Sound as a wave

To understand standing waves it is necessary to understand a little about sound as a wave.

Sound in air is a longitudinal wave, that is the pressure fluctuations which are the sound wave take place in the direction of travel of the wave. A pure tone is a sine wave where the wavelength is the distance between two successive compressions or rarefractions and the frequency is the number of waves that pass a point in space every second.

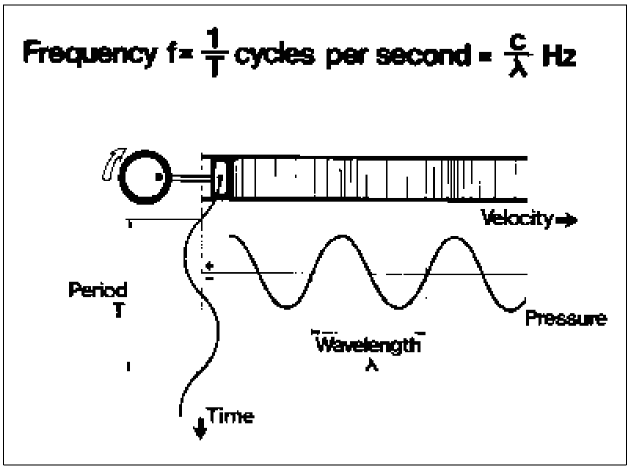

Fig 4

The range of audible sound stretches from a frequency of 20 Hz to 20000 Hz (Hz = Hertz = waves per second). As we grow older our hearing at the high frequencies falls off (presbycusis) . Additionally hearing loss caused by excessive noise during a lifetime (the permanent threshold shift as opposed to the temporary threshold shift which is experienced when coming out of a noisy space such as a disco) occurs at high frequencies around 4 kHz.

Standing waves are caused by the incident and reflected wave at a surface interfering with each other. The result is a series of nodes and antinodes in space, the former being places where there is no change in the relevant property (e.g. sound pressure) with time and the latter where the property fluctuates at a maximum. A pressure fluctuation maximum (antinode) is produced against the wall whereas the air particles can barely move against the hard wall and give rise to a particle velocity node. A partial standing wave is formed against any surface but a full standing wave will not be set up unless the nodes and antinodes from another partial standing wave formed against an opposite parallel surface coincide. The room dimension under which this will occur is related to the wavelength by the expression:

l = n8/2 where

l = room dimension
8 = wavelength
and n is an integer

These are known as the axial room modes but they can occur in two or three dimensions known as correspondingly as the tangential and oblique modes.

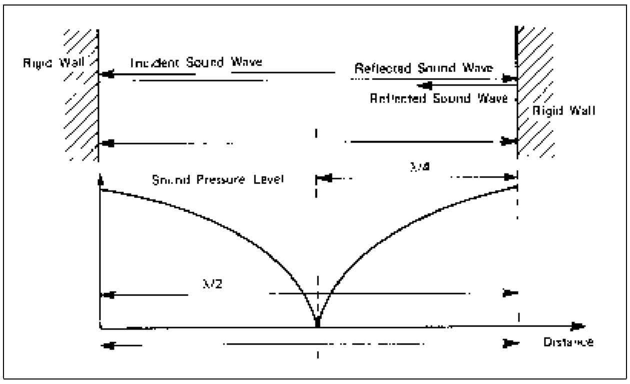

Fig 5 (Source ref 2) Axial Modes

The room modes (frequencies) for a simple (undamped) rectangular room are given by the expression:

$f= c/2\{(n_x/l_x)^2 + (n_y/l_y)^2 + (n_z/l_z)^2\}^{1/2}$

where f is the frequency
c is the velocity of sound in air (340 m/s at room temp.)
$n_{x,y,z}$ are integers
and $l_{x,y,z}$ are the room dimensions

If a room is cubic the room modes are widely spaced at the lower frequencies and can lead to very poor acoustics. With small room dimensions the shortest wavelength to give rise to a standing wave is within the audible range e.g for a room dimension of 3.4m a room mode (an axial mode) is formed at 50 Hz and if the room is cubic the next mode (a tangential mode) would be at 71 Hz. For larger room dimensions the fundamental standing waves where the large spacing will occur are below the audible range and so there is less of a problem. In order to avoid as far as possible these low frequency standing wave problems room dimensions are chosen for acoustically critical spaces to produce as many evenly spaced modes as possible. One commonly used room ratio is the 'golden ratio' $n_x : 2^{1/3}n_y : 2^{2/3}n_z$

where $n_{x,y,z}$ are integers

If all integers = 1 then this produces a ratio 1 : 1.26 : 1.6. Another suggestion from the BBC in London is in relation to room height 1.14 +/- 0.1 : 1.4 +/- 0.14 (ref 3).

The increase in the number of modes with frequency can be shown from analysis of a large hall with dimensions 50m x 24m x 14m with a volume of 16 800 m^3 which between 0 to 10 000 Hz has about 1.8 x 10^9 modes and at 1000 Hz the number of modes is about 5400 per Hz(ref 4).