial plane** A plane containing an axis of symmetry.

**axial section** A plane containing the axis of a gear, screw or shaft.

**axial thrust** (Unit N) Loading induced along the axis of a shaft by a propeller, fan blade, helical gearing, etc.

**axial turbine** (axial-flow turbine) A turbine in which the principal flow direction of the working fluid (gas, steam or water) is parallel to the axis of rotation of the rotor.

**axial winding** In the manufacture of filament-reinforced composite vessels, where the windings are mainly in an axial direction.
axis

1. See axis of symmetry. 2. (axis of rotation) The imaginary straight line about which a body, gear, screw, etc. rotates.

axis of freedom In a gyroscope, an axis about which a gimbal provides a degree of freedom.

axis of symmetry (axis) The imaginary line about which an axisymmetric body is generated. In a body of uniform density, the centre of gravity lies on this axis.

axis of torsion (axis of twist) The line about which a body twists when subjected to a torque.

axle The cross-shaft that carries the wheels of a vehicle. In a live axle, the wheel is rigidly fixed thereto and power is transmitted; in a dead axle, the wheel turns on a stationary axle.

axlebox The assembly, including an oil reservoir, in which axles having plain bearings fit.

axle ratio The ratio of the rotation speed of a drive shaft to that of the driven shaft.

axle windup The torsional deflexion of a shaft due to applied torque.

azeotrope A liquid mixture whose composition is the same as that of the vapour in equilibrium with it.

azimuthal velocity See tangential velocity.