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A HANDBOOK OF SOUND & VIBRATION PARAMETERS

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A HANDBOOK OF SOUND and VIBRATION PARAMETERS

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I

GLOSSARY

I

GLOSSARY

This is a glossary of Navy-oriented sound and vibration terms. Definitions from applicable standards have been rewritten in most cases to make them easier to understand. For complete rigor the Standards themselves should be consulted.

Absorption of Sound: Sound absorption is the property possessed by materials and objects, including air, of absorbing sound energy. Sound absorption, as a process, is the change of sound energy into some other form, usually heat, in passing through a medium or on striking a surface. (Reference 1.)

Absorption Coefficient: The sound absorption coefficient of a surface is the fraction of incident sound energy absorbed or otherwise not reflected by the surface. Unless otherwise specified, a diffuse sound field is assumed. (See Sabin.) (Reference 1.)

Acceleration: Acceleration is a vector that specifies the time rate of change of velocity. Various self-explanatory modifiers such as peak, average, and rms are often added to the term. The time interval must be indicated over which the average (for example) was taken. Acceleration may be (1) oscillatory, in which case it may be defined by the acceleration amplitude (if simple harmonic) or the rms acceleration (if random), or (2) non-oscillatory, in which case it is designated "sustained" or "transient acceleration." (Reference 1.)

Acceleration, Vibratory Level (L_a): Vibratory acceleration level, in dB, is twenty times the logarithm to the base ten of the ratio of the vibratory acceleration to the reference acceleration a which is $10\,\mu m/s^2$ ($=10^{-5} m/s^2 = 10^{-3} cm/s^2 = 0.394 \times 10^{-3} in/s^2$). The former term for L_a is AdB. The reference acceleration is nearly one-millionth of the standard acceleration of free fall ($1\,\mu g_n$). For brief reporting in accordance with MIL-STD-1621A (Navy), the reference acceleration may be described as $a_o \simeq 1\,\mu g_n$. (Reference 2.)

Accelerometer: An accelerometer is a transducer which produces a change in voltage or electrical charge proportional to the acceleration of the structure to which it is attached.

Acoustic, Acoustical: The qualifying adjectives "acoustic" and "acoustical" mean containing, producing, arising from, actuated by, related to, or associated with sound. "Acoustic" is used when the term being qualified designates something that has the properties, dimensions, or physical characteristics associated with sound waves; "acoustical" is used when the term being qualified does not designate explicitly something that has such properties, dimensions or physical characteristics. The following examples take acoustic: impedance, output, energy, wave, medium, signal, and transducer. The following examples take acoustical: society, method, engineer, glossary, symbol, problem, measurement, and device. (Reference 1.)

Acoustic Center: The effective acoustic center of an acoustic generator is the point from which the spherically divergent sound waves, observable at remote points, appear to diverge. The acoustic center and geometrical center of a sound source do not necessarily coincide. (Reference 1.)

Acoustic Impedance: The acoustic impedance of a fluid medium on a given surface lying in a wave front is the complex ratio of the sound pressure (force per unit area) on that surface to the flux (volume velocity, or particle velocity multiplied by the area) through the surface. When concentrated rather than distributed impedances are considered, the impedance of a portion of the medium is based on the pressure difference effective in driving that portion and the flux (volume velocity). The acoustic impedance may be expressed in terms of mechanical impedance divided by the square of the area of the surface considered. Velocities in the direction along which the impedance is to be specified are considered positive. The real part of an acoustic impedance is acoustic resistance and the imaginary part is acoustic reactance. The basic unit for acoustic impedance is the Pascal-second per meter, formerly called the acoustic ohm. (Reference 1.)

Acoustic Resistance: Acoustic resistance is the real component of the acoustic impedance.

Acoustic Reactance: Acoustic reactance is the imaginery component of acoustic impedance.

Acoustic Mass: Acoustic mass is the quantity which, when multiplied by 2π times the frequency, gives the acoustic reactance.

Acoustic Stiffness: Acoustic stiffness is the quantity which, when divided by 2π times the frequency, gives the acoustic reactance.

Acoustic Compliance: Acoustic compliance is the reciprocal of acoustic stiffness.

Specific Acoustic Impedance (Unit Area Acoustic Impedance): The specific acoustic impedance at a point in the medium is the complex ratio of sound pressure to particle velocity. The basic unit for specific acoustic impedance is the Pascal-second per cubic meter, formerly called the Rayl.

Specific Acoustic Resistance: Specific acoustic resistance is the real component of the specific acoustic impedance.

Specific Acoustic Reactance: Specific acoustic reactance is the imaginary component of the specific acoustic impedance.

Acoustic Intensity: (See Sound Intensity)

Acoustic Mobility: The acoustic mobility of a fluid medium on a given surface lying in a wave front is the complex ratio of the flux (volume velocity, or particle velocity multiplied by the area) to the acoustic stress acting normal to the surface. When concentrated rather than distributed mobilities are considered, the mobility of a portion of the medium is based on the flux and the acoustic stress acting through that portion. The acoustic mobility may be expressed in terms of the mechanical mobility multiplied by the square of the area of the surface considered. (Reference 1.)

Specific Acoustic Mobility: (Unit Area Acoustic Mobility). The specific acoustic mobility at a point in a medium is the complex ratio of particle velocity to acoustic stress. (Reference 1.)

Acoustic Radiation Pressure: Acoustic radiation pressure is a unidirectional, steady-state pressure exerted upon a surface exposed to an acoustic wave. (Reference 1.)

Acoustic Scattering: Acoustic scattering is the irregular reflection, refraction, or diffraction of a sound in many directions. (Reference 1.)

Acoustic Sea State: Acoustic sea state is a level of sea noise in the ocean which corresponds to a sea state condition 0 through 6. Acoustic sea state and sea state do not always correspond. See "Parameters of Sonar Performance" for acoustic sea state curves.

Acoustic Signature: The acoustic signature is the graphical representation of the noise characteristic identified with a specific noise source; for example, a one-third octave band plot of radiated noise of a particular class of submarine is one of its acoustic signatures.

Acoustics: Acoustics is the science of sound including its production, transmission, and effects. The acoustics of a room are those qualities that together determine its character with respect to distinct hearing. (Reference 1.)

Active Transducer: An active transducer is a source of acoustical or vibration waves as opposed to a passive transducer which simply detects them.

Active Sonar (Echo-Ranging Sonar): Active sonar is the method or equipment by which information concerning a distant object is obtained by evaluation of sound generated by the equipment and reflected by the distant object. (Reference 1.)

Ambient Noise: Ambient noise is the all-encompassing noise associated with a given environment, being usually a composite of sounds from many sources near and far. (Reference 1.)

AN/---: AN/ is the prefix of a descriptive code for all military electronic devices. AN stands for Army-Navy. The key to the code is given in the text.

Analyzer: (See Sound Analyzer.)

Anechoic Room (Free-Field Room): An anechoic room is one whose boundaries absorb effectively all the sound incident thereon, thereby affording essentially free-field conditions. (Reference 1.)

Angle of Incidence: The angle of incidence, defined for plane acoustic waves incident on a surface, is the angle between the direction of arrival of a sound wave and the normal or perpendicular, to the surface of the arrival point. Angles of incidence vary from 0° to 90°. Angles of incidence near 90° are called grazing angles.

Angular Frequency (Circular Frequency): The angular frequency of a periodic quantity, in radians per unit time, is the frequency multiplied by 2π. The usual symbol is ω. (Reference 1.)

Anti-Node: An anti-node is a point, line, or surface in a standing wave where some characteristic of the wavefield has a relative maximum amplitude. (Reference 1.) An appropriate adjective should be used to differentiate between velocity anti-nodes, pressure anti-nodes, etc.

Antiresonance: For a system in forced oscillation, antiresonance exists at a point and frequency when any change, however small, in the frequency of excitation causes an increase in the response at this point. (Reference 1.)

Array: A receiving array is a group of two or more transducers arranged in a pattern which helps the reception of signals from some directions and reduces reception from other directions. A transmitting array can transmit in chosen directions. The directivity of both types of arrays derives both from the relative placement of the transducers and the way the transmitted or received signals are added. The addition is accomplished by weighting and phasing the signals pertinent to each array element.

Audio Frequency: An audio frequency is any frequency corresponding to a sound wave which can be heard by a human. Audio frequencies range roughly from 15 to 20,000 cycles per second. The word "audio" may be used as a modifier to indicate a device or system intended to operate at audio frequencies; e.g., "audio amplifier." (Reference 1.)

Automatic Tracking Function (ATF): An automatic tracking function is a feedback control system which steers a sonar beam toward a chosen target.

A-Weighted Sound Level (dBA): dBA refers to levels measured with a sound level meter with a filter that approximates the loudness response of a human ear to sounds of low to medium intensity. (See "Decibels, Frequency Analyses and Standard Graphs" for the filter shape of A-weighting.) dBA should not be confused with AdB, which is a superseded term for the level of vibratory acceleration.

Background Noise: Background noise is the total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal. Ambient noise detected, measured, or recorded with the signal becomes part of the background noise. Included in this definition is the interference resulting from primary power supplies; that separately is commonly described as hum.

Baffle: A baffle is an acoustic barrier.

Band Elimination Filter: A band-elimination filter is a wave filter that has a large insertion loss for one frequency band, neither of the critical or cutoff frequencies being zero or infinite. If the band of insertion loss is narrow, this is also called a notch filter. (Reference 1.)

Band-Pass Filter: A band-pass filter is a wave filter that has a single transmission band extending from a lower cut-off frequency greater than zero to a finite upper cut-off frequency. (Reference 1.)

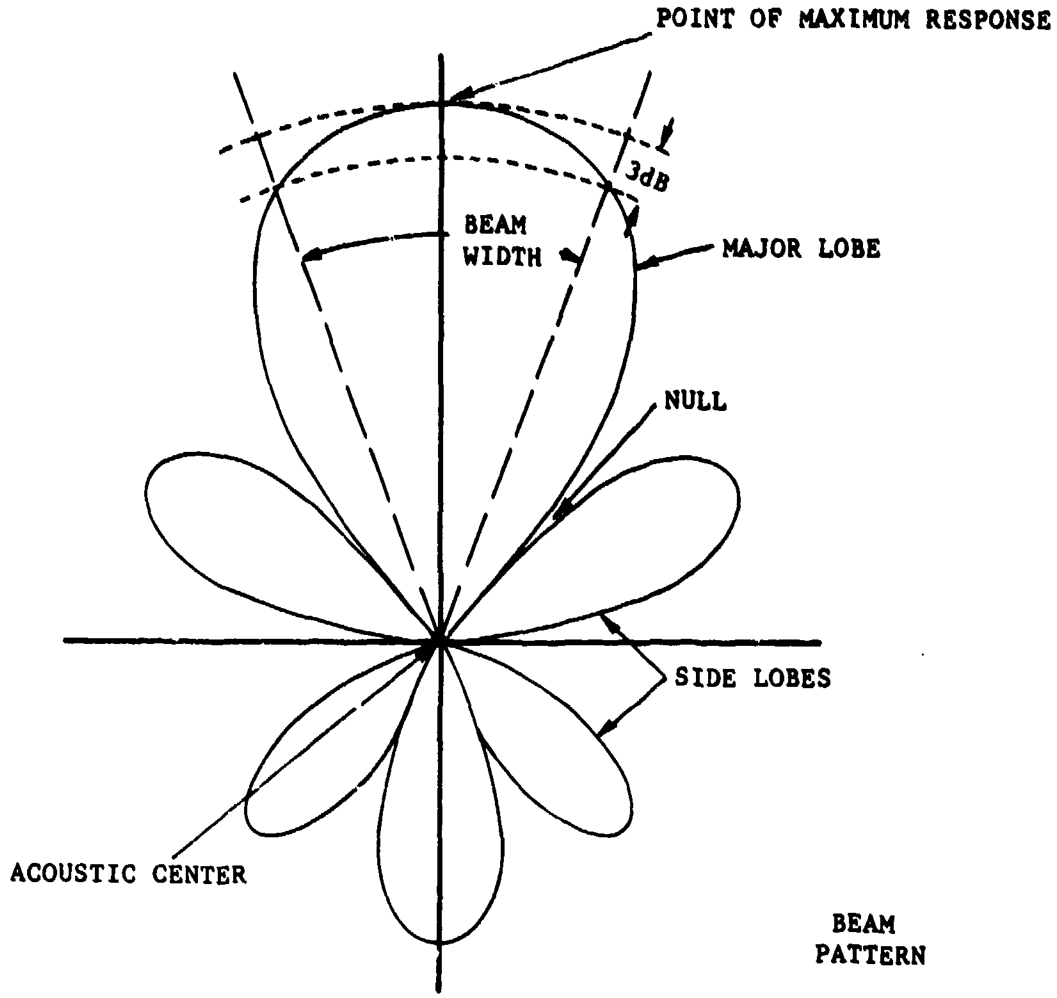
Band Pressure Level: The band pressure level of a sound for a specified frequency band is the sound pressure level for the sound contained within the restricted band. The band may be specified by its lower and upper cut-off frequencies, or by its geometric center frequency and bandwidth. The width of the band may be indicated in terms of octave band (sound pressure) level, half-octave band level, third-octave band level, 50-cps band level, etc. (See "Decibels, Frequency Analyses and Standard Graphs.") (Reference 1.)

Bandwidth: The "nominal" bandwidth of a filter is the difference between the nominal upper and lower cutoff frequencies. The difference may be expressed (1) in Hz; (2) as a percentage of the band-pass center frequency; or (3) as the interval between the upper and lower nominal cutoffs in octave fractions. The "effective" bandwidth of a specified transmission system is the bandwidth of an ideal system which (1) has uniform transmission in its pass band equal to the maximum transmission of the specified system, and (2) transmits the same power as the specified system when the two systems are receiving equal input signals having a uniform distribution of energy at all frequencies. (Reference 1.)

Bathothermic Trace (BT): (See Sound Velocity Profile.)

Beamformer: (See Compensator Plate.)

Beam Pattern: The beam pattern or directional response pattern of a transducer or array of transducers used for sound emission or reception is a description, often presented graphically (see sketch), of the response of a transducer as a function of the direction of the transmitted or incident sound waves in a specified plane and at a specified frequency. A complete description of the directional response pattern would require a three-dimensional presentation. Beam patterns are often plotted as response relative to the maximum response. (Reference 1.)



BEAM PATTERN

Beamwidth: The beamwidth of a directional transducer, at a given frequency in a given plane including the beam axis, is the angle included between the two directions, one to the left and the other to the right of the axis, at which the angular deviation loss has a specified value. Beamwidths are commonly specified for an angular deviation loss of 3, 6, or 10 decibels, the choice depending upon the directivity of the transducer or upon its intended application. The particular angular deviation loss can be indicated conveniently by use of a term such as "3-dB beamwidth." (See sketch of beam pattern.) (Reference 1.)

Bearing Deviation Indicator (BDI): A bearing deviation indicator is a device which produces a voltage roughly proportional to the angular difference between the main response axis of a sonar and the direction of arrival of an incoming signal wave. Its signal originates from the difference of two half-beams of the sonar using the principle of null steering. (See Null Steering.)

Bearing-Time Recorder (BTR): A bearing-time recorder is a sonar display on which received broad-band signal level is plotted as blackness of a horizontal trace line over all bearings at a given time. The traces are plotted under one another, the vertical axis representing time. Targets and self-noise both appear as stripes on this display.

Beats or Beating: Beats are periodic variations that result from the superposition of two simple quantities of different frequencies, f_1 and f_2. They involve the periodic increase and decrease of amplitude at the beat frequency ($f_1 - f_2$). Beating is commonly heard on vehicles with two or more engines running at nearly the same speed, such as boats or airplanes. (Reference 1.)

Bending Waves: Bending waves, common to beams and plates, are waves initiated by the alternate bending and unbending of a plate or beam. (See "Basic Acoustics," Type of Waves.)

Bistatic: (See Monostatic.)

Blocked Impedance: The blocked impedance of a mechanical system is the impedance at the input when the impedance of the system output is blocked so that it cannot move. For example, in the case of an electromechanical transducer, the blocked electric impedance is the impedance measured at the electric terminals when the mechanical system is blocked or clamped; the blocked mechanical impedance is measured at the mechanical side when the electric circuit is open-circuited.

Bottom Bounce: Bottom bounce is a term applied to the reflection of sound rays off the ocean floor.

Bottom Reverberation: (See Reverberation.)

Boundary Layer: A boundary layer is a very thin layer in the neighborhood of a body which moves relative to a fluid where fluid friction causes a thin layer of fluid to move with the body. This is the only region where friction (or viscosity) has to be considered in any analysis. The boundary layer, depending upon the Reynold's number, may be either laminar or turbulent.

Boundary Layer Tripping: A laminar boundary layer may be tripped to become turbulent at lower Reynold's numbers by placing a small obstruction in the boundary layer near the body. Tripping destroys the laminar flow and causes turbulence. When the Reynold's number gets high enough, the boundary layer will trip even without an obstruction. (See Transition Point.)

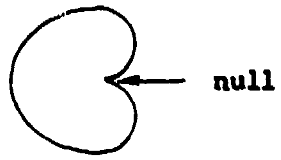
Broad Band: Broad band is a term which applies to a wide, or broad, band of frequencies. A broad band is typically one octave or wider.

Bulk Modulus: (See Modulus of Elasticity.)

Bump Test: A bump test is a means of finding the major resonant frequencies of a mechanical vibrating system. The "bump" is generally a blow with a rubber hammer. It excites free vibrations which in theory are at all the system resonant frequencies, but which in practice are limited to only a few major resonances. A bump test is a mechanical version of the classic (electrical) impulse response test of electrical systems. Theoretically, the frequency response of any system is simply the Fourier Transform of its impulse response, the impulse being the bump.

Cardioid: A cardioid is the beam pattern of a hydrophone or microphone which is a combination of an omnidirectional and a dipole receiver. A cardioid is sketched below:

cardioid pattern



A cardioid will reject sounds from a chosen direction as indicated by the null.

Caustic: A caustic is a point in a sound field where many refracted sound rays from a distant source converge or focus. The focal point of an acoustic lens is a caustic, for example.

Cavitation: Sonically induced cavitation in a liquid is the formation, growth, and collapse of gaseous and vapor bubbles due to the action of intense sound waves. (Reference 1.)

Cavitation Noise: Cavitation noise is the noise produced in a liquid by gaseous or vaporous cavitation. (Reference 1.)

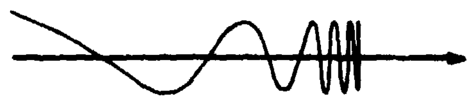
Center Frequency: The nominal passband center frequency, f_c, is the geometric mean of the nominal cutoff frequencies, f_1 and f_2. The formula is $f_c = \sqrt{f_1 \times f_2}$. The term center frequency is used only with constant percentage bandwidths, i.e., one third octave, 10 percent, etc. (Reference 1.)

Characteristic Acoustic Impedance: The characteristic impedance of an acoustic medium is the ratio of the effective sound pressure at a given point to the effective particle velocity at that point in a free plane progressive sound wave. The characteristic acoustic impedance is equal to the product of the density and the speed of sound in the medium (ρc). (Reference 1.)

Characteristic Mechanical Impedance: Characteristic mechanical impedance is the mechanical drive point impedance in the absence of any energy reflected from structural boundaries back to the drive point.

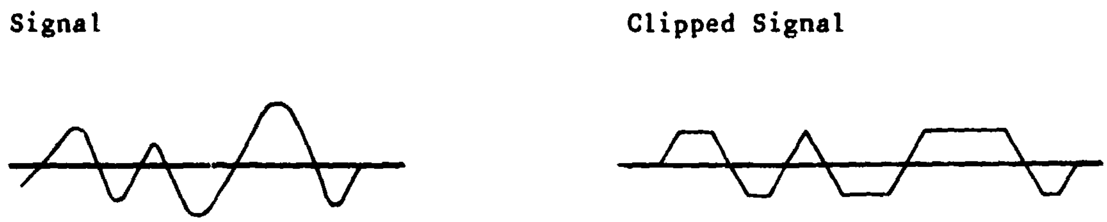
Chatter ("Stick-Slip"): Chatter is a type of vibration characterized by a "Stick, Slip" type of motion. Chalk, when pushed across a blackboard, chatters, for example.

Chirp: Chirp describes a type of sonar ping which sweeps over a band of frequencies.



Time trace of a "chirp" or FM sweep

Clipper: A clipper is an electronic device which amplifies a signal, then strongly limits its amplitude.



Clipping is, by extension, any sharp limitation on signal amplitude.

Clipper Correlator: A clipper correlator is a device to generate the error signal for null steering. (See Null Steering.) It clips the two half-beam sonar signals (one of which is delayed), then multiplies (or correlates) them, producing the required error signal.

Coincidence Effect: The coincidence effect occurs when the distance between pressure maxima as seen by the plate upon which a plane acoustic wave is incident (trace wavelength) coincides with the flexural or bending wave on the plate at the same frequency. In this case, the plate is nearly a perfect transmitter of the wave. Coincidence can occur only above the critical frequency of the plate. (See Critical Frequency.)

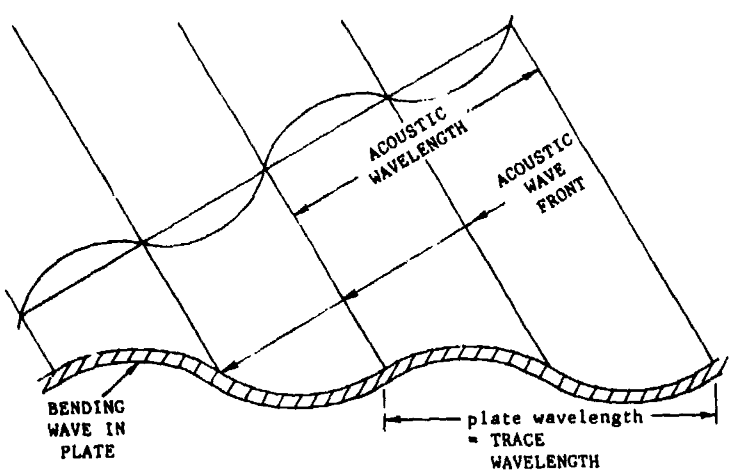


Illustration of the Coincidence Effect

Compensator Plate: A compensator plate is that part of a sonar which electrically forms and steers the beam by appropriate selections of hydrophones to be time lagged. A compensator plate eliminates the need to mechanically steer a sonar array.

Complex Conjugate: The conjugate of a complex number, a + jb, is a - jb. (See Complex Numbers.)

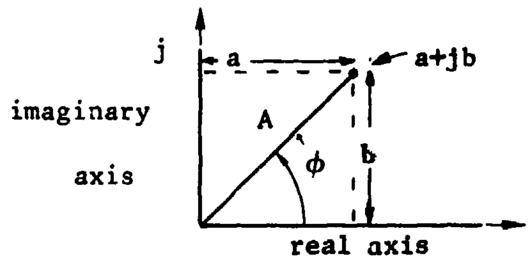
Complex Numbers: The complex number system is a mathematical contrivance that is very convenient for describing systems which have both amplitude and phase. Amplitude and phase are contained in a complex number which has a "real" part, a, and an imaginary part, jb, where $j = \sqrt{-1}$ and a and b are real. a and b are related to amplitude and phase by the following relationship:

A, amplitude $= \sqrt{a^2 + b^2}$

ϕ, phase = arc tan $\frac{b}{a}$

$a = A \cos \phi$

$b = A \sin \phi$



Sometimes the letter i is used for $\sqrt{-1}$ instead of j.

Compliance: Compliance is the inverse of stiffness.

Compliant Tubes: Compliant tubes are oval or elliptical air-filled tubes which, because they are compliant, can be used to form underwater acoustic reflectors or refractors with many different characteristics, depending on the configuration. They are also called Toulis tubes, after their inventor, William J. Toulis.

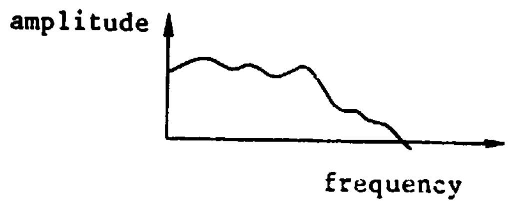
Compressional Wave (Also Dilatational Wave): (See "Basic Acoustics" - Types of Waves.)

Condenser Transducer: A condenser transducer as a receiver converts force on, or motion of, one plate of a two-plate condenser into a voltage. As a projector, a variable voltage is applied to the condenser plates, causing them to produce a force or motion signal. It is also called an electrostatic transducer.

Conjugate Impedances: Conjugate impedances are impedances having resistance components which are equal and reactance components which are equal in magnitude but opposite in sign. Conjugate impedances are expressible by conjugate complex quantities. Conjugate impedance is important as a concept, because of the power transfer theorem. (See Power Transfer Theorem.) (Reference 1.)

Continuous Spectrum: A continuous spectrum is the spectrum of a wave the components of which are continuously distributed over a frequency region. A continuous spectrum must represent either a random or a transient signal. A periodic signal has a line spectrum. (Se Line Spectrum.)

Continuous Spectrum



Continuous Vibrating System (Distributed Vibrating System): A continuous vibrating system is one with an infinite number of possible distributions of vibration displacement, e.g., a vibrating string, beam, or plate. An example of a non-continuous system, by contrast, is the spring-mass system inside an accelerometer. The latter is called a lumped parameter system.

Convergence Zone: Convergence zones are concentric circular areas near the ocean surface where many sound rays from a source at their center are particularly intense. As a rule of thumb, convergence zones occur at ranges of roughly 25, 50, 75, . . . miles in the Atlantic Ocean and at 30, 60, 90, . . . miles in the Pacific. Convergence zones are examples of caustics.

Convolution Theory for Hydrophone or Microphone Array Directivity: The convolution theory for directivity of an array of hydrophones or microphones states that the total array directivity is the directivity of an equivalent array of omnidirectional hydrophones convolved with the directivity of an array element by itself. Convolution is a mathematical process of multiplication and summing. In effect, this theorem confirms the obvious: an array of highly directive hydrophones has more directivity than an equivalent array of omnidirectional hydrophones.

Correlation: The correlation of two signals is the time average of the value of one multiplied by the other. Correlation is generally calculated with one signal delayed or lagged behind the other by varying the amounts. Auto-correlation refers to one signal correlated with itself. Cross-correlation refers to two signals being correlated.

Correlator: A correlator is an instrument which will measure the correlation of two signals.

Coulomb Damping: Coulomb damping, or dry friction damping, is the dissipation of energy that occurs when an element of a vibrating system is resisted by a force whose magnitude is roughly constant, independent of displacement and velocity, and whose direction is opposite to the direction of the velocity of the element. (Reference 1.)

Coupled Modes: Coupled modes are modes of vibration that are not independent, but which influence one another because of energy transfer from one mode to the other. (Reference 1.)

Coupling Factor, Electromechanical: The electromechanical coupling factor is a factor used, for example, to characterize the extent to which the electrical characteristics of a transducer are modified by a coupled mechanical system, and vice versa.

Critical Damping: Critical damping is the minimum viscous damping that will allow a displaced mechanical system to return to its initial position without oscillation. (See "Mechanical Vibrating Systems".) (Reference 1.)

Critical Damping Ratio: The critical damping ratio in a mechanical vibrating system is the ratio of the actual damping to the critical damping. (See "Mechanical Vibrating Systems".) (Reference 1.)

Critical Frequency: The critical frequency is the frequency where the free bending wavelength, as determined in vacuo, of a plate is the same length as acoustic waves in the surrounding medium. Below critical frequency, plates radiate acoustically with less efficiency than above critical frequency. (See wavelength chart for plates under "Miscellaneous Fluid - Solid Interaction".)

Critical Speed: A critical speed is a characteristic speed such that the predominant response occurs at a resonance of the system. In the case of a rotating system, the critical speed is the speed that corresponds to a resonance frequency of the system (it may also include multiples and sub-multiples of the resonance frequency). An example is speed in revolutions per unit time equals the resonance frequency in cycles per unit time. Where there are several rotating speeds, there will be several corresponding sets of critical speeds, one for each mode of the overall system. (Reference 3.)

Cutoff Frequency: The nominal upper and lower cutoff frequencies of a filter pass-band are those frequencies above and below the frequency of maximum response of a filter at which the response to a sinusoidal signal is 3 dB below, or half the power of, the maximum response. (Reference 1.)

Damping: Damping is the dissipation of energy with time or distance in a mechanical vibrating system. Damping, in general, affects system response only at or near resonant frequencies. (See "Mechanical Vibrating Systems".) (Reference 1.)

Damping Factor (Loss Tangent): When an elastic material modulus is written in complex form to include damping effects, as for example $E(1 + j\delta)$, the term δ is called the damping factor or loss tangent and is the relative effect of damping on the total material modulus in question.

dBA: (See Sound level.)

Dead Room: A dead room is a room that is characterized by an unusually large amount of sound absorption. (Reference 1.)

Decade Band: A decade band, by formal (and former) definition, is 10 Hz wide, just as a decade of time is 10 years. In common use, however, decade band is used to describe any frequency band with the upper cutoff frequency equal to 10 times the lower cutoff frequency.

Decay Rate: The rate of decay is the time rate at which the sound pressure level, or any other stated characteristic, decreases at a given point. A commonly used unit to express the rate of decay is the decibel per second.

Decibel (dB): A decibel is a unit of level (see Level) which is 20 times the logarithm to the base 10 of a ratio of the amplitude quantity in question to a reference quantity or 10 times the logarithm to the base ten of the ratio of a power or squared quantity to its appropriate reference quantity.

Examples:
Decibel level of x, reference quantity x_o.

$$20 \log_{10} \frac{x}{x_o}$$

Decibel level of x^2, reference quantity $x_o{}^2$

$$10 \log_{10} \frac{x^2}{x_o{}^2}$$

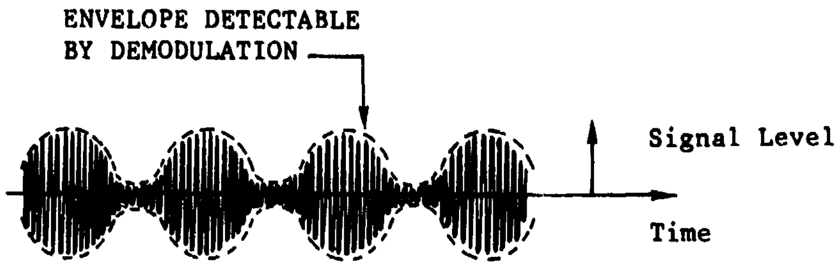
Decoupler: (See Pressure Release.)

Deep Sound Channel: The deep sound channel is an acoustical channel in the deep ocean which tends to "trap" acoustic waves so that they travel great distances. The axis of the deep sound channel is at the depth of minimum velocity in the sound velocity profile. (See Sound Velocity Profile.) The depth of the axis varies from 4000 ft at mid-latitudes to near the ocean surface in polar regions. (See SOFAR.)

Degrees of Freedom: The number of degrees of freedom of a mechanical system is equal to the minimum number of coordinates required to define completely the positions of all parts of the system at any instant of time. (See Single-Degree-of-Freedom System and Multiple-Degree-of-Freedom.) (Reference 1.)

Deltic: A deltic is a device which "compresses" a long digital signal into a short period of time to simplify signal processing.

Demodulation: Demodulation is the process of recovery of a signal that has been frequency-modulated or amplitude-modulated, for example. Demodulation can also apply to the detection of a low frequency "envelope" on a higher frequency noise.



Demodulation removes the high frequency noise, leaving only the envelope - the dotted line. The case shown is amplitude demodulation.

Depth Deviation Indicator (DDI): A depth deviation indicator is simply a bearing deviation indicator in a vertical plane. (See Bearing Deviation Indicator.)

Diffracted Wave: A diffracted wave is one whose front has been changed in direction by an obstacle or other nonhomogeneity in a medium, other than by reflection or refraction. (Reference 1.)

Diffraction: Diffraction is that process which produces a diffracted wave. It occurs when the dimensions of an obstacle are comparable or larger than the wavelength of the incident sound wave. (Reference 1.)

Diffuse Acoustic Reflector: A diffuse acoustic reflector is a reflector which is rough in terms of the acoustic wavelengths involved, therefore it reflects an incident acoustic wave in all directions. An acoustically rough surface, by the Rayleigh roughness criteria, has roughness details with dimensions greater than one-quarter of an acoustic wavelength.

Diffuse Reflection: Diffuse reflection is reflection of a wave in many directions with no direction having significantly greater reflection than any other. Diffuse reflection is a characteristic of rough areas of the ocean floor, for example.

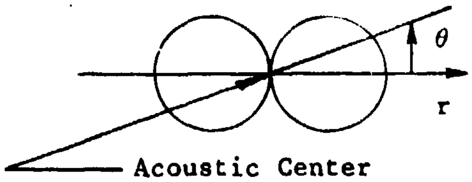
Diffuse Sound Field: A diffuse sound field is one in which the mean-square sound pressure is every where the same and the flow of energy in all directions is equally probable. A diffuse sound field is created, for example, by design to serve as a standard for testing architectural acoustic materials for absorption and transmission loss. A diffuse noise field is also called an isotropic noise field. (Reference 1.)

Dilatational Wave: (See "Basic Acoustics" - Types of Waves.)

DIMUS: DIMUS is an acronym from DIgital MUltibeam Steering, a digital process whereby the signals from every hydrophone in a sonar array are used to form many different beams simultaneously. DIMUS is a major improvement over scanning sonars. Without DIMUS, sonars must scan each beam sequentially which slows target detection.

Dipole Hydrophone, Dipole Microphone: A dipole hydrophone or microphone has a maximum response from two opposite directions along its axis and is insensitive to any sound arriving perpendicular to that axis. Its response pattern is independent of frequency:

Dipole Beam Pattern $r = |\cos\theta|$



Directional Gain (Directivity Index): The directional gain of a transducer or array, in decibels, is 10 times the logarithm to the base 10 of the directivity factor. (Reference 1.)

Directivity Factor: The directivity factor of a transducer used for sound emission is the ratio of the sound pressure squared, at some fixed distance and specified direction, to the mean-square sound pressure at the same distance averaged over all directions from the transducer. The distance must be great enough so that the sound appears to diverge spherically from the effective acoustic center of the source. Unless otherwise specified, the reference direction is understood to be that of maximum response. The directivity factor of a transducer used for sound reception is the ratio of the square of the open-circuit voltage produced in response to sound waves arriving in a specified direction to the mean-square voltage that would be produced in a perfectly diffused sound field of the same frequency and mean-square sound pressure. (For comparison, the directivity factor of an omnidirectional source or receiver is 1.) (Reference 1.)

Directivity Index: (See Directional Gain.)

Discrete: Discrete means single, as in discrete frequency, which is a single frequency as opposed to a band of frequencies.

Dispersion: Dispersion is a characteristic of a medium in which wave speed depends on the frequency of the wave. For example, flexural waves in a beam or plate experience dispersion. In general, high frequency flexural waves travel along a beam or plate faster than low frequency waves.

Dispersive Medium: A dispersive medium is a medium characterized by dispersion. (See Dispersion.)

Displacement: Displacement is a vector quantity that specifies the change of position of a body or particle and is usually measured from the mean position or position of rest. In general, it can be represented by a rotation vector or translation vector, or both. (Reference 1.)

Displacement, Vibratory Level (L_d): Vibratory displacement level in dB, is twenty times the logarithm to the base 10 of the ratio of the vibratory displacement to the reference displacement of 10 picometers ($=10^{-11}$m $=10^{-9}$cm $= 0.394 \times 10^{-9}$ in.). (Reference 2.)

Distortion: Distortion is an undesired change in waveform. Noise and certain desired changes in waveform, such as those resulting from modulation or detection, are not usually classed as distortion. (Reference 1.)

Distributed Isolation Material (DIM): DIM is sheets of compliant material which can be cut to arbitrary shapes to provide vibration isolation between a machine and its foundation. DIM is generally stiffer than standard vibration mounts, therefore it is less effective. It is often desired, nontheless, because of shock requirements and ease of installation.

Distributed Vibrating System: (See Continuous Vibrating System.)

Divergence: Divergence is an instability of a body in a strong fluid flow field. When divergence occurs, there is an extraordinary force on a body which increases, up to a point, with increasing body displacement in the flow field. There are static divergence (a large displacement in a wing, for example) leading to failure and dynamic divergence, characterized by vibrations which also commonly lead to failure. (See Flutter.)

Dome: A dome is an acoustically transparent transducer enclosure, usually streamlined, used with sonars to minimize turbulence and cavitation noises which would arise from the passage of the bare hydrophones through the water.

Doppler Effect: The Doppler effect is the change in the observed frequency of a wave in a transmission system if either the source, the observer, or both are moving. The formula for Doppler effect is:

$$f_r = \frac{(1 + v_r/c)}{(1 - v_s/c)} f_s$$

where

f_r = observed frequency
f_s = frequency of source
v_r = component of velocity (relative to the medium) of observation point toward source
v_s = component of velocity (relative to the medium) of source toward observation point
c = speed of sound in the stationary medium

It is obvious from the equation that the apparent frequency of a departing source drops lower and lower as the source speed increases, to become zero as the source reaches the speed of sound.

Doppler Shift: The Doppler shift is the change in the observed frequency of a wave due to the Doppler effect.

Driving-Point Impedance: (See "Mechanical Vibrating Systems". Mechanical Impedance and Mechanical Mobility.)

Driving-Point Mobility: (See "Mechanical Vibrating Systems". Mechanical Impedance and Mechanical Mobility.)

Dry Friction Damping: (See Coulomb Damping.)

Dynamic Divergence: (See Flutter.)

Dynamic Range: Dynamic range is the range of useful signal levels in a system of interest, from the smallest to the largest. System noise generally limits the smallest signal while the upper limit of the linear range of the individual system elements generally limits the largest signals. Dynamic range is expressed as decibels, or twenty times the logarithm of the ratio of the largest undistorted signal to the smallest one detectable in the system noise.

Dynamic Vibration Absorber: A passive dynamic vibration absorber is an auxiliary mass-spring system which tends to neutralize vibration of a structure to which it is attached. The basic principle of operation is vibration out-of-phase with the vibration of such structure, thereby producing a counteracting force. There are also active dynamic vibration absorbers which are feedback systems to generate forces which cancel the forces causing vibration.

Echo: An echo is a sound wave that has been reflected or otherwise returned with sufficient magnitude and delay to be detected as a wave distinct from that directly transmitted. (Reference 1.)

Edge Effects: When a sound wave impinges on an object, the reflected or diffracted waves have components that appear to originate from edges on the object. These components of the reflected or diffracted wavefields are called edge effects.

Edge Tones: An edge tone is produced by placing a small, pointed body within the flow field of a jet. In any given situation, the edge tone frequency is related to the distance between the edge and the nozzle - the closer the edge to the nozzle, the higher the frequency.

Efficiency: The efficiency of a device with respect to a physical quantity which may be stored, transferred, or transformed by a device is the ratio of the useful output of the quantity to its total input. Unless specifically stated otherwise, the term "efficiency" means efficiency with respect to power.

Eigen Frequency, Eigen Function: Eigen is a German adjective, meaning natural or characteristic, which is commonly used in technical papers. An eigen frequency is the resonant frequency of a vibration mode, the shape of which is described by an eigen function. (Reference 1.)

Electret Microphone: An electret microphone is similar in construction to a condenser microphone. It differs in that no DC bias voltage is required. Instead, the electrostatic field is produced by charges permanently stored in the polymer diaphragm.

Electric Hammer: An electric hammer is a device, originally designed to drive chisels and other tools, which has been adapted to serve as a mechanical shaker.

Electroacoustic Transducer: An electroacoustic transducer is a transducer for receiving waves from an electric system and delivering waves to an acoustic system, or vice versa. (Reference 1.)

Electromechanical Transducer: An electromechanical transducer is a transducer for receiving waves from an electrical system and delivering waves to a mechanical system, or vice versa. (Reference 1.)

Electrostatic Transducer: (See Condenser Transducer.)

Electrostriction Transducer: An electrostriction transducer is a transducer that depends for its operation upon the production of an elastic strain in certain crystals proportional to the square of the applied voltage. In the absence of a bias signal, an electrostriction transducer will double the frequency of the input signal. (Reference 1.)

Equalization (Frequency Response Equalization): Frequency response equalization is the effect of all frequency discriminative means employed in a transmission system to obtain a desired over-all frequency response. (Reference 1.)

Exponential Horn: An exponential horn is a horn whose cross-sectional area increases exponentially with axial distance.

If:

S = the area of a plane section normal to the axis of the horn at a distance x from the throat of the horn,

S_o = the area of the plane section normal to the axis of the horn at the throat, and

m = a constant which determines the rate of taper or flare of the horn,

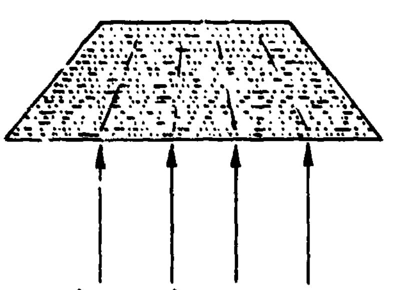
then:

$$S = S_o e^{mx}$$

Exponential horns are a particularly efficient way to generate sound.

Eyeball Integration: Eyeball integration, in spite of its slangy name, is a legitimate technique for detecting signals in noise. The technique involves inspection of a frequency-time plot of a signal at a low grazing angle. Steady frequencies may be detected this way because the perspective of this view makes them appear more prominent.

EYEBALL INTEGRATION



Target lines seen in oblique view on sonar print-out.

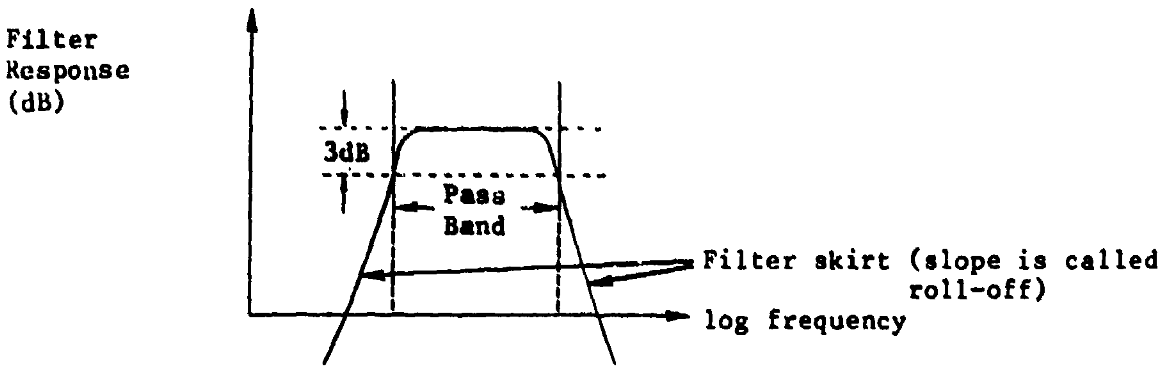
Farfield: Farfield, as a term, applies to sound fields that are far enough from the source that the wavefronts are nearly spherical. A criterion for farfield is if the sound pressure is reduced 6 dB when the distance from the source is doubled. The farfield of a source is known as the Fraunhofer region.

Fast Fourier Transform (FFT): A fast Fourier transform is a new, fast, simple method for computing a Fourier transform of a digitized signal. The technique has made digital frequency analyzers practical.

Figure of Merit (FOM): Figure of Merit is the ratio, in decibels, of echo level or target source level at a point to the ambient noise. (See "Parameters of Sonar Performance.")

Filter (Wave Filter): A wave filter is a transducer for separating waves on the basis of their frequency. It introduces relatively small insertion loss to waves in one or more frequency bands and relatively large insertion loss to waves of other frequencies. (Reference 1.)

Filter Skirt: A filter skirt is the part of the filter response which is outside of the nominal filter pass-band.



Finite Element Structural Analysis: Finite element structural analysis is a technique which mathematically represents a mechanical system by a large number of simple elements of the same physical properties as the system.

Flanking Paths: Flanking paths are paths of sound energy which bypass vibration isolators.

Flexural Waves: (See "Basic Acoustics", Types of Waves.)

Flow-Excited Noise: Flow-excited noise is noise radiated from a body which is excited by pressure variations in a flow field; e.g., turbulence or vortex shedding.

Flow Noise: Flow noise is noise from flow alone, such as noise from a jet. Flow noise is not to be confused with flow-excited noise. (See Flow-Excited Noise.)

Flow Tones: Any tone which is caused by fluid flow is a flow tone. Tones can originate from flow past rigid or non-rigid bodies. In some cases, the dynamic response of a non-rigid body can amplify the strength of a flow tone. (See Flutter, for example.)

Flutter: Flutter is dynamic divergence. (See Divergence.) The term flutter is used more in aerodynamics, while dynamic divergence is a term more common in hydrodynamic problems.

Flux: (See Intensity.)

Force Gauge: A force gauge is a transducer that produces a voltage in response to a force. A force gauge is required, for example, to help measure mechanical impedance.

Forced Vibration: The vibration of a system is considered to be forced if the response is imposed by an external oscillatory force. (Reference 1.)

Foundation: A foundation is a structure that supports the gravity load of a mechanical system. It may be fixed in space, or it may undergo a motion that provides excitation for the supported system. (Reference 1.)

Fourier Series: A Fourier series is the series of sine waves of different harmonically related frequencies that are the components of a periodic signal.

Fourier Transform: A Fourier transform is the mathematical process which yields the continuous frequency spectrum of either a transient or random signal.

Free Bending Wavelength: The free bending or flexural wavelength of a beam or plate is that wavelength of free wave propagation in an ideal plate of infinite dimensions. In general, the free bending wavelength is shorter for higher frequencies.

Free Field (Free Sound Field): A free sound field is a field in a homogeneous, isotropic medium, free from boundaries. In practice, it is a field in which the effects of the boundaries are negligible over the region of interest. (Reference 1.)

Free Vibration: Free vibration of a system is vibration that occurs in the absence of forced vibration. (Reference 1.)

Frequency: The frequency of a function periodic in time is the reciprocal of the period of the time length of a cycle. The unit is the Hertz, equal to the number of cycles per second. (Reference 1.)

Frequency Analyzer: (See Sound Analyzer.)

Frequency Modulation (FM): Frequency modulation involves the combination of a variable low frequency signal with a steady high frequency signal called a carrier. The low frequency signal amplitude is stored in the carrier wave as modulations of the carrier frequency. The carrier wave amplitude remains constant.

Fundamental Frequency: The fundamental frequency of a periodic quantity is the reciprocal of the longest period.

Fundamental Mode of Vibration: The fundamental mode of vibration of a system is the mode having the lowest natural frequency. (Reference 1.)

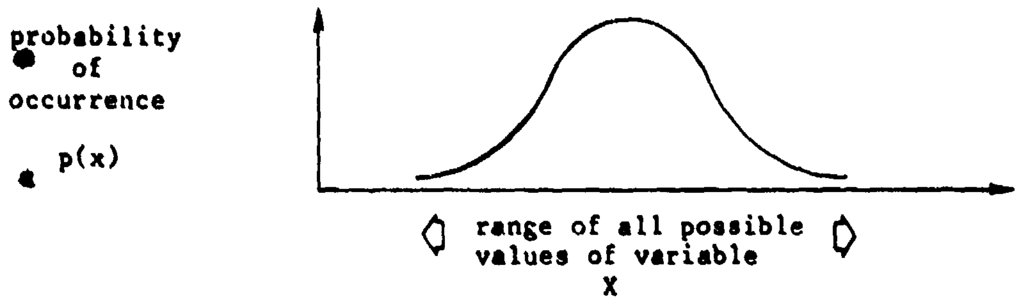
Fundamental Resonant Frequency: The fundamental resonant frequency is the resonant frequency of the fundamental mode of vibration of a system.

Fundamental Rotational Frequency: The fundamental rotational frequency is the forcing frequency associated with the rotation of a machine (rmp/60) Hz. The fundamental rotational frequency is usually spoken of as once per revolution.

g_n, (Standard Acceleration): The international standard acceleration of free fall is: $g_n = 9.80665\ m/s^2 = 386.089\ in/s^2$. (Reference 2.)

Gaussian Probability Distribution: A Gaussian probability distribution, describing some random variable, means that the plot of probability of the variable occurring within any given narrow range of values is the familiar bell-shaped curve. Another term is "Normal" which is synonymous with Gaussian.

GAUSSIAN PROBABILITY DENSITY



probability density

$$p(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{(x-\bar{x})^2}{2\sigma^2}}$$

when

σ = standard deviation

$\bar{x}$ = mean value of x

Grazing Angle: (See Angle of Incidence.)

Ground Loop: When electrical or electronic instruments are connected, they must have one "ground" or point of zero voltage in the combined circuits. Otherwise, a current will flow between the ground points producing a voltage which often swamps the signal. Ground loops generally have the same frequency as the line voltage.

Group Velocity: When a short sinusoidal wave propagates in a dispersive medium, there are two velocities of interest, the group velocity and the phase velocity. The envelope of the wave propagates at the group velocity; the individual wave fronts have an apparent velocity called the phase velocity. In a non-dispersive medium, they are equal.

pulse

group velocity is velocity of envelope

phase velocity is velocity of wave fronts

Harmonic: A harmonic is a sinusoidal quantity having a frequency that is an integral multiple of the fundamental frequency of a periodic quantity to which it is related. For example, a fundamental frequency, f, can have harmonics, 2f, 3f, 4f, etc. The 2nd harmonic is 2f; the third 3f; etc. (The first harmonic is the fundamental itself.) (Reference 1.)

Harmonic (Simple) Motion: A simple harmonic motion is a motion such that the displacements, velocity, and acceleration, are sinusoidal functions of time. (See "Mechanical Vibrating Systems", Harmonic Motion.)

Harmonic Signal: A simple harmonic signal, x(t), is a periodic quantity that is a sinusoidal function of time. (See "Mechanical Vibrating Systems", Harmonic Motion.)

Helmholtz Resonator: A Helmholtz or cavity resonator is a fluid-filled cavity with a relatively small entrance. The fluid in the entrance acts as a piston mass against the stiffness of the fluid in the cavity. Sound waves at or near the resonant frequency of the cavity and fluid mass will cause the fluid mass to oscillate at the cavity entrance and to amplify sound at the resonance frequency. (See "Miscellaneous Fluid - Solid Interaction".)

Heterodyning: Heterodyning is the shifting of an entire signal spectrum higher or lower along the frequency scale without changing its shape. In some analyzers, the filters have fixed frequency characteristics and the signal is heterodyned past the filter to produce the required frequency analysis.

Higher-Order Modes of Vibration: (See Modal Numbers.)

High-Pass Filter: A high-pass filter is a wave filter having a single transmission band extending from some cutoff frequency, not zero, up to infinite frequency or frequencies beyond the range of interest. (Reference 1.)

Homogeneous Noise Field: A homogeneous noise field is characterized by a uniformity of the sound pressure level. As opposed to isotropic noise fields (see isotropic noise fields), homogeneity implies no restrictions on the direction of the flow of sound energy.

Hooke's Law: Hooke's Law states that for an elastic medium (e.g., a spring), stress is proportional to strain; or, more simply, force is proportional to compression or extension in a spring governed by Hooke's Law. The range of compression or extension of a spring governed by Hooke's Law is called the linear range of the spring.

Hot-Wire Transducer: A hot-wire transducer is a transducer that depends for its operation on the change in resistance of a hot wire produced by the cooling or heating effects of a sound wave. The resistance varies roughly proportional to the fluid particle velocity. Hot wire transducers are used for studies of turbulence and fluid flow. (Reference 1.)

Hydroacoustic Transducer: A hydroacoustic transducer generates sound waves in fluids by converting a continuous liquid flow through an orifice into piston vibrations which radiate sound.

Hydrophone: A hydrophone is a device which transforms waterborne sound energy into electrical energy, or vice versa.

Hysteresis: Hysteresis is an effect where a system retains some effect of excitation after the excitation is removed. In the case of a spring, hysteresis is the slight deformation or set of the spring from its preload length after the load is removed. Hysteresis in springs adds damping to vibrating systems.

Impedance: (See Acoustic Impedance, Mechanical Impedance.)

Impedance Matching: (See Power Transfer Theorem.)

Impedance Mismatch: (See Power Transfer Theorem.)

Impedance Tube: An impedance tube is a long thin cylindrical cavity in which the acoustic performance of various materials is measured from their effect on standing waves within the tube. As a rule of thumb, impedance tubes can only be used at frequencies less than 7730 divided by their diameter in inches (in air). (See "Miscellaneous Fluid-Solid Interaction".)

Infrasonic Frequency: An infrasonic frequency is a frequency lying below the audio frequency range, nominally below 15 Hz.

Input Impedance: (See "Mechanical Vibrating Systems", Mechanical Impedance, and Mechanical Mobility.)

Input Mobility: (See "Mechanical Vibrating Systems", Mechanical Impedance, and Mechanical Ability.)

Insertion Loss: The insertion loss, in decibels, resulting from the insertion of an element into a transmission system is 10 times the logarithm to the base 10 of the ratio of the power delivered through the system before the insertion of the element to the power through the system after the element is inserted. (Reference 1.)

Intensity: (See Acoustic Intensity.)

Interference: When two waves or signals of the same or nearly the same frequency are added together they tend to reinforce or cancel each other. The reinforcement or cancellation is called interference. Lloyd's mirror is an example of wave interference. (See Lloyd's Mirror.)

Inviscid: Inviscid is an adjective meaning the absence of viscosity in a fluid. Most acoustic propagation theories assume that the medium is an inviscid fluid. In general, this is a valid assumption for acoustics.

Isolation: (See Vibration Isolation.)

Isotropic: Isotropic as applied to an acoustic medium means that wave propagation is of equal speeds in all directions.

Isotropic Sound Field: (See Diffuse Sound Field.)

K_{13}, K_{33}, K_{15}, K_t, K_p: These constants are coupling coefficients between strain and voltage in piezoelectric materials. (See Piezoelectricity.)

Laminar Flow: Laminar means layered; in laminar flow the flow is equivalent to many thin layers of fluid sliding over one another with no mixing between layers. The forces which control the slippage rate between layers of ideal fluids (called Newtonian fluids) are linearly proportional to the slippage rate and are related to the slippage rate by the viscosity coefficient of the fluid. In non-Newtonian fluids the relationships are more complicated. Laminar flow, characterized by low Reynold's numbers (see Reynold's number), produces no flow noise. At higher Reynold's numbers, the flow becomes disorganized or turbulent. In turbulent flow there are rapid, random pressure fluctuations which produce noise. (See Flow Noise, Flow Induced Noise.)

Lateral Wave: (See "Basic Acoustics", Types of Waves.)

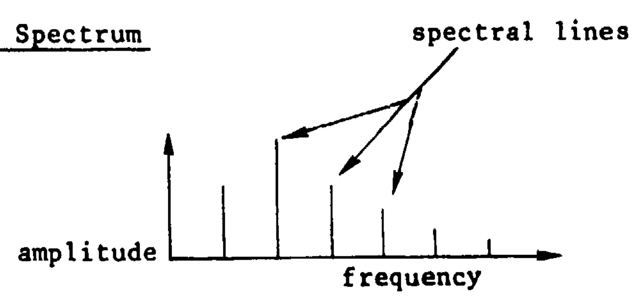
Layer: Layer is an abbreviated expression taken to mean the surface layer of water in the deep ocean which, because of wave-induced mixing, has a relatively constant velocity of sound propagation. The sound propagation characteristics within the layer are quite different from those beneath the layer so its existance must be taken into account when trying to predict sonar performance. Surface layer thickness varies from nearly zero in calm weather to on the order of several hundred feet, according to the weather, latitude, time of day, etc.

Lazan Shaker: A Lazan shaker produces a linear oscillating force from counter-rotating eccentric weights. Lazan shakers are useful for generating large forces at low frequencies, such as required to shake ship hulls or buildings.

Leakage: (See Shadow Zone.)

Level, (L): A level of a quantity, in decibels, is twenty times the logarithm of the ratio of that quantity to a reference quantity of the same kind. The base of the logarithm, the reference quantity, and the kind of level must be indicated. The kind of level is usually indicated by the use of a compound term such as sound power level or sound pressure level. The reference quantity remains unchanged, whether the given quantity is peak, root-mean square, or otherwise. (Reference 3.)

Line Spectrum: A line spectrum is a spectrum whose components occur only at a number of discrete frequencies. A spectrum of a periodic signal is a line spectrum. (Reference 1.)



Linear System: A linear system is a system in which the output amplitude is characteristically proportional to the input amplitude.

Live Room: A live room is a room that is characterized by an unusually small amount of sound absorption, resulting in long decay times for reverberant sound. (Reference 1.)

Lloyd's Mirror Effect: Lloyd's mirror effect is an interference effect observed when both source and receiver are near the ocean surface and are separated by a range much greater than their depth. (See Interference.)

Lobes: (See Beam Pattern.)

Logarithmic Decrement (Δ): The logarithmic decrement is the natural logarithm of the ratio of any two successive amplitudes of like sign in the decay of a single-frequency oscillation. (See "Mechanical Vibrating Systems".)

Longitudinal Wave: (See "Basic Acoustics", Types of Waves.)

Loss Tangent: The loss tangent of a material is the tangent of the damping factor. (See Damping Factor.)

Loudness: Loudness is the intensity attribute of an auditory sensation, in terms of which sounds may be ordered on a scale extending from soft to loud. Loudness depends primarily upon the sound pressure of the stimulus, but it also depends upon the frequency and wave form of the stimulus. (See Sone.) (Reference 3.)

Loudness Contour: A loudness contour is a curve that shows the related values of sound pressure levels and frequency required to produce a given loudness sensation for the typical listener. (Reference 3.)

Loudness Level: Loudness level of a sound, in phons, is numerically equal to the median sound pressure level, in decibels, relative to 20μ Pa, of a free progressive wave of frequency 1000 Hz presented to listeners facing the source of the sound, which in a number of trials is judged by the listeners to be equally loud. The manner of listening to the unknown sound, which must be stated, may be considered one of the characteristics of that sound. (Reference 3.)

Low-Pass Filter: A low-pass filter is a wave filter having a single transmission band extending from zero frequency up to some critical or cutoff frequency, not infinite. It passes low frequencies and does not pass high frequencies. (Reference 1.)

Lumped Parameter Vibrating System: (See Continuous Vibrating Systems.)

Magnetostriction: Magnetostriction is the phenomenon wherein ferromagnetic materials deform when subjected to an external magnetic field. Also, magnetostriction is the converse phenomenon in which mechanical strains cause a change in the magnetic induction of a ferromagnetic material. (Reference 1.)

Magnetostriction Transducer: A magnetostriction transducer is a transducer that depends for its operation on the interaction between the magnetization and the deformation of a material having magnetostrictive properties. The strain produced by a magnetic field on magnetostrictive material does not reverse when the field reverses, so a bias field is necessary to avoid frequency doubling in this type of transducer. (Reference 3.)

Main Response Axis (MRA): (See Principal Axis.)

Major Lobe: (See Beam Pattern.)

Mass: Mass is the property of a body which resists changes of velocity. Mass is one of three types of elements of a mechanical vibrating system, the other two being damping and stiffness.

Mass-Law: Mass-law describes the behavior of sound transmission through walls or barriers over certain frequency ranges and angles of incidence in which the amount of sound transmitted is inversely related to the mass per unit area of the wall and directly proportional to the frequency of the sound.

Mechanical Impedance: Mechanical impedance is the ratio of driving force to velocity during simple harmonic motion. (See "Mechanical Vibrating Systems".)

Mechanical Mobility: Mechanical mobility is the ratio of velocity to driving force during simple harmonic motion. (See "Mechanical Vibrating Systems".)

Microbar (μ bar): A microbar is a pressure of 1.019 $\sim$ 1 Dyne/cm^2. The microbar was formerly used as a reference pressure for sound pressure levels in decibels. Currently approved references are 20 μPa = 0.0002 μbar for sound pressure level in gaseous media and 1 μPa (see Micropascal) for sound pressure levels in liquids.

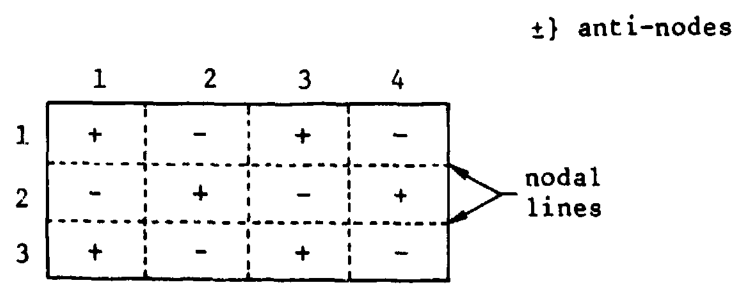
Micropascal: One micropascal is 10^{-6} n/m^2. One micropascal is the reference pressure unit for sound pressure level in decibels in liquids.

Microphone: A microphone is an electroacoustic transducer that responds to sound waves and delivers essentially equivalent electric waves. (Reference 1.)

Mobility: (See "Mechanical Vibrating Systems".)

Modal Numbers: Modal numbers are used to designate normal or resonant modes in a vibrating system. The normal modes are commonly numbered beginning with the mode of lowest resonant frequency and following in order of resonant frequency. Higher numbered modes are called higher order modes. Two or more modes may have the same resonant frequency. For more complicated plate or shell vibration modes, designation is by number pairs (m, n) where m and n are the number of anti-nodes in two dimensions.

The (4, 3) mode of a vibrating plate



Mode of Vibration: In a system undergoing vibration, a mode of vibration is a characteristic pattern assumed by the system, in which the motion of every particle is simple harmonic with the same frequency. Two or more modes may exist concurrently in a multiple-degree-of-freedom system. (Reference 1.)

Modulus of Elasticity: the modulus of elasticity of a solid is a factor which relates its stress vs strain under different test configurations. Different moduli are Young's modulus, shear modulus, and bulk modulus. (See "Sound in Solids".)

Monopole: A monopole is a point source of sound which radiates equally in all directions. A monopole receiver responds equally to excitation from all directions. A monopole is described as omnidirectional. (See "Basic Acoustics".)

Monostatic: Monostatic refers to a situation where an active sonar projector and a receiver are at the same position relative to a target, as opposed to bistatic which places the projector and echo receiver in different positions.

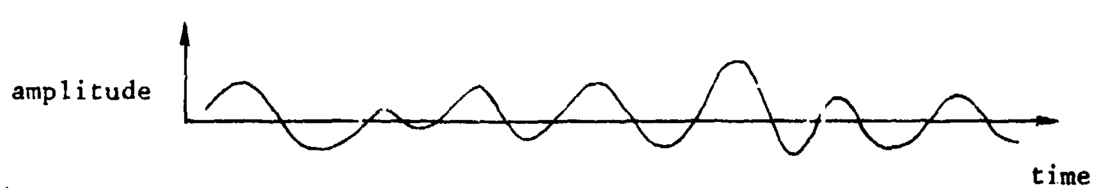
Moving-Coil Transducer: A moving-coil transducer is a transducer in which a moving coil either generates a force against a permanent magnet when supplied with a voltage or generates a voltage at the coil output when the coil is moved in the field of a permanent magnet. Two basic equations governing moving coil transducers are F=Bli, where the force, F, is the product of the magnetic field, B, the length of wire, l, and the current, i, in the wire; and E=Blv where the voltage out, E, is the product of B, l, and the relative velocity, v, of the coil and magnet.

Multi-Mode Hydrophone: A multi-mode hydrophone is a hydrophone which is designed to take advantage of the directivity of a higher order mode of transducer element vibration. Higher modes are directive and are ordinarily an undesirable feature in hydrophone designs which are intended to be omnidirectional.

Multiple-Degree-of-Freedom System: A multiple-degree-of-freedom system is one for which two or more coordinates are required to define completely the position of the system at any instant. (Reference 1.)

Narrow-band Random Noise: Narrow-band random noise is random noise having frequency components only within a narrow band. It has the appearance of a sine wave whose amplitude and phase slowly vary.

Narrow-band
Random Noise



Natural Frequency: (See Normal Modes of Vibration.)

Near-Field: The acoustic near-field is best defined in a negative manner. It is the acoustic field too near the source to be considered far-field. (See Far-Field.) The near-field is called the Fresnel region.

Neper (Np): The neper is a unit of level when the logarithm is on the Napierian base e. A level in Nepers of a quantity p with reference quantity p_o is Level = $\log_e \frac{p}{p_o}$. Nepers are rarely used. 1 Neper = 8.686 dB. (Reference 1.)

Node: A node is a point, line, or surface in a standing wave where some characteristic of the wave field has essentially zero amplitude. The appropriate modifier should be used before the word "node" to signify the type that is intended; e.g., displacement node, velocity node, and pressure node. (Reference 1.)

Noise: Noise is any undesired sound. By extension, noise is also any unwanted disturbance such as undesired electric waves in a transmission channel or device. (Reference 1.)

Noise Criteria: Noise criteria are a series of curves developed to give a quantitative measure of noisiness.

Noise Dosimeter: A noise dosimeter is a device that records its accumulated exposure to airborne noise over a given period of time. Noise dosimeters commonly measure A-weighted sound level. (See A-Weighted Sound Level.)

Noise Level: Noise level is the level of noise, the type of which must be indicated by further modifier or context. The physical quantity measured (e.g., voltage), the reference quantity, the instrument used, and the bandwidth or other weighting characteristics must be indicated. (Reference 1.)

Noise-Limited Condition: A noise-limited condition is one in which signals to be measured are masked or nearly masked by noise.

Non-Linear: A system or system element is non-linear if it fails to meet requirements for linearity. (See Linear System.) All systems are ultimately non-linear if the input is large enough, a situation called overdriving. Examples of common non-linear system elements for any input are coulomb dampers and snubbers. Systems that chatter are also non-linear. Non-linear systems have a unique characteristic of "locking in" to a single frequency. This "locking in" is one means of identifying a non-linear system. (See "Mechanical Vibrating Systems".)

Non-Linear Array: (See Parametric Array.)

Non-Newtonian Fluid: (See Laminar Flow.)

Normal Probability Density or Distribution: (See Gaussian Probability Distribution.)

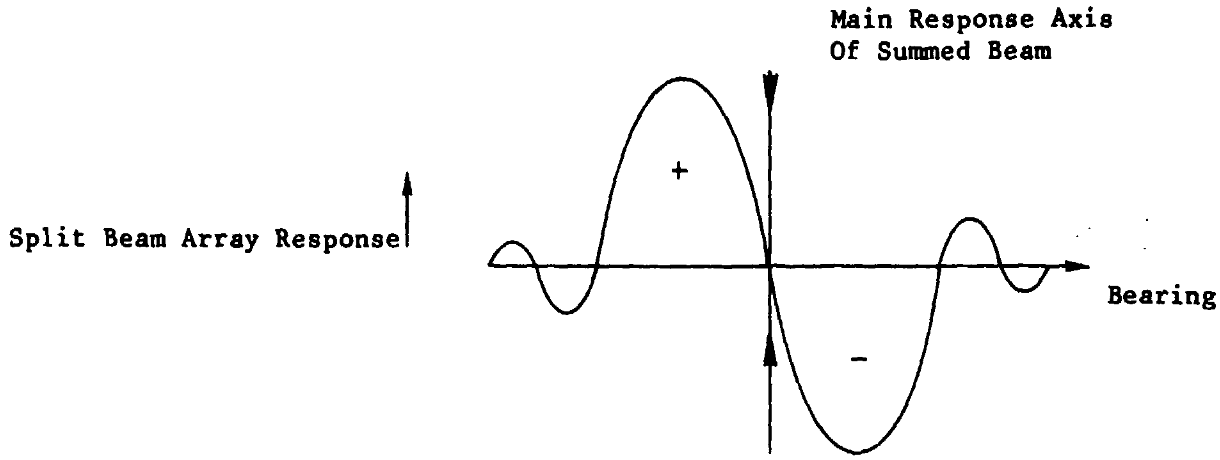
Normal Incidence: (See Angle of Incidence.)

Normal Mode of Vibration: A normal mode of vibration is a mode of free vibration of an undamped system. In general, any composite motion of the system is analyzable into a summation of its normal modes. Vibration in a normal mode occurs at a natural frequency of the undamped system. (Reference 1.)

Notch Filter: (See Band Elimination Filter.)

Null: A null is a direction in a beam pattern of a transducer or array which has zero response. (See Beam Pattern.)

Null Steering: Null steering describes a feedback system that keeps an array of hydrophones steered toward a target. The array of hydrophones is split in half (into split beams), the signal on one half is delayed, then recombined to produce a null in the receiving beam on the principal axis of the array. If the target signal is to the right or left of the null, an error signal is generated to steer the array toward the target. A bearing deviation indicator is the error sensing portion of the null steering system. (See Bearing Deviation Indicator.)



Null in Split Beam

Octave: An octave is the interval between two frequencies having a ratio of two to one. Standard octave bands have been specified and are given in the text. (See "Decibels, Frequency Analyses and Standard Graphs.") (Reference 1.)

Omnidirectional Hydrophone, Omnidirectional Microphone: An omnidirectional hydrophone or microphone has a response essentially independent of angle of arrival of the incident sound wave. (Reference 1.)

Oscillation: Oscillation is the variation with time of the magnitude of a quantity so that it is alternately greater and smaller than a given reference. (Reference 1.)

Output Impedance: (See "Mechanical Vibrating Systems"/Mechanical Impedance and Mechanical Mobility.)

Output Mobility: (See "Mechanical Vibrating Systems"/Mechanical Impedance and Mechanical Mobility.)

Overside Noise: Overside noise is the noise measured by hydrophones hanging over the side of a moored ship. During an overside noise survey a selected sequence of auxiliary machines are run to obtain an estimate of their contribution to the ship's overside noise spectrum. (Reference 4.)

Own-Ship's Noise: (See Platform Noise, Self-Noise.)

Parametric Array: A parametric hydrophone array is one which radiates two or more high frequency sounds at high intensity. The frequencies radiated beat against each other in a non-linear manner to produce a very narrow beam pattern at the (low) difference frequency. The beam pattern so radiated is much narrower than could be directly radiated from the array at such a low frequency which is a desirable effect. Parametric arrays are very inefficient, however. Parametric arrays are also called non-linear or virtual arrays.

Particle Velocity: The particle velocity in a sound-field is the velocity of a given infinitesimal part of the medium, with reference to the medium as a whole. Particle velocity is proportional to the pressure gradient (see Pressure Gradient). The reference unit for particle velocity is 10^{-6}cm/s = 0.394×10^{-6}in./s. If small particles are suspended in a medium (such as smoke in air or silt in water), particle velocity can be observed directly through a microscope as minute oscillations of individual particles. (Reference 1.)

Pascal (Pa): A Pascal is a unit of pressure of one newton per square meter.

Passive Sonar (Listening Sonar): Passive sonar is the method or equipment by which information concerning a distant object is obtained by evaluation of the sound received from it. (References 1 and 4.)

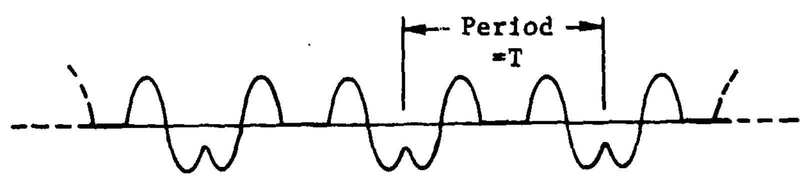
Passive Transducer: (See Active Transducer.)

Peak Sound Pressure: The peak sound pressure for any specified time interval is the maximum absolute value of the instantaneous sound pressure in that interval. (Reference 1.)

Peak-to-Peak Value: The peak-to-peak value of an oscillating quantity is the algebraic difference between the extremes of the quantity. Peak-to-peak value is obviously twice the peak value of an oscillating quantity with zero mean. (Reference 1.)

Period: (See Periodic Quantity.)

Periodic Quantity: A periodic quantity is an oscillating quantity whose values recur for certain increments of the independent variable which is generally time. (Reference 1.)



Example of a Periodic Quantity

If a periodic quantity v is a function of t, then

$$v = f(t) = f(t + T) = f(t + nT)$$

where T, a constant, is a period of v, and n is any whole number.

In general, a periodic function can be expanded by Fourier Series into an equivalent sum of sine waves whose frequencies are harmonics of the fundamental frequency which is 1/T Hz.

Phase: The phase of a point on a plot of a periodic function is that fraction of the period between that point and an arbitrary reference point. Phase angle is that fraction multiplied by 2π (for radian angles) or 360° (for phase angle in degrees). The phase between two signals is that fraction of a period between the arrival times of comparable points on each signal. Again, this phase may be represented as an angle in radians or degrees. (Reference 1.)

Phase Angle: (See Phase.)

Phase Velocity: (See Group Velocity.)

Phon: (See Loudness Level.)

Pickup: (See Transducer.)

Piezoelectric Transducer: A piezoelectric transducer is a transducer that depends for its operation on the interaction between the electric charge and the deformation of piezoelectric crystals or ceramics. (Reference 1.)

Piezoelectricity: Piezoelectricity is the property exhibited by some natural crystals and manufactured ceramics which, when subjected to strain in suitable directions, develop an electric charge proportional to the strain. Inverse piezoelectricity is the effect in which mechanical strain is produced when these materials are subjected to an external electric field; the strain is proportional to the electric field.

Ping: Ping is the word used to describe the transmitted sound of an active sonar. It is usually a gated sine wave that is cyclically repeated.

Pink Noise: Pink noise is noise whose noise-power-per-unit-frequency is inversely proportional to frequency over a specified range. (Reference 5.)

Plan Position Indicator (PPI): A plan position indicator is a polar display of the output of an active sonar. Positions of the target are displayed relative to the own ship's position which is in the center of the display.

Plane Wave: A plane wave is a wave in which the wave fronts are everywhere parallel planes normal to the direction of propagation. (Reference 4.)

Platform Noise: Platform noise is own ship's noise as measured by omnidirectional hydrophones located in various positions throughout the ship.

Power Spectral Density: Power spectral density is the spectrum of the power of a signal, the power present in each frequency band.

Power Transfer Theorem: The power transfer theorem states that for maximum possible power transfer between two systems, the output impedance of one must be matched with the conjugate of the input impedance of the other. Conversely, there is relatively little power transferred if the output and input impedances are greatly mismatched. (See Conjugate Impedance.)

Precursor: A precursor is the part of a broad band pulse from a distant source that arrives first in a dispersive medium.

Pressure Doubling: Pressure doubling describes an acoustic boundary which is perfectly rigid (zero acoustic velocity) where the pressure doubling results from the addition of the incident and reflected waves. A water/air surface, as seen from the air, is very nearly a pressure doubling boundary. Pressure doubling implies total reflection.

Pressure Gradient: Pressure gradient is the slope of the instantaneous acoustic pressure distribution in an acoustic wave field. Special hydrophones and microphones can detect pressure gradient which is proportional to particle velocity and frequency.

Pressure Microphone: (See Microphone.)

Pressure Release: Pressure release describes an acoustic boundary characterized by zero acoustic pressure. Reflection is complete but out of phase at a pressure release boundary. Sample pressure release boundaries are the water/air surface as seen from the water side, and very soft underwater acoustic tiles which have large air-filled cavities. Decouplers are acoustic materials which provide a pressure release surface. Compliant tubes are an example of a pressure release surface.

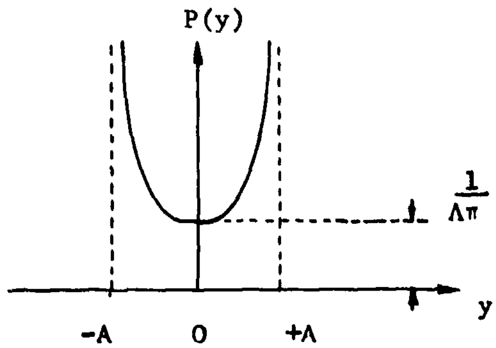
Pressure Wave: A pressure wave is a sound wave or compressional wave. (See Basic Acoustics - Types of Waves.)

Principal Axis: The principal axis of a transducer or array used for sound emission or reception is a reference direction for angular coordinates used in describing the directional characteristics of the transducer or array. It is usually an axis of structural symmetry, or the direction of maximum response; but if these do not coincide, the reference direction must be described explicitly. The principal axis of an array is called its main response axis (MRA) (see Beam Pattern.) (Reference 1.)

Probability: Probability is the likelihood of given occurrence, expressed as a fraction of unity.

Probability Density: Probability density is a graph of the probability of an event occurring, plotted against the different possible events. The most common probability density is the Gaussian probability density. (See Gaussian Probability Density.) Another plot of interest is the probability density of a sine wave which is plotted below:

Probability Density of a Sine Wave, $y = A \sin x$



Probability Density, $P(y) = \dfrac{1}{A\pi\sqrt{1-\dfrac{y^2}{A^2}}}$

for $|y| < A$; $P(y) = 0$ for $|y| > A$.

Probe Hydrophone: (See Sound Probe.)

Probe Microphone: (See Sound Probe.)

Projector: A projector is an underwater acoustic transmitter or sound source.

Propagation Loss: Propagation loss may be defined as the transmission loss associated with any given length of ray path in the water.

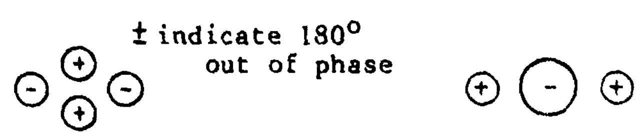
Propeller Singing: (See Singing.)

Pulse Trap: A pulse trap is a chamber which dissipates or cancels pressure fluctuations in a fluid piping system. These pulsations are caused by pump impellers.

Pulse Tube: A pulse tube is an impedance tube where the acoustic pulses which are reflected or transmitted by an acoustic material are the measured parameters rather than standing wave amplitude and phase. As a rule of thumb, in water, pulse tubes must be used where frequencies are less than 35.141 divided by the diameter in inches. Discarded large bore gun barrels make good pulse tubes. (See Impedance Tubes.)

Quadrupole: A quadrupole is a combination of four monopole sound sources phased in pairs and used to represent an elemental source of sound from a turbulent source of flow noise.

Quadrupoles of Four Sources



Tesseral Quadrupole   Axial Quadrupole

Quality Factor (Q): The quality Q is a measure of the sharpness of resonance or frequency selectivity of a resonant vibratory system having a single degree of freedom, either mechanical or electrical. (See "Mechanical Vibrating Systems.") (Reference 1.)

Radiated Noise: Radiated noise is the noise radiated underwater by an underwater vehicle that can be detected at large distances. (Reference 4.)

Radiation Impedance: Radiation impedance is the acoustic impedance effect on an object due to its own vibration (see Acoustic Impedance.)

Random Noise: Random noise is an oscillation whose instantaneous magnitude is not specified for any given instant of time. The instantaneous magnitudes of a random noise are specified only by probability distribution functions giving the fraction of the total time that the magnitude, or some sequence of magnitudes, lies within a specified range. A random noise whose instantaneous magnitudes occur according to the Gaussian distribution is called "Gaussian random noise." (See Gaussian Probability Distribution.) (Reference 1.)

Ray: A ray is a conceptual quantity which represents the direction of travel of an acoustic wave front.

Ray Path: The energy associated with a point on a wave front moves along a line known as a ray path. The sound ray paths encountered in acoustics are analogous to the light ray of optics. Ray paths and wave fronts are mutually perpendicular. Ray paths are governed by Snell's law. (See Snell's Law.)

Ray Trace: Ray trace is a process for predicting the regions of sound reception from a given source in the deep ocean. The process is based on Snell's law and the sound velocity profile of the ocean (See Sound Velocity Profile) and is almost always computerized.

Rayl: The rayl is the formerly used unit of specific acoustic impedance. A Rayl in the MKS system (generally capitalized) is equal to 1 n-sec/m^3. A cgs rayl (not capitalized) is 1 dyne-sec/cm^3. 10 MKS Rayls = 1 cgs rayl. In the standard metric system, the unit of specific acoustic impedance is the Pascal-second per meter which is equal to the MKS Rayl.

Rayleigh Wave: (See "Basic Acoustics," Types of Waves.)

Recognition Differential: The recognition differential is the excess signal necessary for a sonar operator to detect a signal above the limiting noise of the system. It is expressed in decibels and is the one parameter in the sonar equation which includes the human factor in sonar operation. (See "Parameters of Sonar Performance".)

Reflectivity: Reflectivity is a level in decibels of the ratio of the reflected sound pressure to the incident sound pressure on a reflecting surface.

Refraction: Acoustic refraction is the process by which the direction of sound propagation is changed due to spatial variation in the speed of sound in the medium. Acoustic refraction is governed by Snell's law. (See Snell's Law.) (Reference 1.)

Refraction Loss: Refraction loss is that part of the transmission loss which is due to refraction in the medium. These losses arise from non-uniformities in the medium. (Reference 1.)

Resonance: Resonance of a system in forced oscillation exists when any change, however small, in the frequency of excitation causes a decrease in the response of the system. (Reference 1.)

Resonance Frequency (Resonant Frequency): A resonance frequency is a frequency at which resonance exists. In case of possible confusion, the type of resonance must be indicated, e.g., velocity resonance frequency, since velocity resonance, for example, may occur at a frequency different from that of displacement resonance. (Reference 1.)

Reverberation: Reverberation, in architectural acoustics, is the persistence of sound in an enclosed space as a result of multiple reflections after the sound source has stopped. In sonar terminology, reverberation is sound scattered back towards the source, principally from the ocean surface (Surface Reverberation) or bottom (Bottom Reverberation), and from small scattering sources in the medium such as bubbles of air and suspended solid matter (Volume Reverberation). In either case, reverberations as defined sound the same to a listener, hence the spill-over of the term from architectural acoustics to sonar. (Reference 1.)

Reverberation Index: Reverberation index is a measure of the ability of an echo-ranging transducer to distinguish the desired echo from the reverberation. It is computed from the directivity patterns as ratio in decibels of the bottom, surface, or volume reverberation response of a specific transducer to the corresponding response of a nondirectional transducer.

Reverberation Room: A reverberation room is a room having a long reverberation time. Design features are always added to make the sound field therein as diffuse as possible so that sound level is independent of its position of measurement. Reverberation rooms are used to measure sound power of a source and characteristics of acoustic materials. (Reference 1.)

Reverberation Time: The reverberation time of a room is the time that is required for the mean-square sound pressure level therein, originally in a steady state, to decrease 60 dB after the sound source is stopped. The effective sound absorption in the room can be computed from the dimensions and the reverberation time. Reverberation time affects speech intelligibility in a room. Long reverberation times reduces intelligibility of speech. (Reference 1.)

Reynold's Number (Re): The Reynold's number is an indicator of the relative values of flow velocity, fluid friction in the flow, and the characteristic length of a body in a flow field. Its magnitude is a common indicator of the characteristic of the flow field past the body, whether it is turbulent or laminar. The formula for the Reynold's number is $R_e = \frac{\rho V d}{\mu}$, where ρ = fluid density, V = flow velocity, μ = kinematic viscosity, and d = a characteristic length associated with the body such as length, distance from leading edge, diameter, etc, depending on the shape of the body. Reynold's numbers are dimensionless and are useful to help insure valid model experiments. The Reynold's number at the onset of turbulence is called the critical Reynold's number.

Ribbon Transducer: A ribbon transducer is a moving-conductor transducer in which the moving conductor is in the form of a thin ribbon. Ribbon transducers respond to particle velocity or pressure gradient. (See Pressure Gradient.) (Reference 1.)

Roll-Off: Roll-off is the slope of a filter skirt (see Filter Skirt) expressed in decibels per octave or decibels per decade. A sharp roll-off would be in excess of about 12 dB per octave or 40 dB per decade. Roll-off is also a form of equalization. (See Equalization.)

Room Constant: The room constant is equal to the product of the average absorption coefficient of the room and the total internal area of the room divided by the quantity one minus the average absorption coefficient. The room constant is used to predict the reverberant sound level in a room due to a source of a given sound power and directivity. (See "Room Acoustics".) (Reference 1.)

Sabin The Sabin is a unit of absorption having the dimensions of square feet. The metric Sabin, which is in internationally recognized units and is therefore preferred, has the dimension of square meters. The Sabin as one square unit is the equivalent of one square unit of total sound absorption, easily visualized as equivalent to an open window of the same area in the wall of a room. (Reference 1.)

Scanning Sonar: An active scanning sonar is an echo-ranging system in which the ping is transmitted simultaneously throughout the entire angle to be searched. Then a rapidly rotating narrow beam scans for returning echoes. A passive scanning sonar does the same scan, listening only.

Scattering: (See Acoustic Scattering.)

Scattering Cross Section: The acoustic scattering cross section of an object is an area equal to 4π times the product of the mean square sound pressure scattered by the object, averaged over a sphere of unit radius surrounding the object, and the square of the unit radius, divided by the square of the sound pressure of the plane wave incident upon the object. The unit of the cross section is the square of the unit radius. In symbols, if σ is the scattering cross section, p_s^2 the average mean-square scattered sound pressure, r_o the unit radius, and p_i^2 the square of the incident sound pressure,

$$\sigma = \frac{4\pi p_s^2 r_o^2}{p_i^2}$$

Actual measurements must be made at a distance sufficiently great that the sound appears to be scattering from a single point called the acoustic center. (Reference 1.)

Scattering Differential: The scattering differential is the amount by which the level of the scattered mean-square sound pressure averaged over all directions at a specified unit distance from the effective acoustic center of the object exceeds the plane-wave free-field pressure level of the sound incident upon the object. The scattering differential of an object is 10 times the logarithm to the base 10 of the ratio of the scattering cross section to the area of the sphere of unit radius surrounding the object. In symbols, if Δ is the scattering differential, and the other symbols are those of the definition above:

$$\Delta = 10 \log \left(\frac{\sigma}{4\pi r_o^2}\right) = 10 \log \frac{p_s^2}{p_i^2}$$

If the scattering differential is a function of frequency or pulse length of the incident sound or of the orientation of the object, these factors should be specified. (Reference 1.)

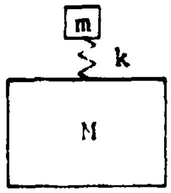
Scattering Loss: Scattering loss is that part of the transmission loss due to scattering within the medium or due to roughness of the reflecting surface. (Reference 1.)

Schlieren Method: The Schlieren method is the technique by which light refracted by the density variations resulting from sound waves is used to produce a visible image of a sound field. (Reference 1.)

Searchlight Sonar: A searchlight sonar is a sonar which uses the same narrow beam to transmit and receive (as opposed to scanning sonar).

Sea State: Sea state is the state of agitation - wave height, swell height, etc - represented by numbers 0 through 6. (See Acoustic Sea State.)

Seismic Mass: A seismic mass is a large mass (some are on the order of five or ten tons) which is isolated by low frequency vibration mounts from any laboratory floor vibrations. Its useful characteristic is that it is of infinite mass as far as many experiments are concerned. Consider a mass, m, on a spring, k, which in turn is mounted on a seismic mass, M. The resonant frequency is $f_n = \frac{1}{2\pi}\sqrt{\frac{k}{\frac{mM}{M+m}}}$. If M is much



bigger than m, then $m+M \approx M$, $\frac{mM}{M+m} \approx m$, and

$f_n \approx \frac{1}{2\pi}\sqrt{\frac{k}{m}}$; i.e., the seismic block is essentially an infinite mass for experimental purposes.

Self-Induced (Self-Excited) Vibration: The vibration of a mechanical system is self-induced if it results from conversion, within the system, of non-oscillatory excitation to oscillatory excitation. Chatter (see Chatter) and flutter (see Flutter) are self-induced vibrations. (Reference 1.)

Self-Noise: Self-noise is own-ship's noise as measured through its sonars.

Separation Point: The separation point is a point at which, under high velocity flow, the boundary layer and a body separate. Separation can occur with both bluff and streamlined bodies. The void left after separation is filled with fluid vortices - a kind of backwash - at reduced pressure. The reduced pressure can cause cavitation in liquids. (Reference 4.)

Shading: Shading is a method of controlling the directional response pattern of a transducer or array through control of the distribution of phase and amplitude of the transducer or array. Generally, shading is used to reduce side lobes and to control the beamwidth of the main lobe. (Reference 1.)

Shadow Zone: A shadow zone is a region of the ocean relative to a sound source which is empty of ray paths from the source. A ray trace is used to define shadow zones. Sound that is received in a shadow zone is said to be "leakage", to have "leaked in" to the shadow zone. Leakage is one piece of evidence that ray acoustics is only an approximation.

Shaker: A shaker is a device which imparts an oscillating force or velocity to a mechanical system. A "velocity" shaker, also called a brute force shaker, imparts an oscillation of fixed velocity or displacement amplitude unless excessive load causes it to stall. (See Lazan Shaker.)

Shake Table: A shake table is a table mounted on a shaker, the table serving as a convenient way to mount objects to be shaken. Shake tables are generally of the brute force type and are used to establish suitability of electronic components for a shipboard environment, for example.

Shape Factor: The shape factor, used for rubber vibration isolation mounts is a number which modifies the elastic material modulus of rubber to account for the geometry of the particular shape of rubber being used. (See text, page 5-5.)

Shear Modulus: (See Modulus of Elasticity.)

Shear Wave: A shear wave is a wave in an elastic medium which causes an element of the medium to change its shape without a change of volume. In an isotropic medium, a shear wave is a transverse wave. (Reference 1.)

Shedding (Strouhal) Frequency: Under certain conditions, steady fluid flow past long thin cylindrical objects, e.g., a hydrophone array suspension cable, will lead to periodic shedding of fluid vortices. Each time a vortex is shed an impulse of force is produced. The frequency of the shedding (hence the frequency of the resulting noise) is predicted by a formula which uses the "Strouhal" number. The formula is:

$$\text{Shedding Frequency (Hz)} = 0.2 \times \frac{\text{fluid velocity in in./sec.}}{\text{Characteristic diameter in inches}}$$

The Strouhal formula is essentially empirically derived and therefore is not exact.

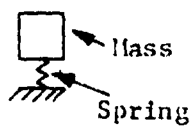
Side Lobes: (See Beam Pattern.)

Signal: A signal is (1) a disturbance used to convey information, (2) the information to be conveyed over a communication system. (Reference 1.)

Simple Sound Source: A simple sound source is a source that radiates sound uniformly in all directions under free-field conditions. A simple sound source is also called a monopole. (Reference 1.)

Singing: Propeller singing is noise radiated from ship propellers at high speeds due to resonant blade vibration excited by vortex shedding.

Single-Degree-of-Freedom System: A single-degree-of-freedom system is one for which only one coordinate is required to define completely the configuration of the system at any instant. (Reference 1.) An example is the simplest possible single-degree-of-freedom spring-mass system.



Smith Chart*: A Smith chart is a graphical means of relating pressure and phase measurements in an impedance tube to the acoustical impedance of a sample material within the tube.

Snell's Law: Snell's Law states that sound waves change direction when passing from one fluid to another in accordance with the formula:

$$\frac{\text{Sin } \Theta_1}{C_1} = \frac{\text{Sin } \Theta_2}{C_2}$$

where C_1 and C_2 are the wave speeds in the media and Θ_1 and Θ_2 are the incident and refracted angles measured from the perpendicular to the fluid interface.

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*P.H. Smith, "An Improved Transmission Line Calculator," Electronics 17, 130 (Jan, 1944) (reference in Beranek, Acoustic Measurements).

Snubber: A snubber is a device used to greatly increase the stiffness of a vibration isolator whenever the displacement becomes larger than a specified value. A snubber is a non-linear element and is intended to limit excursions under shock.

SOFAR: A method of signaling in which most of the sound energy is trapped by and propagates along the deep sound channel. (See Deep Sound Channel.) The signal is usually generated by small explosive charges fired by pressure-actuated fuses upon reaching the critical pressure, or minimum velocity level, which is the axis of the deep sound channel. It is an acronym of the expression "SOund Fixing And Ranging."

Sonar: Sonar is the method or equipment for determining, by underwater sound, the presence, location, or nature of objects in the sea. It is an acronym of the expression "SOund NAvigation and Ranging."

Sonar Dome: (See Dome.)

Sonar Equations: Sonar equations relate the basic sonar parameters - source, target, medium, and signal detection system - for the purpose of describing the detection range of a sonar system under specified conditions or the signal excess at a given range. (See "Parameters of Sonar Performance.") (Reference 1.)

Sone: The sone is a unit of loudness. By definition, a simple tone of frequency 1000 cycles per second, 40 decibels above a listener's threshold, produces a loudness of 1 sone. The loudness of any sound that is judged by the listener to be n times that of 1-sone tone is n sones. (Reference 1.)

Sonic: Sonic is a term which applies to frequencies of sound which are audible.

Sonics: Sonics is the technology of sound in processing and analysis. Sonics includes the use of sound in any noncommunication process. (Reference 1.)

Sound: Sound is an oscillation in pressure, stress, particle displacement, particle velocity, etc, in a medium with internal forces (e.g., elastic, viscous), or the superposition of such propagated oscillations. Sound is also an auditory sensation evoked by the oscillations described above. (Reference 1.)

Sound Absorption Coefficient: (See Absorption of Sound.)

Sound Analyzer: A sound analyzer is a device for measuring the band-pressure level or pressure-spectrum level of a sound as a function of frequency. (Reference 1.)

Sound Channel: (See Wave Guide.)

Sound Energy: The sound energy of a given part of a medium is the total energy in this part of the medium minus the energy which would exist in the same part of the medium with no sound waves present. (Reference 1.)

Sound-Energy Density: The sound-energy density at a point in a sound field is the sound energy contained in a given infinitesimal part of the medium divided by the volume of that part of the medium. (Reference 1.)

Sound-Energy Flux: The sound-energy flux is the average rate of flow of sound energy for one period through any specified area. In a medium of density, ρ, for a plane or spherical free wave having a velocity of propagation, c, the sound-energy flux, J, through the area, S, corresponding to an effective sound pressure, p, is

$$J = \frac{p^2 S}{\rho c} \cos \theta$$

where θ = the angle between the direction of propagation of the sound and the normal to the area S.

Sound Field: A sound field is a region containing sound waves. (Reference 1.)

Sound Intensity (Sound-Energy Flux Density): The sound intensity in a specified direction at a point is the average rate of sound energy transmitted in the specified direction through a unit area normal to that direction at the point considered. In the case of a free plane or spherical wave having the effective sound pressure, p, and the velocity of propagation, c, in a medium of density, ρ, the intensity in the direction of propagation is given by:

$$I = \frac{p^2}{\rho c}.$$

Units of intensity are picowatts (pW) per meter ^{2}. (Reference 1.)

Sound Level. Sound level (not to be confused with sound pressure level) is a weighted sound pressure level, obtained by the use of metering characteristics and the weightings A, B, or C specified in ANSI S1.4-1971. The weighting employed is understood to be A-weighting unless otherwise stated. The reference pressure is 20 μPa. (See "Decibels, Frequency Analyses and Standard Graphs.")

Sound-Level Meter: A sound-level meter is an instrument including an attenuator, microphone, an amplifier, an output meter, and frequency weighting networks for the measurement of noise and and sound levels in a specified manner. Specifications for sound-level meters are given in American Standard Sound Level Meters for Measurement of Noise and Other Sounds. (Reference 1.)

Sound Power Level (Lp): Sound power level in decibels is ten times the logarithm to the base ten of the ratio of a given sound power to a reference sound power. Unless otherwise specified, the reference sound power is 1 pW. (References 1, 2, and 3.)

Sound Pressure (p): Sound pressure is the root mean square sound pressure at a point, unless identified otherwise such as by instantaneous, average (arithmetic mean), or peak. Note that sound pressure as defined by ANSI S1.1-1960(R1971) specifies sound pressure as the instantaneous value rather than rms. The definition above coincides with ANSI's effective sound pressure. (Reference 2.)

Sound Pressure Level (Lp): Sound pressure level in decibels is twenty times the logarithm to the base ten of the ratio of a given sound pressure to the reference sound pressure. Unless otherwise specified, the reference sound pressure is 20μPa in air and 1μPa in liquids. (Reference 3.)

Sound Probe: A sound probe is a device that responds to some characteristic of an acoustic wave (e.g., sound pressure or particle velocity) and that can be used to explore and determine this characteristic in a sound field without appreciably altering that field. (Reference 1.)

Sound-Reflection Coefficient: The sound-reflection coefficient of a surface is the fraction of incident sound energy reflected by the surface. Unless otherwise specified, reflection of sound energy in a diffuse sound field is assumed. (Reference 1.)

Sound Short: A solution in which an intential sound isolation feature is rendered ineffective by an oversight in construction or maintenance techniques.

Sound-Transmission Coefficient: The sound-transmission coefficient of a partition is the fraction of incident sound energy transmitted through it. Unless otherwise specified, transmission of sound energy is assumed to be between two diffuse sound fields. (Reference 1.)

Sound Transmission Loss (R): The sound transmission loss, R, of a partition in dB, in a specified frequency band is the difference between the space-mean-square sound pressure level through a reverberant source room and the space-mean-square sound pressure level in the adjacent reverberant receiving room, plus ten times the logarithm to the base ten of the ratio of the area of the common partition to the total sound absorption in the receiving room. (Reference 3.)

Sound Velocity Profile (SVP): The sound velocity profile is a plot, versus ocean depth for the deep ocean, of the velocity of sound which varies with depth, temperature, pressure, and salinity. Sound velocity profiles are obtained with a bathythermograph, a device lowered from a ship from which the data is being taken. They form the basis for ray traces which predict sound propagation in the ocean. (See Ray Trace.)

Sound Wave: (See "Basic Acoustics" - Types of Waves.)

Sparker: A sparker is a device that transmits an intense pulse of sound underwater. The pulse is generated by an electric arc between two electrodes. A sparker is used, for example, for geological studies of the floor of a body of water. There are other devices which serve the same purpose

Specific Acoustic Impedance: (See Acoustic Impedance.)

Specific Acoustic Mobility: (See Acoustic Mobility.)

Spectrum: The spectrum of a function of time is a description of its resolution into frequency components - amplitude and phase. Spectrum is also used to signify a continuous range of components, usually wide in extent, within which waves have some specified common characteristic; e.g., "audio-frequency spectrum." The term "spectrum" is also applied to functions of variables other than time; e.g., spectrum of spatial frequencies. (Reference 1.)

Spectrum Density: (See Power Spectral Density.)

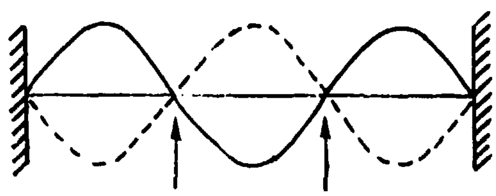
Split Beam: (See Null Steering.)

Spokes: Spokes or spoking is the pattern of sonar self-noise on a PPI scope. (See Plan Position Indicator.)

Spreading Loss: Spreading loss is that part of the transmission loss due to the divergence or spreading of the sound rays in accordance with the geometry of the system; e.g., spherical waves emitted by a point source lose 6 dB in amplitude every time the distance doubles; cylindrical waves lose 3 dB for a doubling of the distance.

Squash Tubes: A squash tube is another term for a compliant tube. (See Compliant Tubes.)

Standing Wave: A standing wave is a periodic wave having a fixed distribution in space which can be the result of interference of progressive waves of the same frequency and kind. Such waves are characterized by the existence of nodes or partial nodes and antinodes that are fixed in space. (Reference 1.)



Static Divergence: (See Divergence.)

Statistical Energy Analysis (SEA): Statistical energy analysis is a technique of dynamically analyzing large mechanical structures by modeling them as circuits for the transmission of vibrational energy. The parameters of the circuits come from statistics of the vibrational characteristics of the structure. Statistical energy analysis is uniquely successful for large structures at high frequencies.

Stave: A stave is part of a sonar array, one or more transducers whose outputs are combined in a fixed manner prior to beam forming. Staves are also constraining rods used in constrained layer pipe damping.

Stiffness: Stiffness is the ratio of change of force (or torque) to the corresponding change in translational (or rotational) displacement of an elastic element. (See Hooke's Law.) (Reference 1.)

Stress Rod: (See Tonpilz Resonator.)

Stripes: Stripes or striping is the appearance of targets or coherent noise on bearing-time recorders. (See Bearing Time Recorder.)

Strouhal Frequency: (See Shedding Frequency.)

Subharmonic: A subharmonic is a sinusoidal quantity having a frequency that is equal to the fundamental frequency divided by a whole number of a periodic quantity to which it is related. (Reference 1.)

Subharmonic Response: Subharmonic response is a system response which is subharmonic to the excitation frequency. (See Subharmonic.) Subharmonic responses are characteristic of some non-linear systems and are impossible with linear systems. (Reference 1.)

Summed Beam: A summed beam is used to mean the total beam formed from the sonar elements, as differentiated from split beam. (See Null Steering.)

Superdirective: Superdirective is an adjective applying to transducers which obtain directivity by measuring pressure gradient instead of pressure.

Surface Duct: Where the sound velocity at some depth near the surface is greater than at the surface, sound rays are refracted toward the surface where they are reflected. The rays alternately are refracted and reflected along the duct.

Surface Layer: (See Layer.)

Surface Reverberation: (See Reverberation.)

Systeme International (SI): The International System of Units was developed by the General Conference of Weights and Measures which is an international treaty organization. The abbreviation SI, derived from the French Systeme International d'Unites is used in all languages. The SI is derived from earlier decimal metric systems and supersedes all of them.

Target Aspect Angle: The angle made by a target heading with the line joining it to the observation point is known as the aspect of the target.

Target Strength: Target strength is equal to ten times the logarithm to the base 10 of the ratio of the intensity of the sound, returned by the target at a distance of one yard from its acoustic center in some direction to the incident intensity from a distant source. As an example, the target strength of a perfectly reflecting sphere with a one-yard radius is 0dB.

Thermal Noise: Thermal noise is the noise of molecules in thermal agitation. In the ocean, thermal noise is detected as acoustic signals which dominate the spectrum of ocean noise above 40 kHz in warm climates.

Third-Octave: The term 1/3-octave band specifies a frequency band whose limits are determined by:

$$f_u/f_l = 2^{1/3},$$

where f_l = lower limit of the frequency band, and
f_u = upper limit of the frequency band.

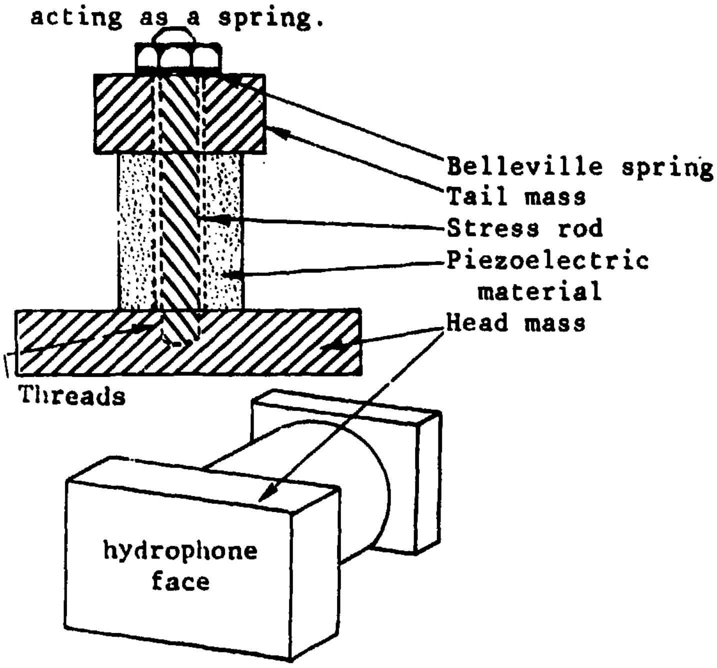
Standard 1/3-octave band center frequencies are given in the text under "Decibel," "Frequency Analyses," and "Standard Graphs."

Time-Bandwidth Product: The product of the time or duration of a sample of a signal and a frequency band of some type enters into many formulas which predict the accuracy of an estimate of signal parameters which can be obtained from a sample.

Time Constant: A time constant is the time required for a system to achieve 36.79% of its ultimate response to a step input.

Tone: A tone is an acoustic signal which is either at a single frequency (a "pure" tone) or is a single dominant frequency with other frequencies present (a "complex" tone). (Reference 1.)

Tonpilz Resonator: A tonpilz resonator (tonpilz is a German word meaning literally "sound mushroom") is a common piezoelectric type of acoustical projector assembled as shown in the sketch. At the design frequency there is a resonance between the head mass and tail mass with the piezoelectric material acting as a spring.



The piezoelectric material is subjected to a static compressive stress by the stress rod and Belleville washer so that the total stress (static plus dynamic) does not lead to tensile failure in the piezoelectric material (which has a low-yield stress in tension). The Belleville washer maintains a high static load, but low dynamic load on the tail mass to keep the stress rod from controlling the resonant frequency. (See Belleville washers.)

Toulis Tubes: (See Compliant Tubes.)

Trace Wavelength: (See Coincidence Effect.)

Transducer: A transducer is a device capable of being actuated by waves from one or more transmission systems or media and of supplying related waves to one or more other transmission systems or media. The waves in either input or output may be of the same or different types (e.g., electric, mechanical, or acoustic). (Reference 1.)

Transfer Impedance: (See "Mechanical Vibrating Systems", Mechanical Impedance and Mechanical Mobility.)

Transfer Mobility: (See "Mechanical Vibrating Systems", Mechanical Impedance and Mechanical Mobility.)

Transient: A transient signal or noise is a signal or noise which is of a shorter duration than the time of observation.

Transition Point: A flow across a surface will be initially laminar at low velocities. As the distance from the leading edge is increased, the stability of the laminar layer will decrease, perhaps until the boundary layer turns completely turbulent. The location at which the transition from laminar to turbulent boundary layer occurs is called the transition point.

Transmissibility: Transmissibility is the non-dimensional ratio of the response amplitude of a system in steady-state forced vibration to the excitation amplitude. The ratio may be one of forces, displacements, velocities, or accelerations. (Reference 1.)

Transmission Loss: Transmission loss is the reduction in the magnitude of some characteristic of a signal, between two stated points in a transmission system. The characteristic is often some kind of level, such as power level or voltage level; in acoustics the characteristic that is commonly measured is sound pressure level. Thus, if the levels are expressed in decibels, the transmission level loss is likewise in decibels. (Reference 1.)

Transverse Wave: (See "Sound in Solids".)

Traveling Wave: A traveling wave is a wave whose wavefronts progress in a specific direction.

Tripping: (See Boundary Layer Tripping.)

Turbulent Flow (Turbulence): (See Laminar Flow.)

Ultrasonic Frequency: An ultrasonic frequency is a frequency lying above the audio frequency range. The term is commonly applied to elastic waves propagated in gases, liquids, or solids. The term "ultrasonic" may be used as a modifier to indicate a device or system intended to operate at an ultrasonic frequency. (Reference 1.)

Ultrasonics: Ultrasonics is the technology of sound at frequencies above the audio range.

Unbalance: Unbalance, as related to a rotor, is that condition which exists when the rotor imparts vibratory force or motion to its bearings as a result of centrifugal forces. (Reference 5.)

Uncoupled Vibration Mode: An uncoupled mode of vibration is a mode that can exist in a system concurrently with and independently of other modes.

Velocity: Velocity is a vector quantity that specifies the time rate of change of position. It is expressed in units of length divided by time and direction relative to a frame of reference.

Velocity Level (L_V): Velocity level, in decibels, is twenty times the logarithm to the base ten of the ratio of a given velocity to the reference velocity. Unless otherwise stated, the reference velocity is 10^{-6}cm/sec (= 0.394 x 10^{-6} in/sec.). The former term for L_V is VdB.

Velocity Microphone: A velocity microphone (or hydrophone) is a microphone (or hydrophone) in which the electric output substantially corresponds to the instantaneous particle velocity in the impressed sound wave. (See Ribbon Transducer, Pressure Gradient.)

Vibration: Vibration is oscillation of a mechanical system.

Vibration Isolation: Vibration isolation is the reduction of forces transmitted from a vibration source to a foundation (or vice versa) achieved by interposing a compliance such as rubber between the two.

Vibration Isolator: A vibration isolator is a resilient support that tends to isolate a system from steady-state excitation.

Vibration, Longitudinal: Longitudinal vibration is a rectilinear vibration caused by the axial compression and extension of bars and wires, including coil springs.

Vibration Meter (Vibrometer): A vibration meter is an apparatus for the measurement of displacement, velocity, or acceleration of a vibrating body. (Reference 1.)

Vibration Mode: (See Mode of Vibration.)

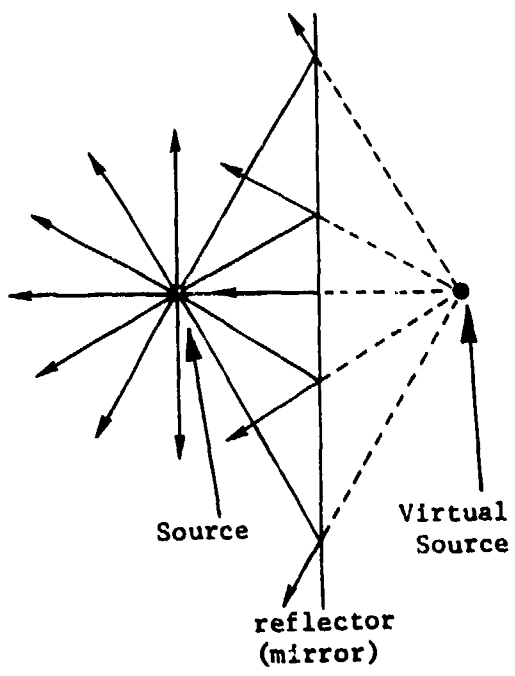
Vibration Transmissibility: Vibration transmissibility is the ratio of response amplitude to excitation amplitude in a vibrating system.

Vibration, Transverse: Transverse vibration is a rectilinear vibration resulting from bending, and is exemplified by a vibrating string.

Virtual Array: (See Parametric Array.)

Virtual Mass: Virtual mass means the apparent mass added to an underwater vibrating system by the water surrounding the system.

Virtual Source: A virtual source is an apparent source of sound waves, at the center of a diverging wavefield. An example of a virtual source is the reflection of an acoustic source from a planar barrier. It helps to visualize an optical analog, a bare light bulb next to a mirror. The light bulb image seen in the mirror is the virtual source.



Viscosity: Viscosity of a fluid is a measure of its resistance to shearing flow. There are two units of viscosity: absolute viscosity, μ, and kinematic viscosity, ν ($= \mu/\rho$) where ρ is the fluid density. In a gas the viscosity increases with increasing temperature; just the opposite occurs with a liquid. Units of viscosity are: (See Boundary Layer.)

$$\nu - \text{ Absolute viscosity} = \text{poise} = 1\ \frac{\text{dyne - sec}}{\text{cm}^2}$$

$$\mu - \text{ Kinematic viscosity} = \text{stoke} = 1\ \frac{\text{cm}^2}{\text{sec}}$$

1 poise = 100 centipoise
1 stoke = 100 centistokes

Viscous Damping: Viscous damping is the dissipation of energy that occurs when a particle in a vibrating system is resisted by a force that has a magnitude proportional to the magnitude of the velocity of the particle and direction opposite to the direction of the particle. (Reference 1.)

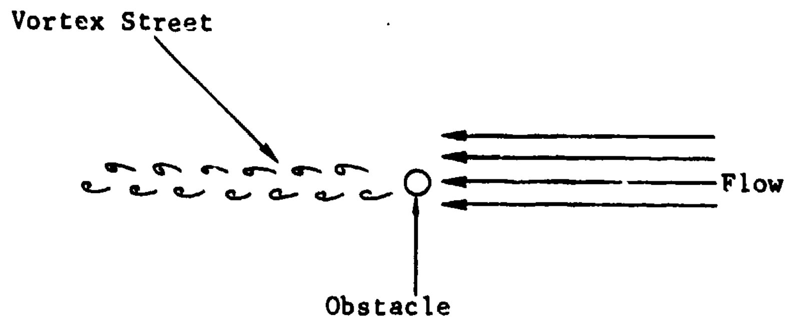
Volume Flow (Volume Velocity): Volume flow is the average acoustic particle velocity over a surface in an acoustic sound field, multiplied by the area of the surface. Volume flow is useful for computing acoustic impedance and the sound radiated through small holes in a barrier.

Volume Reverberation: (See Reverberation.)

Vortex: A vortex is a unit of fluid spinning around a central axis. The axis may or may not be moving. Vortices are generated by flow past bluff bodies, for example. As the flow increases each vortex builds up near the object, then breaks away or sheds, imparting a small impulse to the object. Vortices are shed at a regular rate into a vortex street. (See Vortex Street.) The shedding frequency can be predicted. (See Shedding Frequency.)

Vortex Shedding Frequency: (See Shedding Frequency.)

Vortex Street: A vortex street is a vortex pattern found in the wake of a two-dimensional body. Vortices are normally shed alternately from the opposite sides of a body such that the resulting pattern will occur.



Wake: A wake is a disturbed region in a flow field downstream from a body. A wake also refers to a "tail" which forms behind an acoustic pulse when the medium is dispersive or when a pulse propagates cylindrically in a non-dispersive medium.

Wave: A wave is a disturbance which is propagated in a medium in such a manner that at any point in the medium the quantity serving as measure of disturbance is a function of the time, while at any instant the displacement at a point is a function of the position of the point. Any physical quantity that has the same relationship to some independent variable (usually time) that a propagated disturbance has, at a particular instant, with respect to space, may be called a wave. (Reference 1.)

Wave Filter: (See Filter.)

Wave Front: The wave front of a progressive wave in space is a continuous surface which is a locus of points having the same phase at a given instant. (Reference 1.)

Wave Guide: A sound wave guide or sound channel is any bounded sound medium in which the propagation distances from a source are great compared to the wave guide width. The boundaries may be reflective or may merely gradually bend sound rays back toward the wave guide center as in the deep sound channel. A pulse tube is a cylindrical wave guide, for example.

Wave Interference: (See Interference.)

Wavelength: The wavelength of a periodic wave is the perpendicular distance between two wave fronts in which the displacements have a difference in phase of one complete period. (Reference 1.)

Wave-Table: A wave-table is a table with a shallow pool of water on top. Objects are placed in the water and surface waves are generated to pass around the objects. If talcum powder is sprinkled on the surface of the water the wave patterns are easily seen. The result is a visualization of a rough approximation of an acoustic wavefield.

Weighting Network: A weighting network is an electrical filter or combination of filters which has a frequency response designed to transmit some frequencies at a deliberately reduced amplitude with respect to other frequencies.

White Noise: White noise is a noise whose spectrum density (or spectrum level) is substantially independent of frequency over a specified range. White noise need not be random. (Reference 1.)

Window: (1) A window is the part of a ship's hull in front of a sonar, fulfilling the same function as a sonar dome (see Dome). (2) A spectral "window" is that band of a signal spectrum separated for study. (3) A time "window" is a time band during which a signal is observed.

Young's Modulus: (See Modulus of Elasticity.)

References for Glossary

*1. USA Standard, Acoustical Terminology (including Mechanical Vibration and Shock), ANSI S1.1-1960 (R1976), Copyright 1960.

2. Acoustical and Vibrational Standard Reference Quantities, MIL-STD-1621A (NAVY).

3. From a draft of revised definitions recommended to ANSI, ISO, provided by Mr. L. Herstein, NAVSEA Code 037.

4. Derived from descriptions in NAVSEA 0900-LP-004-3000, Revision 1.

*5. American Standard Terminology for Balancing Rotating Machinery, ANSI S2.7-1964 (R1971); copyright 1964.

*These standards are available from the American National Standards Institute at 1430 Broadway, New York, New York 10018. Material from these standards is reproduced with permission from the American National Standards Institute. In some cases standard definitions have been corrected to bring them up to date, and have been paraphrased where portions do not apply to Navy use. At the time of this writing, S1.1 (reference 1) is being revised. This glossary will be revised when the new S1.1 is issued.

II

MECHANICAL VIBRATING SYSTEMS

CONTENTS

SYMBOLS AND PREFERRED UNITS FOR THIS CHAPTER

Symbol	Quantity	Symbols of Preferred Unit	Preferred Unit
a	Acceleration	m/s^2	Meter per second squared
c	Mechanical Resistance or Damping	N·s/m	Newton second per meter
c_c	Critical Damping Value	N·s/m	Newton second per meter
c_r	Torsional Mechanical Resistance or Damping	N·m·s	Newton meter second
d	Plate Thickness	m, cm	Meter, centimeter
e	Base of Naperian Logarithms	-	(numeric) = 2.71828
f_c	Characteristic Frequency	Hz	Hertz
f_r	Resonance Frequency	Hz	Hertz
f_1, f_2	Frequencies Near f_r With 3dB Less Response	Hz	Hertz
g	Acceleration Due to Gravity	m/s^2	9.80665 meters per second squared
l	Length	m	Meter
m_m	Dynamic Mass	Kg	Kilogram
r	Frequency Ratio f/f_r	-	(numeric)
t	Time	s	Second
v	Velocity	m/s	Meter per second
x	Linear Displacement	m	Meter
A	Area	m^2	Square meter
E	Young's Modulus	Pa/m^2	Pascal per meter squared
F	Force	N	Newton
F_T	Transmitted Force	N	Newton
I	Second Moment of Inertia	m^4	Meter to the fourth power
J	Moment of Inertia	$Kg \cdot m^2$	Kilogram meter squared

SYMBOLS AND PREFERRED UNITS FOR THIS CHAPTER (Cont'd)

SYMBOL	QUANTITY	SYMBOL OF PREFERRED UNIT	PREFERRED UNIT
K	Dynamic Stiffness	N/m	Newton per meter
K_t	Dynamic Torsional Stiffness	Nm/rad	Newton meter per radias
Q	Quality Factor	-	(numeric)
v	Voltage	V	Volts
V	Volume	m^3	Cubic meter
T	Torque	N·m	Newton meter
Y_m	Mechanical Mobility	m/(N·S)	Meter per newton - second
Z	Mechanical Impedance	N·s/m	Newton - second per meter
Z_c	Characteristic Impedance	N·s/m	Newton - second per meter
α	Angular Displacement	rad	Radian
δ	Decay Rate	dB/s	Decibel per second
ζ	Critical Damping Ratio	-	(numeric) $\zeta = c/c_c$
ν	Poisson's Ratio	-	(numeric)
ρ	Density	Kg/m^3	Kilogram per cubic meter
ω	Angular Frequency	rad/sec	Radian per second
Θ	Phase Angle	rad	Radian
Λ	Logarithmic Decrement	-	(numeric)
ψ	Phase Angle	rad	Radian
Ω	Angular Velocity	rad/sec	Radian per second

ELEMENTS OF A LUMPED-PARAMETER VIBRATING SYSTEM

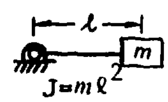
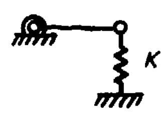
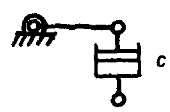
The three types of elements of a lumped-parameter vibrating system are mass, stiffness, and damping. They are in different forms in translational and rotational vibrating systems and must be identified in order to understand any system.

TRANSLATIONAL ELEMENTS

Element	Standard Symbol	Units	Impedance $\left(\frac{F}{V}\right)$	Symbol of Element
Mass	m_m	kilograms pounds	$j\omega m_m$	
Stiffness	K_m	kilograms/meter pounds/inch	$\frac{K_m}{j\omega}$	
Damping	c	kilogram seconds/meter pound seconds/inch	c	

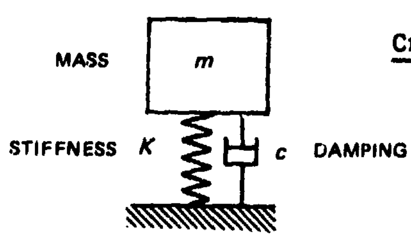
(f = force, v = velocity)

ROTATIONAL ELEMENTS

Element	Standard Symbol	Units	Impedance $\left(\frac{T}{\Omega}\right)$	Symbol of Element
Rotational Inertia	J	kilogram meter^2 pound foot^2	$j\omega J$	
Rotational Stiffness	K_r	newton meter/radian pound foot/radian	$\frac{K_r}{j\omega}$	
Rotational Damping	c_r	newton meter second/radian pound foot second/radian	c_r	

(T - torque, Ω = angular velocity)

Damping and impedance have the same units in each case: impedance is force/velocity for translational systems and torque/angular velocity for torsional systems.

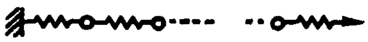
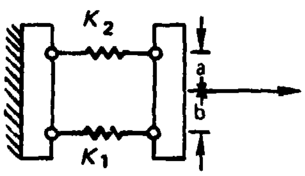
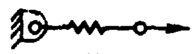


Critical Damping Ratio Defined

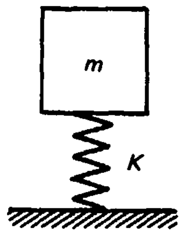
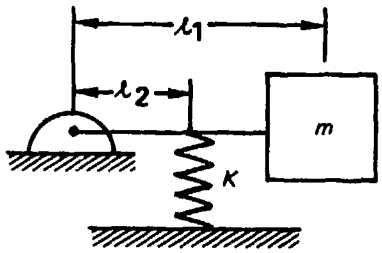
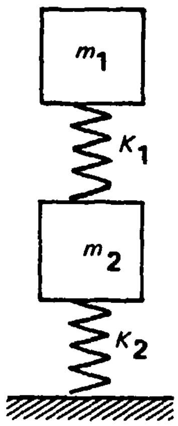
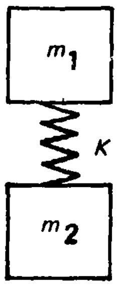
$c_c = \sqrt{4Km}$ Critical value of damping

$\zeta = \frac{c}{c_c}$ Critical damping ratio

EQUIVALENT STIFFNESS OF COMBINED SPRINGS OR VIBRATION MOUNTS

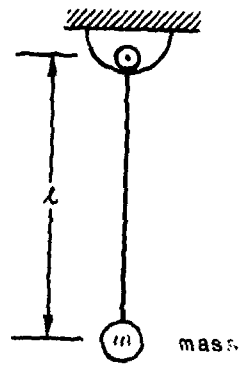
Combined Springs or Vibration Mount		Equivalent Spring or Vibration Mount
	SERIES	
Two Spring		 $K_{eq} = \frac{K_1 K_2}{K_1 + K_2}$
Three Springs		$K_{eq} = \frac{K_1 K_2 K_3}{K_1K_2 + K_2K_3 + K_1K_3}$
"N" Springs		$\frac{1}{K_{eq}} = \frac{1}{K_1} + \frac{1}{K_2} + \text{-----} + \frac{1}{K_N}$
	PARALLEL	
		a = b  $K_{eq} = K_1 + K_2$
		a ≠ b $K = \frac{(a+b)^2}{\frac{a^2}{K_1} + \frac{b^2}{K_2}}$

NATURAL FREQUENCIES OF SOME SIMPLE SPRING-MASS SYSTEMS

SYSTEM	RESONANT FREQUENCY
	$f_r = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$
	$f_r = \frac{1}{2\pi}\sqrt{\frac{K\ell_2^2}{m\ell_1^2}}$
	$f_r = \frac{1}{4\pi}\left\{\frac{K_1}{m_1} + \frac{K_2}{m_2}\left(1+\frac{m_2}{m_1}\right) \pm\sqrt{\left[\frac{K_1}{m_1} + \frac{K_2}{m_2}\left(1+\frac{m_2}{m_1}\right)\right]^2 - \frac{4K_1 K_2}{m_1 m_2}}\right\}$
	$f_r = \frac{1}{2\pi}\sqrt{\frac{K}{\frac{m_1 m_2}{m_1+m_2}}}$

NATURAL FREQUENCIES OF MISCELLANEOUS SYSTEMS

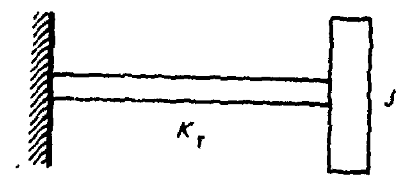
PENDULUM



$$f_r = \frac{1}{2\pi}\sqrt{\frac{g}{\ell}}$$

(INDEPENDENT OF MASS)

ROTOR AND SHAFT

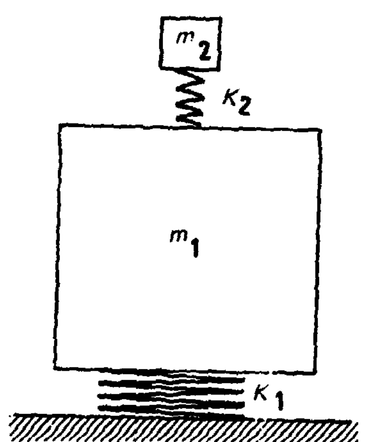


J = MASS MOMENT OF INERTIA

K_r = TORSIONAL STIFFNESS

$$f_r = \frac{1}{2\pi}\sqrt{\frac{K_r}{J}}$$

SEISMIC MASS (WITH ATTACHED SPRING MASS SYSTEM)



TWO RESONANT FREQUENCIES

LOWER:

$$f_{r_1} = \frac{1}{2\pi}\sqrt{\frac{K_1}{m_1+m_2}} \approx \frac{1}{2\pi}\sqrt{\frac{K_1}{m_1}}$$

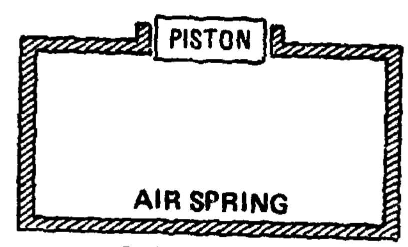
HIGHER:

$$f_{r_2} = \frac{1}{2\pi}\sqrt{\frac{K_2}{\frac{m_1 m_2}{m_1+m_2}}} \approx \frac{1}{2\pi}\sqrt{\frac{K_2}{m_2}}$$

if $m_1 >> m_2$

PISTON WITH AIR RESERVOIR

A = AREA OF PISTON
m = MASS OF PISTON
c = SPEED OF SOUND IN AIR
ρ = DENSITY OF AIR
V = VOLUME OF AIR SPRING



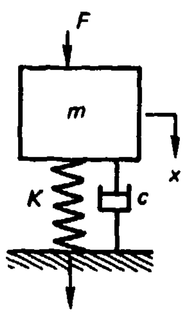
$$f_r = \frac{1}{2\pi}\sqrt{\frac{\rho c^2 A^2}{m V}}$$

Reference: Harris & Crede

STEADY STATE RESPONSE OF TWO SIMPLE SPRING-MASS-DAMPER SYSTEMS

Many vibrating systems can be shown to be equivalent to one of the two systems below:

SYSTEM 1 - DRIVEN MASS



F_T = TRANSMITTED FORCE

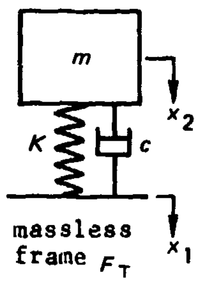
DISPLACEMENT RESPONSE OF SYSTEM 1

$$X = \frac{F \sin(\omega t - \Theta)}{K\sqrt{(1-r^2)^2 + (2\zeta r)^2}}$$

PHASE RESPONSE OF SYSTEM 1

$$\Theta = \text{arc tan} \left(\frac{2\zeta r}{1-r^2}\right)$$

SYSTEM 2 - DRIVEN FOUNDATION



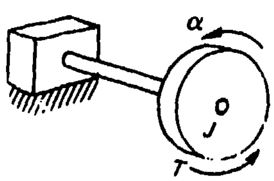
FORCE TRANSMITTED TO FOUNDATION $\left(\frac{F_T}{F}\right)$ OF SYSTEM 1 OR DISPLACEMENT RATIO x_2/x_1 OF SYSTEM 2

$$\frac{F_T}{F} = \frac{x_2}{x_1} = \sqrt{\frac{1 + (2\zeta r)^2}{(1-r^2)^2 + (2\zeta r)^2}} \quad \sin(\omega t - \psi)$$

PHASE RESPONSE OF F_T/F or x_2/x_1 OF SYSTEM 2

$$\psi = \text{arc tan} \left[\frac{2\zeta r^3}{(1-r^2) + (2\zeta r)^2}\right]$$

TERMS FOR EQUIVALENT TORSIONAL SYSTEMS

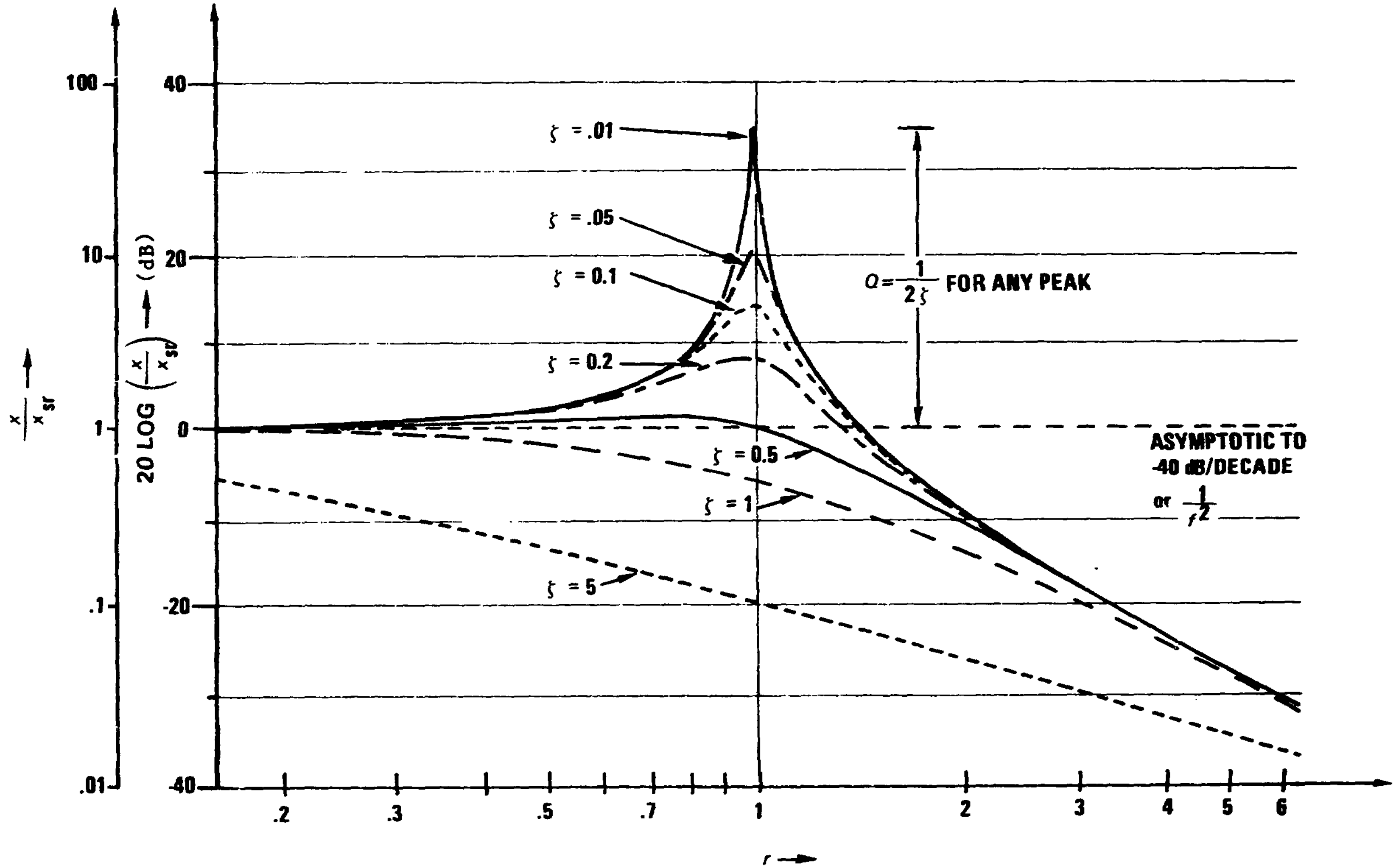


instead of $\begin{Bmatrix} x \\ K \\ F \\ c \\ m \end{Bmatrix}$ use $\begin{Bmatrix} \alpha \text{ - angular displacement} \\ K \text{ - torsional spring constant} \\ T \text{ - torque} \\ c \text{ - angular damping constant} \\ J \text{ - polar movement of inertia} \end{Bmatrix}$

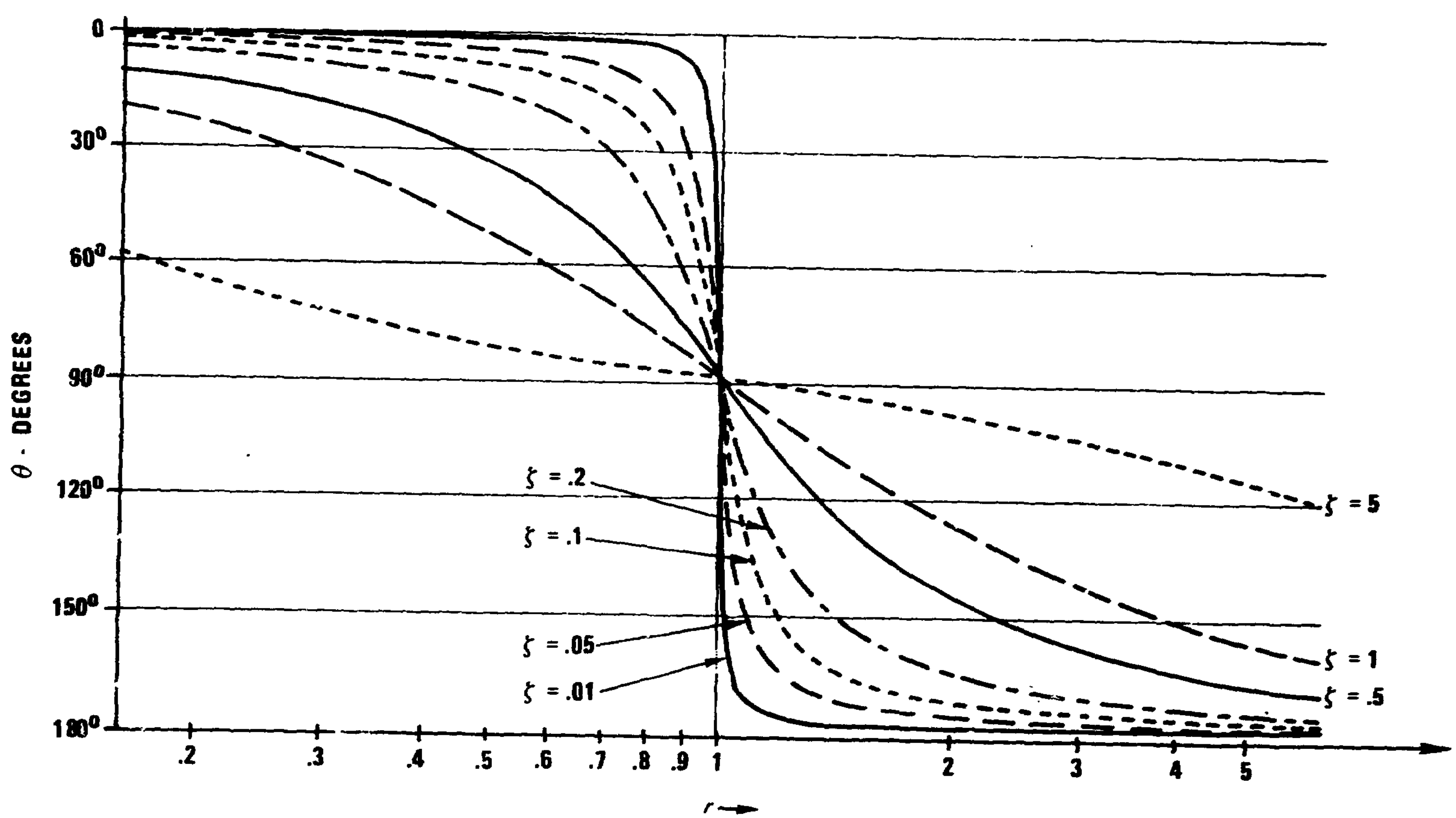
STEADY STATE RESPONSE OF TWO SIMPLE SPRING-MASS-DAMPER SYSTEMS

STEADY STATE RESPONSE: SPRING-MASS-DAMPER

DISPLACEMENT RESPONSE OF SYSTEM 1, PAGE 2-7



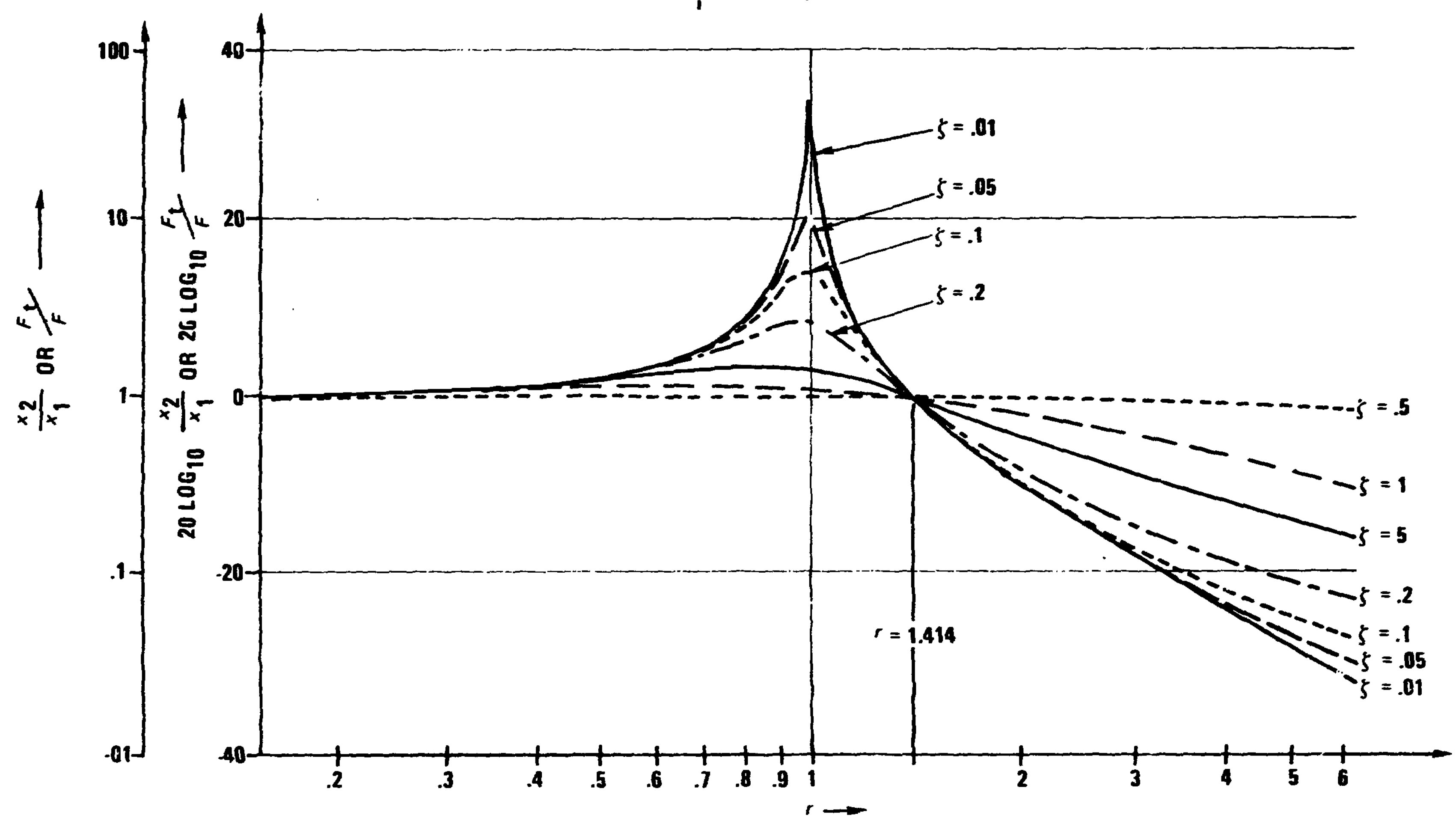
PHASE ANGLE RESPONSE OF SYSTEM 1, PAGE 2-7



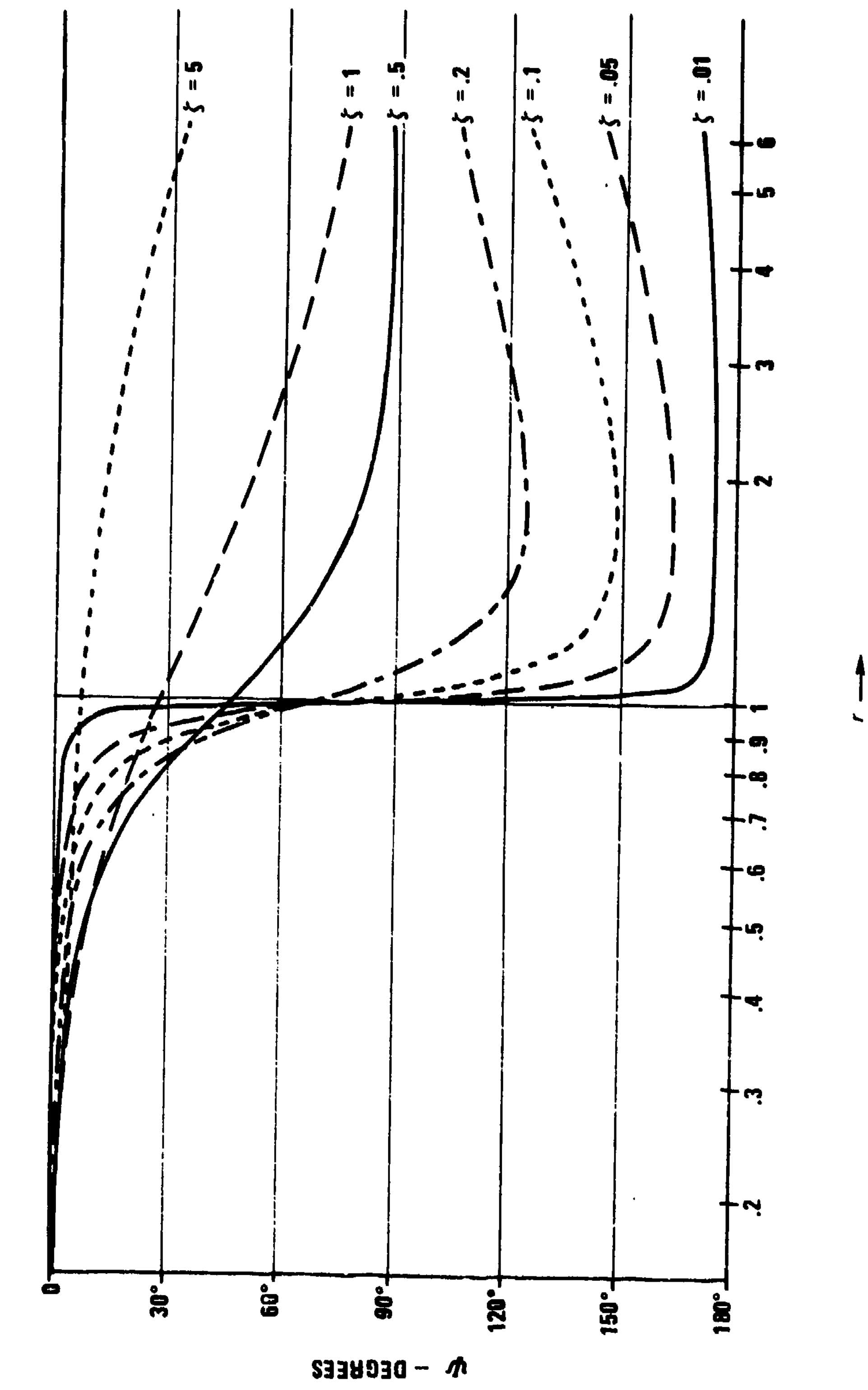
STEADY STATE RESPONSE: SPRING-MASS-DAMPER

STEADY STATE RESPONSE: SPRING-MASS-DAMPER

PLOT OF $\frac{x_2}{x_1}$ OR $\frac{F_t}{F}$ FROM PAGE 2-7



PLOT OF ψ FROM PAGE 2-7



STEADY-STATE RESPONSE: SPRING–MASS–DAMPER

DAMPING IN MECHANICAL VIBRATING SYSTEMS

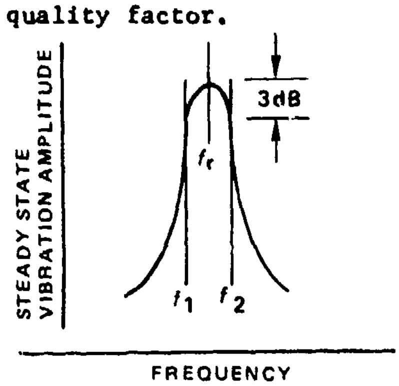
Damping in mechanical vibrating systems is the dissipation of the vibration energy in the system. Damping can be a result of the natural damping qualities of the system, or can be the result of an applied damping treatment. If the system is partially immersed in water or another liquid, it will be damped acoustically; i.e., energy will be lost to the fluid in the form of acoustic radiation.

It is often necessary to measure the damping of a mechanical vibrating system, one reason being to determine if additional damping will reduce the vibrations. Damping is also more difficult to model mathematically than mass or stiffness. There are several measurement methods which apply to underdamped systems which are described below. The measurement parameters described are summarized on a common table at the end of this section (pg 2-15).

STEADY-STATE MEASUREMENT OF DAMPING

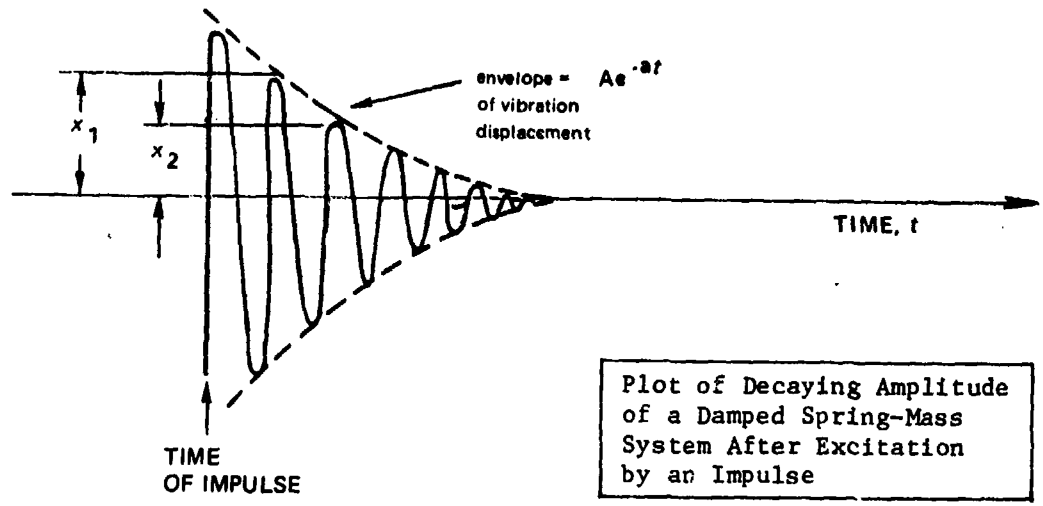
Let a mechanical system be driven by a sinusoidal force, $F = F_0 \sin 2\pi ft$, where f is near the resonant frequency f_r. Three frequencies are recorded, f_r, and the neighboring frequencies, f_1 and f_2, where the response of the system is down 3dB. The parameter measured is "Q", or quality factor.

$$Q = \frac{f_r}{f_1 - f_2}$$



TRANSIENT MEASUREMENT OF DAMPING

If a system has one major resonance, it may be "bumped" to produce a decaying sinusoidal response at the resonant frequency. If there are many resonances, it may have to be excited at the exact frequency where damping is to be measured. Then, when the excitation is removed, the decay can be observed at the selected resonant frequency without interference from other resonances.



Plot of Decaying Amplitude of a Damped Spring-Mass System After Excitation by an Impulse

In either case, the decaying signal is $Ae^{-at} \sin 2\pi f_r t$, where a is a constant equal to $\zeta\omega r$.

There are several ways to infer damping from a time plot of the decaying signal.

Logarithmic Decrement, Λ

$\Lambda = \text{Log}_e \; x_1/x_2$, where x_1 and x_2 are any two successive peak amplitudes in the decay curve. For very light damping, $\Lambda \approx \frac{x_1 - x_2}{x_1} = 1 - \frac{x_2}{x_1}$

Logarithmic Decay Rate, δ

To minimize error when determining logarithmic decrement, many values must be averaged. A simple way to accomplish the same effect is to convert the signal to decibels, then record the decay on a recorder such as an oscilloscope with a memory cathode ray tube. When recorded in decibels, the decay envelope, e^{-at}, becomes a straight line. Damping may be inferred accurately from the slope of the line using the following formula:

$$Q = \frac{27.287 \text{ x frequency}}{\text{Decay rate in dB/sec}}$$

CRITICAL DAMPING RATIO AND TRANSIENT RESPONSE

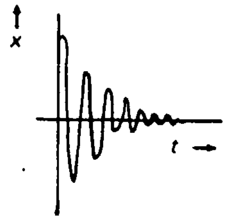
Mechanical vibrating systems can be characterized by their damping as under-damped, critically damped, or overdamped.

Underdamped systems oscillate in response to impulses. Overdamped systems do not. Critical damping is the minimum damping required for no oscillation.

Underdamped

$c < c_c$

$\zeta < 1$

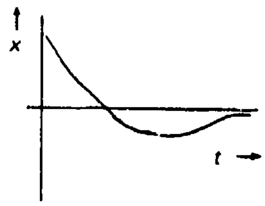


$$x = Ae^{-\zeta \omega_r t} \sin\left(\sqrt{1-\zeta}\, \omega_r t + \theta\right)$$

Critically Damped

$c = c_c$

$\zeta = 1$

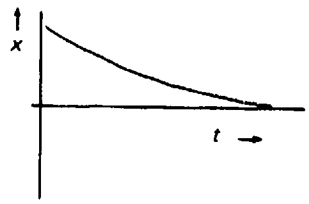


$$x = (A + Bt)e^{-\omega_r t}$$

Overdamped

$c > c_c$

$\zeta > 1$



$$x = e^{-\zeta \omega_r t}\left(Ae^{\omega_r \sqrt{\zeta^2-1}\, t} + Be^{-\omega_r \sqrt{\zeta^2-1}\, t}\right)$$

RELATIONSHIP OF DAMPING PARAMETERS

	Q No units	ζ No units	δ dB/sec	Λ No units
Q		$Q = \frac{1}{2\zeta}$	$Q = \frac{27.3 f_r}{\delta}$	$Q = \sqrt{\frac{1}{4} + \left(\frac{\pi}{\Lambda}\right)^2}$
ζ	$\zeta = \frac{1}{2Q}$		$\zeta = \frac{\delta}{54.6 f_r}$	$\zeta = \frac{1}{\sqrt{1 + \left(\frac{2\pi}{\Lambda}\right)^2}}$
δ	$\zeta = \frac{27.3 f_r}{Q}$	$\delta = 54.6 f_r \zeta$		$\delta = \frac{27.3 f_r}{\sqrt{\left(\frac{\pi}{\Lambda}\right)^2 + \frac{1}{4}}}$
Λ	$\Lambda = \frac{2\pi}{\sqrt{4Q^2 - 1}}$	$\Lambda = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}}$	$\Lambda = \frac{2\pi}{\sqrt{\left(\frac{54.6 f_r}{\delta}\right)^2 - 1}}$	

Q = Quality Factor

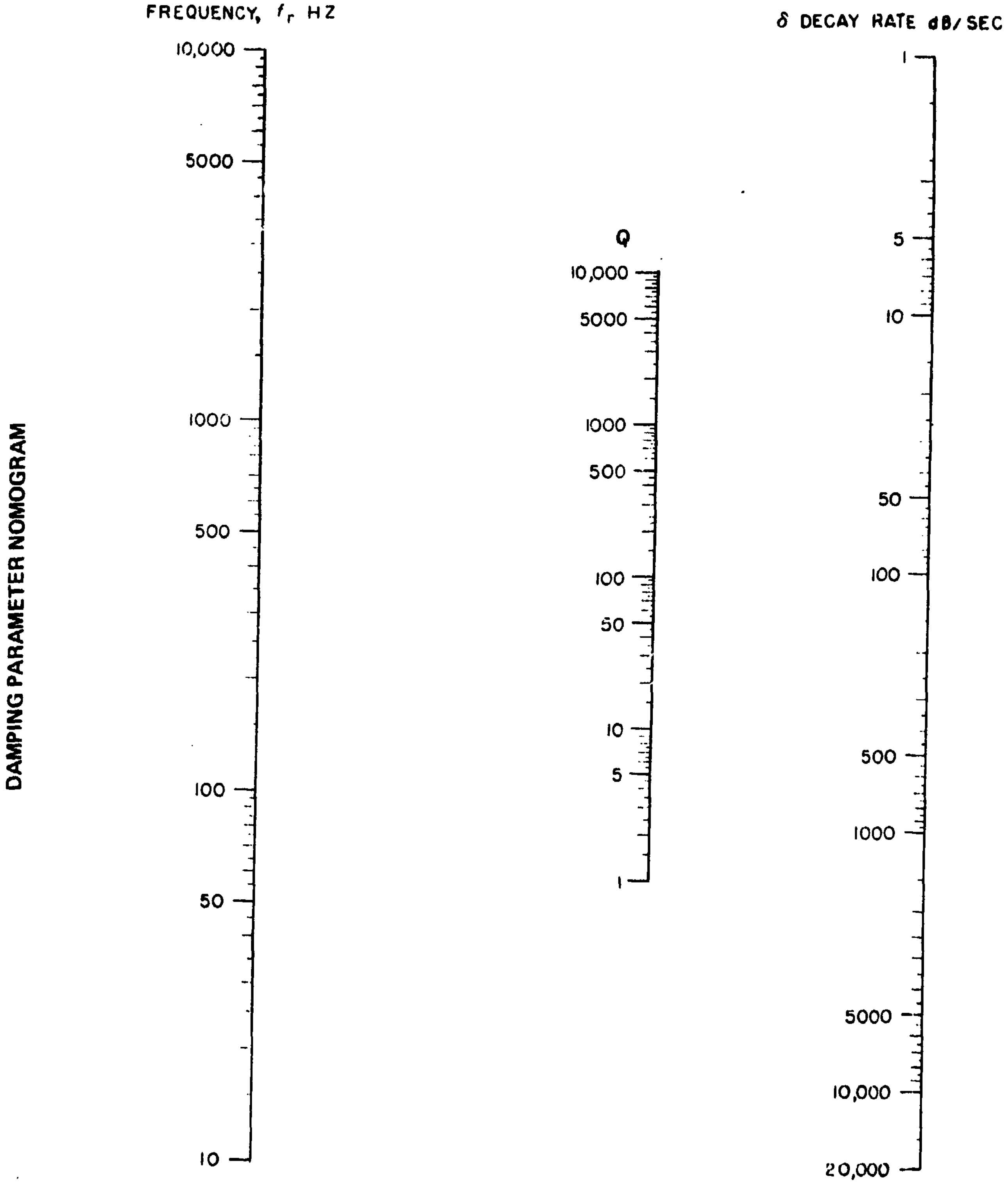
ζ = Critical Damping Ratio

δ = Decay Rate

Λ = Logarithmic Decrement

f_r = Resonant Frequency

DAMPING PARAMETER NOMOGRAM RELATING f_r, Q, and δ



TABULATED CHARACTERISTICS OF MACHINERY VIBRATION MOUNT PERFORMANCE

Vibration Parameters	Defintion	Location and Source of Input Force	Location and Types of Pickups	Equations* for Simple Spring-Mass System on a Non-rigid Foundation	Comments
A Mount Attenuation	The ratio of above to below mount vibration levels when the machine is running or when it is being excited by a shaker.	Machine itself or shaker driving on machine body.	Accelerometers above and below mounts in direction(s) of applied force(s).	$A = 1 + \frac{Z_B}{Z_K}$	Most common type of measurement made. $Z_k = K/j\omega$, K = mount stiffness Z_B = impedance of foundation
T_F Force Transmissibility	The ratio of the force transmitted from the mounts into the foundation to the input force acting on the machine.	Shaker driving on machine body.	Force gauges between shaker and machine and between mounts and foundation.	$T_F = \frac{1}{1 + \frac{Z_M}{Z_K}\left(1 + \frac{Z_K}{Z_B}\right)}$	Very difficult to measure experimentally. $Z_M = j\omega m$, m = mass of isolated machine
T_V Velocity Transmissibility	The ratio of above to below mount vibration levels when the foundation is excited with a shaker.	Shaker driving below mounts on foundation.	Accelerometers above and below the mount in direction of applied force.	$T_V = \frac{1}{1 + \frac{Z_M}{Z_K}}$	a) Ratio independent of foundation impedance. b) Quite simple to measure experimentally and identical to T_F for the case where the foundation is rigid, i.e., $Z_B \gg Z_K$.
E Mount Effectiveness	The ratio of below mount vibration with the isolator installed normally to below mount vibration with the isolator shorted out.	Machine itself or shaker driving on machine body.	Accelerometers below mounts in direction(s) of applied force(s).	$E = \frac{1}{1 + \frac{Z_M}{Z_K}\left(\frac{Z_B}{Z_B + Z_M}\right)}$	

$*Z_M = j\omega M$
$Z_K = K/j\omega$
Z_B = Impedance of foundation

TABULATED CHARACTERISTICS OF MACHINERY VIBRATION MOUNT PERFORMANCE

COMPUTATION OF MECHANICAL IMPEDANCE

Mechanical impedance is measured by simultaneously measuring input force to, and the resulting velocity of, a mechanical system. Mechanical impedance, Z, is simply their ratio: $Z = \frac{F}{v}$. The value Z consists of an amplitude, $|Z|$, and a phase angle. The amplitude, $|Z|$, can be calculated from the outputs of the force gauge and velocity pickup, or accelerometer using the following formulas.

<u>FOR VELOCITY PICKUPS</u>

$$|Z| = \frac{F}{v} K \text{ , N·s/m or \#·s/in.}$$

where F = output of force gauge in mV

v = output of velocity pickup in mV, and

$$K = \frac{\text{sensitivity of velocity pickup in mV·s/m or mV·s/in.}}{\text{sensitivity of force gauge in mV/N or mV/\#}}$$

<u>FOR ACCELEROMETERS</u>

$$|Z| = 2\frac{F}{A} \pi K f \text{ , N·s/m or \#·s/in.}$$

where F = output of force gauge in mV

A = output of accelerometer in mV

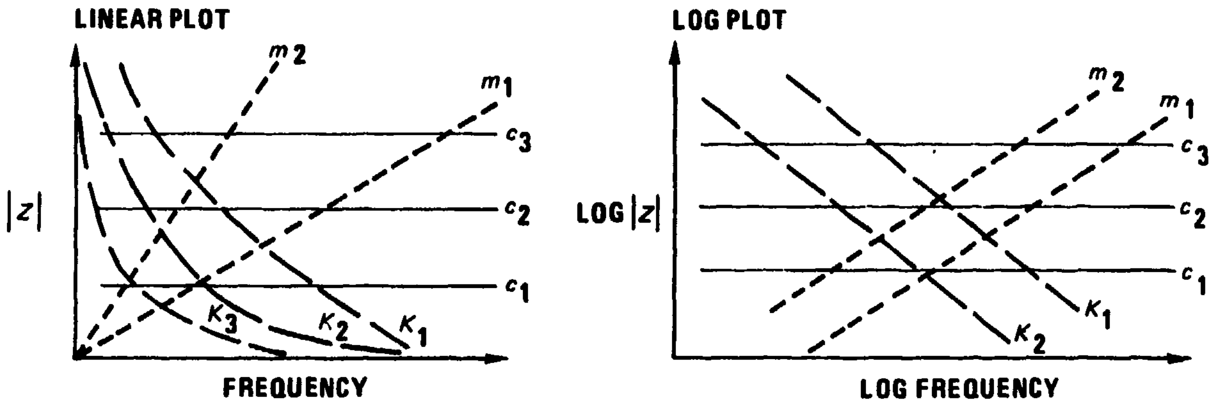
$$K = \frac{\text{sensitivity of accelerometer in mV·s}^2\text{/m or mV/}g}{\text{sensitivity of force gauge in mV/N or (mV/\# x 386)}}, \text{ and}$$

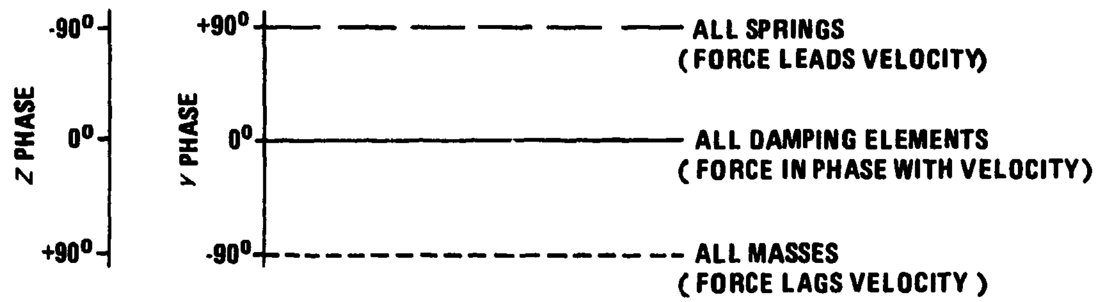
f = frequency in Hertz.

Phase may be read from a phase meter or estimated from oscilliscope traces.

PLOTS OF IMPEDANCE AND MOBILITY OF MASSES, SPRINGS, AND DAMPERS

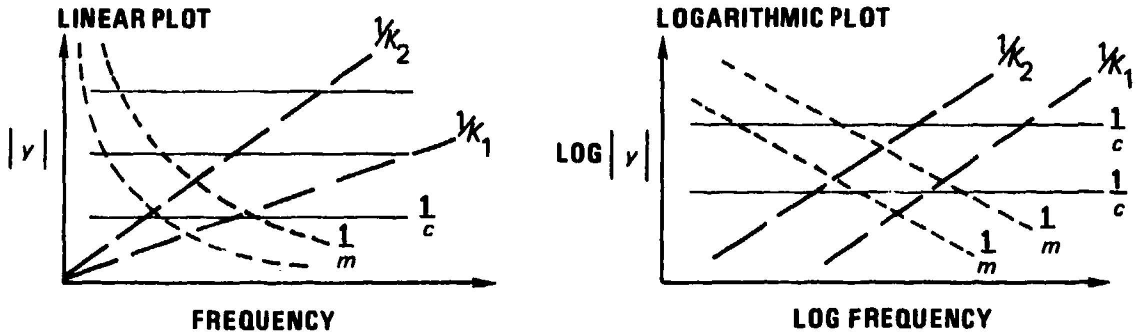
IMPEDANCE





SOLID LINES = CONSTANT DAMPING
LONG DASHES = CONSTANT STIFFNESS
SHORT DASHES = CONSTANT MASS

MOBILITY



MECHANICAL IMPEDANCE AND MOBILITY

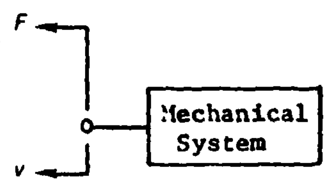
Mechanical impedance is a measure of how hard it is to make a mechanical system vibrate. It is a ratio of the exciting force to the velocity response. Low impedance means low force and/or high velocity - a system that is easy to excite. Mechanical mobility is the inverse of mechanical impedance for a system with a single driving and response point, a one-port system. Mobility is the ratio of velocity response to the exciting force. Further definitions are given below:

F = force, v = velocity, Z = impedance, Y = mobility

<u>ONE-PORT SYSTEM</u> (A port is a point of mechanical attachment.)

$$F = Zv$$

$$v = YF$$



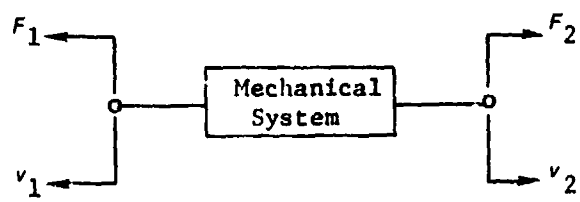
<u>TWO-PORT SYSTEM</u>

$$F_1 = Z_{11} v_1 + Z_{12} v_2$$

$$F_2 = Z_{21} v_1 + Z_{22} v_2$$

$$v_1 = Y_{11} F_1 + Y_{12} F_2$$

$$v_2 = Y_{21} F_1 + Y_{22} F_2$$



- For an N-port network, the impedance and mobility **matrices** are inverses of each other.

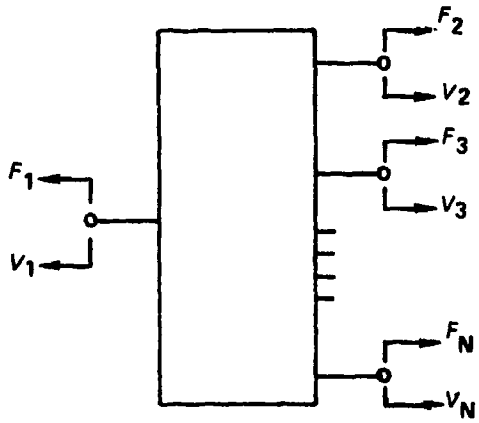
- Mobility matrix terms are generally easier to measure than impedance matrix terms. For example: $Z_{11} = F_1/V_1$ only if $V_2 = 0$ or the second port is blocked so that the velocity is zero. It is hard to constrain a system in this manner. $Y_{11} = V_1/F_1$ if $F_2 = 0$ or the second port is free from constraining forces. It is easy to make $F_2 = 0$.

- As an aid to evaluating measured data, it should be noted that the phase of measured **drive point impedance or mobility can never exceed $\pm 90^{\circ}$.**

"N" - PORT SYSTEM

$$\begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1N} \\ Z_{21} & & & \\ \vdots & & & \\ Z_{N1} & \cdot & \cdots & Z_{NN} \end{bmatrix} \begin{bmatrix} V_1 \\ \vdots \\ V_N \end{bmatrix} = \begin{bmatrix} F_1 \\ \\ F_N \end{bmatrix}$$

$$\begin{bmatrix} Y_{11} & Y_{12} & & Y_{1N} \\ Y_{21} & & & \\ \vdots & & & \\ Y_{N1} & \cdot & \cdots & Y_{NN} \end{bmatrix} \begin{bmatrix} F_1 \\ \vdots \\ F_N \end{bmatrix} = \begin{bmatrix} V_1 \\ \\ V_N \end{bmatrix}$$



COMMENTS:

- Z_{11} and Y_{11} are called driving point impedance and mobility respectively.
- Z_{ij} and Y_{ij} $(i \neq j)$ are transfer impedances and transfer mobilities.
- Z_{NN} and Y_{NN} are output impedance and output mobility respectively.
- For almost every case, $Z_{12} = Z_{21}$, $Y_{12} = Y_{21}$, $Z_{21} = Z_{12}$, etc.
- For a one-port system, $Z = 1/Y$, but for two or more ports $Z_{12} \neq 1/Y_{12}$, etc. For a two-port system, the relationships between impedance and mobility are:

$$Z_{11} = Y_{22}/\Delta' \qquad Y_{11} = Z_{22}/\Delta''$$

$$Z_{12} = -Y_{12}/\Delta' \qquad Y_{12} = -Z_{12}/\Delta''$$

$$Z_{21} = -Y_{21}/\Delta' \qquad Y_{21} = -Z_{21}/\Delta''$$

$$Z_{22} = Y_{11}/\Delta' \qquad Y_{22} = Z_{11}/\Delta''$$

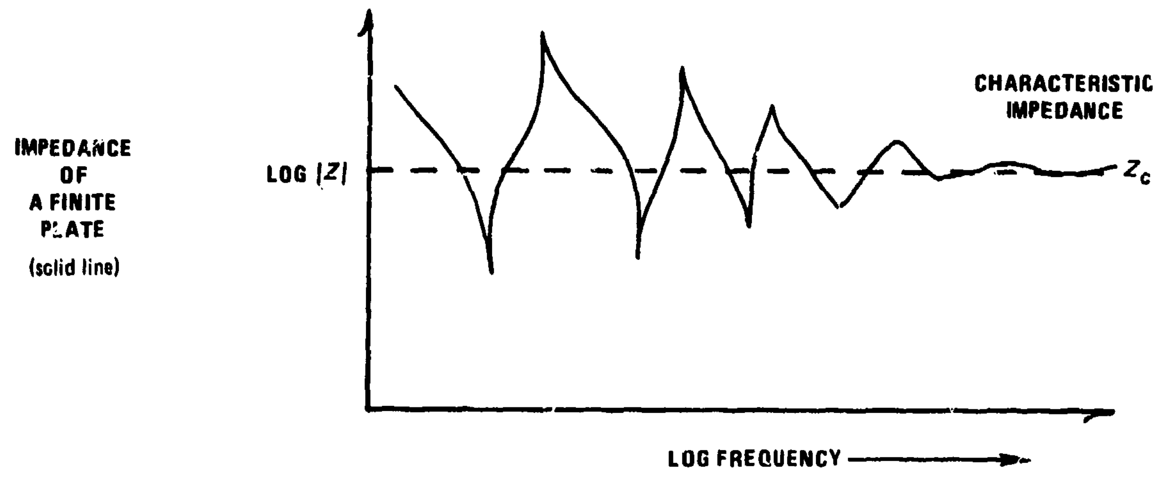
where:

$$\Delta' = Y_{11}\,Y_{22} - Y_{12}\,Y_{21} \qquad \Delta'' = Z_{11}\,Z_{22} - Z_{12}\,Z_{21}$$

CHARACTERISTIC DRIVING POINT IMPEDANCE OF A PLATE

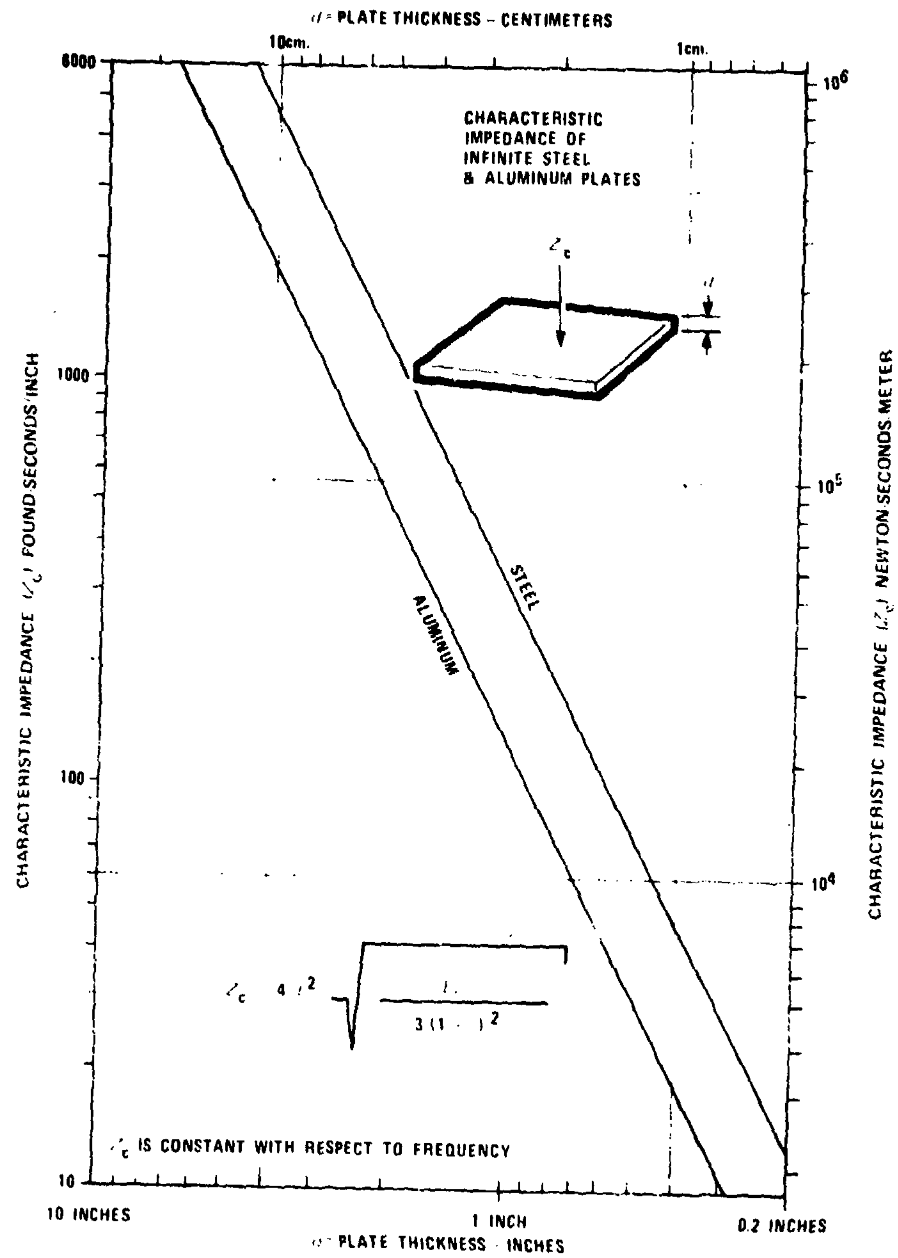
If any infinite plate is driven at a point (or over a small area), its impedance is constant with frequency and is easily calculated. That impedance is called the "characteristic impedance" of the place. Characteristic impedances for steel and aluminum plates are plotted on the following page.

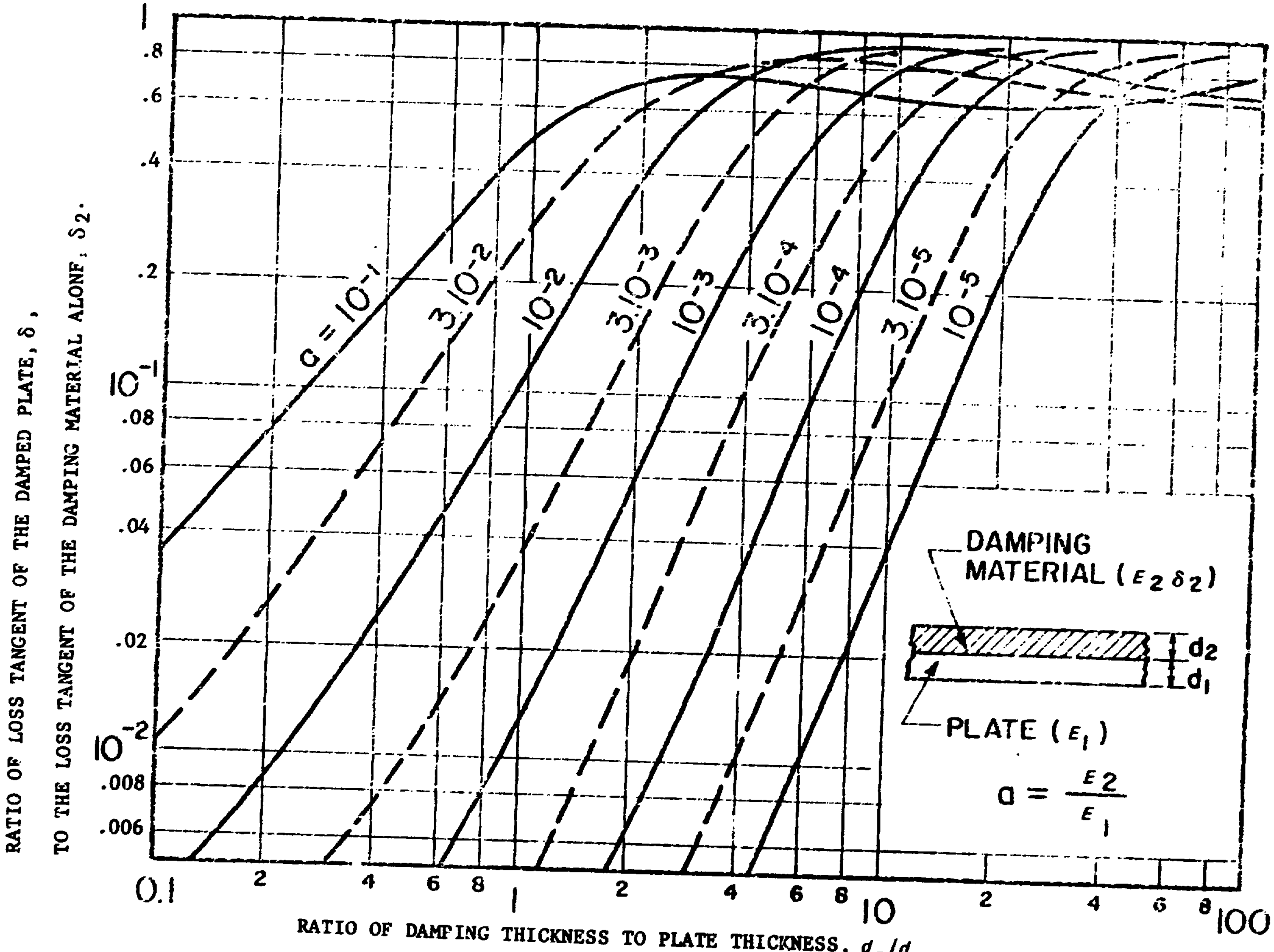
Although the characteristic impedance is calculated for an infinite plate, it happens that for a finite plate the characteristic impedance is the geometric mean between impedance maxima and minima. Moreover, the maxima and minima tend to converge as frequency increases to the characteristic impedance. Thus, an estimate of the characteristic impedance is an aid toward ensuring accurate impedance measurements.



For a beam, characteristic impedance is more complicated. (See Cremer & Heckl, pp 274 & 281.)

CHARACTERISTIC POINT IMPEDANCE OF INFINITE PLATES





E_1 = Young's Modulus of Plate

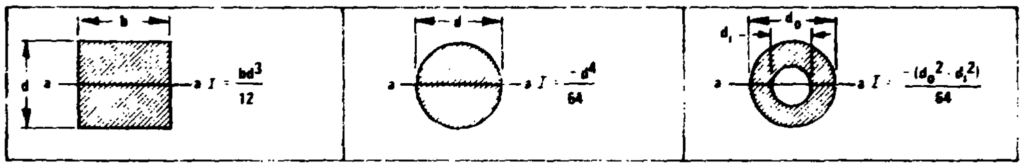
E_2 = Young's Modulus of Damping Material

DAMPING RATIO VS DAMPING THICKNESS FOR PLATES

PLATE DAMPING EFFECTIVENESS

RESONANT FREQUENCIES AND MODES OF SIMPLE BEAMS

SAMPLE VALVES OF I (a—a : NEUTRAL AXIS)



$f_r = \frac{A}{2\pi}\sqrt{\frac{EI}{m\ell^4}}$

f_r = RESONANT FREQUENCY

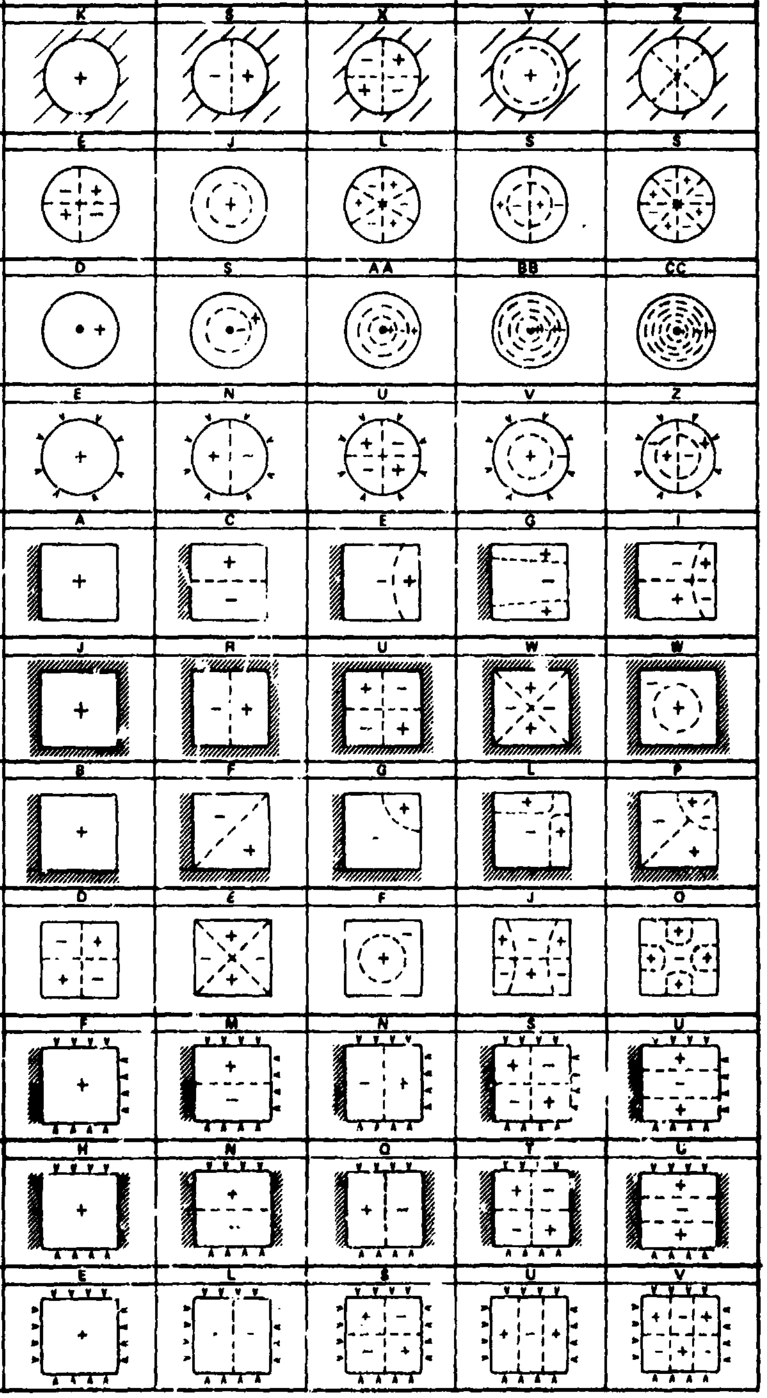
A = COEFFICIENT FROM TABLE BELOW

M_L = MASS PER UNIT LENGTH OF THE BEAM

MODES ARE INDICATED IN TABLE BELOW AS A PROPORTION OF LENGTH ℓ MEASURED FROM LEFT END

BEAM SUPPORT CONDITIONS	1ST MODE	2ND MODE	3RD MODE	4TH MODE	5TH MODE
FIXED–FREE (CANTILEVER)	A = 3.52	0.774 A = 22.4	0.500 0.868 A = 61.7	0.356 0.644 0.906 A = 121.0	0.279 0.500 0.723 0.926 A = 298.0
HINGED–HINGED (SIMPLE)	A = 9.87	0.500 A = 39.5	0.333 0.667 A = 88.9	0.25 0.50 0.75 A = 158	0.20 0.40 0.60 0.80 A = 247
FIXED–FIXED (BUILT-IN)	A = 22.4	0.500 A = 61.7	0.359 0.641 A = 121	0.278 0.500 0.722 A = 200	0.227 0.409 0.591 0.773 A = 298
FREE–FREE	0.224 0.776 A = 22.4	0.132 0.500 0.868 A = 61.7	0.094 0.356 0.644 0.906 A = 121	0.073 0.277 0.500 0.723 0.927 A = 200	0.050 0.227 0.409 0.591 0.773 0.948 A = 298
FIXED–HINGED	A = 15.4	0.560 A = 50.0	0.384 0.692 A = 104	0.294 0.529 0.765 A = 178	0.238 0.429 0.619 0.810 A = 272
HINGED–FREE	0.736 A = 15.4	0.446 0.853 A = 50.0	0.308 0.616 0.898 A = 104	0.235 0.471 0.707 0.922 A = 178	0.190 0.381 0.581 0.763 0.937 A = 272

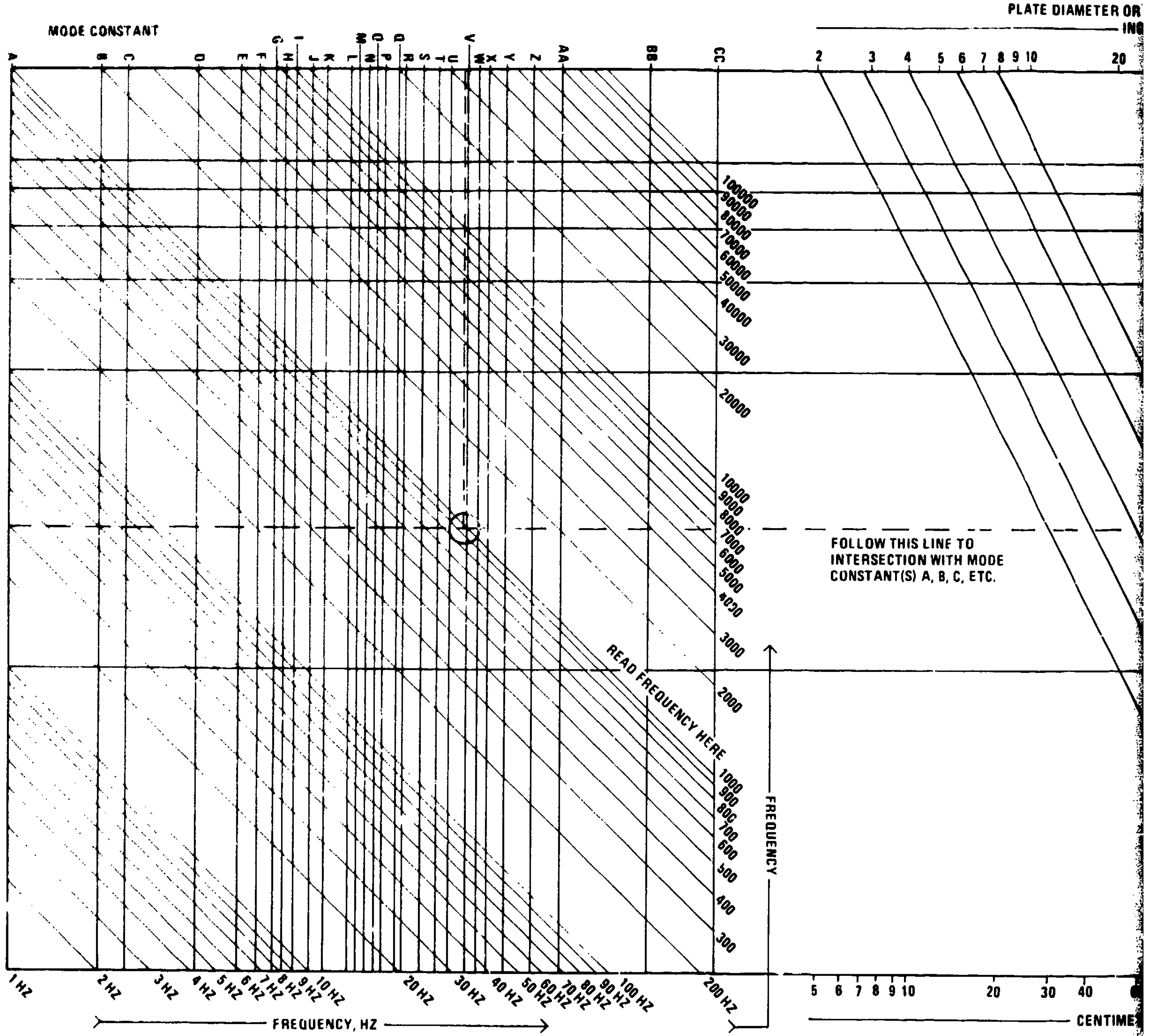
RESONANT FREQUENCIES AND MODE SHAPES OF SQUARE AND CIRCULAR PLATES



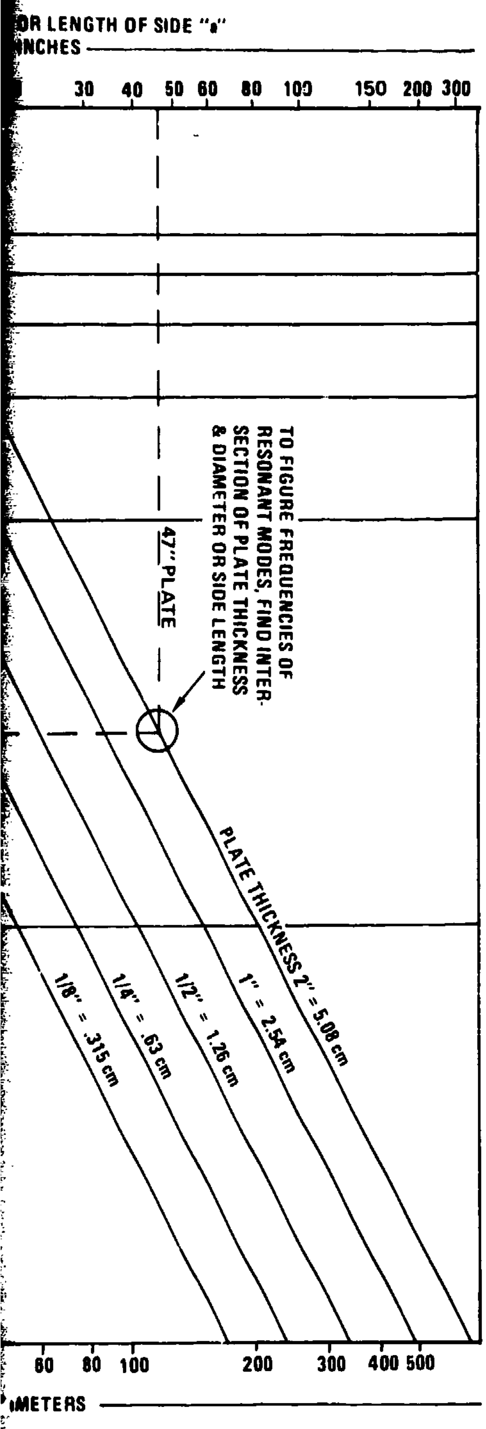
EDGE SUPPORTS	MODE NUMBER & MODE CONSTANT				
	1ST MODE	2ND MODE	3RD MODE	4TH MODE	5TH MODE
CLAMPED AT EDGE	K	S	X	Y	Z
FREE (NO SUPPORTS OR VERY SOFT SUPPORTS)	E	J	L	S	S
CLAMPED AT CENTER	D	S	AA	BB	CC
SIMPLY SUPPORTED AT EDGE	E	N	U	V	Z
ONE EDGE CLAMPED THREE EDGES FREE	A	C	E	G	I
ALL EDGES CLAMPED	J	R	U	W	W
TWO EDGES CLAMPED TWO EDGES FREE	B	F	G	L	P
ALL EDGES FREE	D	E	F	J	O
ONE EDGE CLAMPED THREE EDGES SIMPLY SUPPORTED	F	M	N	S	U
TWO EDGES CLAMPED TWO EDGES SIMPLY SUPPORTED	H	N	Q	T	U
ALL EDGES SIMPLY SUPPORTED	E	L	S	U	V

TO FIND THE RESONANT FREQUENCIES OF EACH MODE, SELECT THE MODE CONSTANT (A, B, E, D, — — ·· BB, CC) FOR THE APPROPRIATE EDGE SUPPORTS TO ENTER THE GRAPH ON THE NEXT PAGE TOGETHER WITH PLATE THICKNESS & EITHER DIAMETER OR LENGTH OF SIDE AS APPROPRIATE.

RESONANT FREQUENCIES AND MODE SHAPES OF SQUARE AND CIRCULAR PLATES



NOMOGRAPH TO FIND RESONANT FREQUENCIES OF SQUARE AND CIRCULAR PLATES

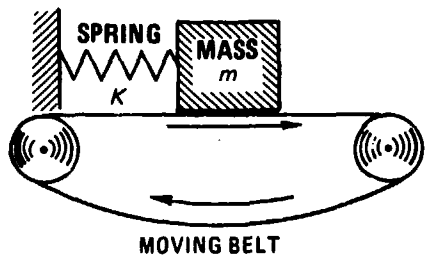


NOMOGRAPH TO FIND RESONANT FREQUENCIES OF SQUARE AND CIRCULAR PLATES

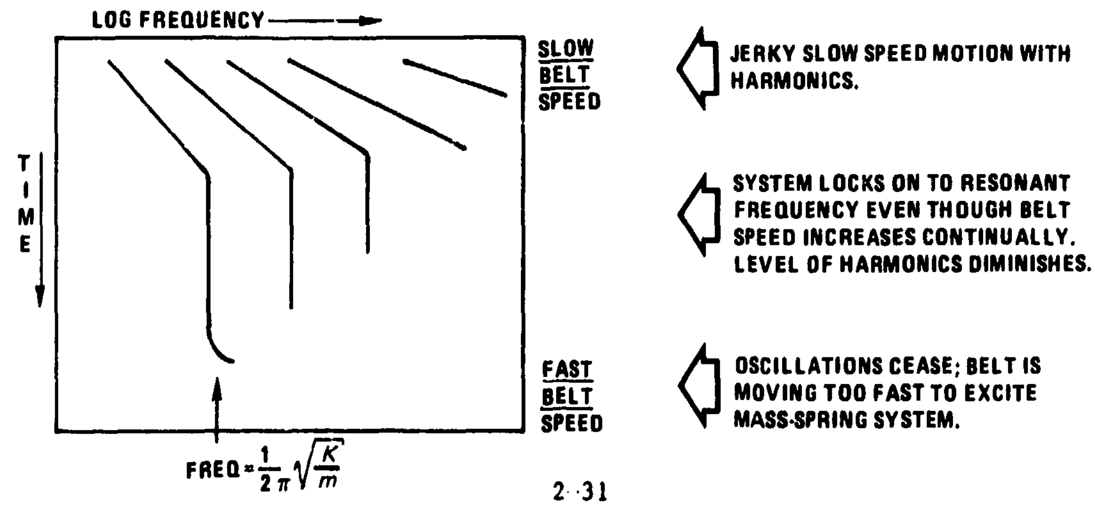
EXAMPLES OF NON-LINEAR VIBRATING SYSTEMS

Non-linear vibrations can sometimes be identified by one or more of the following characteristics: sub-harmonics, harmonics, extremely stable frequencies, or a dependence of frequency on driving force. If a noise problem can be identified as originating from a non-linear vibrating system, that fact can be a clue to the identification of the system as a first step toward solving the noise problem. Some sample cases of non-linear vibration are discussed below.

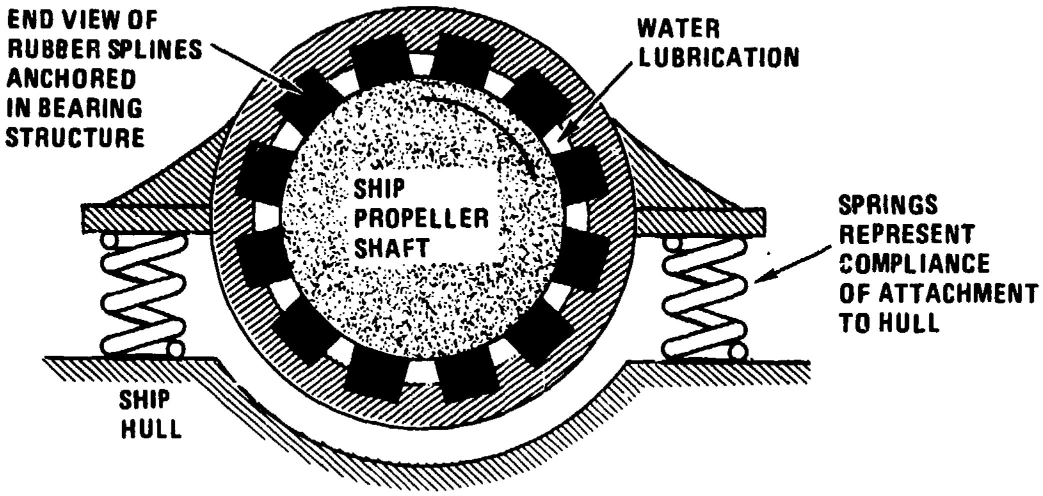
1) <u>Chatter or Stick-slip</u>



The conceptual system sketched helps visualize stick-slip. Imagine the belt moving very slowly. The mass moves with the belt until the spring force breaks static friction on the belt. The mass then snaps back until stopped by the spring and dynamic friction on the belt. It will again ride the belt until the spring pulls it back. If the belt moves very rapidly, it is easily seen that there will be a speed above which the mass will not oscillate, it will simply slide. Between these two cases there will be a wide range of belt speeds where the mass will vibrate at its natural frequency on the spring $f = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$. Consider a plot of the vibration spectrum vs time as the belt speed steadily increases from very slow to very fast.



A more realistic system subject to stick-slip is a water-lubricated bearing of rubber splines for a propeller shaft of a ship.



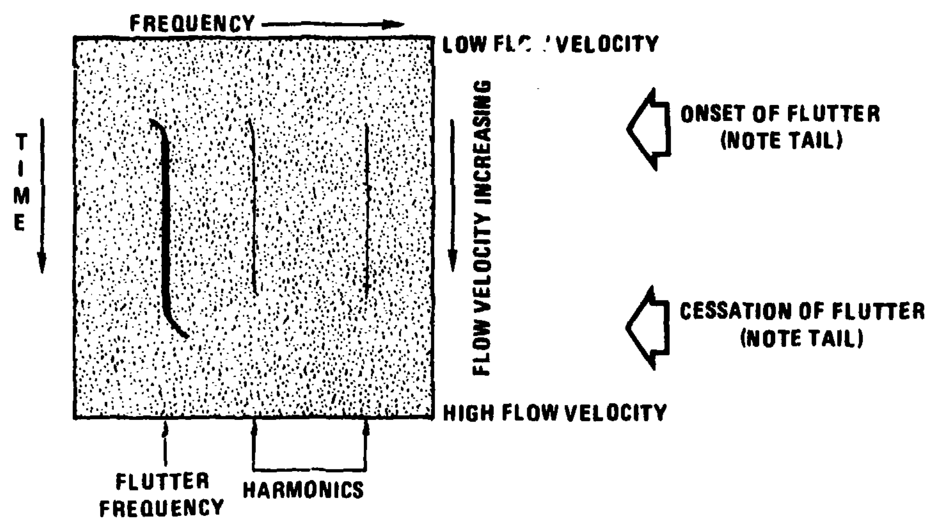
CROSS-SECTION OF SHIP
PROPELLER SHAFT BEARING

Occurrence of stick-slip in this bearing is exactly like the spring-mass on a belt just described. For very low shaft speeds, there is a jerky movement. As the shaft speed increases, there is a "lock-on" to a resonant frequency determined by the hull compliance (shown above as two springs) and the rotary inertia of the structure holding the splines. The locked-on resonance will continue at a steady frequency as shaft speed increases until the shaft speed is too fast to excite vibration. The dynamics of this stick-slip situation are affected by the compliance of the rubber splines, unlike the mass-spring-belt system previously described.

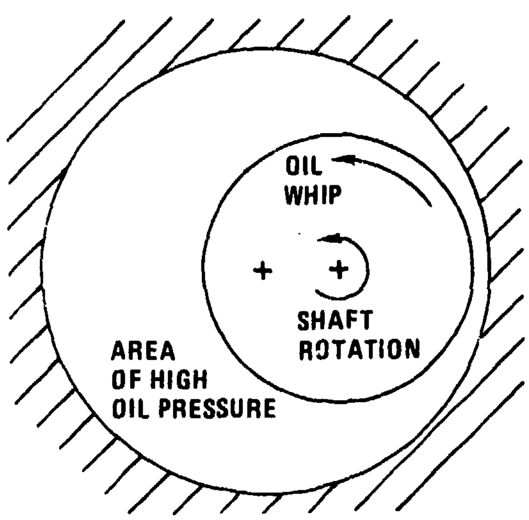
2) <u>Flutter</u>

Flutter was once thought to be restricted to high speeds (>50 kts) in water, but recent studies have shown that it can occur at speeds as low as 9 knots. Flutter is a flow-excited vibration of a strut which can both deflect and rotate. The basic excitation force is vortex shedding, but flutter dynamics are a combination of hydrodynamic lift, vortex shedding, virtual mass of the water, mass of the member, and deflectional and torsional stiffness of the strut. The classic cure for aerodynamic flutter is to greatly increase torsional stiffness of the strut.

Flutter has the same "lock-on" resonance frequency quality as the stick-slip phenomenon just described. A frequency time plot of flutter for continually increasing flow velocity is sketched below:



3) Bearing Oil Whip



CROSS-SECTION OF VERTICAL SLEEVE BEARING

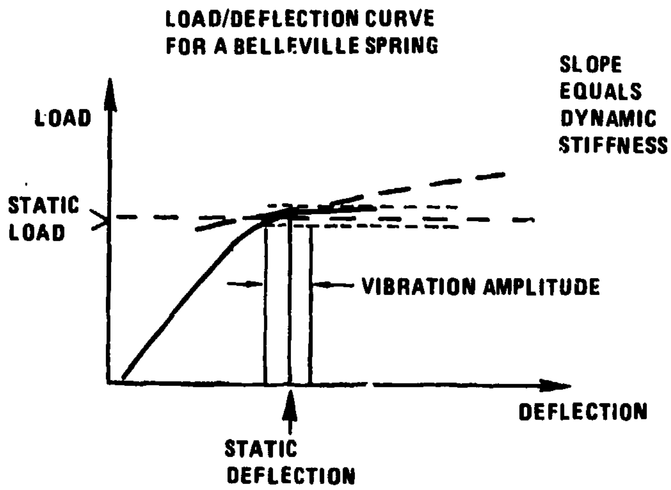
In well lubricated sleeve journal bearings on vertical rotating shafts, there is a vibratory shaft phenomenon called "oil whip". Its characteristic frequency is 1/4 to 1/2 of the rotational frequency of the shaft.

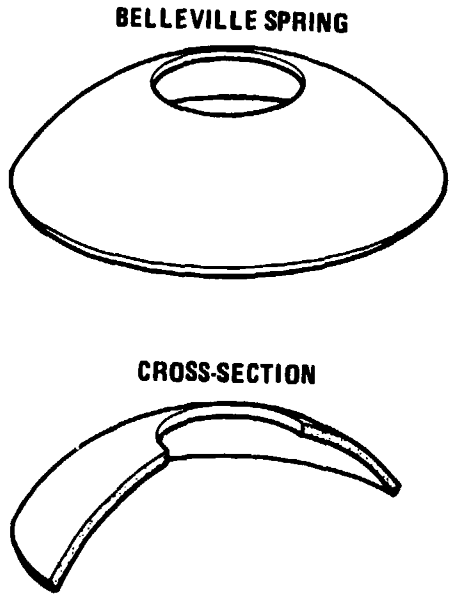
4) <u>Rattles</u>

Rattles are vibrations of systems controlled by extremely non-linear springs or restoring forces. They are characterized by either a random frequency or a relatively constant frequency, both with perhaps intermittent occurrence. Rattles are generally of much higher amplitude vibration than other structural vibrations. Rattles are avoided by careful inspection of assembled machinery. When they occur, they are located by banging anything that looks like it might rattle with a rubber hammer and listening. It is very difficult to localize a rattle to one area of a ship; therefore, the search for rattles should include the whole ship, if necessary, not just one area.

5) <u>Belleville Spring</u>

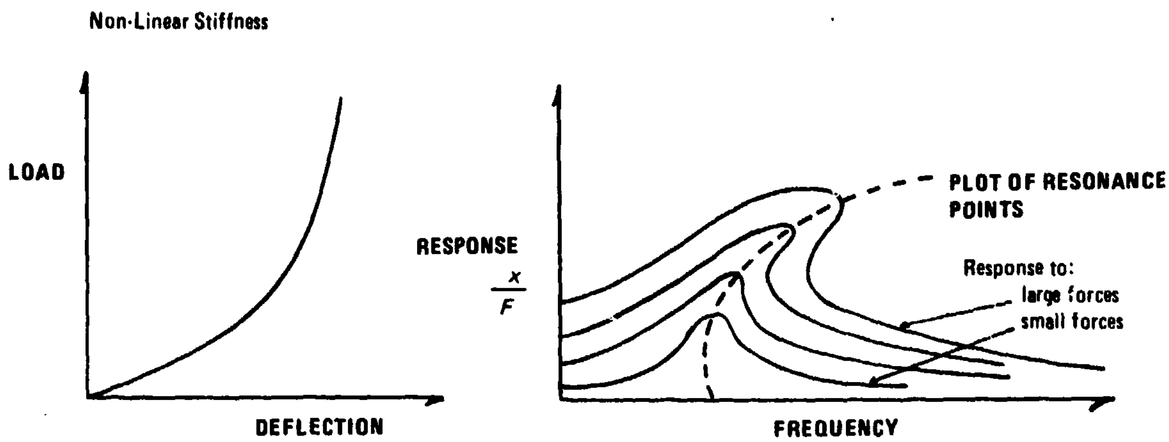
A Belleville spring (alternately Belleville washer or spherical spring) can apply a high static force and at the same time be very compliant to low amplitude vibrations. Its load deflection curve starts off steep, then falls off. An example of the application of a Belleville spring is under the stress rod retainer of a tonpilz hydrophone.





6) Snubbers

Snubbers or hard springs have a load/deflection curve just opposite to that of a Belleville spring. The resonant frequency of a mass on a snubber depends on the amplitude of the vibration. Typical response curves $\frac{x}{F}$ are sketched below.



The response indicated above is the response which would be produced by System #1, p. 2-7, if the spring were to have the non-linear stiffness indicated above.

III

BASIC ACOUSTICS

CONTENTS

SYMBOLS AND PREFERRED UNITS FOR THIS CHAPTER

SYMBOL	QUANTITY	SYMBOL OF PREFERRED UNIT	PREFERRED UNIT
c	Speed Sound in a Fluid	m/s	Meter per second
e	Base of Naperian Logarithms	--	(numeric) = 2.71828
f	Frequency	Hz	Hertz
k	Wave Number of Sound in a Fluid	rad/m	Radian per meter
p	Sound Pressure Acoustic Pressure	Pa	Pascal
p_1	Incident Sound Pressure	Pa	Pascal
p_T	Transmitted Sound Pressure	Pa	Pascal
p_R	Reflected Sound Pressure	Pa	Pascal
r	Radial Coordinate, Distance from an Acoustic Source	m	Meter
t	Time	s	Second
v	Acoustic Particle Velocity	m/s	Meter per second
x, y, z	Cartesian Coordinates	m	Meter
A	A Constant		
I	Acoustic Intensity	W/m^2	Watt per square meter
K	Bulk Modulus of a Fluid	Pa	Pascal
P	Acoustic Power	W	Watt
P_s	Static Pressure of a Fluid	Pa	Pascal
T	Absolute Temperature	^oK	Degrees Kelvin
Z_a	Acoustic Impedance	N·s/m	Newton - second per meter
Z_c	Characteristic Impedance	N·s/m	Newton - second per meter

SYMBOLS AND PREFERRED UNITS FOR THIS CHAPTER

SYMBOL	QUANTITY	SYMBOL OF PREFERRED UNIT	PREFERRED UNIT
γ	* Ratio of Specific Heat at Constant Pressure to Specific Heat at Constant Volume for Gases	--	(numeric) ≈ 1.4 for air, oxygen and nitrogen
θ	Angular Coordinate	rad	Radian
θ_1	Angle of Incidence and Reflection at a Surface	rad	Radian
θ_2	Angle of Transmitted Sound at a Surface	rad	Radian
θ_c	Critical Angle of Incident Sound	rad	Radian
ρ	Mass Density of a Fluid	kg/m^3	Kilogram per cubic meter
ϕ	Phase Angle	rad	Radian
ψ	Angular Coordinate	rad	Radian
ω	Angular Frequency	rad/s	Radian per second
Θ	Angle Between x and x' Axes	rad	Radian
Φ	Acoustic Velocity Potential	m^2/s	Meter squared per second
$\frac{\partial p}{\partial x}$	Pressure Gradient	Pa/m	Pascal per meter

ACOUSTIC PARAMETERS OF FLUIDS

All equations except those for speed of sound are for both gases and liquids.

- SPEED OF SOUND IN A GAS

$$c = \sqrt{\frac{\gamma P_S}{\rho}} \propto \sqrt{T}$$

(first approximation)

- SPEED OF SOUND IN A LIQUID

$$c = \sqrt{\frac{K}{\rho}}$$

- WAVELENGTH OF SOUND

$$\lambda = \frac{c}{f}$$

- WAVE NUMBER OF SOUND

$$k = \frac{\omega}{c} = \frac{2\pi f}{c} = \frac{2\pi}{\lambda}$$

- RELATIONSHIP OF P, v, AND Φ

$$v_x = \frac{i}{\omega\rho}\frac{\partial p}{\partial x} = -\frac{\partial \Phi}{\partial x}$$

$$p = \frac{\rho \partial \Phi}{\partial t} = j\omega\rho\Phi$$

WAVE EQUATIONS FOR A LOSSLESS ACOUSTIC MEDIUM

WAVE EQUATIONS FOR A LOSSLESS ACOUSTIC MEDIUM

ONE DIMENSION

$$\frac{\partial^2 p}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0,$$

Cartesian Coordinate x

TWO DIMENSIONS

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0,$$

Cartesian Coordinates x, y

Polar Coordinates r, θ

$$\frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial r} + \frac{1}{r^2}\frac{\partial^2 p}{\partial \theta^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0$$

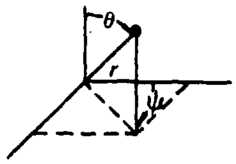
THREE DIMENSIONS

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0$$

Cartesian Coordinates x, y, z

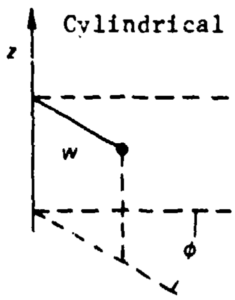
Spherical Coordinates

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial p}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial p}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2 p}{\partial\psi^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0$$

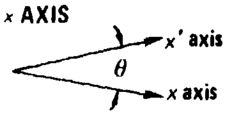


Cylindrical Coordinates

$$\frac{1}{w}\frac{\partial}{\partial w}\left(w\frac{\partial p}{\partial w}\right) + \frac{1}{w^2}\frac{\partial^2 p}{\partial\phi^2} + \frac{\partial^2 p}{\partial z^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0$$



BASIC SOLUTIONS TO THE WAVE

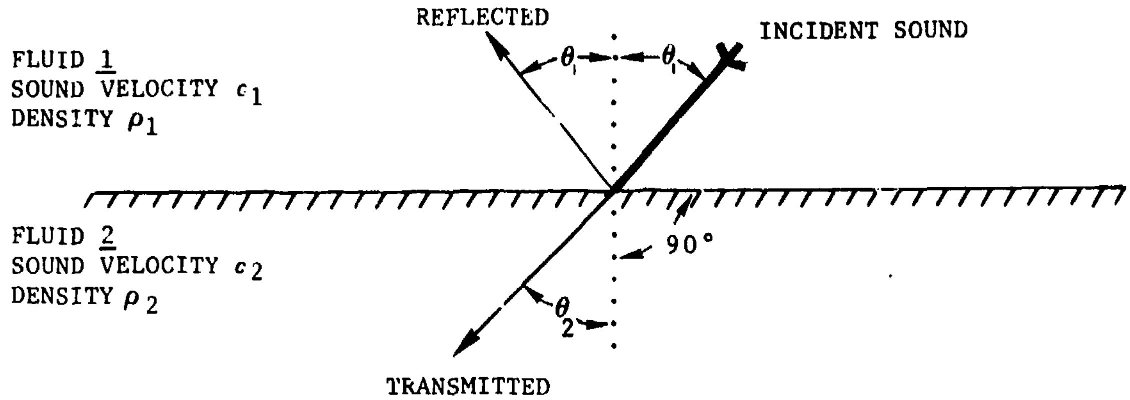
	ACOUSTIC PRESSURE p	ACOUSTIC PRESSURE GRADIENT $\frac{\partial p}{\partial x'}$	ACOUSTIC PARTICLE VELOCITY $v_{x'}$	ACOUSTIC INTENSITY (DEPENDS ON DIRECTION) I	AC W IM (D ON
PLANE WAVE TRAVELING ALONG + x AXIS  x' axis, θ, x axis	$p = Ae^{j(\omega t \mp kx + \varphi)}$	$\frac{\partial p}{\partial x'} = \pm jkp\cos\theta$	$v_{x'} = \pm \frac{p}{\rho c}\cos\theta$ $v_{x'} = \frac{-j}{\rho c} Ae^{j(\omega t \mp kx + \varphi)}$	$I_{x'} = \pm \frac{A^2}{2\rho c}\cos\theta$	Z_x
PLANE WAVE STANDING ALONG x AXIS x_0 = point on x axis	$p = A\cos[k(x-x_0)]$ $\times\, e^{j(\omega t + \varphi)}$	$\frac{\partial p}{\partial x'} = -kA\, e^{j(\omega t + \varphi)}\cos\theta$ $\times\, \sin[k(x-x_0)]$	$v_{x'} = jkA\, e^{j(\omega t + \varphi)}\cos\theta$ $\times\, \sin[k(x-x_0)]$	$I_{x'} = \frac{-A^2}{2\rho c}\sin[k(x-x_0)]$ $\times\, \cos\theta$	Z_x
CYLINDRICAL WAVE (SPREADING)	LINE SOURCE $p = \frac{A}{\sqrt{r}}\, e^{j(\omega t - kr + \varphi)}$	$\frac{\partial p}{\partial r} = -(jk + \frac{1}{2r})\, p$ ⇨ $-jkp$	$v_r = (1 - \frac{j}{2kr})\frac{p}{\rho c}$ ⇨ $\frac{p}{\rho c}$	$I_r = \frac{A^2}{2\rho c r}$	Z_r ⇨
SPHEPICAL WAVE (SPREADING)	POINT SOURCE $p = \frac{A}{r}\, e^{j(\omega t - kr + \varphi)}$	$\frac{\partial p}{\partial r} = -(jk + \frac{1}{r})\, p$ ⇨ $-jkp$	$v_r = (1 + \frac{1}{jkr})\frac{p}{\rho c}$ ⇨ $\frac{p}{\rho c}$	$I_r = \frac{A^2}{2\rho c r^2}$	Z_r ⇨
DIPOLE (EQUIVALENT TO TWO OF THE POINT SOURCES ABOVE, SEPARATED BY A DISTANCE dx ALONG THE x AXIS)	$p = \frac{jkAdx}{r}\cos\theta$ $\times\, (1 + \frac{1}{jkr})\, e^{j(\omega t - kr + \varphi)}$	$\frac{\partial p}{\partial r} = \frac{k^2 Adx}{r}\left[1 + \frac{2}{jkr} + \frac{2}{(jkr)^2}\right]$ $\times\, \cos\theta\, e^{j(\omega t - kr + \varphi)}$ $\frac{\partial p}{\partial \theta} = -j\frac{kAdx}{r}\sin\theta$ $\times\, (1 + \frac{1}{jkr})\, e^{j(\omega t - kr + \varphi)}$	$v_r = j\frac{kAdx}{\rho c r}\left[1 + \frac{2}{jkr} + \frac{2}{(jkr)^2}\right]$ $\times\, \cos\theta\, e^{j(\omega t - kr + \varphi)}$ $v_\theta = \frac{Adx}{\rho c r}\left[1 + \frac{1}{jkr}\sin\theta\right]$ $\times\, e^{j(\omega t - kr + \varphi)}$	$I_r = \frac{A^2 dx^2 k^2 \cos^2\theta}{\rho c r^2}$ $I_\theta = 0$	Z_r ⇨

NOTES: 1. θ = ANGLE OF x' FROM THE x AXIS. X = MULTIPLY
2. VELOCITY POTENTIAL $\Phi = p/j\omega\rho$

EQUATIONS

COUSTIC AVE PEDANCE EPENDS N DIRECTION) Z_a	ACOUSTIC POWER P	COMMENTS
$= \rho c$	POWER = INTENSITY X AREA	NO SPREADING LOSS
$= j\rho c \cot an\,[k(x-x_0)]$	POWER = INTENSITY X AREA	NO SPREADING LOSS PRESSURE AND VELOCITY POTENTIAL NULL AT $x-x_0 = (2n+1)\lambda/4$ (n = any integer) GRADIENT AND VELOCITY NULL AT $x-x_0 = n\lambda/4$
$= \dfrac{\rho c}{1 - \dfrac{j}{2kr}}$ ⇨ ρc	POWER/UNIT LENGTH OF LINE SOURCE $P = \dfrac{\pi A^2}{\rho c}$	SHORT PULSES GROW "TAILS" AS THEY PROPAGATE ⇨ INDICATES VALUE FOR LARGE r WHICH IS THE SAME AS FOR A PLANE WAVE.
$r = \dfrac{\rho c}{1 + \dfrac{1}{jkr}}$ ⇨ ρc	POWER OF POINT SOURCE $P = \dfrac{2\pi P^2}{\rho c}$	⇨ INDICATES VALUE FOR LARGE r AT LARGE r THE INTENSITY IS THE SAME AS THAT FOR A PLANE WAVE
$= \rho c \left[\dfrac{k^4 r^4}{4+k^4 r^4} + jkr \times \dfrac{2+k^2 r^2}{4+k^2 r^2}\right]$ ρc	POWER OF DIPOLE SOURCE $P = \dfrac{2\pi A^2 k^2 dx^2}{3\rho c}$	DISTANCE dx IS CALLED DIPOLE MOMENT

SOUND TRANSMISSION AND REFLECTION AT A FLUID INTERFACE



NOTE: Arrows represent sound rays

GOVERNING EQUATIONS FOR θ_1 & θ_2

1. The angle of reflection equals the angle of incidence (shown as $\theta_1 = \theta_1$ above).

2. $\dfrac{\sin\theta_1}{c_1} = \dfrac{\sin\theta_2}{c_2}$ Snell's Law

GOVERNING EQUATIONS FOR TRANSMITTED AND REFLECTED ACOUSTIC PRESSURE

p_I = Incident Pressure; p_T = Transmitted Pressure; p_R = Reflected Pressure

$$\frac{p_R}{p_I} = \frac{\dfrac{\rho_2}{\rho_1}\cos\theta_1 - \sqrt{\left(\dfrac{c_1}{c_2}\right)^2 - \sin^2\theta_1}}{\dfrac{\rho_2}{\rho_1}\cos\theta_1 + \sqrt{\left(\dfrac{c_1}{c_2}\right)^2 - \sin^2\theta_1}} = \frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1} \left(\text{if } \theta_1 = 0\right)$$

$$\frac{p_T}{p_I} = \frac{2\dfrac{\rho_2}{\rho_1}\cos\theta_1}{\dfrac{\rho_2}{\rho_1}\cos\theta_1 + \sqrt{\left(\dfrac{c_1}{c_2}\right)^2 - \sin^2\theta_1}} = \frac{2\rho_2 c_2}{\rho_2 c_2 + \rho_1 c_1} \left(\text{if } \theta_1 = 0\right)$$

SOUND TRANSMISSION AND REFLECTION AT A FLUID INTERFACE

CRITICAL ANGLE (FOR ANGLES OF INCIDENCE GREATER THAN THE CRITICAL ANGLE, REFLECTION IS TOTAL)

If $c_2 > c_1$, CRITICAL ANGLE $\theta_c = \sin^{-1} \frac{c_1}{c_2}$

For $\theta_1 > \theta_c$, there is total reflection; no transmission at fluid-fluid interface.

TRANSMISSION AND REFLECTION OF SOUND INTENSITY

$$\text{Transmitted Sound Intensity Ratio} = \frac{\rho_1 c_1}{\rho_2 c_2} \left(\frac{2 \frac{\rho_2}{\rho_1} \cos \theta_1}{\frac{\rho_2}{\rho_1} \cos \theta_1 + \sqrt{\left(\frac{c_1}{c_2}\right)^2 - \sin^2 \theta_1}} \right)^2 = \frac{\text{Transmitted Intensity}}{\text{Incident Intensity}}$$

$$= \frac{4 \rho_1 c_1 \rho_2 c_2}{\rho_2 c_2 + \rho_1 c_1} \quad \text{For Normal Incidence}$$

$$\left(\text{Reflected Sound Intensity Ratio}\right) = 1 - \left(\text{Transmitted Sound Intensity Ratio}\right)$$

USEFUL NUMBERS

θ_c (air to water) $= \sin^{-1} \left(\frac{c\ \text{air}}{c\ \text{water}} \right) \approx 13.2^\circ$

$\frac{p_T}{p_I}$ (air to water, $0 \leq \theta_1 \leq 13.2^\circ$) $= 1.99 \approx 2 \rightarrow + 6$dB

$\frac{p_R}{p_I}$ (air to water, $0 \leq \theta_1 \leq 13.2^\circ$) $= .99 \approx 1 \rightarrow 0$dB

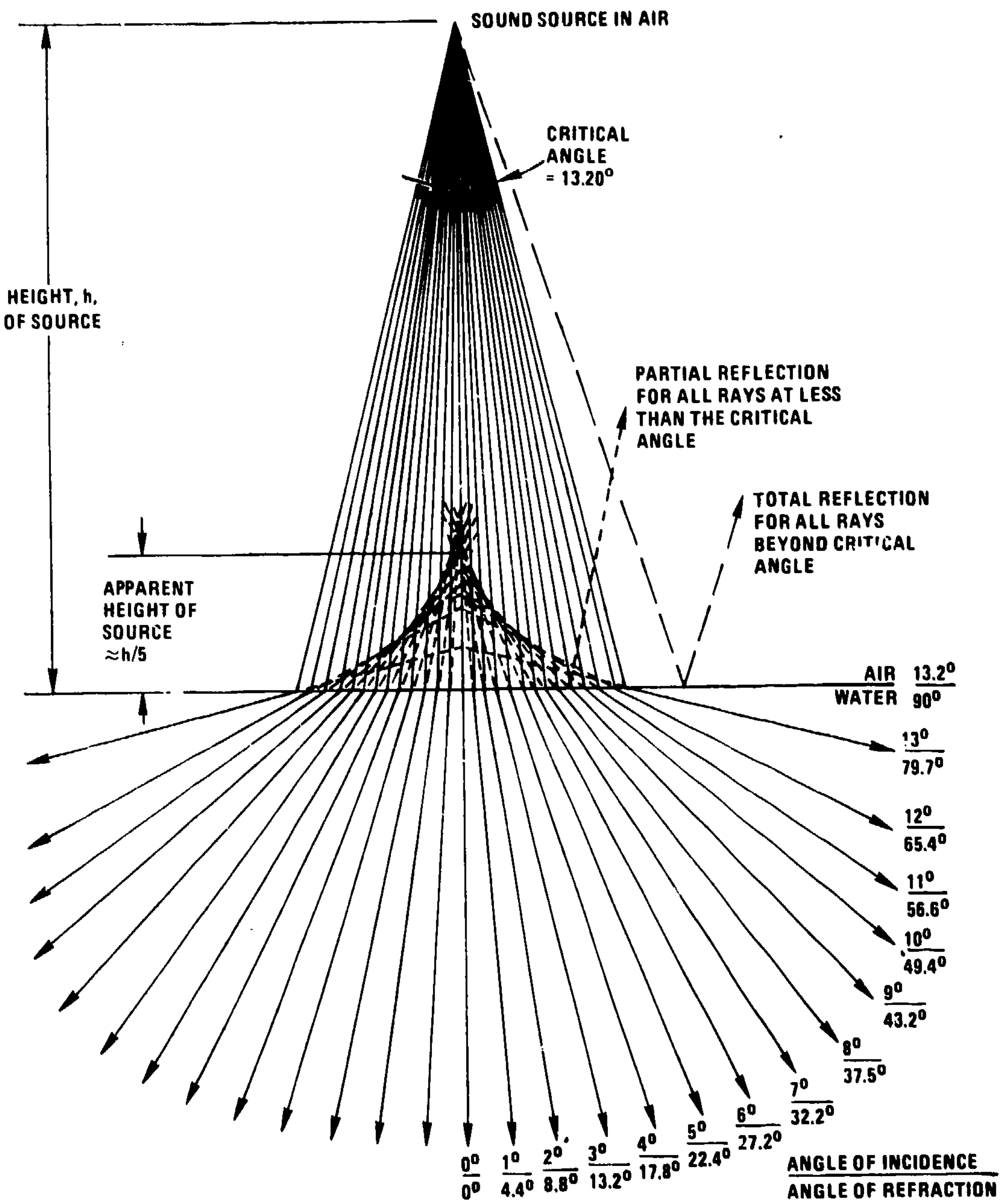
Transmitted Sound Power Ratio (air to water) $0 \leq \theta_1 \leq 13.2^\circ \rightarrow 0.00111 = -29.6$dB

120 dB re 10^{-12} watt acoustic source will produce

→ 109 dB re 20 μ Pa in air at a radius of one meter.

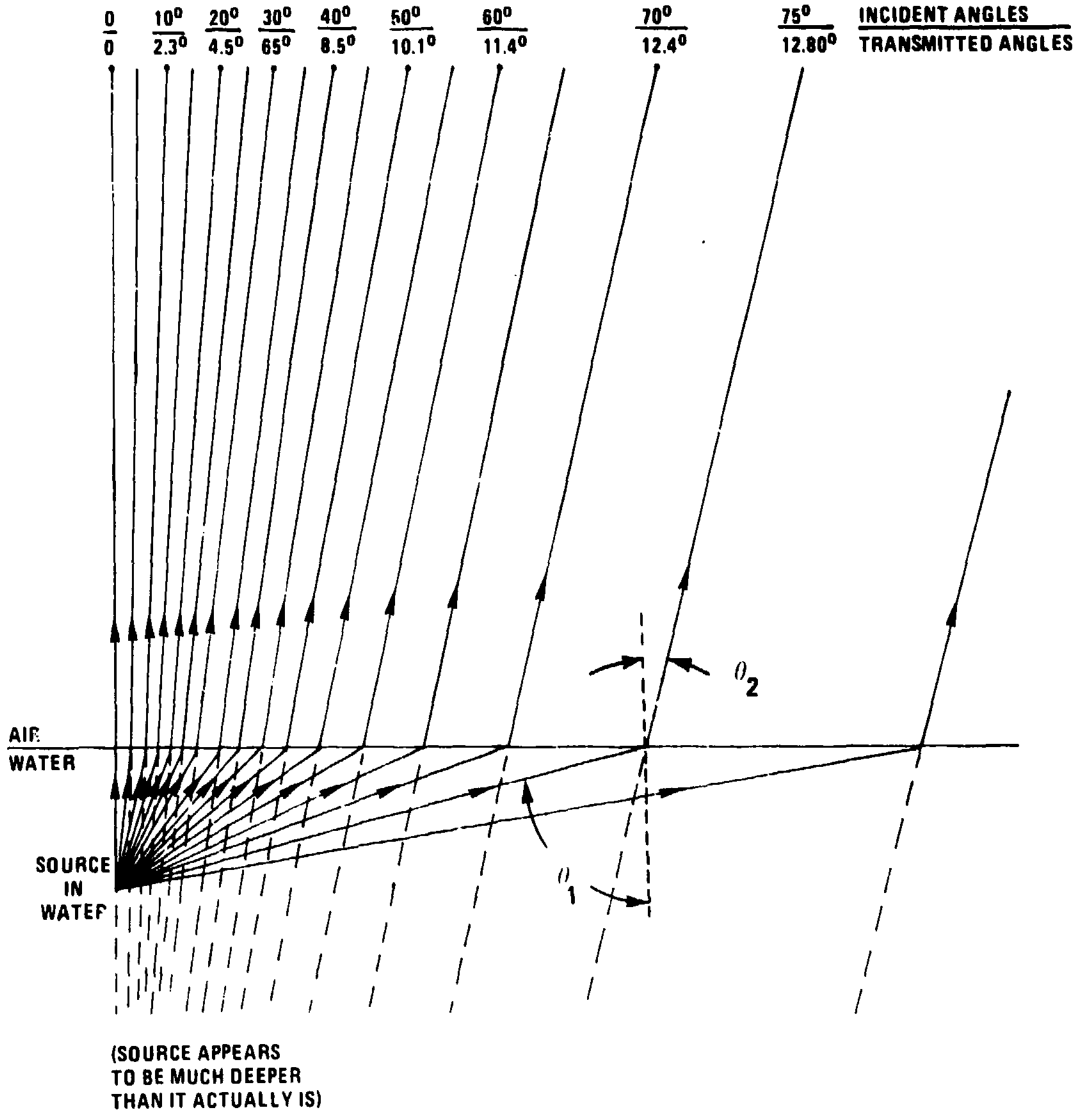
→ 171 dB re 1 μ Pa in water at a radius of one meter.

SOUND TRANSMISSION AIR-TO-WATER RAY DIAGRAM



SOUND TRANSMISSION AIR-TO-WATER RAY DIAGRAM

SOUND TRANSMISSION WATER-TO-AIR RAY DIAGRAM



TRANSMITTED SOUND POWER RATIO, WATER-TO-AIR

(WATER TO AIR)

θ_1	POWER RATIO	dB	θ_2
0°	.00111	−29.6dB	0°
10°	.00111	−29.7dB	2.3°
20°	.00098	−30.1dB	4.5°
30°	.00084	−30.8dB	6.5°
40°	.00066	−31.8dB	8.5°
50°	.00047	−33.3dB	10.1°
60°	.00029	−35.4dB	11.4°
70°	.00014	−38.7dB	12.4°
80°	.00004	−44.5dB	13.0°

IV

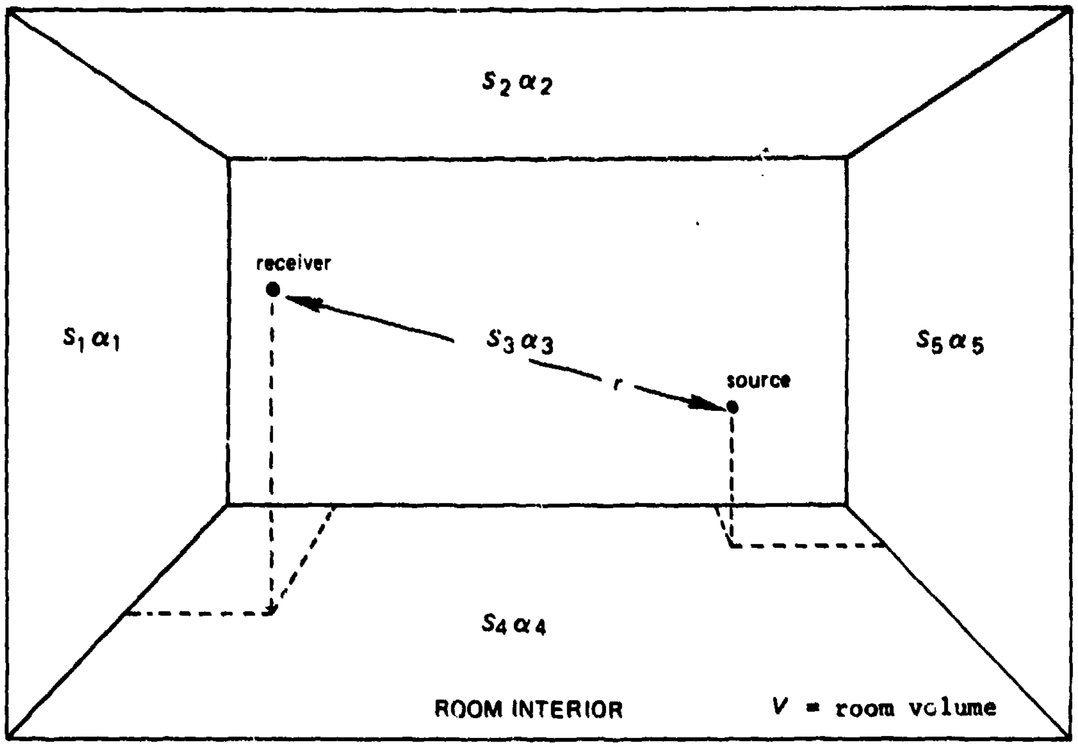
ROOM ACOUSTICS

CONTENTS

SYMBOLS AND PREFERRED UNITS FOR THIS CHAPTER

SYMBOL	QUANTITY	SYMBOL OF PREFERRED UNIT	PREFERRED UNIT
a'	Sound Absorption Units	m^2	Square meter
c	Sound Velocity	m/s	Meter per second
r	Distance Between Sound Source and Receiver	m	Meter
A	Sabine Absorption of a Room Interior	Sa	Metric Sabine (= square meter)
C	A Constant	dB	Decibels
R	Room Constant	m^2	Square meter
S	Surface Area of a Room Interior	m^2	Square meter
T	Reverberation Time	s	Seconds for a 60 dB decay
V	Room Volume	m^3	Cubic meter
PWL	Sound Power Level	dB	Decibels re 10^{-12}w
SPL	Sound Pressure Level	dB	Decibels re 20μPa
TL	Transmission Loss	dB	Decibels

EQUATIONS OF ROOM ACOUSTICS



STATISTICAL ABSORPTION COEFFICIENT

Calculated: $$\alpha = \frac{S_1 \alpha_1 + S_2 \alpha_2 + \cdots + S_n \alpha_n}{S}$$ dimensionless

Where the α_i are the sound absorption coefficients of the areas S_i, measured individually or taken from a handbook or catalog, and $\Sigma S_i = S$.

Measured from reverberation time, T: $$\alpha = 1 - 10^{\frac{-24V}{cTS}}$$

RELATIONSHIP OF SOUND POWER LEVEL (PWL) AND SOUND PRESSURE LEVEL (SPL) IN AN ENCLOSURE

$$\text{SPL} = \text{PWL} + 10 \log_{10} \left(\frac{\gamma}{4\pi r^2} + \frac{4}{R} + C \right)$$

If r is in meters, C = 0 (R in m^2)

(See next page for values of γ and R) If r is in feet, C = 10.3dB (R in ft^2)

NOTE: If the enclosure is filled with water instead of air, the same equation holds, but C = 62 if r is in meters and C = 72.3 if r is in feet. In water, SPL is in dB re 1μPa.

CALCULATED ROOM CONSTANT, R, GIVEN α

$$R = \frac{S\alpha}{1 - \alpha} \text{ units of } m^2$$

EFFECTIVE DIRECTIVITY, γ, OF SMALL OMNIDIRECTIONAL SOUND SOURCES

Position of Source	γ
Near Center of Room Volume	1
In Center of One Wall, Ceiling, or Floor	2
In a Corner Between Two Walls, a Wall and Ceiling, or a Wall and Floor	4
In a Corner Where Two Walls Meet the Ceiling or Floor	8

T - calculated reverberation time (Time, in seconds for 60dB decay in SPL)

$$T = \frac{55.3V}{ca'} = 0.161\frac{V}{a'} \text{ where}$$

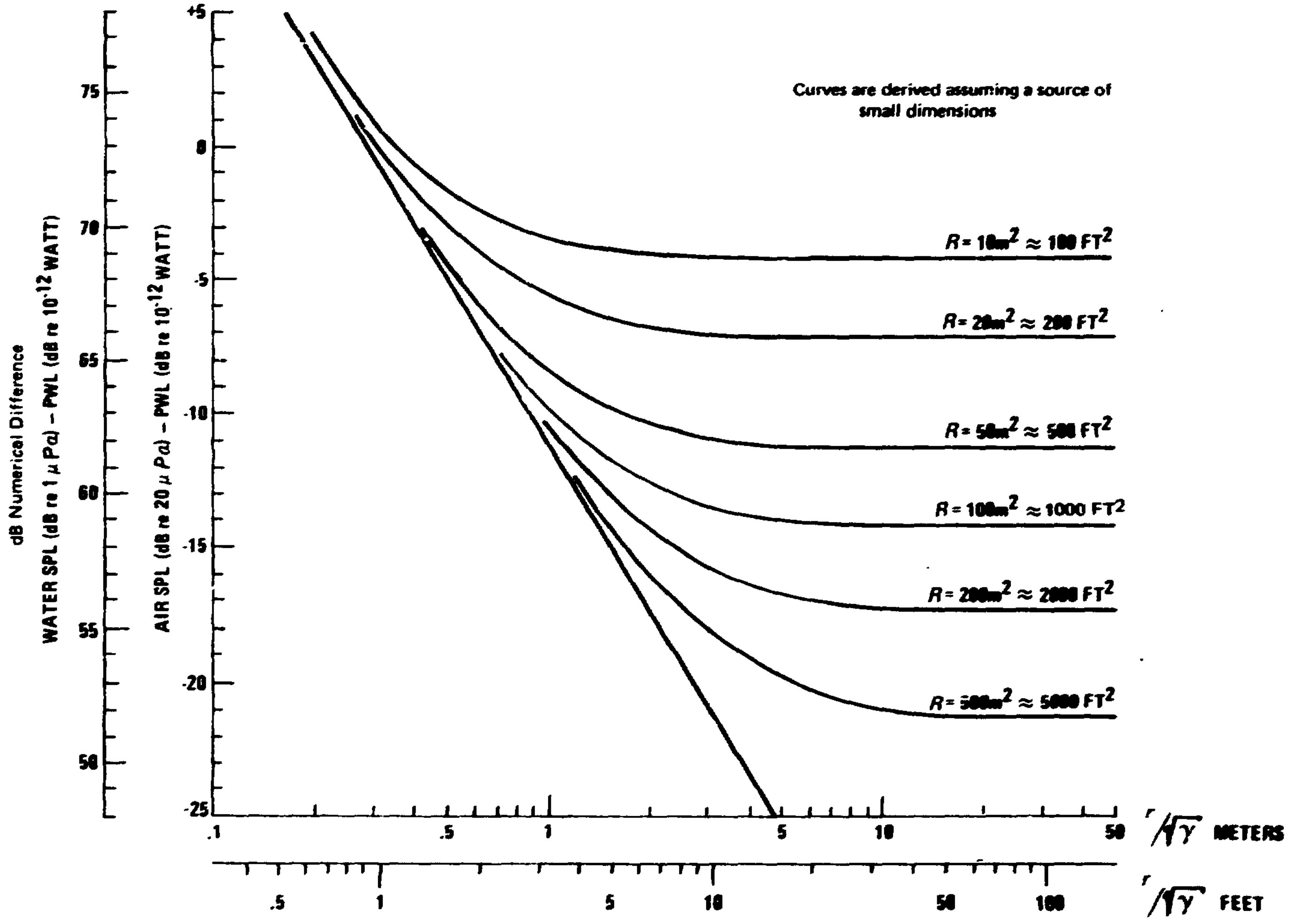
V = room volume in m^3
c = sound speed in m/s
a' = metric absorption units in m^2

$$a' = S\left[-2.30 \log_{10}(1-\alpha)\right] \text{ units of } m^2$$

TABLE OF a'/S vs α DIMENSIONLESS

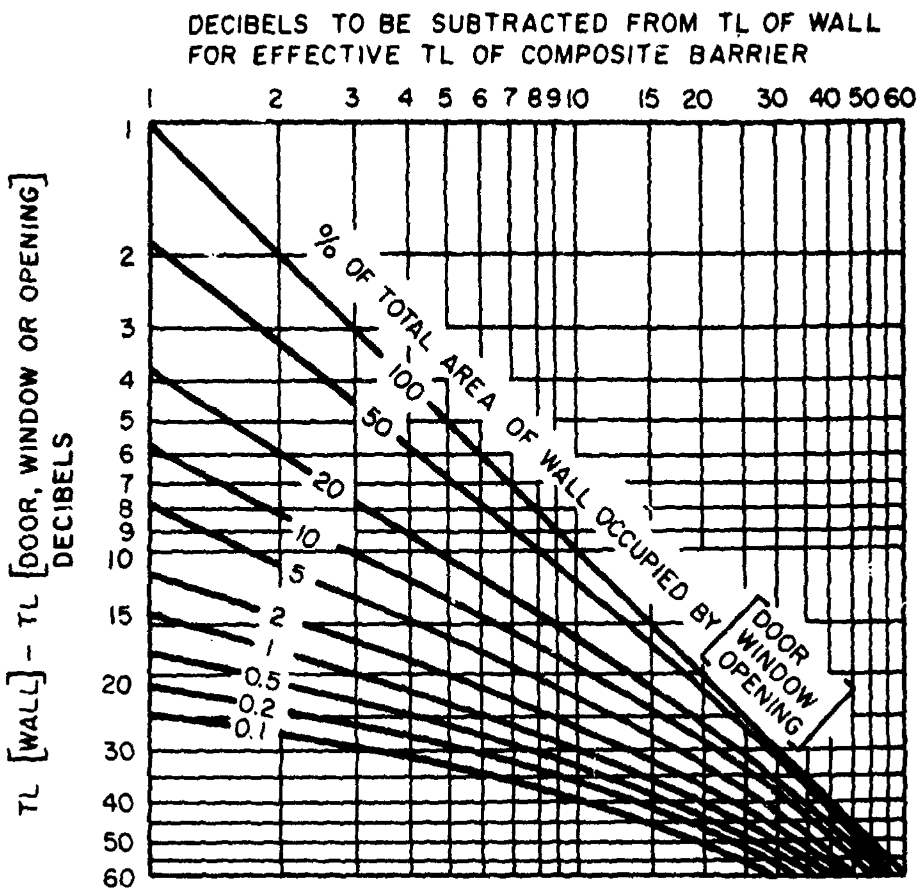
α	a'/S	α	a'/S	α	a'/S	α	a'/S
.01	.010	.21	.235	.41	.527	.61	.941
.02	.020	.22	.248	.42	.544	.62	.966
.03	.030	.23	.261	.43	.561	.63	.993
.04	.041	.24	.274	.44	.579	.64	1.02
.05	.051	.25	.287	.45	.597	.65	1.05
.06	.062	.26	.301	.46	.615	.66	1.08
.07	.072	.27	.314	.47	.634	.67	1.11
.08	.083	.28	.328	.48	.653	.68	1.14
.09	.094	.29	.342	.49	.673	.69	1.17
.10	.105	.30	.356	.50	.692	.70	1.20
.11	.116	.31	.371	.51	.713	.71	1.24
.12	.128	.32	.385	.52	.733	.72	1.27
.13	.139	.33	.400	.53	.754	.73	1.31
.14	.151	.34	.415	.54	.776	.74	1.35
.15	.162	.35	.430	.55	.798	.75	1.38
.16	.174	.36	.446	.56	.820	.76	1.43
.17	.186	.37	.462	.57	.843	.77	1.47
.18	.198	.38	.477	.58	.867	.78	1.51
.19	.210	.39	.494	.59	.891	.79	1.56
.20	.223	.40	.510	.60	.915	.80	1.61

SOUND PRESSURE VS LOCATION IN A ROOM



DESIGN CURVE FOR PREDICTING SOUND PRESSURE LEVELS AT SELECTED POINTS IN A ROOM OR ACOUSTIC ENCLOSURE GIVEN SOURCE POWER (PWL), SOURCE DIRECTIVITY (γ), AND DISTANCE BETWEEN SOURCE & POINT IN QUESTION, (r).

TRANSMISSION LOSS OF WALLS WITH PANELS OF DIFFERENT TL.



EFFECTIVE TRANSMISSION LOSS OF COMPOSITE BARRIERS

Extracted from NAVSHIPS - 250-645-3

V

SOUND IN SOLIDS

CONTENTS

SYMBOLS AND PREFERRED UNITS FOR THIS CHAPTER

SYMBOL	QUANTITY	SYMBOL OF PREFERRED UNIT	PREFERRED UNIT
c	Wave Speed	m/s	Meter per second
d	Thickness	m	Meter
f	Frequency	Hz	Hertz
m	Mass per Unit Area	kg/m^2	Kilogram per square meter
r	Speed Correction for Rayleigh Waves	-	(numeric)
D	Dilatational Modulus	Pa	Pascal
E	Young's Modulus	Pa	Pascal
E_a	Effective Modulus	Pa	Pascal
G	Shear Modulus	Pa	Pascal
K	Bulk Modulus	Pa	Pascal
S	Shape Factor	-	(numeric)
T	String or Membrane Tension Material	N or N/m	Newton or newton per meter
β	Correction Factor	-	(numeric)
δ_K, δ_D, δ_E, δ_G	Dynamic Modulus Damping Factors	-	(numeric)
ν	Poisson's Ratio	-	(numeric)
ρ	Mass Density	kg/m^3	Kilogram per cubic meter
ω	Angular Frequency	rad/s	Radians per second

TYPES OF WAVES IN SOLIDS

Waves are a means of transmitting energy - vibrational energy for the purposes of this handbook. Descriptions of different types of waves are given below.

Compressional Wave (also Pressure or Dilational Wave): A compressional wave in an elastic medium is a wave which propagates by alternately compressing and stretching the medium in the direction of wave propagation. It causes an element in the medium to change its volume without a change in shape.

P-Wave: In seismological terminology, a p-wave is a primary (as opposed to secondary, see below) wave or a pressure wave.

Shear Wave: A shear wave is a transverse wave in an elastic medium which undergoes a rotational motion. It causes an element in the medium to change its shape without a change in volume.

S-Wave: An S-wave in seismological terminology is a shear wave. S-waves are subdivided into horizontally polarized shear waves (SH-Waves) and vertically polarized shear waves (SV-Waves). The S is also derived from "secondary", from the fact that the shear waves from earthquakes arrive later than the primary or p-waves.

Lateral Wave: A lateral wave is a sound wave, most noticeable in shallow water, that travels from source to receiver via a path that is partly in the solid bottom of the body of water.

Rayleigh Wave: A Rayleigh wave is a surface wave near a free boundary whose amplitude decreases exponentially with distance from a surface. It is, in effect, a shear wave which is on the surface. Because the restoring force is somewhat less than a shear wave (one side is free), it propagates slightly slower than a shear wave. The presence of fluid will alter the speed of a Rayleigh wave. Turbulent fluid flow can excite Rayleigh waves.

Love Wave: A Love wave is a shear wave in a beam, plate, or other layered medium, the motion of which is confined to the surface layer along the horizontal direction.

Bending Wave: A bending or flexural wave is a wave in a beam or a plate which is a combination of shear and compressional waves accompanied by relatively large transverse displacements.

Transverse Wave: A transverse wave is a wave in which the direction of displacement is parallel to the wave front.

Longitudinal Wave: A longitudinal wave is a dilational wave which propagates along a bar, rod, or similar slender solid object where the direction of displacement is perpendicular to the wave front.

Creeping Waves: Creeping waves are circumferential waves induced in a solid sphere or cylinder, for example, which are subjected to radiation of sound waves. Creeping waves are present on the side away from the sound radiation and travel at a slower speed than the incident sound waves.

MATERIAL ELASTIC CONSTANTS AND THEIR INTERRELATIONSHIP

FIND / GIVEN	SHEAR MODULUS G	YOUNG'S MODULUS E	BULK MODULUS K	DILATATIONAL MODULUS D	POISSON'S RATIO ν
G, E			$\frac{EG}{3(3G-E)}$	$G\left(\frac{4G-E}{3G-E}\right)$	$\frac{E}{2G}-1$
G, K		$\frac{9KG}{3K+G}$		$K+\frac{4G}{3}$	$\frac{3K-2G}{6K+2G}$
G, ν		$2G\ (1+\nu)$	$\frac{2G(1+\nu)}{3(1-2\nu)}$	$\frac{2G\ (\nu-1)}{2\nu-1}$	
E, B	$\frac{3KE}{9K-E}$			$3K\left(\frac{3K-E}{9K-E}\right)$	$\frac{1}{2}-\frac{E}{6B}$
E, ν	$\frac{E}{2(1+\nu)}$		$\frac{E}{3(1-2\nu)}$	$\frac{E(\nu-1)}{(1+\nu)(2\nu-1)}$	
K, ν	$\frac{3K(1-2\nu)}{2(1+2\nu)}$	$3K(1-2\nu)$		$\frac{3K(1-\nu)}{1+\nu}$	

MATERIAL ELASTIC CONSTANTS MODIFIED TO INCLUDE DAMPING

G ➡ $G(1+j\delta_G)$ complex shear modulus

E ➡ $E(1+j\delta_E)$ complex Young's modulus

K ➡ $K(1+j\delta_K)$ complex bulk modulus

D ➡ $D(1+j\delta_D)$ complex dilatational modulus

δ = damping factor or loss factor corresponding to the appropriate strain - shear, dilatational, etc.

(For rubberlike materials, $\delta_E \simeq \delta_G$)

ATTENUATION OF WAVES WITH DISTANCE

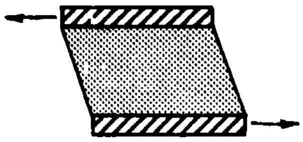
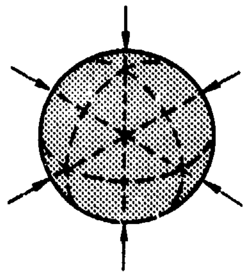
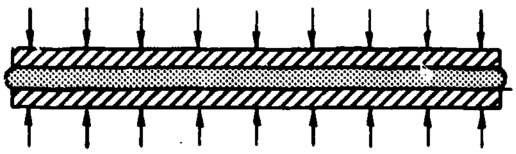
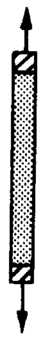
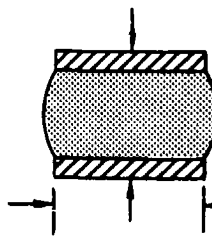
$$\text{Wave amplitude} = Ae^{-\frac{\omega\delta x}{2c}}$$

$$\text{Decay rate} = \frac{\omega\delta}{2c} \text{ nepers/unit length}$$

$$= \frac{4.34\omega\delta}{c} \text{ dB/unit length}$$

ATTENUATION OF WAVES WITH DISTANCE

TYPES OF SIMPLE MATERIAL DEFORMATIONS AND THEIR CORRESPONDING ELASTIC MODULI SHOWN FOR RUBBER-LIKE MATERIALS

Deformation	Elastic Modulus
	**Shear Modulus - G** Change in Shape No Change in Volume
	**Bulk Modulus - K** Change in Volume - No Change in Shape
	**Dilatational Modulus - D** Change in Shape & Volume $D = K + \frac{4G}{3} \approx K$ for rubber Where Edge Effects are Negligible
	**Young's Modulus - E** Change in Shape and Volume $E = \frac{9KG}{3K+G} \approx 3G$ for rubber NOTE: Poisson's Ratio, $\nu = \frac{E}{2G} - 1 \approx 0.5$ for rubber
	**Effective Modulus - E_a** Change of Shape & Volume $E_a = (1+\beta S^2)\,E = 3(1+\beta S^2)\,G$ S = Shape factor = ratio of area of one loaded surface to force-free area = $D/4\mathcal{L}$ for cylinder shown β = 2 for rubber, greater for hardened rubber (NOTE: $E < E_a < D$)

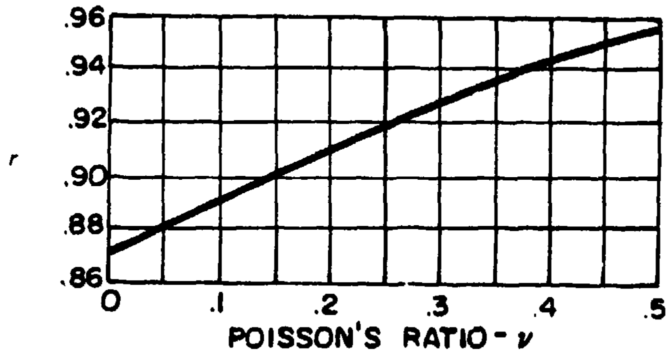
From Snowdon.

WAVE SPEEDS IN VARIOUS SOLIDS

BULK SOLIDS

- Dilatational wave speed $c = \sqrt{\frac{D}{\rho}}$
- Shear wave speed $c = \sqrt{\frac{G}{\rho}}$
- Rayleigh wave speed $c = r\sqrt{\frac{G}{\rho}}$

The value of r is found from Poisson's ratio and the graph below:



BARS

- Longitudinal bar velocity $c = \sqrt{\frac{E}{\rho}}$
- Torsional bar velocity $c = \sqrt{\frac{G}{\rho}}$

BEAMS

Bending wave velocity in an elementary (Bernoulli-Euler) beam

$$c = \sqrt[2]{2\pi f}\;\sqrt[4]{\frac{Ed^2}{12\rho}}$$

Bending wave velocity in a Timoshenko Mindlin beam

$$c = \sqrt{\frac{1}{1.7\frac{\rho}{E} + \sqrt{\frac{12\rho}{\omega^2 Ed^2} + \left\{0.7\,\frac{\rho}{E}\right\}^2}}}$$

PLATES

Bending wave velocity in an elementary plate

$$c = \sqrt[2]{2\pi f}\ \sqrt[4]{\frac{Ed^2}{12\rho\,(1-\nu^2)}}$$

Bending wave velocity in a Timoshenko - Mindlin plate

$$c = \sqrt{\frac{1}{\frac{\rho}{E}(1+\nu)\left[1.2+\frac{(1-\nu)}{2}\right]+\sqrt{\frac{12\rho(1-\nu^2)}{\omega^2 E d^2}+\left\{\frac{\rho(1+\nu)}{E}\left[1.2-\frac{(1-\nu)}{2}\right]\right\}^2}}}$$

Longitudinal plate velocity $c = \sqrt{\frac{E}{\rho\,(1-\nu^2)}}$

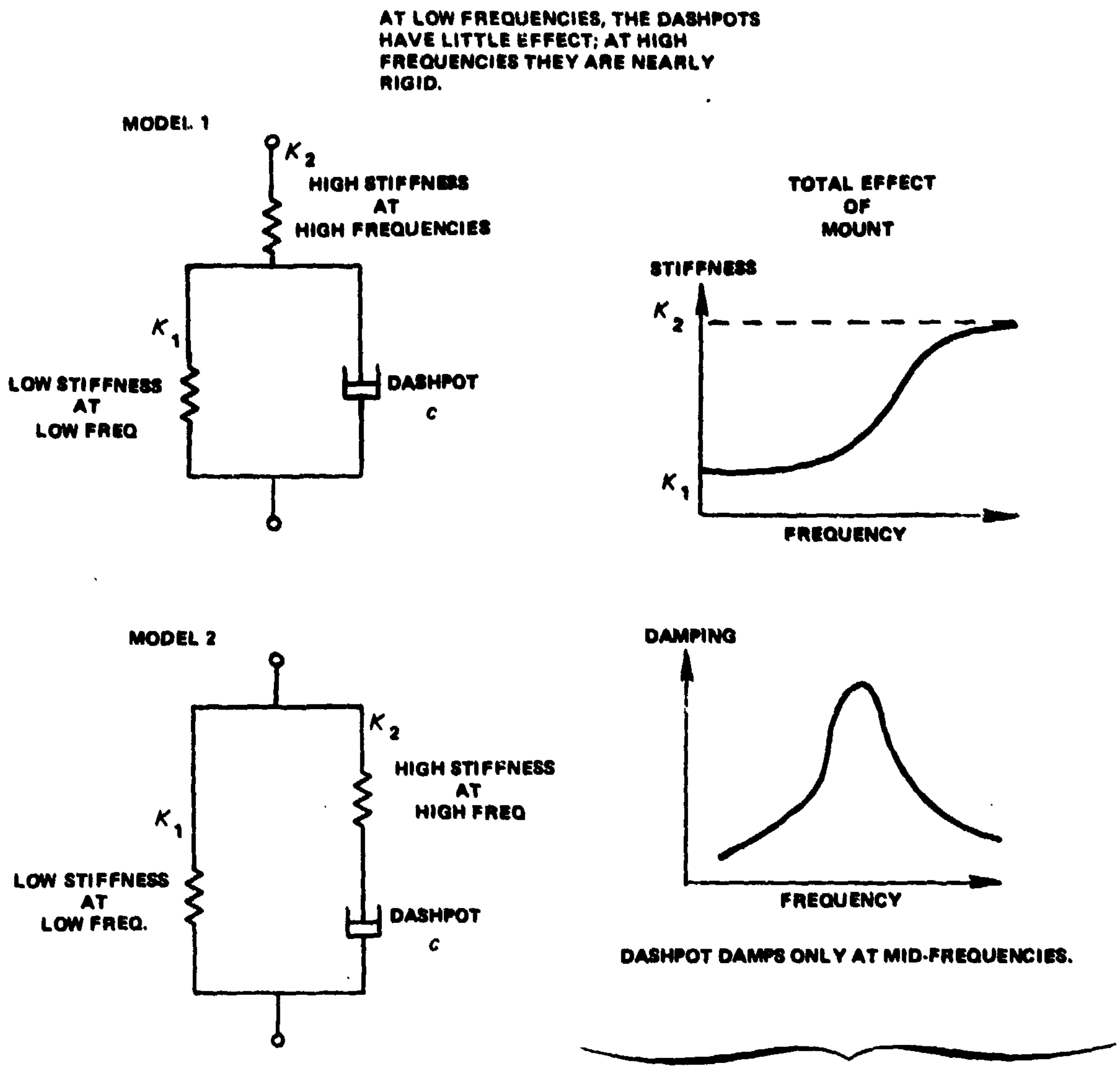
STRINGS AND MEMBRANES

Transverse waves on strings $c = \sqrt{\frac{T}{\bar{m}}}$ — T = Tension, m = mass/unit length

Transverse waves on membranes $c = \sqrt{\frac{T}{\bar{m}}}$ — T = Tension, m = mass/unit area

SIMPLE SPRING-DASHPOT MODELS FOR RUBBER MOUNTS AND COMPONENTS

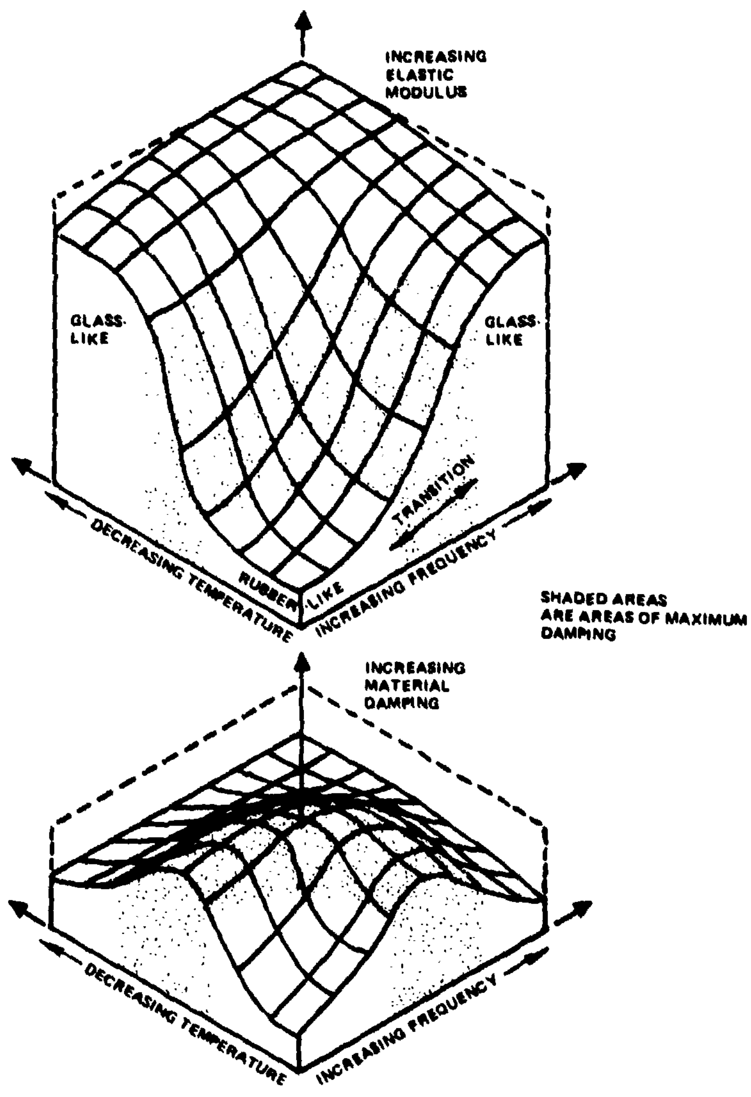
SIMPLE SPRING-DASHPOT MODELS FOR RUBBER MOUNTS AND COMPONENTS



SAME DAMPING AND STIFFNESS CHARACTERISTICS FOR BOTH MODELS

VARIATIONS OF ELASTIC MODULI OF RUBBER AND RUBBER-LIKE MATERIALS WITH TEMPERATURE AND FREQUENCY

Rubber and rubber-like materials are compliant (rubber-like) at high temperatures and low frequencies and brittle (glass-like) at low temperatures and high frequencies. The damping qualities are at a maximum at transition frequencies. The isometric sketches below illustrate the variations.



VI

MISCELLANEOUS FLUID-SOLID INTERACTIONS

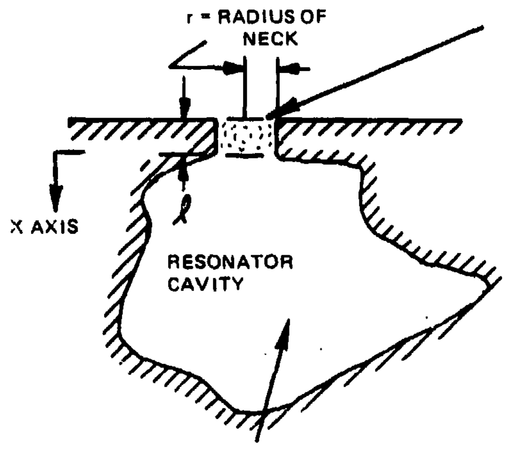
CONTENTS

SYMBOLS AND PREFACED UNITS FOR THIS CHAPTER

SYMBOL	QUANTITY	SYMBOL OF PREFERRED UNIT	PREFERRED UNIT
c	Speed of sound in a fluid	m/s	Meter per second
d	Thickness	m	Meter
f	Frequency	Hz	Hertz
f_r	Resonant frequency	Hz	Hertz
l	Length	m	Meter
m	Mass per unit area of a plate	Kg/m^2	Kilogram per square meter
p_I	Incident acoustic pressure	Pa	Pascal
p_R	Reflected acoustic pressure	Pa	Pascal
p_T	Transmitted Acoustic pressure	Pa	Pascal
r	Radius	m	Meter
A	Area	m^2	Square meter
A	Peak amplitude of incident sound pressure	Pa	Pascal
B	Peak amplitude of reflected sound pressure	Pa	Pascal
E	Young's modulus	Pa	Pascal
K	Bulk modulus of a fluid	Pa	Pascal
K	Stiffness of a compliant layer	N/m^3	Newton per cubic meter
R	Radius	m	Meter
R	Reflectivity	-	(Numeric)
V	Volume	m^3	Cubic meter
Z	Acoustic impedance	N-s/m	Newton-second per meter
γ	Poisson's ratio	-	(Numeric)
ρ	Mass density of a fluid	Kg/m^3	Kilogram per cubic meter
ω	Angular frequency	Rad/s	Radian per second
Im	Abbreviation for Imaginary	-	-
Re	Abbreviation for Real	-	-

HELMHOLTZ RESONATORS

IN AIR



VOLUME, V, OF CAVITY

"Plug" of air in neck acts as a mass to resonate with the compliance of the air in the cavity. The effective length, ℓ eff., of the plug is equal to the length of the neck, ℓ, plus a correction factor:

$.8r$ for each flanged end

$.6r$ for each end with no flange

The resonant frequency, f_r, of the mass and cavity compliance is

$$f_r = \frac{c}{2\pi}\sqrt{\frac{A}{V\ell\ \text{eff.}}},$$ where A is the area of the opening and c is the speed of sound in air.

IN LIQUID (Because liquid bulk moduli are relatively high, container compliance can affect the resonant frequency)

- Resonant frequency of a cavity with rigid walls:

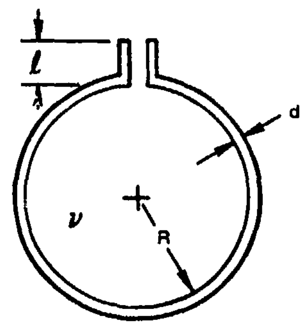
$$f_r = \frac{1}{2\pi}\sqrt{\frac{KA}{V\rho\ell}}$$ K = Bulk modulus of fluid

- Resonant frequency of an incompressible fluid in an elastic spherical container:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{2\ AEd}{3\ \rho\ell\ \ VR\,(1-\nu)}}$$

- Combined resonant frequency

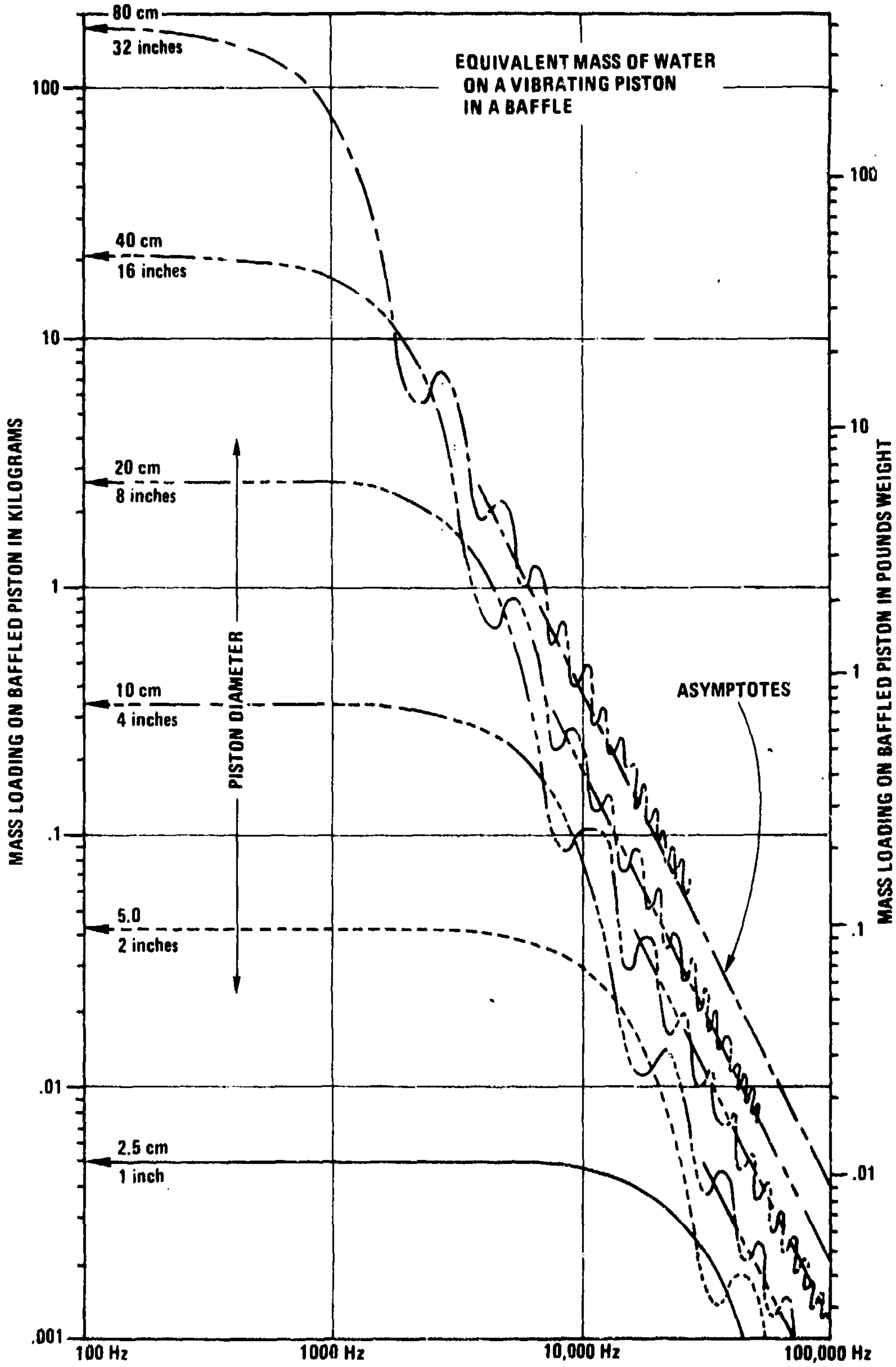
$$f_r = \frac{1}{2\pi}\sqrt{\frac{2}{\rho V\ell\ [3\,KR(1-\nu)\ +\ 2\,Ed]}}$$



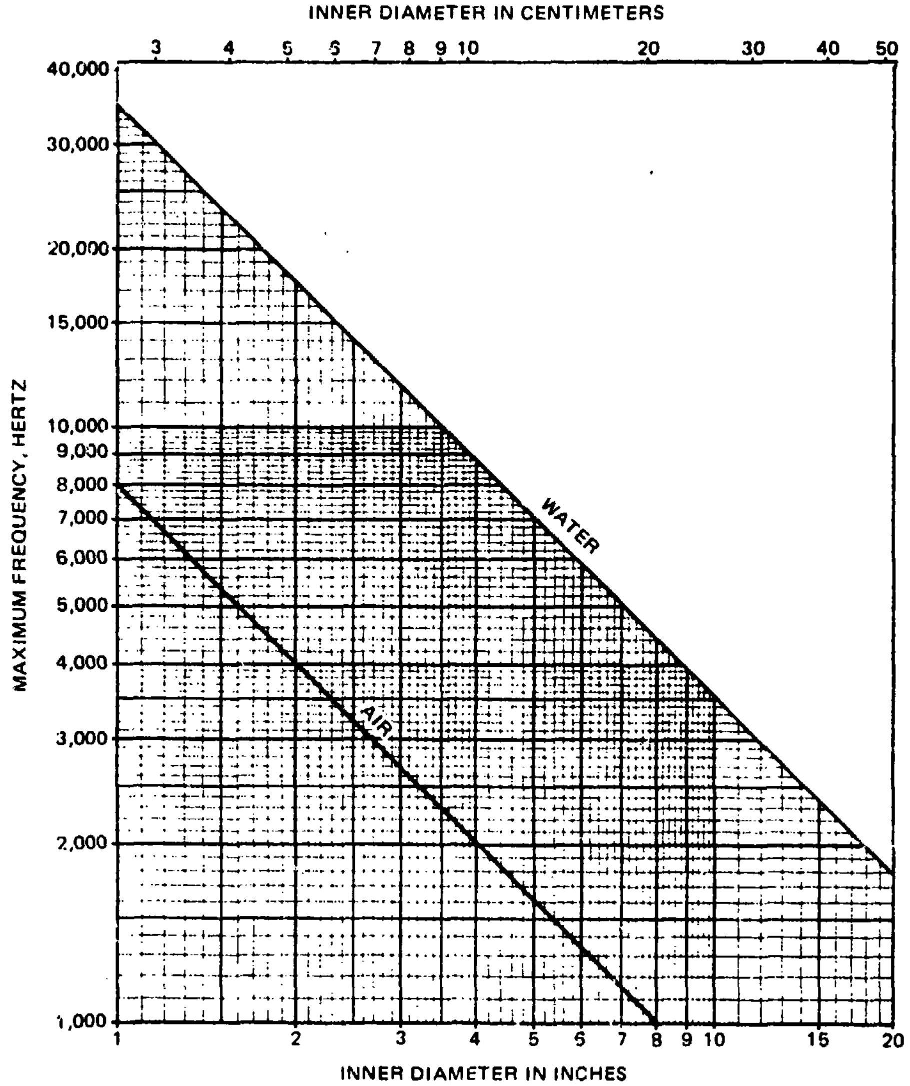
ν = POISSON'S RATIO

E = YOUNG'S MODULUS

MASS LOAD OF FLUID ON THE FACE OF A PISTON IN A BAFFLE



(Adapted from Kinsler & Frey, 1962, Figure 7.12)

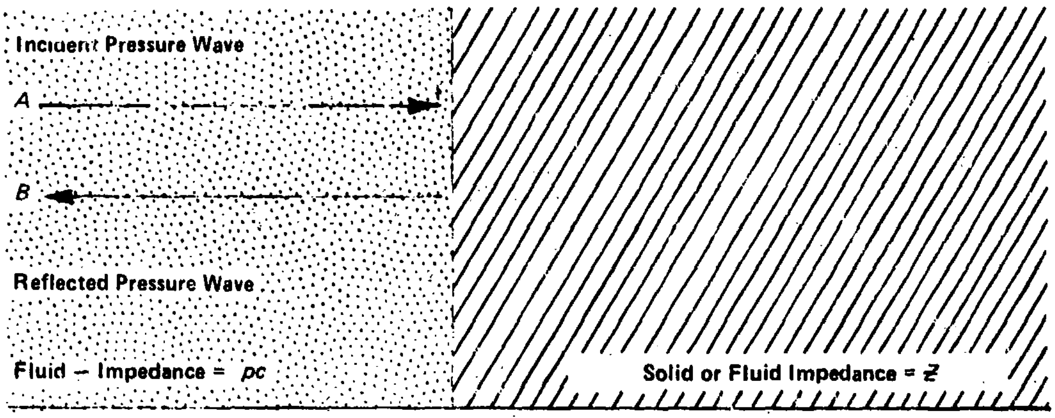


THECRETICAL UPPER FREQUENCY LIMIT FOR WATER-AND-AIR-FILLED PULSE & IMPEDANCE TUBES WITH RIGID WALLS

CONVERSION OF REFLECTIVITY

TO

SURFACE IMPEDANCE

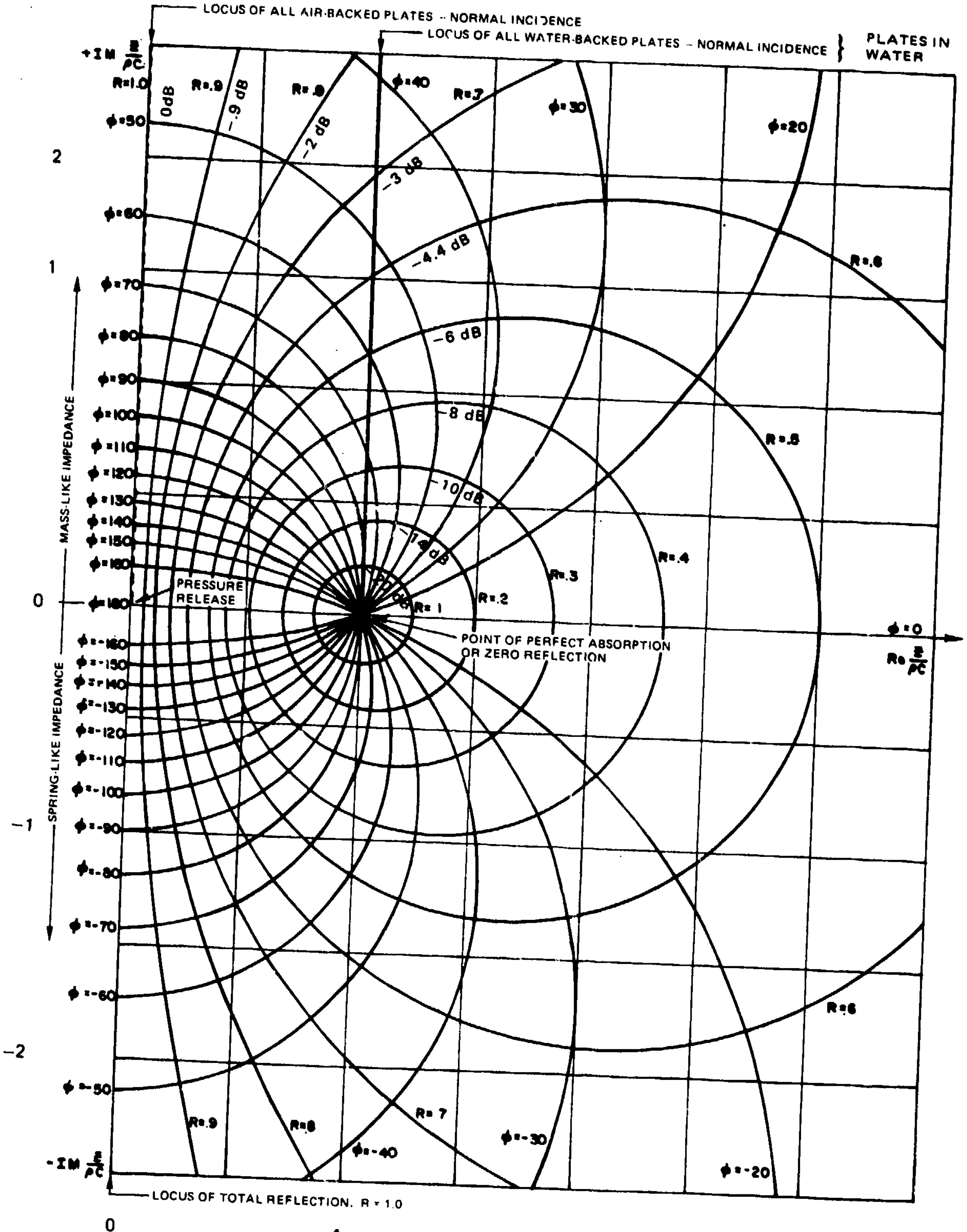


$$R\text{, Reflectivity} = \frac{B}{A} = \frac{\frac{z}{\rho c} - 1}{\frac{z}{\rho c} + 1} = R$$

The graph on the next page allows conversion from reflectivity (magnitude, R, and phase, ϕ) to the ratio of impedances, $\frac{z}{\rho c}$, given in real and imaginary components.

RELATIONSHIP OF ACOUSTIC IMPEDANCE AND REFLECTIVITY

RELATIONSHIP OF ACOUSTIC IMPEDANCE AND REFLECTIVITY

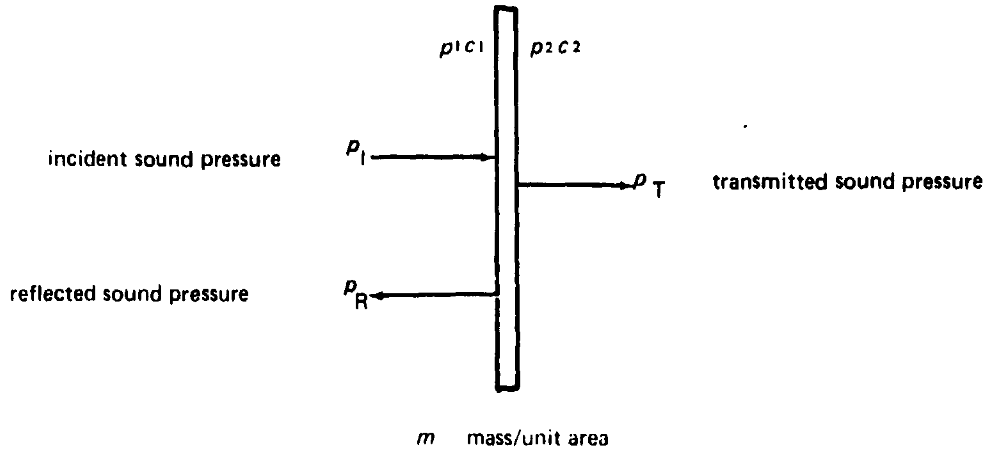


ρc = Impedance of Fluid, Z = Impedance of Surface

SOUND REFLECTION AND TRANSMISSION:

FLUID – PLATE – FLUID

NORMAL – INCIDENCE ACOUSTIC FORMULAS



$$\frac{p_R}{p_I} = \frac{\rho_2 c_2 - \rho_1 c_1 + j\omega m}{\rho_2 c_2 + \rho_1 c_1 + j\omega m} \qquad \frac{p_T}{p_I} = \frac{2\rho_2 c_2}{\rho_2 c_2 + \rho_1 c_1 + j\omega m}$$

WATER ON BOTH SIDES

$$\frac{p_R}{p_I} = \frac{j\omega m}{2\rho c_{water} + j\omega m} \qquad \frac{p_T}{p_I} = \frac{2\rho c_{water}}{2\rho c_{water} + j\omega m}$$

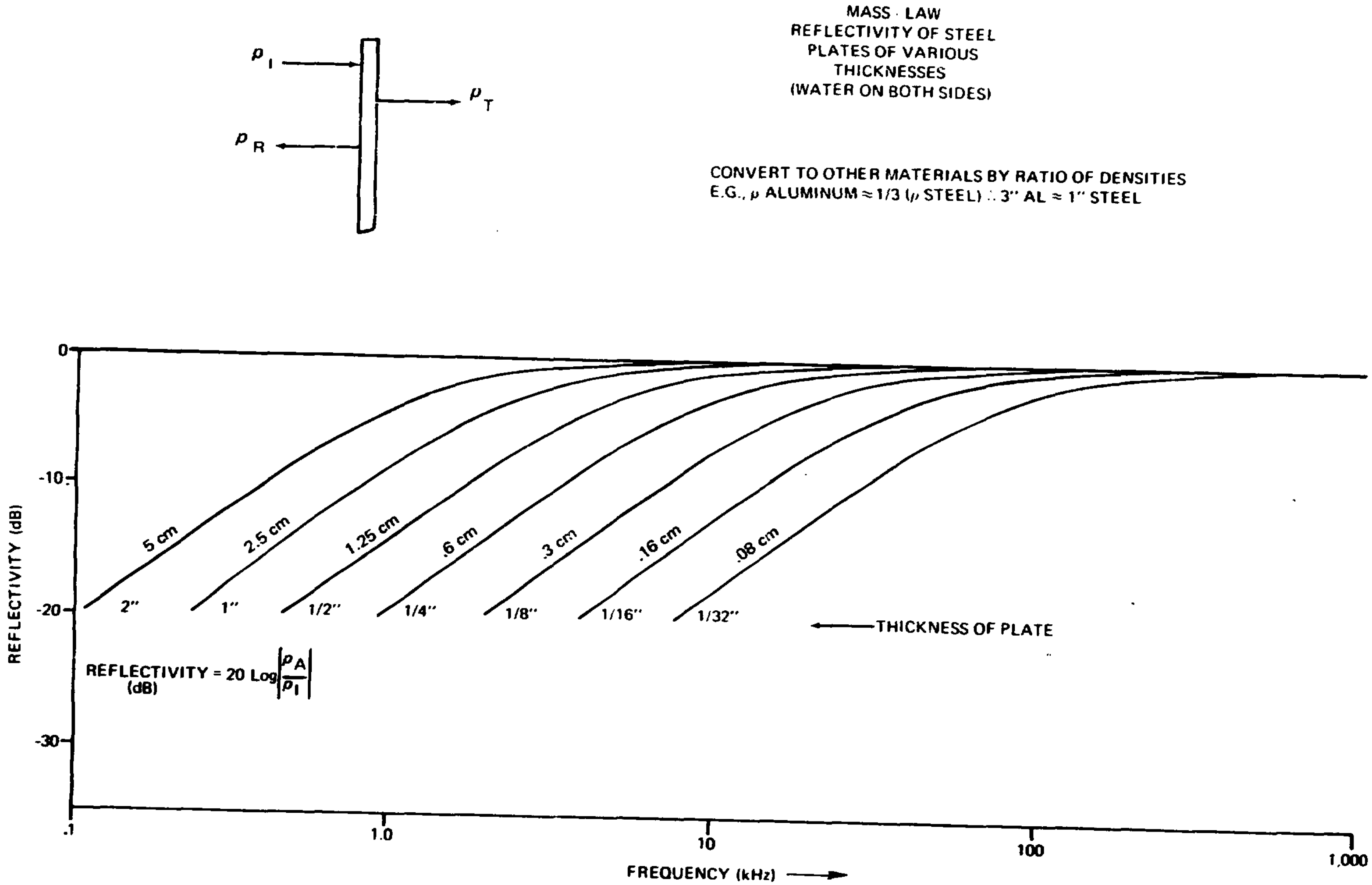
WATER - PLATE - AIR

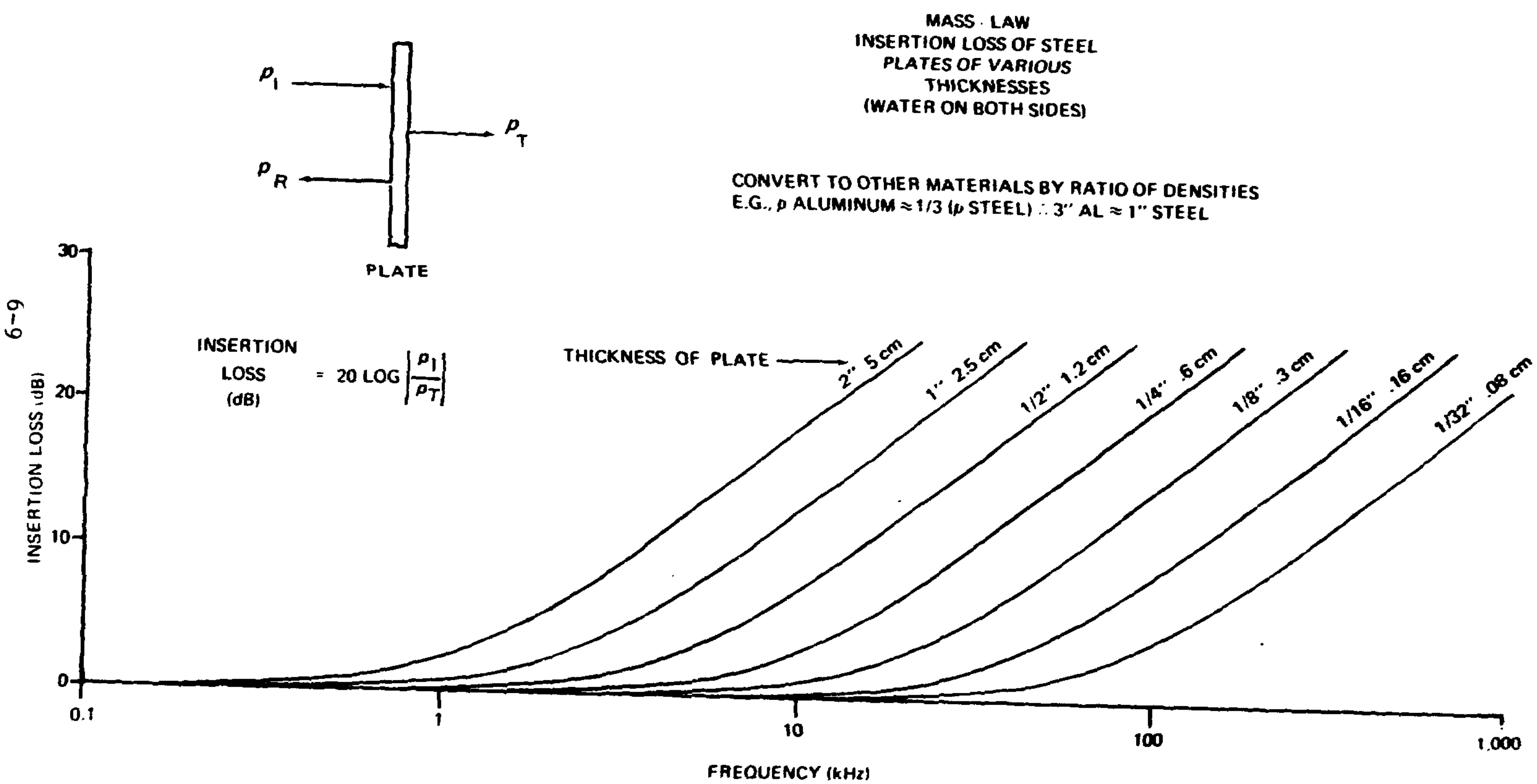
$$\frac{p_R}{p_I} = \frac{j\omega m - \rho c_{water}}{j\omega m + \rho c_{water}} \approx 1 \qquad \frac{p_T}{p_I} = \frac{2\rho c_{air}}{\rho c_{water} + j\omega m} \approx 0$$

AIR - PLATE - WATER

$$\left|\frac{p_R}{p_I}\right| \approx 1 \qquad \frac{p_T}{p_I} = \frac{2\rho c_{water}}{\rho c_{water} + j\omega m} \approx 2$$

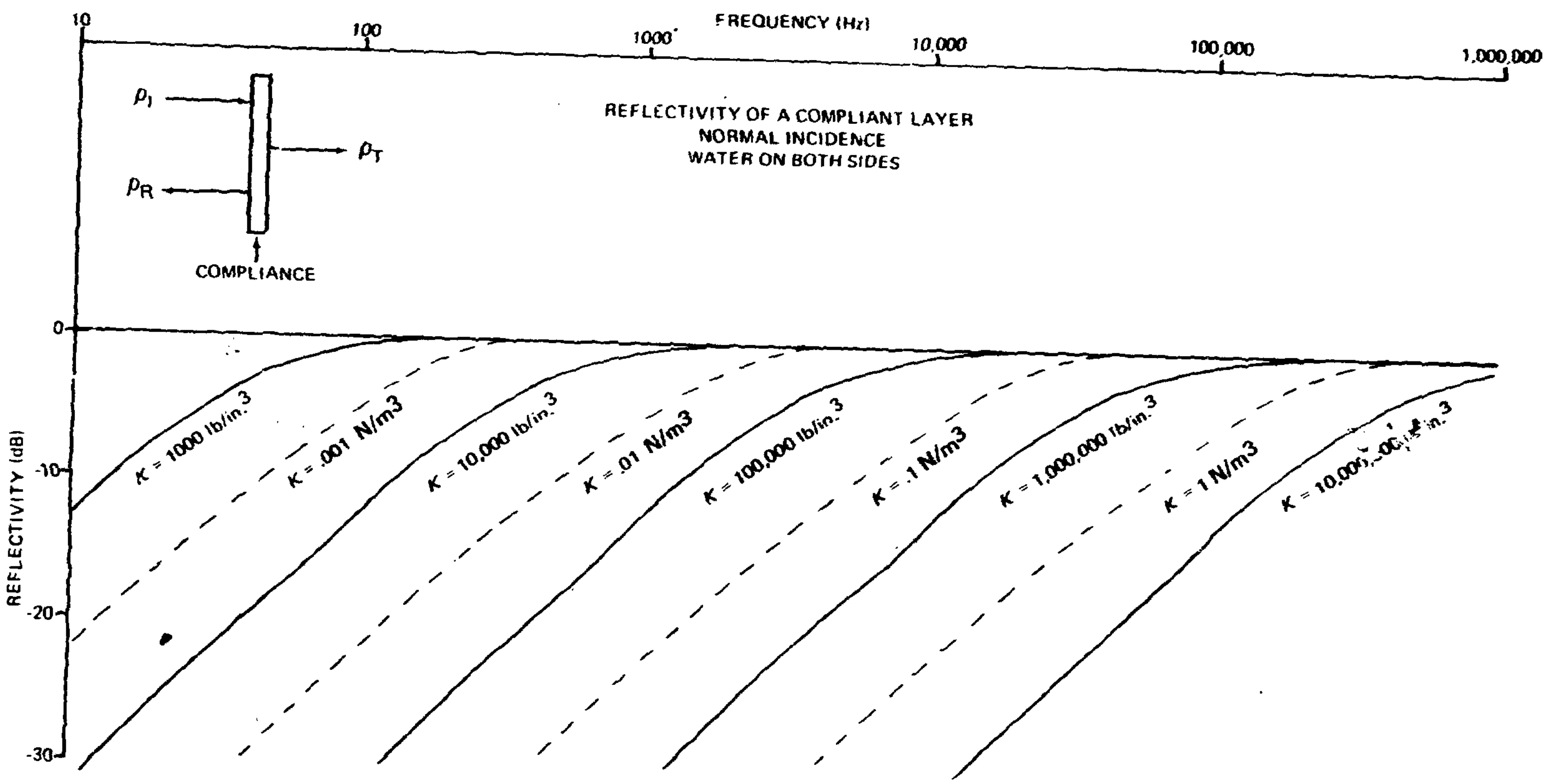
SOUND REFLECTION: WATER – PLATE – WATER





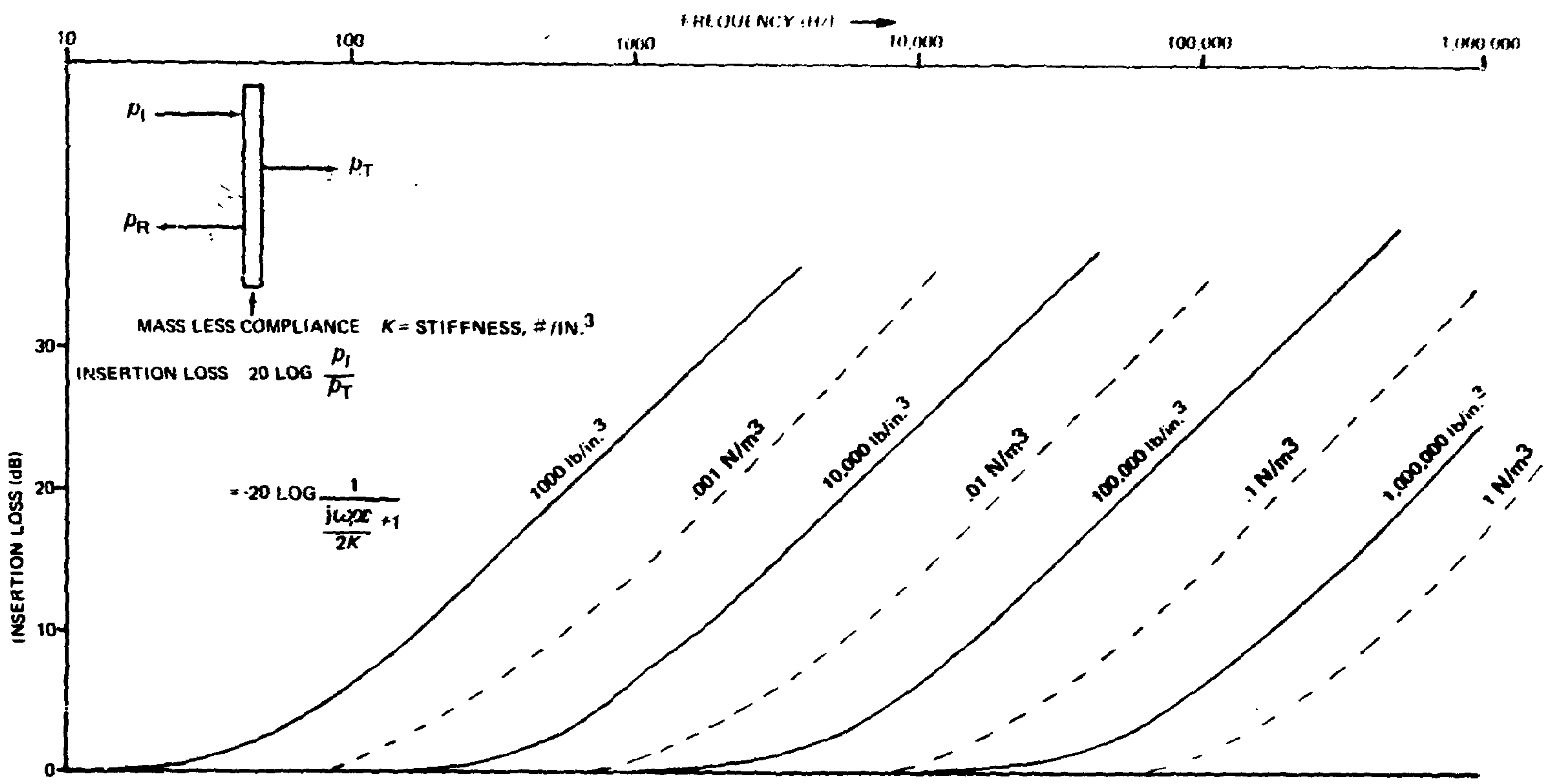
SOUND TRANSMISSION: WATER – PLATE – WATER

SOUND REFLECTION: WATER – COMPLIANCE – WATER



$$\text{REFLECTIVITY} = 20 \text{ LOG} \frac{p_R}{p_I} = 20 \text{ LOG} \frac{\frac{-j\omega\rho c}{2K}}{\frac{j\omega\rho c}{2K} + 1}$$

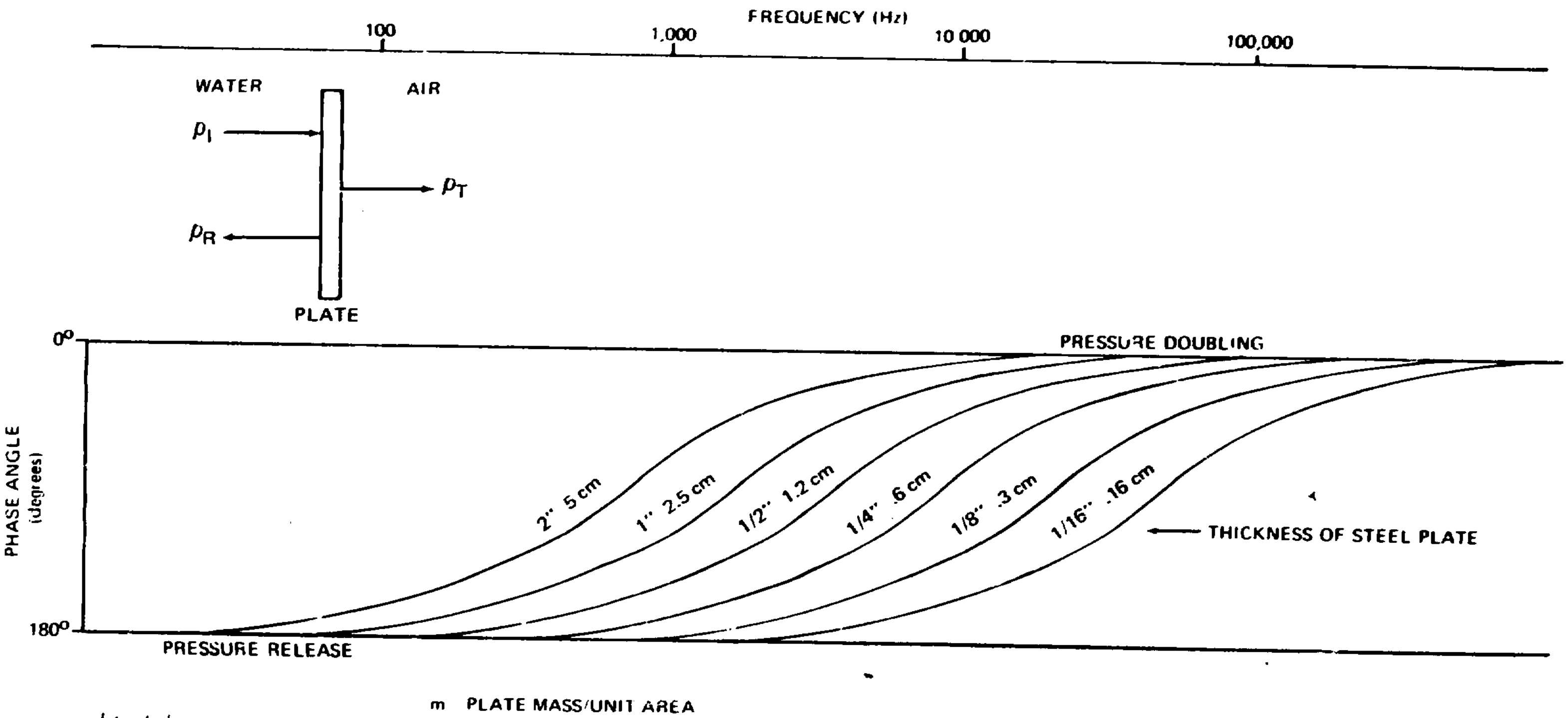
K = STIFFNESS OF COMPLIANT LAYER



INSERTION LOSS OF A MASS LESS COMPLIANCE WATER ON BOTH SIDES

SOUND TRANSMISSION – WATER – COMPLIANCE – WATER

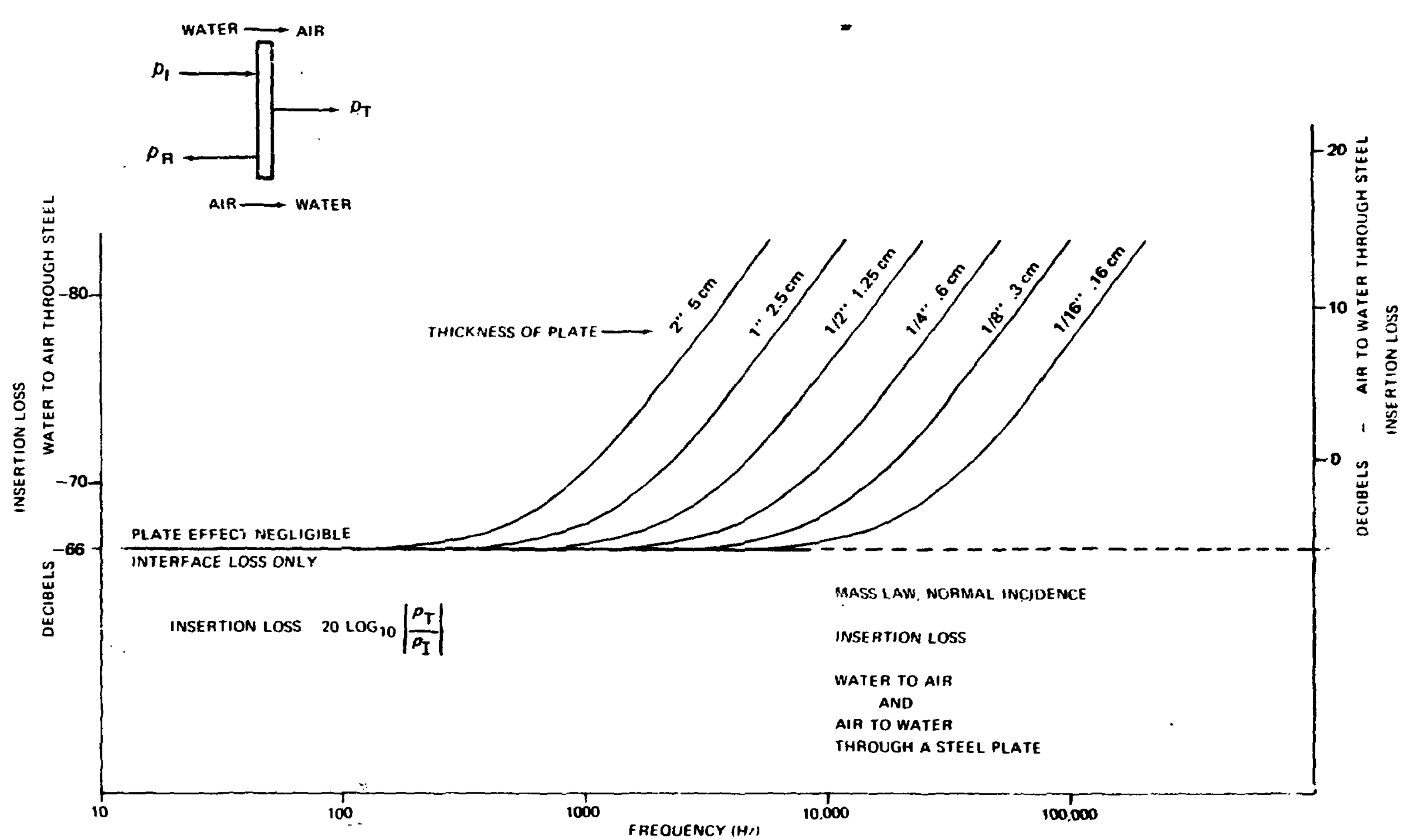
SOUND REFLECTION: WATER – PLATE – AIR



$$\left|\frac{p_R}{p_I}\right| = \left|\frac{j\omega m - \rho c_{WATER}}{j\omega m + \rho c_{WATER}}\right| = 1$$

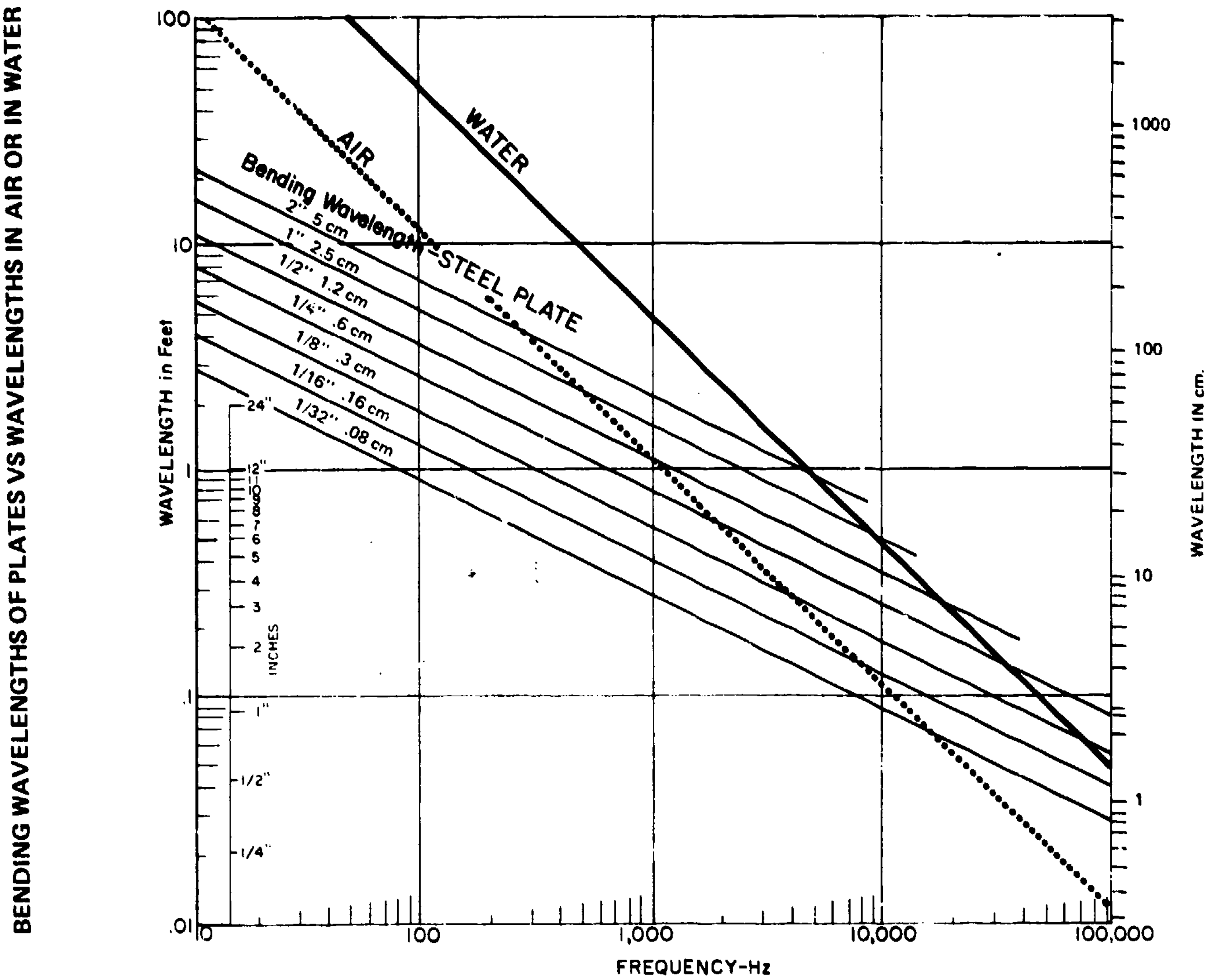
PHASE ANGLE, $\angle \left|\frac{p_R}{p_I}\right|$ →

REFLECTIVITY – PHASE ANGLE·
WATER TO AIR-BACKED STEEL PLATE



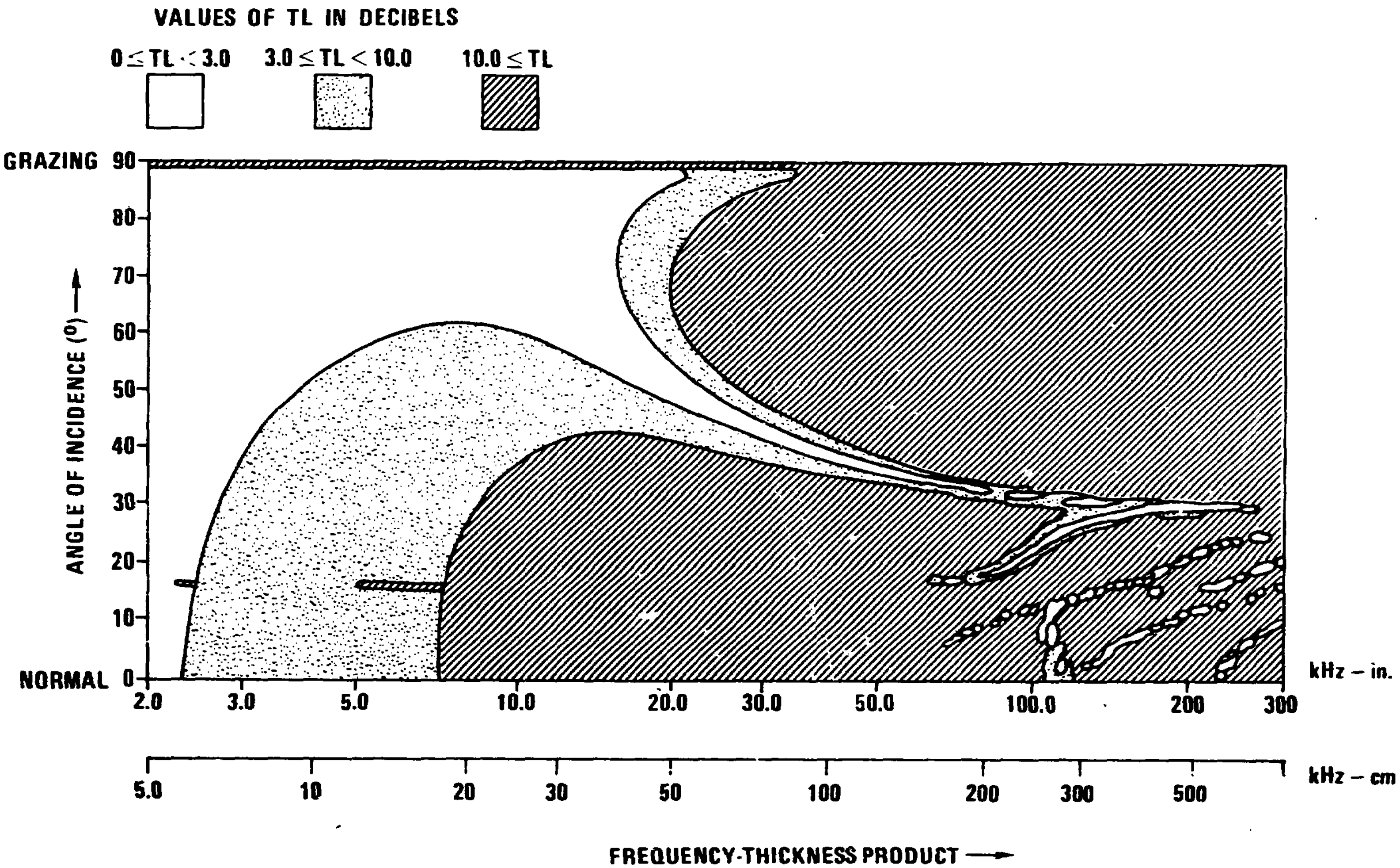
SOUND TRANSMISSION: WATER – PLATE–AIR, AIR – PLATE – WATER

WAVELENGTH vs FREQUENCY - AIR, WATER, & STEEL PLATES



Wavelengths for plates of other materials may be taken from this graph, remembering that wavelength varies as $\sqrt[4]{\frac{E}{\rho}}$.

TRANSMISSION LOSS (TL) CONTOUR PLOT FOR AN INFINITE STEEL PLATE
WITH WATER ON BOTH SIDES (EXACT THEORY)

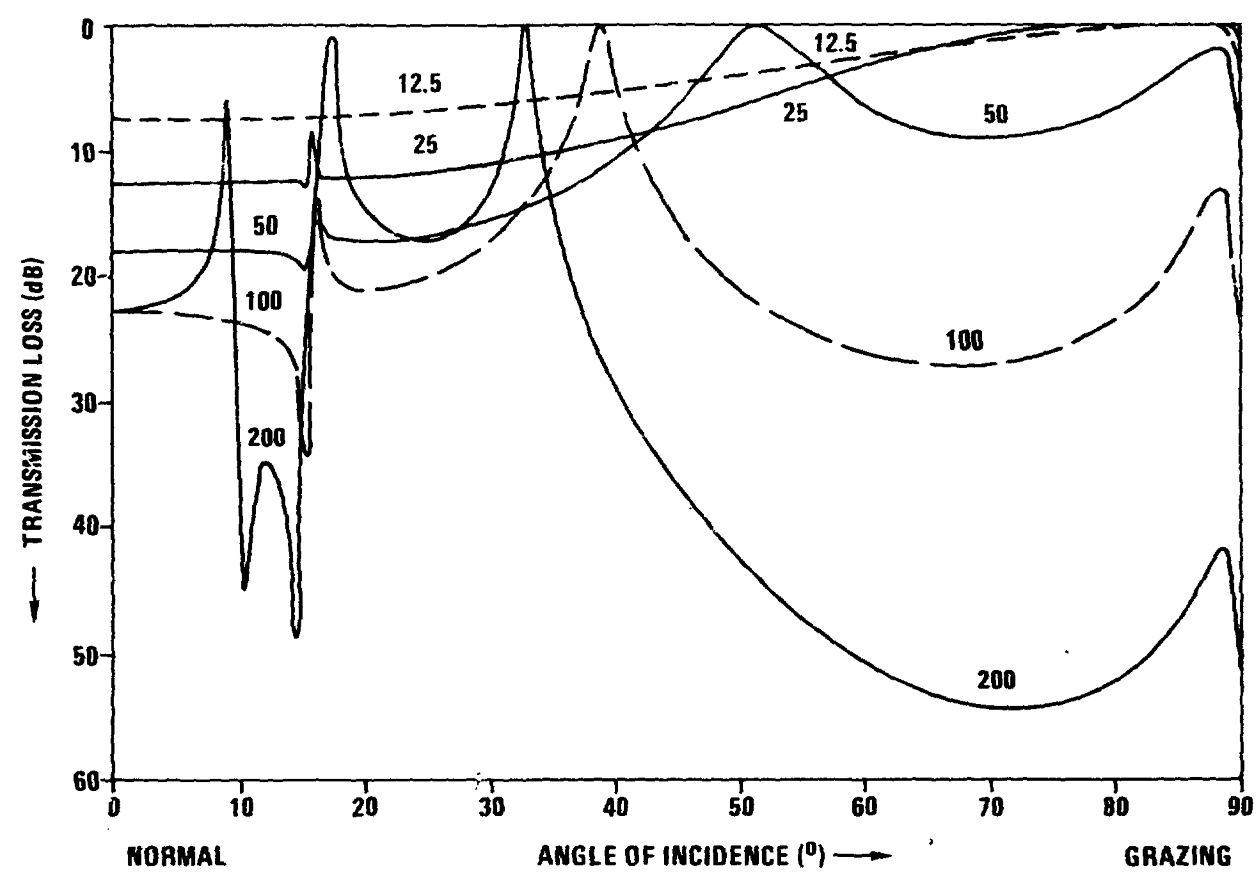


(COURTESY OF DR. J.W. YOUNG, AMETEK-STRAZA, EL CAJON, CALIF.)

TRANSMISSION OF SOUND THROUGH PLATES: EXACT THEORY

TRANSMISSION OF SOUND THROUGH PLATES: EXACT THEORY

TRANSMISSION LOSS VS ANGLE OF INCIDENCE FOR AN INFINITE STEEL PLATE WITH WATER ON BOTH SIDES (EXACT THEORY)



NUMBERS ON CURVES ARE FREQUENCY – THICKNESS PRODUCTS IN KHZ-CM

(COURTESY OF DR. J.W. YOUNG, AMETEK-STRAZA, EL CAJON, CALIF.)

VII

PARAMETERS OF SONAR PERFORMANCE

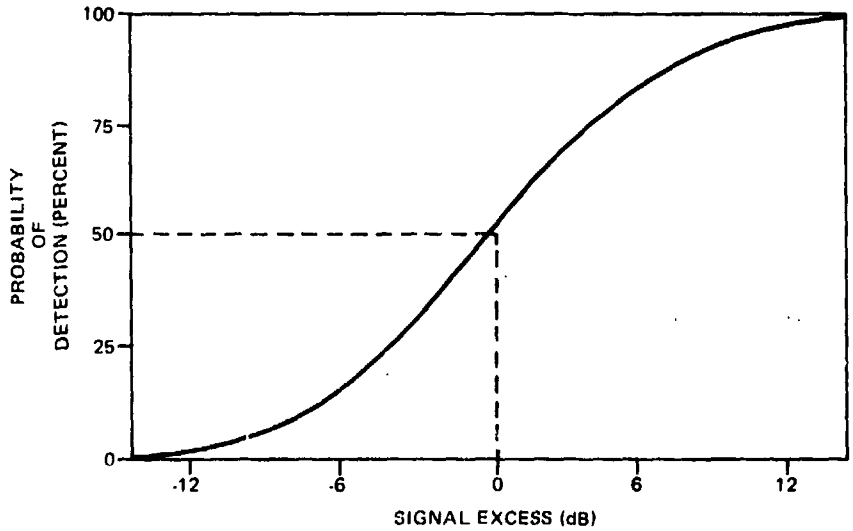
CONTENTS

SYMBOLS AND PREFERRED UNITS FOR THIS CHAPTER

SYMBOL	QUANTITY	SYMBOL OF PREFERRED UNIT	PREFERRED UNIT
c	Speed of sound in water	m/s	Meter per second
f	Frequency	Hz	Hertz
f_K	Frequency	kHz	Kilohertz
f_{rb}	Relaxation frequency of boron salts in the ocean	kHz	Kilohertz
f_{rm}	Relaxation frequency of magnesium salts in the ocean	kHz	Kilohertz
r	Range	m	Meter
z	Water depth	m	Meter
L_N	Platform Noise	dB	Decibel re 1 μ Pa
L_R	Reverberation level	dB	Decibel re 1 μ Pa
L_S	Source level	dB	Decibel re 1 μ Pa
L_T	Thermal noise level in the ocean	dB	Decibel re 1 μ Pa
N_{attn}	Attenuation loss	dB	Decibel
N_{DI}	Directivity index	dB	Decibel
N_{SE}	Signal excess	dB	Decibel re 1 μPa
N_{spr}	Spreading loss	dB	Decibel
N_{TS}	Target strength	dB	Decibel
N_W	Propagation loss	dB	Decibel; $N_w = N_{attn} + N_{spr}$
P	Gauge pressure	Atm	Atmosphere
S	Salinity	ppt	Parts per Thousand
T	Temperature	°C	°Celcius
α	Absorption	dB/m	Decibel per meter
μ_f	Dynamic shear viscosity of water	Kg/m.s	Kilogram per meter second
μ_f'	Dynamic bulk viscosity of water	Kg/m.s	Kilogram per meter second
ρ	Density of water	Kg/m^3	Kilogram per cubic meter
pH	Acidity index	-	-

SONAR EQUATIONS

The sonar equations combine all of the parameters of sonar operation to predict the performance of a sonar in a given tactical situation. There are different forms of the sonar equations. In one form, the product is a term called signal excess, N_{se}, which may be related to the probability of detection using the figure below:



<u>SONAR EQUATIONS IN TERMS OF SIGNAL EXCESS</u>
(MONOSTATIC CASE)

<u>ACTIVE SONAR, NOISE LIMITED</u>

$$N_{SE} = L_S - 2N_W - (L_N - N_{DI}) + N_{TS}$$

<u>ACTIVE SONAR, REVERBERATION LIMITED</u>

$$N_{SE} = L_S - 2N_W + N_{TS} - L_R$$

<u>PASSIVE SONAR</u>

$$N_{SE} = L_S - N_W - (L_N - N_{DI})$$

NOTE: $N_W = N_{spr} + N_{attn}$

TERMS IN THE SONAR EQUATIONS

N_{SE} Signal Excess - Signal excess is the signal-to-noise ratio at the receiver for active or passive sonars.

L_S Source Strength for Active Sonar - Source strength is the sound pressure level, in decibels, radiated by an active sonar and corrected to a distance of 1 yard from the acoustic center of the sonar.

L_S Source Strength for Passive Sonar - Source strength is the sound pressure level, in decibels, radiated by a target ship and corrected to a distance of 1 yard from the acoustic center of the target ship.

L_N-N_{DI} Platform Noise - Directivity Index - The terms L_N and N_{DI} are often combined because it is often their difference which is measured. L_N is own-ship's platform noise and N_{DI} is the directivity index of own-ship's sonar.

L_R Reverberation Level - Reverberation level is the SPL due to active sonar pings being reflected or scattered back toward own-ship's sonar by the ocean surface, bottom, or inhomogeneities in the ocean itself.

N_{TS} Target Strength - Target strength is equal to twenty times the logarithm to the base 10 of the reflected sound divided by the incident sound, both corrected to a range of one yard. As an example, the target strength of a perfectly reflecting sphere with a radius of one yard is OdB. Target strengths of some simple shapes are given in the tables on pages 7-9 through 7-12.

N_W Propagation Loss - N_W is propagation loss, one way, between own-ship and target. Propagation loss is an erratic function of range because of the vagaries of propagation of sound in the ocean. Five aids to predict N_W are given below:

- Spherical Spreading: $N_{spr} = +20 \text{ Log } r/r_o$ where r, r_o = ranges, good for close ranges compared to water depth.
- Cylindrical Spreading: $N_{spr} = +10 \text{ Log } r/r_o$,good for somewhat longer ranges.
- Ray Trace: From a sound velocity profile, paths of sound ray propagation in the ocean are predicted. Propagation loss is determined from the amount that neighboring rays spread as they propagate. Ray trace is an excellent technique, but it requires the use of a computer.
- Measured Propagation Loss Data: Actual propagation losses measured for many ocean areas are available from classified sources. One good unclassified source is Urick.
- Absorption: Absorption (α) in seawater, in dB per meter, is predicted using the formulas on the following pages.

$$N_{attn} = \alpha \times r \ .$$

ABSORPTION OF SOUND IN WATER

Between 0.1 and 1,000 kHz, the absorption of sound in water, α, can be described by the sum of three terms:

$$\alpha = \frac{1.71 \times 10^{8}\left(\frac{4}{3}\mu_f + \mu_f'\right) f^2}{\rho c^3}$$

viscous losses common to both seawater and freshwater

$$+ \frac{2.03\times10^{-5} S\, f_{rm}\, f^2\,(1-1.23\times10^{-3}P)}{f^2 + f_{rm}^2}$$

relaxation losses due to dissolved magnesium salts (seawater only)

$$+ \frac{53.9\, f_{rb}\, f^2}{c\,(f^2 + f_{rb}^2)} \times 10^{(0.69\,\mathrm{pH}-8)}$$

relaxation losses due to the presence of boric acid (seawater only)

MEANING OF SYMBOLS

α = absorption - dB/m

μ_f = dynamic shear viscosity - kg/m-s

μ_f' = bulk viscosity - kg/m-s

ρ = density - kg/m^3

c = sound speed - m/s

S = salinity - parts per thousand

f = frequency - kHz

f_{rb} = Boron salt relaxation freq. - kHz

f_{rm} = Mag. salt relaxation freq. - kHz

P = gauge pressure - atmospheres

pH = acidity of seawater

T = temperature - °C

Z = water depth - m

VALUES OF PARAMETERS FOR SOUND ABSORPTION EQUATION

SPEED OF SOUND

$$C = 1449.2 + 4.6T - 0.055\,T^2 + 0.00029\,T^3$$

$$+(1.34 - 0.010T)\ (S-35) + 0.016Z \qquad \text{m/sec}$$

DYNAMIC SHEAR VISCOSITY μ_f

Temperature, °C	μ_f
0	1.787×10^{-3} kg/m-s
5	1.519×10^{-3}
10	1.307×10^{-3}
15	1.139×10^{-3}
20	1.002×10^{-3}
25	$.8904 \times 10^{-3}$
30	$.7975 \times 10^{-3}$

BULK VISCOSITY, μ_f'

Bulk viscosity for water is 2.81 times the dynamic shear viscosity.

MAGNESIUM SULFATE RELAXATION FREQUENCY, f_{rm}

$$f_{rm} = 21.9 \times 10^{\left(6-\frac{1520}{273+T}\right)} \ \text{kHz}$$

Sample Values:

Temperature, °C	f_{rm}, kHz
0	59.2
5	74.6
10	93.2
15	116
20	142
25	174
30	211

BORIC ACID RELAXATION FREQUENCY, f_{rb}

$$f_{rb} = 6.1 \sqrt{S/35 \times 10^{\left(3 - \frac{1051}{273 + T}\right)}} \text{ kHz}$$

Sample Values for S = 35 parts per thousand

Temperature, °C	f_{rb} kHz
0	.862
5	1.01
10	1.18
15	1.37
20	1.58
25	1.81
30	2.07

DENSITY OF WATER

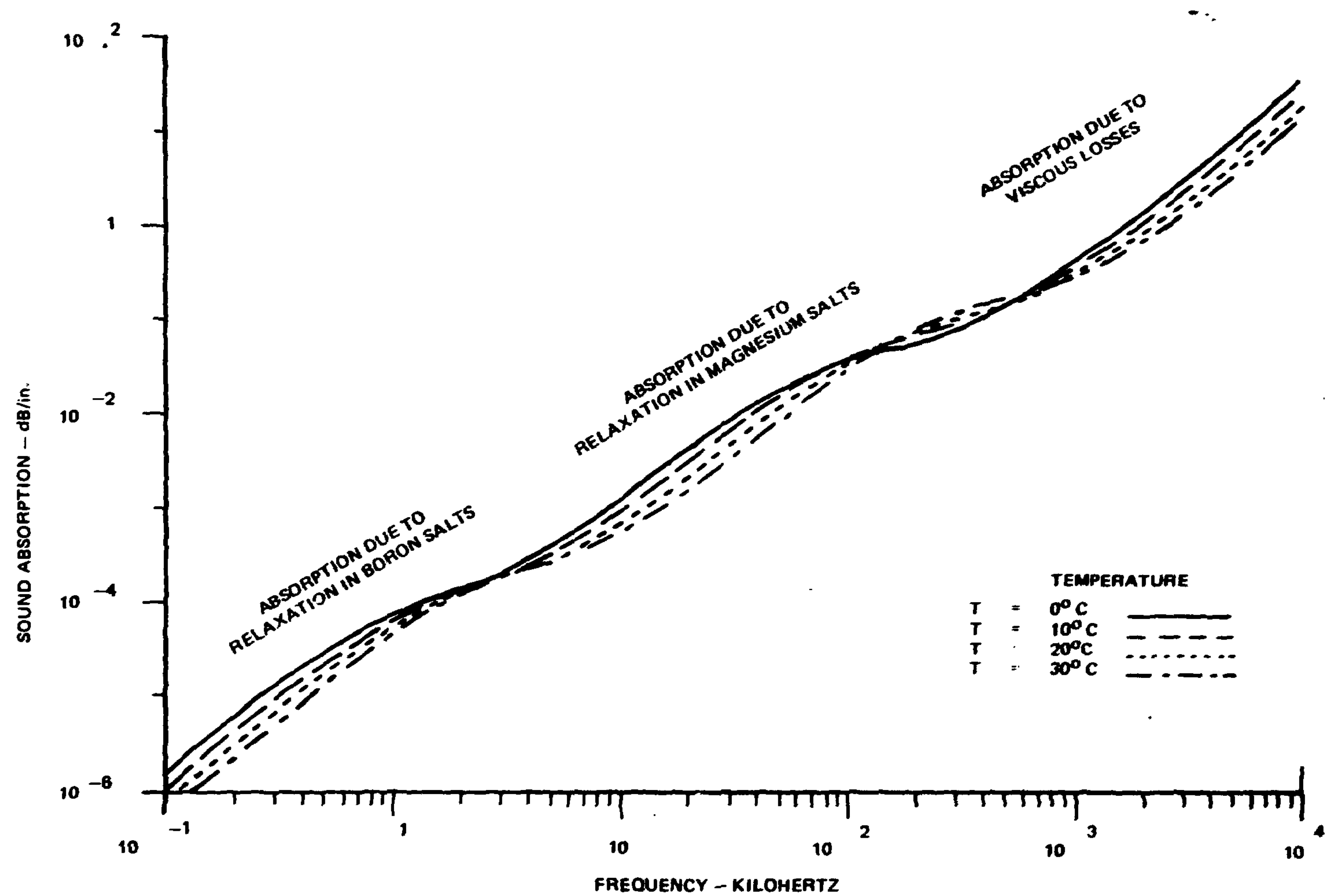
$$\rho = \begin{array}{ll} 998 \text{ kg/m}^3 & \text{fresh water} \\ 1026 \text{ kg/m}^3 & \text{seawater} \end{array}$$

SALINITY

Assume a value for salinity, S, equal to 35 parts per thousand unless otherwise known.

ACIDITY OF SEAWATER - pH

pH values of seawater range between about 7.3 and 8.5. A value of pH = 8 may be assumed in the absence of measured values.



SOUND ABSORPTION IN SEAWATER

DEPTH – 100 m; DENSITY – 1026 Kg/m^3;
SALINITY – 35 ppt; ACIDITY – pH = 8

SOUND ABSORPTION IN SEAWATER

REFERENCES FOR SOUND ABSORPTION IN SEAWATER

Leonard, R.W., et al, "Attenuation of Sound in Synthetic Sea Water" J. Acoust. Soc. Am 20, pp 868 ff. (1948)

Medwin, H., unpublished class notes, U.S. Naval Post Graduate School, Monterey, California.

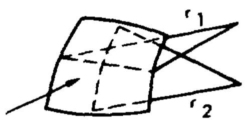
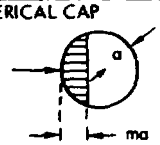
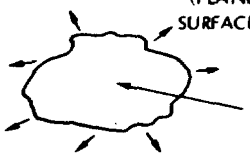
Schulkin, M., and H. W. Marsh, "Sound Absorption in Sea Water", J. Acoust. Soc. Am, 34, pp 864 ff. (1962)

Schulkin, M., and H. W. Marsh, "Low Frequency Sound Absorption in the Ocean", J.A.S.A. 63, No. 1, January, 1978, pp. 43-48.

Urick, R.J., Principles of Underwater Sound, McGraw-Hill, New York, 1975, pp. 96 ff.

Yeager, E., et al, "Origin of the Low-Frequency Sound Absorption in Sea Water" J. Acoust. Soc. Am. 53, pp 1705-1707.

TARGET STRENGTH OF SIMPLE GEOMETRIC FIGURES

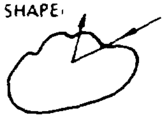
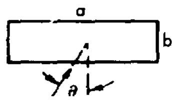
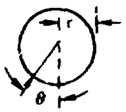
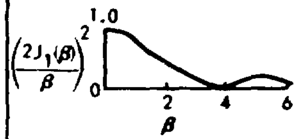
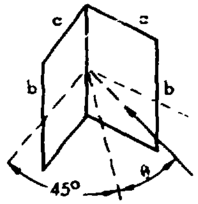
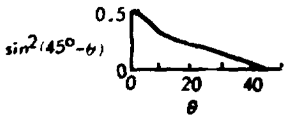
GEOMETRIC FORM	SYMBOLS	BACKSCATTERING TARGET STRENGTH T.S. = 10 log $(\sigma/4\pi)$; $\sigma/4\pi$ IS TABULATED	VARIATION WITH ASPECT	CONDITIONS
ANY CONVEX SURFACE 	r_1, r_2 ARE PRINCIPAL RADII OF CURVATURE; R IS RANGE; K IS $2\pi/\lambda$	$\frac{r_1 r_2}{4}$	DETERMINED BY r_1, r_2 AT POINT OF TANGENCY OF INCIDENT WAVEFRONT	$Kr_1, Kr_2 \gg 1$; $R > r_1, r_2$
SPHERE (LARGE) (RIGID OR PRESSURE RELEASE) 	r IS RADIUS OF SPHERE	$\frac{r^2}{4}$	UNIFORM	$Kr \gg 1$; $R > r$
(SMALL) (RIGID) 	V IS VOLUME OF SPHERE	$61.7 \frac{V^2}{\lambda^4}$	UNIFORM	$Kr \ll 1$; $KR \gg 1$
(PRESSURE RELEASE) 	r IS RADIUS OF SPHERE	r^2	UNIFORM	$Kr \ll 1$
SPHERICAL CAP 	a IS RADIUS OF SPHERE; m IS DEFINED IN THE FIGURE; $K = 2\pi/\lambda$; R IS RANGE	$\frac{a^2}{4}\left[4(1-m)\sin^2(Kma) + m^2\left\{1 - \frac{\sin(2Kma)}{(Kma)} + \left(\frac{\sin(Kma)}{Kma}\right)^2\right\}\right]$	DEPENDS ON INDIVIDUAL CASE	$KR \gg 1$; $Ka > 1$
INFINITE PLATE (PLANE SURFACE) 	R IS RANGE	$\frac{R^2}{4}$	UNIFORM	NONE

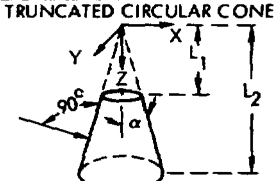
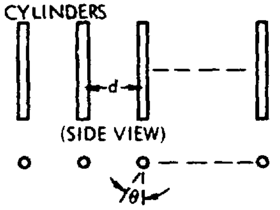
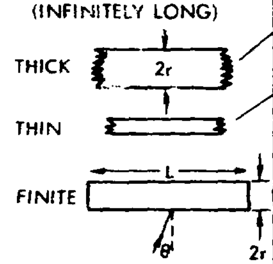
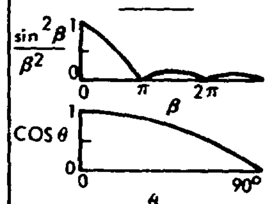
This table is a compilation - from:

F. P. Fessenden "Target Strength Modeling for Three Classes of Submarines (U)".

NUSC Report, November, 1972

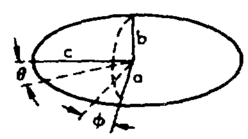
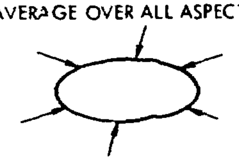
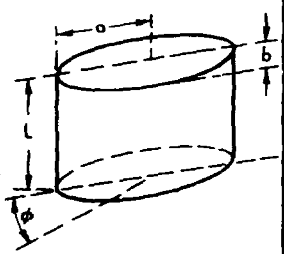
TARGET STRENGTH

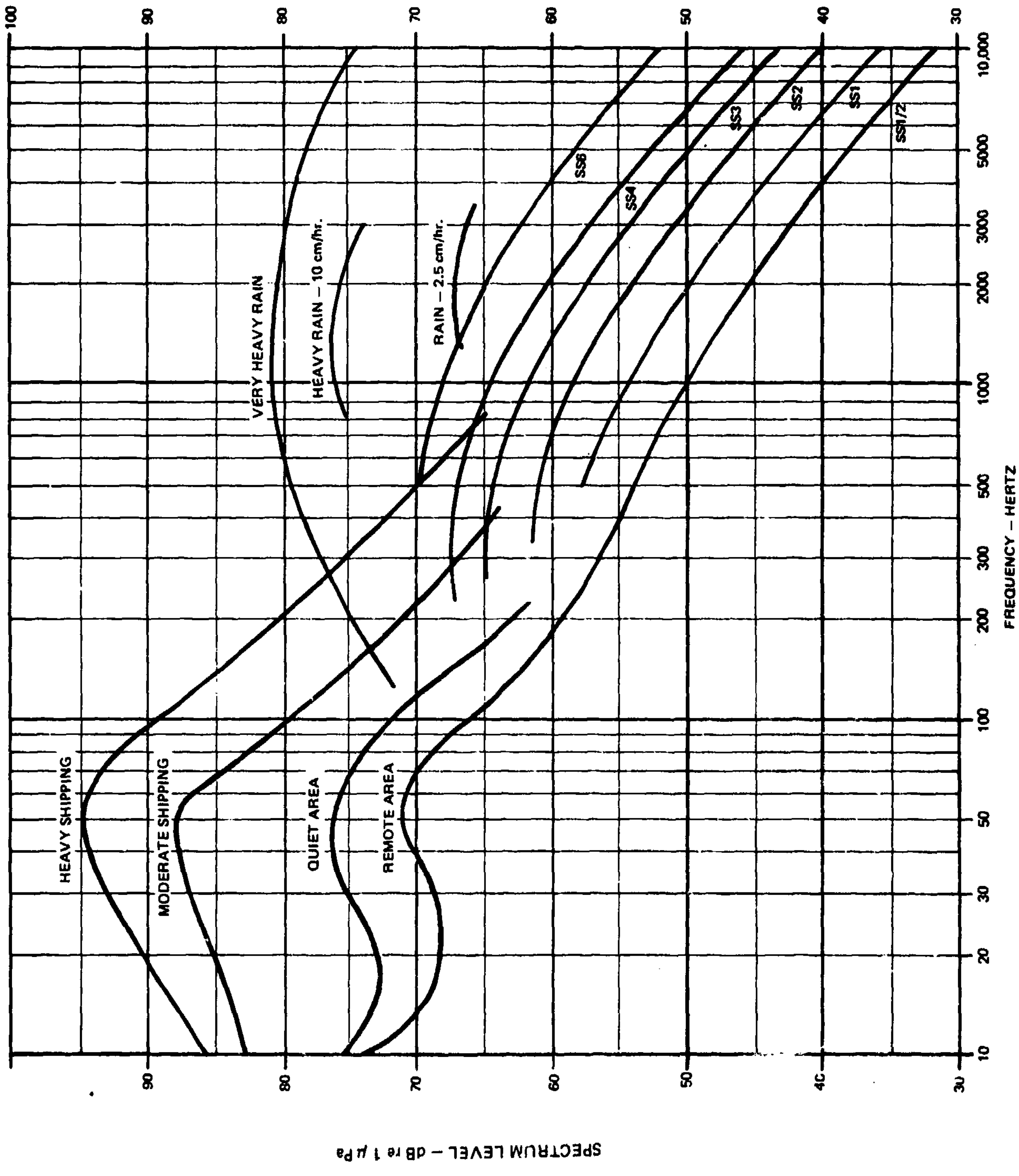
GEOMETRIC FORM	SYMBOLS	BACKSCATTERING TARGET STRENGTH T.S. = 10 log (σ/4π) σ/4π IS TABULATED	VARIATION WITH ASPECT	CONDITIONS
FINITE PLATE ANY SHAPE 	A IS AREA OF PLATE L IS GREATEST LINEAR DIMENSION IN PLANE CONTAINING NORMAL AND INCIDENT RAY ℓ IS SMALLEST LINEAR DIMENSION $\beta = KL \sin\theta$	$\left(\frac{A}{\lambda}\right)^2 \left(\frac{\sin\beta}{\beta}\right)^2 \cos^2\theta$	SEE FINITE CYLINDER	$R > L^2/\lambda$ $K\ell \gg 1$
RECTANGULAR PLATE 	a, b ARE SIDES OF PLATE $\beta = Ka \sin\theta$	$\left(\frac{ab}{\lambda}\right)^2 \left(\frac{\sin\beta}{\beta}\right)^2 \cos^2\theta$	SEE FINITE CYLINDER	$R > a^2/\lambda$ $Kb \gg 1$ $a > b$
CIRCULAR PLATE 	r IS RADIUS OF PLATE $\beta = 2Kr \sin\theta$ $J_1(\beta)$ IS BESSEL FUNCTION	$\left(\frac{\pi r^2}{\lambda}\right)^2 \left(\frac{2J_1(\beta)}{\beta}\right)^2 \cos^2\theta$		$R > r^2/\lambda$ $Kr \gg 1$
DIHEDRAL CORNER REFLECTOR 	a, b ARE LENGTHS OF EDGES OF REFLECTOR θ IS ANGLE OF INCIDENCE WITH RESPECT TO BISECTOR OF DIHEDRAL ANGLE	$\left(\frac{2ab}{\lambda}\right)^2 \sin^2(45^\circ - \theta)$		DIMENSION IS LARGE COMPARED TO λ

GEOMETRIC FORM	SYMBOLS	BACKSCATTERING TARGET STRENGTH T.S. = 10 log ($\sigma/4\pi$) $\sigma/4\pi$ IS TABULATED	VARIATION WITH ASPECT	CONDITIONS
TRUNCATED CIRCULAR CONE  (NORMAL INCIDENCE)	L_1, L_2 AS SHOWN α IS HALF ANGLE OF CONE	$\frac{2}{9\lambda}\left[L_2^{3/2} - L_1^{3/2}\right]^2 \frac{\sin\alpha}{\cos^4\alpha}$	FOR AN APPROXIMATION FOR OTHER THAN NORMAL INCIDENCE, ASSUME DIRECTIVITY OF CYLINDER OF SAME LENGTH	DIMENSIONS LARGE COMPARED TO λ
UNIFORM ARRAY OF PARALLEL CYLINDERS  (TOP VIEW)	N IS NUMBER OF CYLINDERS d IS SEPARATION	THE PRODUCT OF THE APPROPRIATE FORMULA FOR TARGET STRENGTH OF SINGLE CYLINDER AND THE DIRECTIVITY FUNCTION IN NEXT COLUMN	$\left[\frac{\sin(NKd\sin\theta)}{\sin(Kd\sin\theta)}\right]^2$	SEE CONDITIONS FOR INDIVIDUAL CYLINDERS
CYLINDER (INFINITELY LONG) THICK / THIN; FINITE 	THICK: r IS RADIUS OF CYLINDER, R IS RANGE THIN: r IS RADIUS OF CYLINDER, R IS RANGE FINITE: L IS LENGTH OF CYLINDER, r IS RADIUS OF CYLINDER, θ IS ASPECT, β= KL sin θ	FINITE: $\frac{rL^2}{2\lambda}\left(\frac{\sin\beta}{\beta}\right)^2 \cos\theta$	THICK: UNIFORM THIN: UNIFORM FINITE: 	THICK: $Kr \gg 1$ THIN: $kr \ll 1$ FINITE: $Kr \gg 1$, $R > L^2/\lambda$

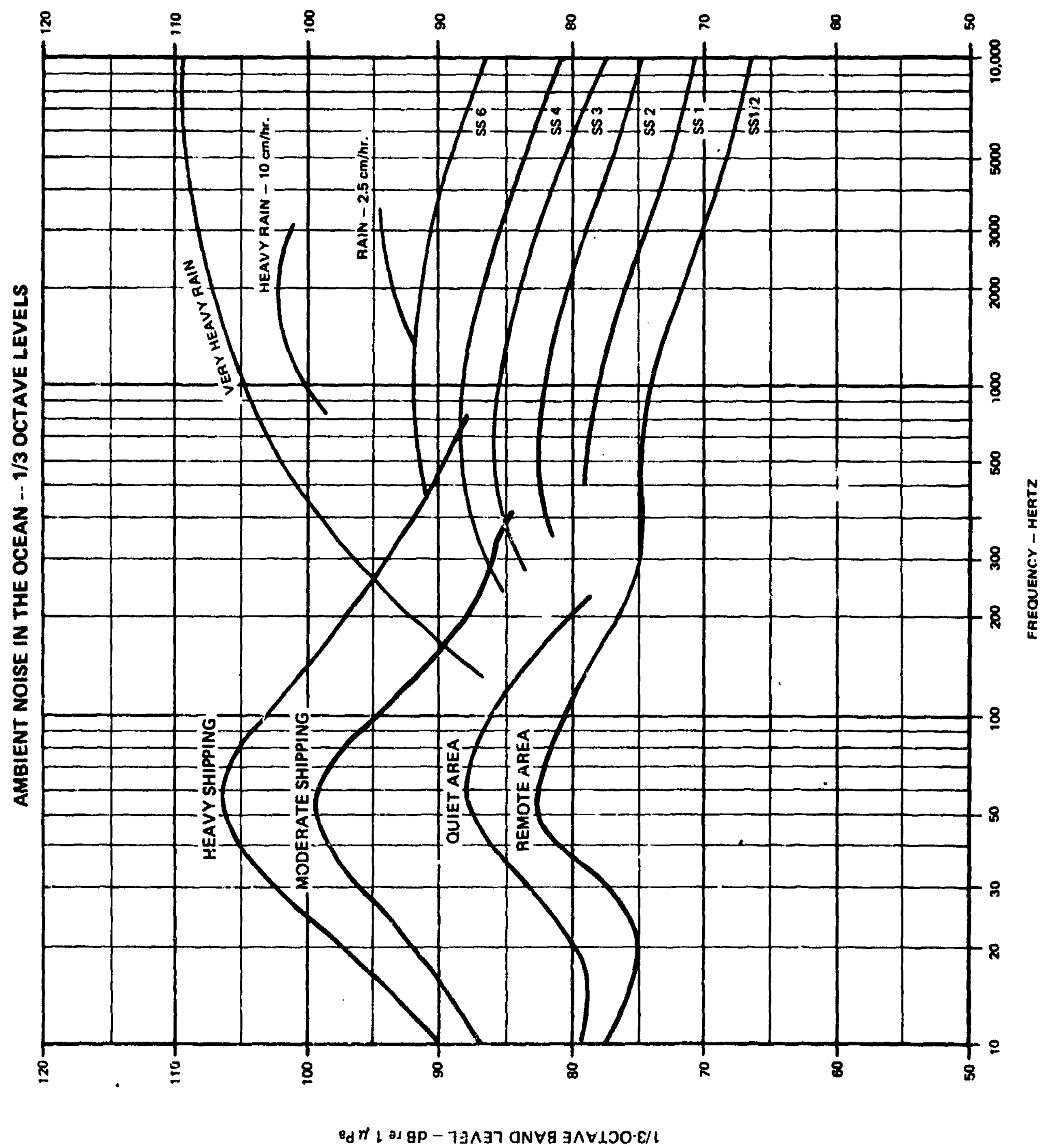
TARGET STRENGTH

TARGET STRENGTH

GEOMETRIC FORM	SYMBOLS	BACKSCATTERING TARGET STRENGTH T.S. = 10 log $(\sigma/4\pi)$ $\sigma/4\pi$ IS TABULATED	VARIATION WITH ASPECT	CONDITIONS
ELLIPSOID 	a, b, c ARE SEMIAXES OF ELLIPSOID θ IS HORIZONTAL ASPECT φ IS VERTICAL ASPECT	$\frac{a^2b^2c^2}{4(a^2\sin^2\theta\cos^2\phi + b^2\sin^2\theta\sin^2\phi + c^2\cos^2\theta)^2}$ (FOR PROLATE SPHEROID, a=b)	SEE FIG. 10 FOR VARIATION WITH HORIZONTAL ASPECT	$Ka, Kb, Kc \gg 1$ $R > a,b,c$
ANY SMOOTH CONVEX OBJECT (AVERAGE OVER ALL ASPECTS) 	S IS TOTAL SURFACE AREA	$\frac{S}{16\pi}$	OVERALL AVERAGE	ALL DIMENSIONS LARGE COMPARED WITH λ
ELLIPSOIDAL CYLINDER 	L IS HEIGHT OF CYLINDER a, b ARE ONE-HALF THE MAXIMUM AND MINIMUM DIMENSIONS OF THE ELLIPSOIDAL CROSS SECTION φ IS ASPECT $K = 2\pi/\lambda$	$\frac{(abL)^2}{2\lambda[(a\cos\phi)^2 + (b\sin\phi)^2]^{3/2}}$	DIRECTIVITY IN TARGET STRENGTH PATTERN AWAY FROM BEAM ASPECT DEPENDS ON RELATIVE MAGNITUDES OF a AND b.	$a > b$ $KL, Ka, Kb > 1$



AMBIENT NOISE IN THE OCEAN - SPECTRUM LEVELS


AMBIENT NOISE IN THE OCEAN -- 1/3 OCTAVE LEVELS
VERY HEAVY RAIN
HEAVY RAIN – 10 cm/hr.
RAIN – 2.5 cm/hr.
SS 6
SS 4
SS 3
SS 2
SS 1
SS1/2
HEAVY SHIPPING
MODERATE SHIPPING
QUIET AREA
REMOTE AREA
FREQUENCY – HERTZ
1/3-OCTAVE BAND LEVEL – dB re 1 μPa
10
20
30
50
100
200
300
500
1000
2000
3000
5000
10,000
50
60
70
80
90
100
110
120

THERMAL NOISE IN THE OCEAN AT 10° C

The following formula produces a good estimate of thermal noise in the ocean at 10°C. It is applicable at frequencies above 30 kHz:

$$L_T = -15 + 20 \, Log_{10} \, f, \text{ where}$$

L_T = Spectrum Level SPL re 1μPa

f = Frequency in Kilohertz

RELATION BETWEEN SEA STATE AND AVERAGE WIND SPEED

Sea State	Average Wind Speed (Kts)
0	1
1/2	2
1	5
2	8.5
3	13.5
4	19
5	24.5
6	30.5
7	37

VIII

DECIBELS, FREQUENCY ANALYSIS,
&
STANDARD GRAPHS

CONTENTS

STANDARD OCTAVE AND ONE-THIRD OCTAVE

FREQUENCY BANDS

Band	Frequency, Hz					
	Octave			One-third octave		
	Lower band limit	Center	Upper band limit	Lower band limit	Center	Upper band limit
12	11	16	22	14.1	16	17.8
13				17.8	20	22.4
14				22.4	25	28.2
15	22	31.5	44	28.2	31.5	35.5
16				35.5	40	44.7
17				44.7	50	56.2
18	44	63	88	56.2	63	70.8
19				70.8	80	89.1
20				89.1	100	112
21	88	125	177	112	125	141
22				141	160	178
23				178	200	224
24	177	250	355	224	250	282
25				282	315	355
26				355	400	447
27	355	500	710	447	500	562
28				562	630	708
29				708	800	891
30	710	1,000	1,420	891	1,000	1,122
31				1,122	1,250	1,413

STANDARD OCTAVE AND ONE-THIRD OCTAVE FREQUENCY BANDS

STANDARD OCTAVE AND ONE-THIRD OCTAVE

FREQUENCY BANDS

STANDARD OCTAVE AND ONE-THIRD OCTAVE FREQUENCY BANDS

Band	Frequency, Hz					
	Octave			One-third octave		
	Lower band limit	Center	Upper band limit	Lower band limit	Center	Upper band limit
32				1,413	1,600	1,778
33	1,420	2,000	2,840	1,778	2,000	2,239
34				2,239	2,500	2,818
35				2,818	3,150	3,548
36	2,840	4,000	5,680	3,548	4,000	4,467
37				4,467	5,000	5,623
38				5,623	6,300	7,079
39	5,680	8,000	11,360	7,079	8,000	8,913
40				8,913	10,000	11,220
41				11,220	12,500	1[illegible],130
42	11,360	16,000	22,720	14,130	16,000	17,780
43				17,780	20,000	22,390

Ref: "Preferred Frequencies and Band Numbers for Acoustical Measurements", ANSI S1.6-1967 (R1971)

CONSTANT PERCENTAGE FREQUENCY BANDS

f_2 = nominal upper band edge frequency in Hz

f_1 = nominal lower band edge frequency in Hz

f_m = nominal mean frequency of band in Hz

BW = nominal bandwidth = $f_2 - f_1$ in Hz

- Basic units of bandwidth are the octave and the decade.

$$\frac{f_2}{f_1} = 2^n \qquad \frac{f_2}{f_1} = 10^m$$

where n is the number or fraction of an octave and m is the number or fraction of a decade

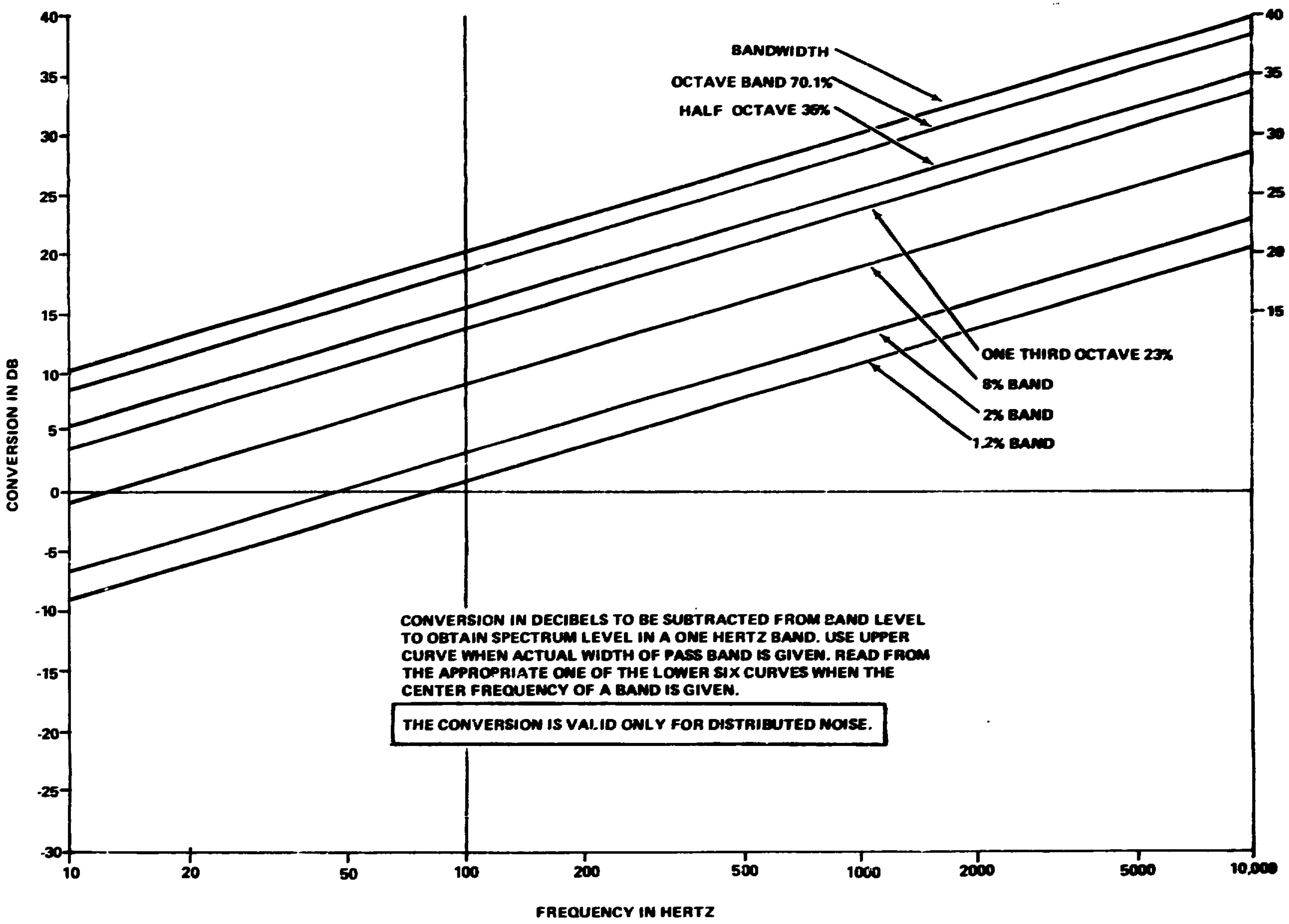
For all values of n, m, $f_m = \sqrt{f_2 f_1}$

FREQUENCY BAND	BW	f_2	f_m
DECADE	2.84 f_m	10 f_1	3.16 f_1 = .316 f_2
OCTAVE	.7071 f_m	2 f_1	1.41 f_1 = .707 f_2
HALF-OCTAVE	.3483 f_m	1.41 f_1	1.91 f_1 = .841 f_2
THIRD-OCTAVE	.2316 f_m	1.26 f_1	1.12 f_1 = .891 f_2
TENTH-OCTAVE	.0707 f_m	1.07 f_1	1.04 f_1 = .97 f_2
1/35 OCTAVE	.01 f_m	1.02 f_1	1.005 f_1 = .995 f_2

There are 3.32 octaves per decade.

$$\left(3.32 = \frac{\text{Log } 10}{\text{Log } 2}\right)$$

CONVERSION BETWEEN SPECTRUM LEVEL AND BAND LEVELS



CONVERSION BETWEEN BAND LEVELS & SPECTRUM LEVELS IN dB

ADDING DECIBELS

Given: $dB_1 = 20 \text{ Log } X_1 = 10 \text{ Log } X_1^2$

$dB_2 = 20 \text{ Log } X_2 = 10 \text{ Log } X_2^2$

Find: $dB_3 = 10 \text{ Log } (X_1^2 + X_2^2)$

Calculate: $\Delta = dB_1 - dB_2$ (Let dB_1 always be larger)

From table below find δ corresponding to Δ.

$$dB_3 = dB_1 + \delta$$

Δ	δ	Δ	δ	Δ	δ
0	3.01				
.25	2.89	5.25	1.13	10.25	.39
.50	2.77	5.50	1.08	10.50	.37
.75	2.65	5.75	1.02	10.75	.35
1.00	2.54	6.00	.97	11.00	.33
1.25	2.43	6.25	.92	11.25	.31
1.50	2.32	6.50	.88	11.50	.30
1.75	2.22	6.75	.83	11.75	.28
2.00	2.12	7.00	.79	12.00	.27
2.25	2.03	7.25	.75	12.25	.25
2.50	1.94	7.50	.71	12.50	.24
2.75	1.85	7.75	.67	12.75	.22
3.00	1.76	8.00	.64	13.00	.21
3.25	1.68	8.25	.61	13.25	.20
3.50	1.60	8.50	.57	13.50	.19
3.75	1.53	8.75	.54	13.75	.18
4.00	1.46	9.00	.51	14.00	.17
4.25	1.39	9.25	.49	14.25	.16
4.50	1.32	9.50	.46	14.50	.15
4.75	1.25	9.75	.44	14.75	.15
5.00	1.19	10.00	.41	15.00	.14

Example: 20dB + 25dB.
First find the difference which is 5dB. Let that equal Δ.
The corresponding term δ from table is 1.19. Add 1.19 to 25 to find the answer: 20dB + 25dB = 26.19dB.

NOTE:

$$\delta = 10 \text{ Log}_{10} (1 + 10^{-\Delta/10})$$

SUBTRACTING DECIBELS

Given: $dB_1 = 20 \text{ Log } x_1 = 10 \text{ Log } x_1^2$

$dB_2 = 20 \text{ Log } \sqrt{x_1^2 + x_2^2} = 10 \text{ Log } (x_1^2 + x_2^2)$

Find: $dB_3 = 20 \text{ Log } x_2 = 10 \text{ Log } x_2^2$

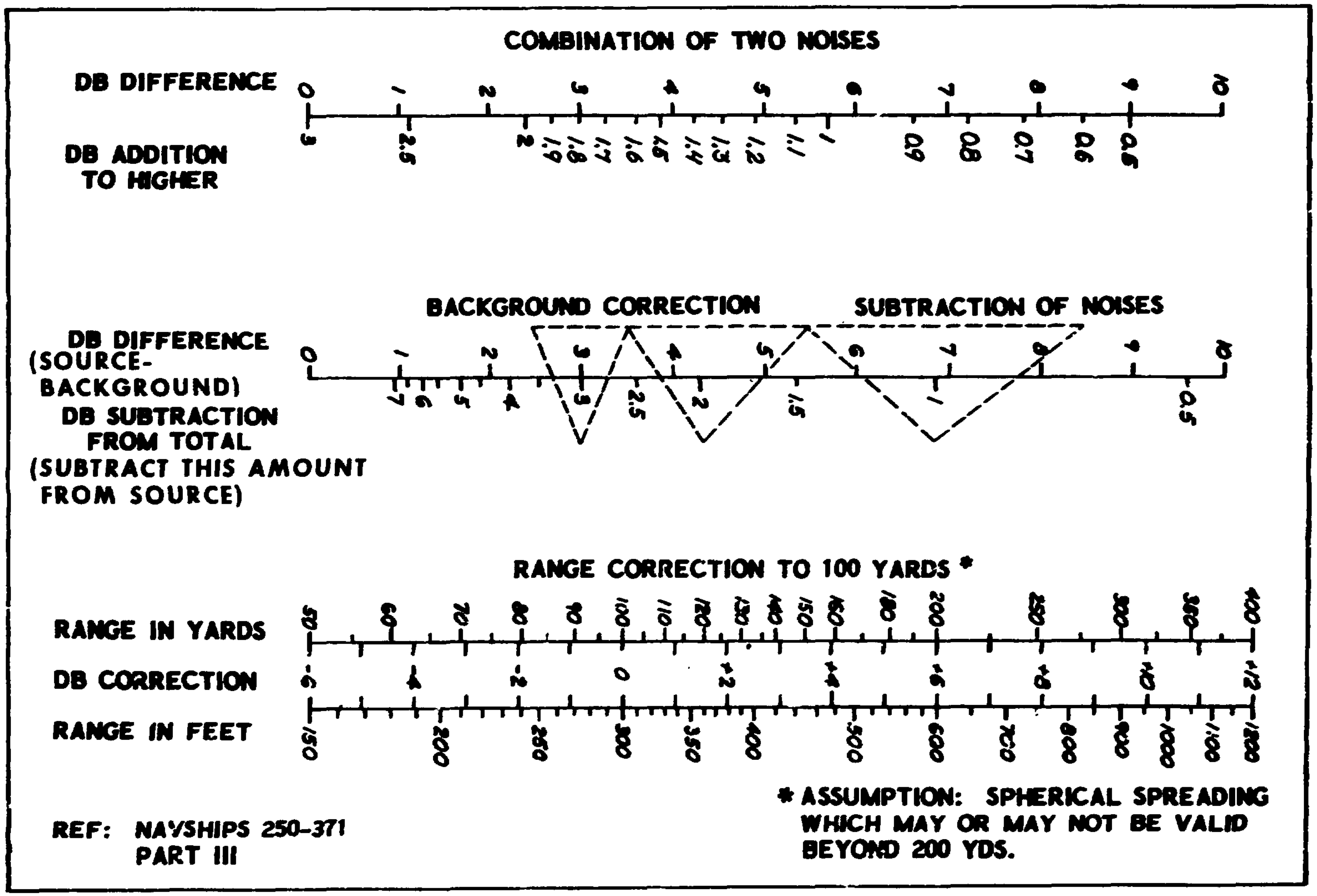
$\Delta = dB_2 - dB_1$

$dB_3 = dB_2 - \delta$

Δ	δ	Δ	δ	Δ	δ
0	∞				
.25	12.52	5.25	1.54	10.25	.43
.50	9.64	5.50	1.44	10.50	.41
.75	8.00	5.75	1.34	10.75	.38
1.00	6.87	6.00	1.26	11.00	.36
1.25	6.02	6.25	1.18	11.25	.34
1.50	5.35	6.50	1.10	11.50	.32
1.75	4.79	6.75	1.03	11.75	.30
2.00	4.33	7.00	.97	12.00	.28
2.25	3.93	7.25	.91	12.25	.27
2.50	3.59	7.50	.85	12.50	.25
2.75	3.29	7.75	.80	12.75	.24
3.00	3.02	8.00	.75	13.00	.22
3.25	2.78	8.25	.70	13.25	.21
3.50	2.57	8.50	.66	13.50	.20
3.75	2.38	8.75	.62	13.75	.19
4.00	2.20	9.00	.58	14.00	.18
4.25	2.05	9.25	.55	14.25	.17
4.50	1.90	9.50	.52	14.50	.16
4.75	1.77	9.75	.49	14.75	.15
5.00	1.65	10.00	.46	15.00	.14

NOTE: $\delta = 10 \text{ Log}_{10} \left(\frac{1}{1 - 10^{-\Delta/10}} \right)$

Example: 25dB - 20dB.
The difference, Δ , is 5dB. The corresponding correction term, δ, is 1.65dB. The answer to 25dB-20dB is equal 23.35dB.



COMBINATION OF TWO NOISES, BACKGROUND CORRECTION, AND RANGE CORRECTION TO 100 YARDS

COMBINED NOISES, BACKGROUND AND RANGE CORRECTION

A, B, & C ELECTRICAL WEIGHTINGS FOR SOUND LEVEL METERS

Frequency, Hz	A-weighting relative response, dB	B-weighting relative response, dB	C-weighting relative response, dB
10	-70.4	-38.2	-14.3
12.5	-63.4	-33.2	-11.2
16	-56.7	-28.5	-8.5
20	-50.5	-24.2	-6.2
25	-44.7	-20.4	-4.4
31.5	-39.4	-17.1	-3.0
40	-34.6	-14.2	-2.0
50	-30.2	-11.6	-1.3
63	-26.2	-9.3	-0.8
80	-22.5	-7.4	-0.5
100	-19.1	-5.6	-0.3
125	-16.1	-4.2	-0.2
160	-13.4	-3.0	-0.1
200	-10.9	-2.0	0
250	-8.6	-1.3	0
315	-6.6	-0.8	0
400	-4.8	-0.5	0
500	-3.2	-0.3	0
630	-1.9	-0.1	0
800	-0.8	0	0
1,000	0	0	0
1,250	+0.6	0	0
1,600	+1.0	0	-0.1
2,000	+1.2	-0.1	-0.2
2,500	+1.3	-0.2	-0.3
3,150	+1.2	-0.4	-0.5
4,000	+1.0	-0.7	-0.8
5,000	+0.5	-1.2	-1.3
6,300	-0.1	-1.9	-2.0
8,000	-1.1	-2.9	-3.0
10,000	-2.5	-4.3	-4.4
12,500	-4.3	-6.1	-6.2
16,000	-6.6	-8.4	-8.5
20,000	-9.3	-11.1	-11.2

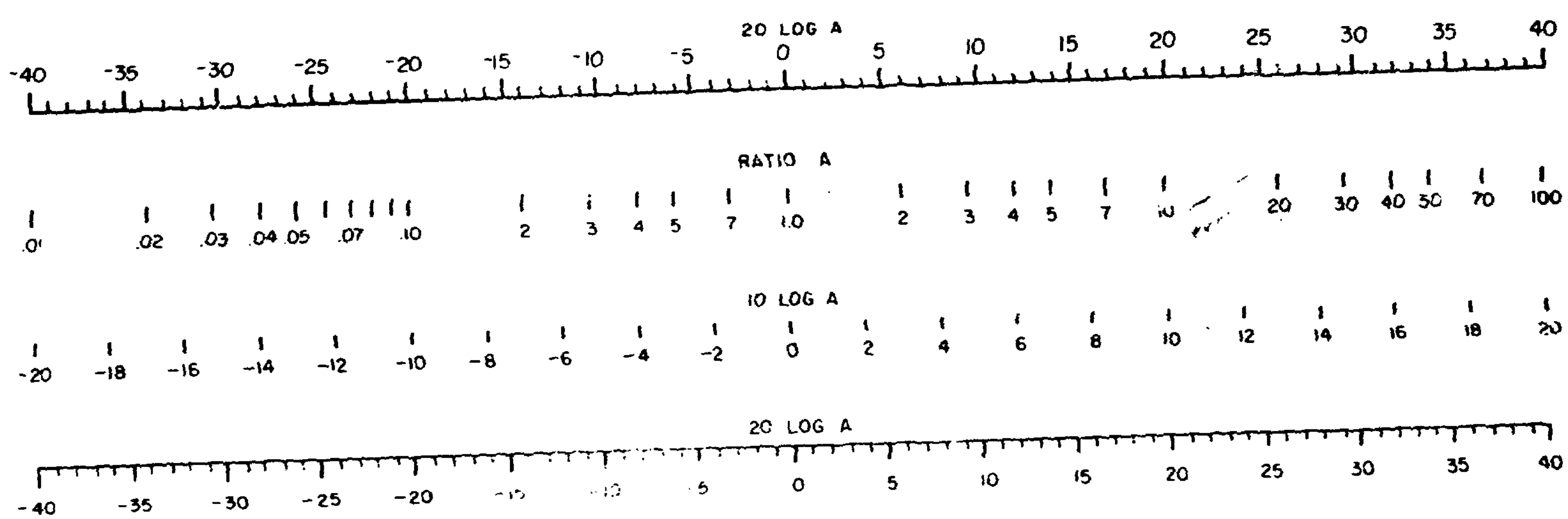
REF: "SPECIFICATION FOR SOUND LEVEL METERS," ANSI S1.4-1971

DECIBELS vs RATIOS

DECIBEL SCALES AND TABULATION FOR ANY NUMBER (A)

SO THAT: A < 1 > A

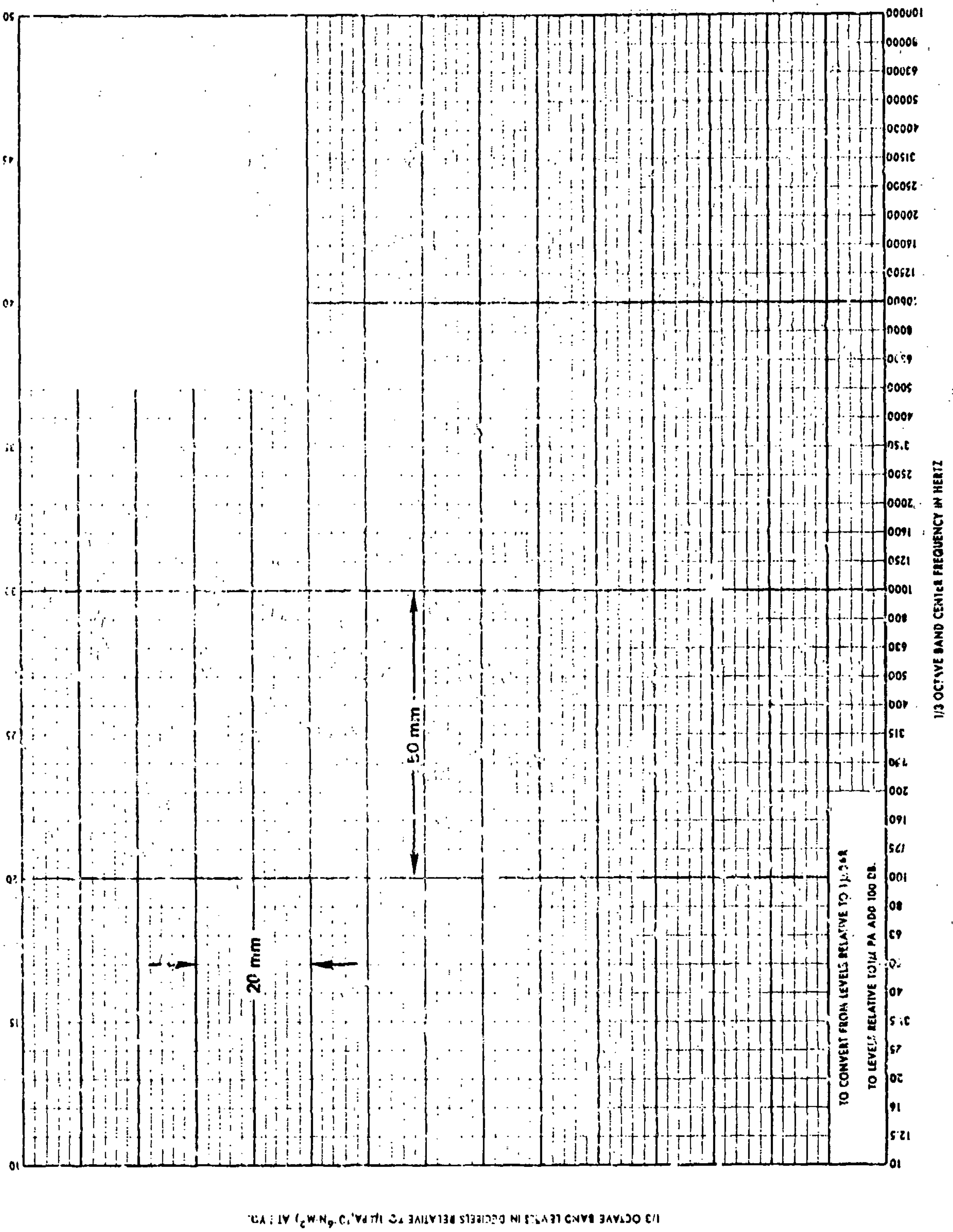
RATIO: A	10 LOG A	20 LOG A
10^{-5}	-50	-100
10^{-4}	-40	-80
10^{-3}	-30	-60
10^{-2}	-20	-40
10^{-1}	-10	-20
10	10	20
10^{2}	20	40
10^{3}	30	60
10^{4}	40	80
10^{5}	50	100



DECIBELS VS RATIOS

STANDARD PAPER FOR 1/3 OCTAVE SPECTRA
FOR ACOUSTICAL & VIBRATIONAL FREQUENCY ANALYSES

STANDARD ONE-THIRD OCTAVE GRAPH PAPER



Ref: MIL-STD 1621A (NAVY) 27 AUGUST, 1973

IX

CONVERSION FACTORS AND TABULATED VALUES

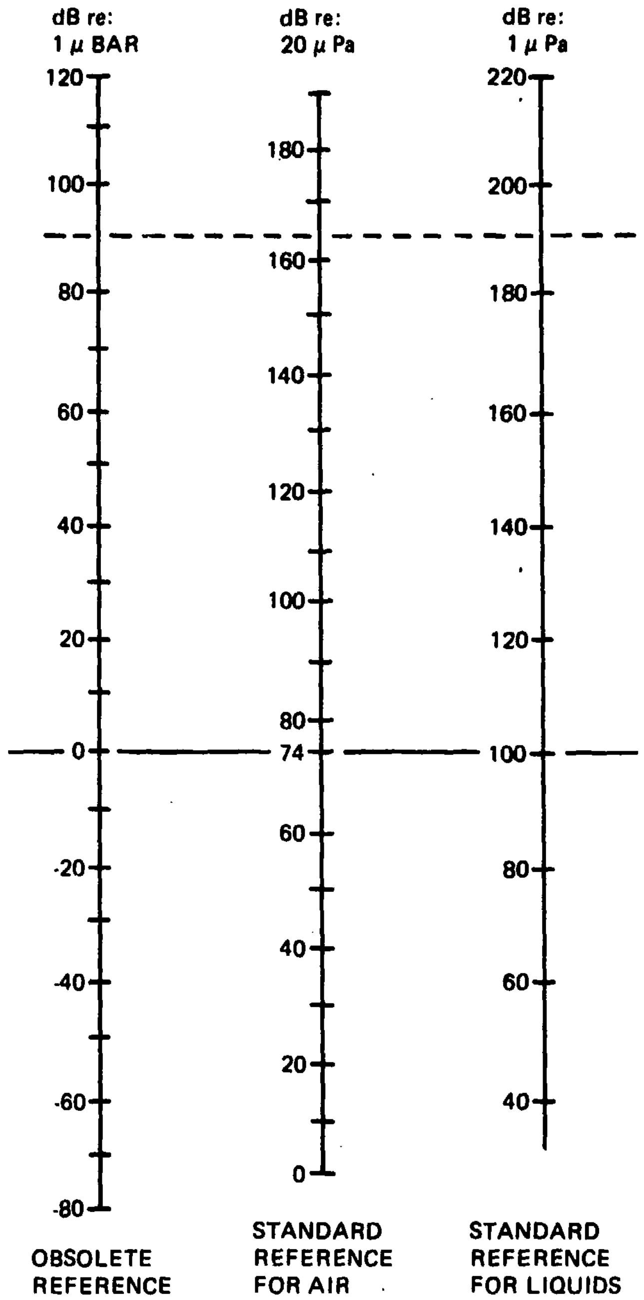
CONTENTS

MISCELLANEOUS VALUES

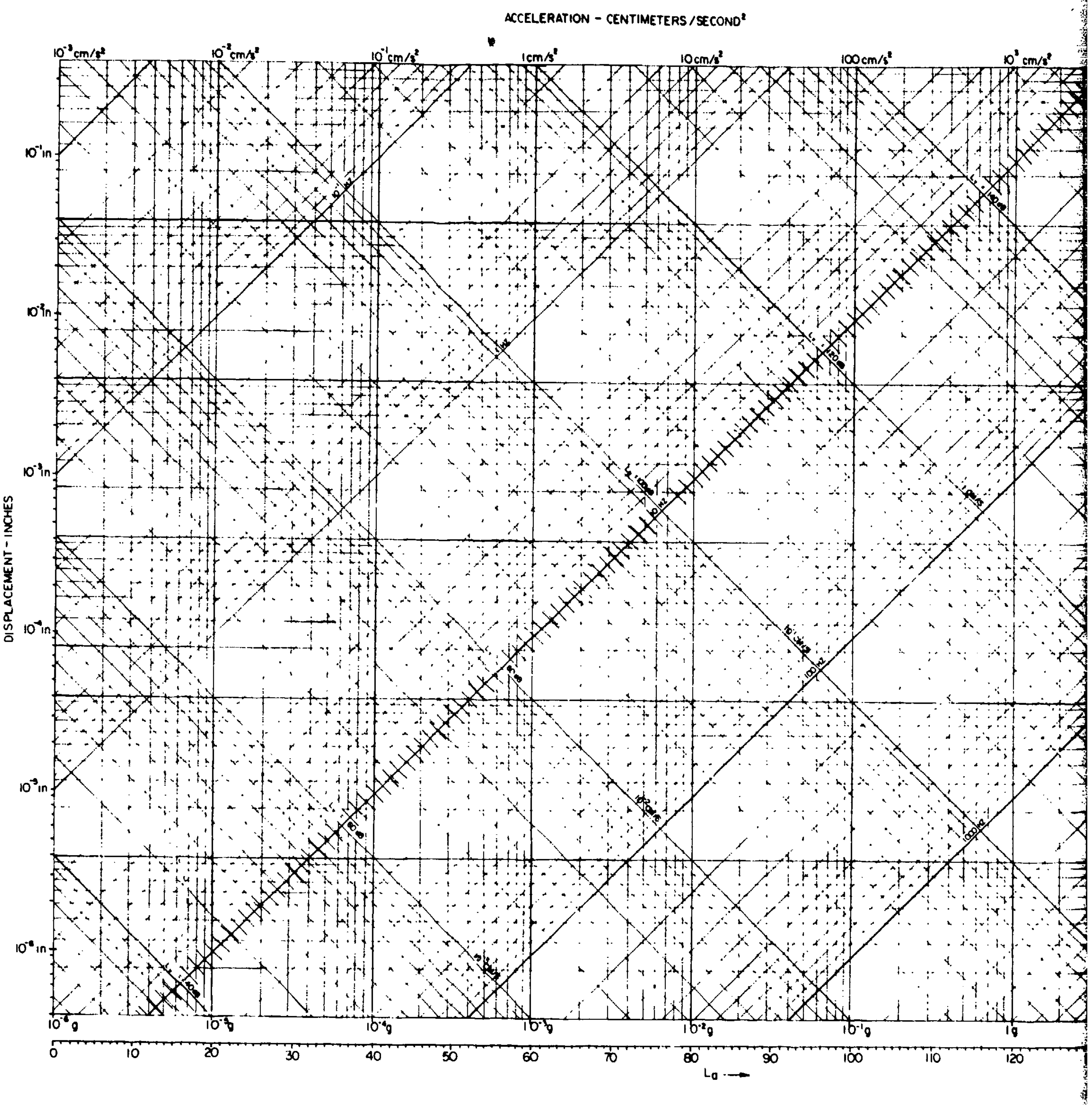
1 micron	=	10^{-6} meters
1 mil	=	10^{-3} in.
$\log_{10} x$	=	$0.4342 \ln x$
$\ln x$	=	$2.303 \log_{10} x$
dB	=	0.115 nepers
neper	=	8.686 dB
$\log_{10} e^x$	=	$0.434 x$
$\log_e 10^x$	=	$2.30 x$
sabin	=	one ft^2 of equivalent 100% sound absorption
metric sabin	=	one m^2 of equivalent 100% sound absorption
"g"	=	980.6 cm/^{2} = 386 in./s^2 = 32.17 ft/s^2

COMPARISON OF STANDARD REFERENCE PRESSURE LEVELS TO OTHER ASSOCIATED UNITS

CONVERSION OF PRESSURE LEVELS

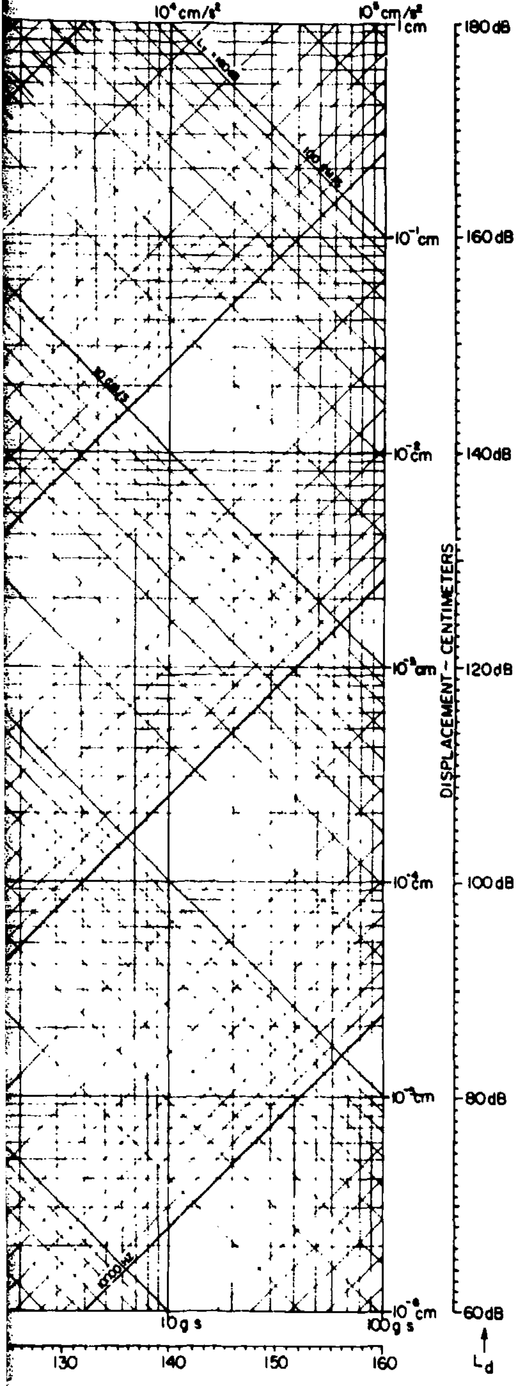


(SEE MIL-STD-1621A (NAVY) 27 AUGUST, 1973)



DISPLACEMENT
CO

ACCELERATION · VELOCITY · DISPLACEMENT



ENT - VELOCITY - ACCELERATION
CONVERSION CHART

CONVERSION
TABLES

LENGTH, AREA, VOLUME

	m	cm	ft	in.
m	1	10^2 cm	3.28 ft	39.4 in.
m^2	-	10^4 cm^2	10.8 ft^2	1550 $in.^2$
m^3	-	10^6 cm^3	35.3 ft^3	6.10×10^4 in.
cm	10^{-2} m	1	3.28×10^{-2} ft	0.394 in.
cm^2	10^{-4} m^2	-	10.8×10^{-4} ft^2	1.55×10^{-1} $in.^2$
cm^3	10^{-6} m^3	-	353×10^{-6} ft^3	6.10×10^{-2} $in.^3$
ft	0.305 m	30.5 cm	1	12 in.
ft^2	0.093 m^2	9.29×10^2 cm^2	-	144 $in.^2$
ft^3	$2.83 \times 10^{-2} m^3$	2.83×10^4 cm^3	-	1728 $in.^3$
in.	2.54×10^{-2} m	2.54 cm	8.33×10^{-2} ft	1
$in.^2$	6.45×10^{-4} m^2	6.45 cm^2	6.94×10^{-3} ft^2	-
$in.^3$	1.64×10^{-5} m^3	16.4 cm^3	5.79×10^{-4} ft^3	-

VOLUME MEASURES

	LITER	U.S. LIQUID GALLON	ft^3	cc
LITER	1	0.264 gal	0.0353 ft^3	1000 cc
GALLON	3.785 l	1	0.134 ft^3	3785 cc
ft^3	28.32 l	7.48 gal	1	2.83×10^4 cc
cc	.001 l	2.64×10^{-4} gal	3.53×10^{-5}	1

DISTANCE

	METER m	KILOMETER km	NAUTICAL MILE n.m.	STATUTE MILE s.m.	YARD yd
METER m	1	1.0×10^{-3} km	5.4×10^{-4} n.m.	6.21×10^{-4} s.m.	1.09 yd
KILOMETER km	1000 m	1	0.540 n.m.	0.621 s.m.	1094 yd
NAUTICAL MILE n.m.	1852 m	1.852 km	1	1.15 s.m.	2025.4 yd
STATUTE MILE s.m.	1609 m	1.61 km	0.869 n.m.	1	1760 yd
YARD yd	0.914 m	9.14×10^{-4} km	4.94×10^{-4} n.m.	5.68×10^{-4} s.m.	1

DISTANCE

SPEED

	m/s	KNOT	MPH	ft/s	
METER PER SECOND m/s	1	1.94 kt	2.24 mph	3.28 $\frac{ft}{s}$	
KNOT kt	0.514 $\frac{m}{s}$	1	1.15 mph	1.69 $\frac{ft}{s}$	
MILE PER HOUR mph	0.447 $\frac{m}{s}$	0.869 kt	1	1.47 $\frac{ft}{s}$	
FOOT PER SECOND ft/s	0.30 $\frac{m}{s}$	0.60 kt	0.68 mph	1	

SPEED

MASS

MASS	KILOGRAM	GRAM	POUND	OUNCE	SLUG
KILOGRAM kg	1	1000 g	2.205 lb	35.27 oz	6.852×10^{-2} slug
GRAM g	0.001 kg	1	2.205×10^{-3} lb	3.527×10^{-2} oz	6.852×10^{-5} slug
POUND lb	0.4536 kg	453.6 g	1	16 oz	3.108×10^{-2} slug
OUNCE	2.835×10^{-2} kg	28.35 g	6.250×10^{-2} lb	1	1.943×10^{-3} slug
SLUG	14.59 kg	1.459×10^{4} g	32.17 lb	514.8 oz	1

FORCE

FORCE	NEWTON N	DYNE dyn	POUND lb	POUNDAL
NEWTON N	1	10^{5} dyn	0.2248 lb	7.233 poundal
DYNE dyn	10^{-5} N	1	2.248×10^{-6} lb	7.233×10^{-5} poundal
POUND lb	4.448 N	4.448×10^{5} dyn	1	32.17 poundal
POUNDAL	0.1383 N	1.383×10^{4} dyn	3.108×10^{-2} lb	1

DENSITY

	KILOGRAM/m³	POUND/ft³	POUND/in.³	GRAM/cm³	SLUG/ft³
kilogram/m³	1	6.24×10^{-2} lb/ft³	3.613×10^{-5} lb/in.³	0.001 g/cm³	1.94×10^{-3} slug/ft³
pound/ft³	16.02 kg/m³	1	5.79×10^{-4} lb/in.³	1.602×10^{-2} g/cm³	3.108×10^{-2} slug/ft³
pound/in.³	2.768×10^{4} kg/m³	1728 lb/ft³	1	27.68 g/cm³	53.71 slug/ft³
gram/cm³	1000 kg/m³	62.43 lb/ft³	3.613×10^{-2} lb/in.³	1	1.94 slug/ft³
slug/ft³	515.4 kg/m³	32.17 lb/ft³	1.862×10^{-2} lb/in.³	0.5154 g/cm³	1

DENSITY

ANGULAR MEASURE

	REVOLUTION	RADIAN	DEGREE	MINUTE OF ARC	SECOND OF ARC
REVOLUTION	1	2π rad	360 deg	2.16×10^{4} min	1.296×10^{6} s
RADIAN	0.159 rev	1	57.3 deg	3.44×10^{3} min	2.06×10^{5} s
DEGREE	2.78×10^{-3} rev	0.0175 rad	1	60 min	3600 s
MINUTE OF ARC	4.63×10^{-5} rev	2.91×10^{-4} rad	0.01667 deg	1	60 s
SECOND OF ARC	7.72×10^{-7} rev	4.85×10^{-6} rad	2.78×10^{-4} deg	0.01667 min	1

ANGULAR MEASURE

ENERGY – WORK – HEAT

ENERGY - WORK - HEAT

	JOULE N.m J	ERG	KILOWATT-HOUR kWh	HORSE-POWER HOUR	FOOT-POUND
JOULE N.m J	1	10^{7} erg	2.78×10^{-7} kWh	3.725×10^{-7} hp-hr	0.737 ft-lb
ERG dyne-cm	10^{-7} J	1	2.78×10^{-14} kWh	3.725×10^{-14} hp-hr	7.37×10^{-8} ft-lb
KILOWATT-HOUR kWh	3.6×10^{6} J	3.6×10^{13} erg	1	1.341 hp-hr	2.65×10^{6} ft-lb
HORSEPOWER-HOUR	2.685×10^{6} J	2.685×10^{13} erg	0.7457 kWh	1	1.980×10^{6} ft-hr
FOOT-POUND	1.356 J	1.356×10^{7} erg	3.766×10^{-7} kWh	5.051×10^{-7} hp-hr	1

1 Joule = 1 N.m = 1 W.s

PRESSURE

	PASCAL $\frac{N}{m^2}$	ATMO-SPHERES (atm)	MICROBAR $\frac{dyne}{cm^2}$	FEET SEAWATER	FEET H_2O	cm Hg	$\frac{pound}{inch^2}$	TORR
$\frac{N}{m^2}$	1	9.87×10^{-6} atm	10 $dyne/cm^2$	3.26×10^{-4} ft	3.35×10^{-4} ft	7.5×10^{-4} cm	1.45×10^{-4} psi	7.50×10^{-3} TORR
ATMOSPHERES (atm)	1.013×10^5 N/m^2	1	1.013×10^6 $dyne/cm^2$	32.97 ft	33.9 ft	76 cm	14.7 psi	760 TORR
$\frac{dynes}{cm^2}$	0.1 N/m^2	9.87×10^{-7} atm	1	3.26×10^{-5} ft	3.35×10^{-5} ft	7.5×10^{-5} cm	1.45×10^{-5} psi	7.5×10^{-4} TORR
FEET SEAWATER	3069 N/m^2	3.03×10^{-2} atm	3.07×10^4 $dyne/cm^2$	1	1.03 ft	2.30 cm	0.446 psi	23.03 TORR
FEET H_2O	2985 N/m^2	2.95×10^{-2} atm	2.99×10^4 $dyne/cm^2$	0.973 ft	1	2.24 cm	0.433 psi	22.4 TORR
cm of Hg	1333 N/m^2	1.32×10^{-2} atm	1.33×10^4 $dyne/cm^2$	0.434 ft	0.446 ft	1	0.1934 psi	10.0 TORR
$\frac{pound}{inch^2}$	6.90×10^3 N/m^2	6.80×10^{-2} atm	6.90×10^4 $dyne/cm^2$	2.24 ft	2.31 ft	5.17 cm	1	51.7 TORR
TORR	1.33×10^2 $N.m^2$	1.32×10^{-3} atm	1.33×10^3 $dyne/cm^2$	4.33×10^{-2} ft	4.47×10^{-2} ft	0.10 cm	1.93×10^{-2} psi	1

Acceleration due to gravity = $9.80665\ m/s^2$

1 bar = $10^5\ N/m^2 = 10^6\ dyne/cm^2$

ABSOLUTE OR DYNAMIC VISCOSITY -- μ

ABSOLUTE VISCOSITY

	N.s / m2	POISE, P dyne-s / cm2	lb force-s / inch2	lb mass / ft-s
N.s / m2	1	10 P	1.45×10^{-9} lbf-s / in.2	6.72×10^{-1} lbm / ft-s
POISE g / s-cm dyne-s / cm2	0.1 N.s / m2	1	1.45×10^{-5} lbf-s / in.2	6.72×10^{-2} lbm / ft-s
pound-force s / inch2	6.89×10^{3} N.s / m2	6.89×10^{4} P	1	4.634×10^{3} lbm / ft-s
pound-mass / ft-s	1.488 N.s / m2	14.88 P	2.158×10^{-4} lbf-s / in.2	1

1 Poise = 100 Centipoise

KINEMATIC VISCOSITY – $\nu = \left(\frac{\mu}{\rho}\right)$

KINEMATIC VISCOSITY

	m^2/s	Stoke St cm^2/s	ft^2/s
m^2/s	1	10000 st	10.76 ft^2/s
STOKE cm^2/s	$10^{-4} m^2/s$	1	1.076×10^{-3} ft^2/s
ft^2 / s	$929 \times 10^{-4} m^2/s$	929 st	1

1 Stoke = 100 Centistokes

POWER

	WATT	ft-lb/s	HORSEPOWER	erg/s
WATT = joule/s = kg.m/s	1 W	0.7376 ft-lb/s	1.341×10^{-3} hp	10^{7} erg/s
ft-lb/s	1.356 W	1	1.818×10^{-3} hp	1.356×10^{7} erg/s
HORSEPOWER	745.7 W	550 ft-lb/s	1	7.457×10^{9} erg/s
erg/s	10^{-7} W	7.376×10^{-8} ft-lb/s	1.341×10^{-10} hp	1

ENERGY DENSITY

ENERGY DENSITY

	joule / m^3	erg / cm^3
joule / m^3	1	10 erg / cm^3
erg / cm^3	0.10 w / m^3	1

INTENSITY

INTENSITY

	watts / m^2	erg / $s.cm^2$
watts / m^2	1	10^3 erg / $s.cm^2$
erg / $s \cdot cm^2$	10^{-3} w / m^2	1

standard reference level = 10^{-12} watts/m^2

MECHANICAL IMPEDANCE

	Pascal•second Pa•s	$\frac{\text{Pound•second}}{\text{inch}}$
Pascal•second Pa•s	1	5.71×10^{-3} $\frac{\text{lb•s}}{\text{in.}}$
$\frac{\text{pound•second}}{\text{inch}}$	175 Pa•s	1

SPECIFIC ACOUSTIC IMPEDANCE

SPECIFIC ACOUSTIC IMPEDANCE

	Pascal·second / meter	pound·second / inch^3
Pascal·second / meter	1	3.68×10^{-6} $\frac{lb \cdot s}{in.^3}$
pound·second / inch^3	2.72×10^{5} $\frac{Pa \cdot s}{in.}$	1

ACOUSTIC IMPEDANCE

ACOUSTIC IMPEDANCE

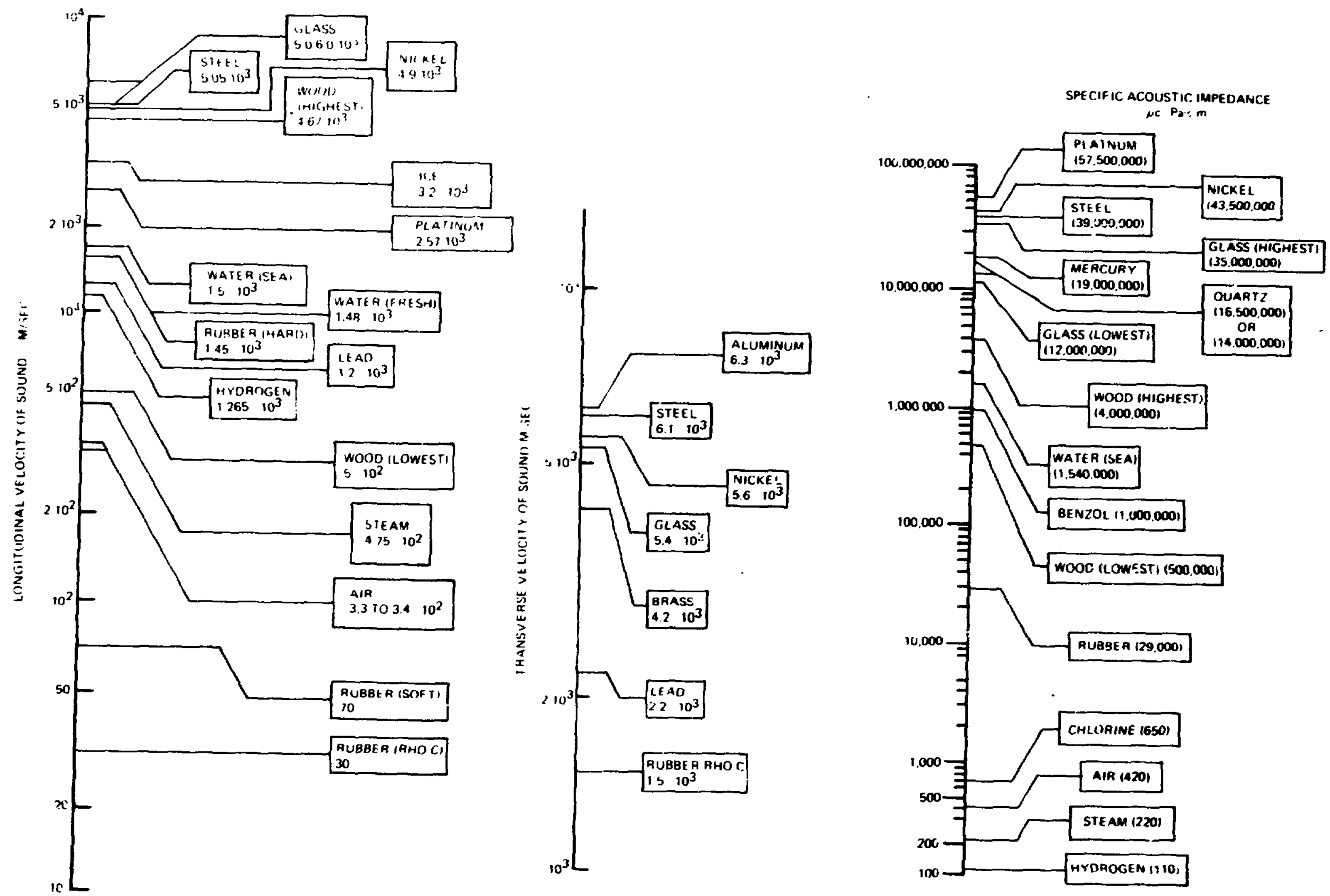
	Pascal·second / meter^3	pound·second / inch^5
Pascal·second / meter^3	1	2.37×10^{-9} $\frac{lb \cdot s}{in.^5}$
pound–second / inch^5	4.22×10^{8} $\frac{Pa \cdot s}{in.^3}$	1

ACOUSTIC CHARACTERISTICS OF SELECTED SOLIDS, LIQUIDS & GASES

compiled principally from:

1. Kinsler & Frey (1962)
2. <u>Handbook of Chemistry & Physics</u>

SOUND VELOCITY & ACOUSTIC IMPEDANCE OF VARIOUS SUBSTANCES



LONGITUDINAL VELOCITY, TRANSVERSE VELOCITY, AND SPECIFIC ACOUSTIC IMPEDANCE FOR VARIOUS SUBSTANCES

SOLID	DENSITY ρ_0		YOUNG'S MODULUS E		SHEAR MODULUS G		BULK MODULUS K		POISSON'S RATIO ν	BAR	
	$\frac{kg}{m^3}$	$\frac{\#}{ft^3}$	Pa x 10^{10}	psi x 10^6	Pa x 10^{10}	psi x 10^6	Pa x 10^{10}	psi x 10^6	dimensionless	m/sec	f
Aluminum (Rolled)	2700	169	7.1	10.0	2.4	3.4	7.5	10.7	0.33	5000	16,4
Brass	8500	531	10.4	14.8	3.8	5.4	13.6	19.3	0.37	3480	11,
Copper	8930	556	12.2	17.3	4.4	6.3	16.0	22.8	0.35	3800	12,
Iron (Cast)	7900	481	10.5	14.9	4.4	6.3	8.6	12.2	0.28	5120	16,7
Lead	11400	706	1.65	2.35	0.55	0.78	4.2	7.1	0.44	1200	3,9
Nickel	8900	550	21.0	29.8	8.0	11.4	19.0	27.0	0.31	4900	16,0
Silver	10400	656	7.8	11.1	2.8	4.0	10.5	14.9	0.37	2680	8,7
Steel	7800	481	19.5	27.7	8.3	11.8	17.0	24.2	0.28	5100	16,7
Glass (Pyrex)	2320	144	6.2	8.8	2.5	3.6	3.9	5.5	0.24	5170	16,9
Quartz (X-cut)	2650	165	7.9	11.2	3.9	5.5	3.3	4.7	0.33	5450	17,8
Lucite	1180	749	0.4	0.57	0.14	0.20	0.65	0.92	0.4	1840	6,0
Concrete	2600	162	2.5	3.5							
Ice	920	57	0.94	1.3							
Cork	240	15	0.0062	.009							
Oak	720	45	1.3	1.8						3850	12,6
Pine	450	28	.71	1.0							
Rubber (Hard)	1100	69	0.23	0.33	0.1	0.14	0.5	0.71	0.4	1450	4,7
Rubber (Soft)	950	59	0.0005	0.0007			0.1	0.14	0.5	70	2
Rubber (pc)	1000	62					0.24	0.34			
Titanium	4500	281	11.8	16.8	4.5	6.5				5080	16,6
Magnesium	1740	109	4.6	6.5	1.62	2.3			0.306	4940	16,2
Molybdenum	10100	631	35.2	50						5400	17,7
Monel	8900	556	17.6	25.0	6.7	9.5	15.8	22.5	0.315	4400	14,43
Stainless steel	7900	493	19.4	27.6	7.5	10.6	16.6	23.6	0.305	5000	16,4
Zinc	7130	445	10.5	15.1	4.2	6.1			0.25	3850	12,6

VELOCITY c					Characteristic Impedance $\rho_0 c$			
AR	BULK		SHEAR		BAR	BAR	BULK	BULK
ft/sec	m/sec	ft/sec	m/sec	ft/sec	$\frac{Pa \cdot s}{m}$ x 10^6	$\frac{pound\text{-}sec}{in.^3}$	$\frac{Pa \cdot s}{m}$ x 10^6	$\frac{pound\text{-}sec.}{in.^3}$
16,404	6420	21,063	3040	9,974	13.9	51.2	17.0	62.6
11,417	4700	15,420	2110	6,923	29.8	110	40.0	147
12,467	4900	16,076	2300	7,546	33.0	121	44.5	163
16,798	5900	19,357	3240	10,630	28.5	105	33.5	123
3,937	2000	6,562	700	2,297	13.6	50.1	23.2	85.5
16,076	6040	19,816	3000	9,843	43.0	158	51.5	190
8,792	3650	11,975	1610	5,282	28.4	105	39.0	144
16,732	5900	19,357	3200	10,499	39.0	143	47.0	173
16,962	5640	18,504	3280	10,761	12.0	44.2	12.9	47.5
17,881	5750	18,865			14.5	53.4	15.3	56.4
6,037	2680	8,793	1100	3,609	2.15	7.9	3.2	11.8
	3100	10,171					8.0	29.5
	3200	10,499					2.95	10.9
	500	1,640					0.12	0.44
12,631	4000	13,123			2.8	10.3	2.9	10.7
	3500	11,483					1.57	5.78
4,757	2400	7,874			1.6	5.8	2.64	9.73
230	1050	3,445			0.065	0.24	1.0	3.69
	1550	5,085					1.55	5.71
16,667	6070	19,915	3125	10,253	22.9	84.4	27.3	101
16,207	5770	18,930	3050	10,007	8.6	31.7	10.0	36.8
17,717	6250	20,505	3350	10,991	54.5	201	63.1	233
14,436	5350	17,552	2720	8,924	39.2	144	47.6	175
16,404	5790	18,996	3100	10,171	39.5	146	45.7	168
12,631	4210	13,812	2440	8,005	27.5	101	30.0	111

LIQUID	TEMPERATURE T		DENSITY ρ_0		BULK MODULUS K		Ratio of Specific Heats γ	VELOCITY OF SOUND c		CHARACTERISTIC IMPEDANCE $\rho_0 c$		COEF[illegible] OF V[illegible]
	°C	°F	$\frac{kg}{m^3}$	$\frac{\#}{ft^3}$	$\frac{N}{m^2} \times 10^9$	psi $\times 10^5$		$\frac{m}{sec}$	$\frac{ft}{sec}$	$\frac{Pa \cdot s}{m} \times 10^6$	$\frac{lb\text{-}sec}{in.^3}$	$\frac{N\ se[illegible]}{m^2}$
Fresh Water	20	68	998	62.1	2.18	3.18	1.004	1481	4856	1.48	5.45	0.001[illegible]
Sea Water	13	55.4	1026	64.1	2.28	3.35	1.01	1500	4918	1.54	5.67	0.001[illegible]
Ethyl Alcohol	20	68	790.	49.3				1150	3771	0.91	3.35	0.001[illegible]
Castor Oil	20	68	950	59.3				1540	5049	1.45	5.34	0.96
Mercury	20	68	13600	849.5	25.3	37.20	1.13	1450	4754	19.7	72.5	0.001[illegible]
Turpentine	20	68	870	54.3	1.07	1.57	1.27	1250	4098	1.11	4.08	0.001[illegible]
Glycerin	20	68	1260	78.7				1980	6492	2.5	9.26	1.2
Kerosene	25	77	810	50.6				1324	4341			
Methyl Alcohol	25	77	791	49.4				1103	3616			

CHARACTERISTICS OF LIQUIDS

COEFFICIENT OF VISCOSITY η		
$\frac{N\ sec}{m^2}$		$-\Delta V/\Delta T$ m/sec°C
0.001		-2.4
0.001		-2.4
0.0012		4.0
0.96		3.6
0.0016		-
0.0015		-
1.2		2.2
		3.6
		3.2

GAS	TEMPERATURE T		STATIC PRESSURE P_0		DENSITY ρ		RATIO OF SPECIFIC HEATS γ	SOUND VELOCITY c		CHARACTERISTIC IMPEDANCE ρc	
	°C	°F	$\frac{N}{m^2}$ x 10^5	PSI	$\frac{kg}{m^3}$	$\frac{\#}{ft^3}$ x 10^{-2}		m/sec	ft/sec	$\frac{Pa\text{-}s}{m}$	$\frac{lb.\text{-}sec}{in.^3}$
Air	0	32	1.013	14.89	1.293	8.08	1.402	331.6	1087	428	1.58 x (10^{-3})
Air	20	68	1.013	14.89	1.21	7.56	1.402	343	1125	415	1.53
Oxygen	0	32	1.013	14.89	1.43	8.93	1.40	317.2	1040	453	1.67
CO_2 (Low Freq)	0	32	1.013	14.89	1.98	12.37	1.304	258	845.9	512	1.88
CO_2 (High Freq)	0	32	1.013	14.89	1.98	12.37	1.40	268.6	880.7	532	1.96
Hydrogen	0	32	1.013	14.89	0.09	0.56	1.41	1269.5	4162	114	0.42
Steam	100	212	1.013	14.89	0.6	3.75	1.324	404.8	1327	242	0.89
Helium	0	32	1.013	14.89	0.18	1.12		965	3164		

CHARACTERISTICS OF GASES

COEFFICIENT OF VISCOSITY η $\frac{N\ sec}{m^2}$	-Δv/ΔT- $\frac{m}{sec\ ^\circ C}$
0.000017	0.59
0.000018	0.59
0.00002	0.56
0.0000145	0.4
0.0000145	0.4
0.0000088	2.2
0.000013	-
	0.8

SPEED OF SOUND, DENSITY, AND CHARACTERISTIC IMPEDANCE OF WATER AT ATMOSPHERIC PRESSURE, FOR VARIOUS TEMPERATURES AND SALINITIES

	FRESH WATER				SEA WATER							
SALINITY (0/00)	0				30				35			
TEMPERATURE (°C)	0	4	15	20	0	4	15	20	0	4	15	
Speed of Sound (meters per second)	1403	1422	1466	1483	1443	1461	1501	1516	1449	1467	1507	1[illegible]
Density (Kg/m^3) x 10^3	0.9998	1.0000	0.9991	0.9982	1.0241	1.0238	1.0222	1.0210	1.0281	1.0278	1.0260	1.[illegible]
Characteristic impedance x 10^{-4}(Pa.s/m)	1.402	1.422	1.465	1.480	1.478	1.496	1.534	1.548	1.490	1.508	1.546	1.[illegible]

ANSI 51.1

20
1522
1.0248
1.560

.1

CHARACTERISTICS OF FRESH AND SALT WATER

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